Responses to a Virtual Reality Grocery Store in Persons with and without Vestibular Dysfunction

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Abstract

People with vestibular dysfunction often complain of having difficulty walking in visually complex environments. Virtual reality may serve as a useful therapeutic tool for providing physical therapy to these people. The purpose of this pilot project was to explore the ability of people with and without vestibular dysfunction to use and tolerate virtual environments that can be used in physical therapy. We have chosen grocery store environments, which often elicit complaints from patients. Two patients and three control subjects were asked to stand and navigate in virtual grocery stores while finding products. Perceived discomfort, simulator sickness symptoms, distance traveled, and speed of head movement was recorded. Symptoms and discomfort increased in one subject with vestibular dysfunction. The older subjects traveled less distance and had greater speed of head movements compared with young subjects. Environments with a greater number of products resulted in more head movements and less distance traveled.

Introduction

Disorders of the vestibular system often cause people to complain of vertigo, dizziness, difficulty with focusing, feeling off balance, and falling.[1, 2] A subset of patients with vestibular dysfunction report that they have increased symptoms in visually complex environments, such as in grocery stores, in crowds, and in buildings that have very high walls.[3-6] Jacob et al.[7] have labeled this symptom complex “space-and-motion discomfort” (SMD). Bowman[6] reported that persons with unilateral peripheral dysfunction who had increased symptoms in confined spaces and busy environments (corridors, shopping aisles, and crowds) were much more likely to have poor recovery.

Bronstein[8] reported that patients with vestibular disorders who experienced symptoms in supermarket aisles or moving visual surroundings demonstrated greater sway when exposed to full-field visual motion, suggesting that these patients have greater reliance on visual cues. One treatment method commonly used to decrease the reliance on the visual system is through the use of habituation exercises.[9] There is mounting evidence that habituation exercises in the form of visually provocative scenes can cause functional changes in patients with vestibular dysfunction.[10-12]

If habituation exercises are a necessary component in the treatment of persons who become symptomatic in complex visual environments, virtual reality could be an ideal method for delivery of these exercises. The advantage of virtual reality for use with persons with vestibular disorders is that one can “dose” the response and immediately change it to fit the needs of the patient.[13, 14] Viirre[15, 16] and Kramer et al.[17] were the first to discuss the use of virtual reality for persons with vestibular dysfunction. In the previous work, it has been demonstrated that virtual reality can be used to induce adaptations in the vestibulo-ocular reflex (VOR) and reduce dizziness.[16, 18] However, virtual reality has not yet been used as a habituation exercise to treat situation-specific dizziness.

The purpose of this study was to obtain preliminary data on the ability of subjects with and without vestibular dysfunction to use a virtual grocery store environment. This pilot work will assist the investigators in design of the virtual grocery store that will be used for physical therapy intervention in the future. A secondary goal of this research was to examine head movement strategies that are used to locate products while shopping in a virtual grocery store.

Methods

Subjects

Two adults (36 y.o. female, 69 y.o. male) with a history of a unilateral vestibular hypofunction (UVH) and 3 healthy adult controls (32 and 71 y.o. males, 67 y.o. female) participated after signing informed consent that had been approved by the University of Pittsburgh Institutional Review Board. All subjects were screened for deficits in visual acuity, contrast sensitivity, and peripheral sensation. Audiometric testing was within age norms for the control subjects. Control subjects had normal vestibular function tests and normal computerized dynamic posturography tests. The older male with UVH had complete unilateral loss subsequent to a vestibular nerve section in 1997 due to an acoustic neuroma. The young female with UVH had a 54% loss subsequent to a peripheral vestibular injury in the second half of 2004.

All subjects completed the Dizziness Handicap Inventory (DHI)[19] and the Activities-specific Balance Confidence scale (ABC),[20] self-report questionnaires that assessed their perceived dizziness handicap (DHI) and provided information about fear of falling (ABC). All subjects also performed 8 gait tasks as part of the Dynamic Gait Index (DGI),[21] as well as the Timed Up and Go (TUG).[22]

Instrumentation

The Balance NAVE Automatic Virtual Environment (BNAVE, http://www.mvrc.pitt), a wide field of view projection-based immersive display system, was developed to investigate multi-sensory interactions in postural control.[14, 23] Three 2.4 m X 1.8 m (vertical X horizontal) back-projected screens are arranged as shown in Figure 1. The side screens make an included angle of 110° with the front screen. The front screen is 1.5 m from the user, and the opening of the BNAVE at the location of the subject is approximately 2.9 m.

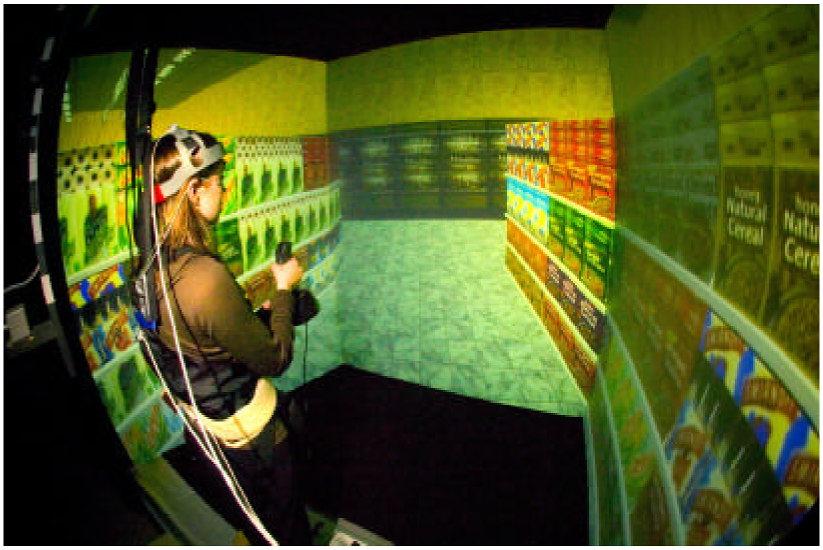

Figure 1. The Balance NAVE Automatic Virtual Environment (BNAVE) includes a Neurotest force platform surrounded on three sides by back-projected screens displaying a full-field of view virtual grocery store environment. The subject is supported by a harness to prevent a fall, and is wearing a Polhemus Fastrak sensor on her head to measure head movements.

The images are displayed using Epson 810p PowerLite LCD monoscopic projectors, with a pixel resolution of 1024 X 768 for each screen. Each projector is 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 2000. The movement of the images on the three PCs is synchronized and controlled by a server via a local area network. The update rate of the images is consistently at least 20 frames per second.

An Airstick (Macally) game controller was used to navigate in the environment. Users could move forward, back, right and left with push-buttons. The speed of forward movement was controlled by pitching the joystick down. The maximum speed of movement was approximately 1.2 m/s, which is the walking pace necessary to walk safely across a signaled intersection.[24] Changes in heading were controlled by rolling the Airstick to the right and left. The speed of rotation was approximately 12°/s.

Subjects stood on a modified Neurotest force platform (Neurocom, Inc.) that was used to measure ground reaction forces and center of pressure at a sampling frequency of 100 Hz. A Polhemus Fastrak electromagnetic sensor was attached to a headband worn by the subjects to monitor head movement at a sampling frequency of 20 Hz.

Design of virtual grocery store environments

Four virtual grocery store environments were created. The first two environments consisted of a 120 m long aisle with either sparsely or densely populated shelves (Figure 2a,b). The other two environments consisted of a store containing six 20 m long aisles with either sparsely or densely populated shelves (Figure 2c). Products covered 6.7 % and 50% of the shelf space in the sparsely and densely populated shelves, respectively. For every environment, the aisle width was 3 m, and the height of the shelves was 2 m.

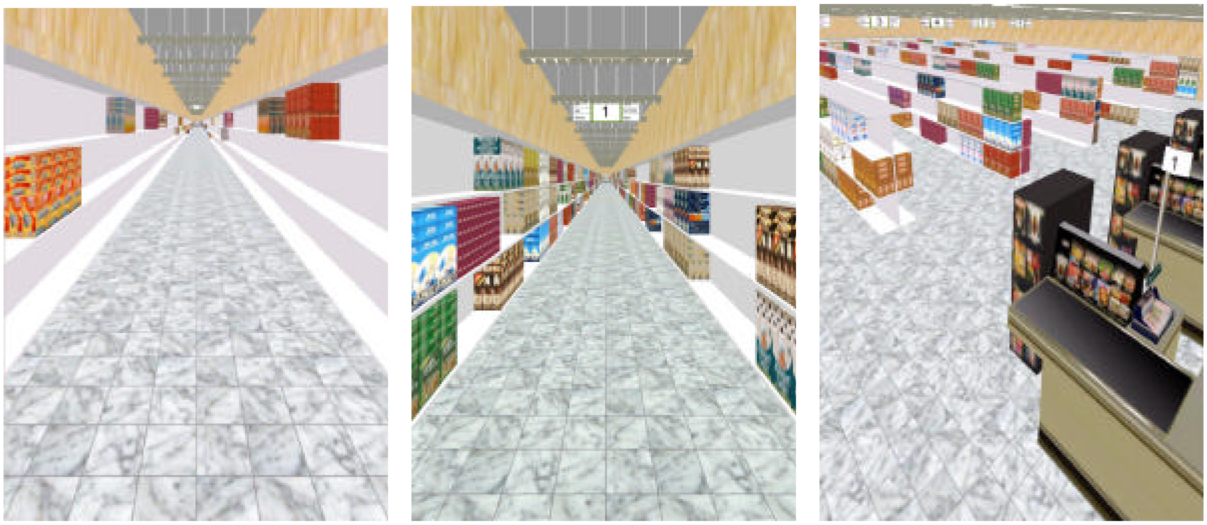
a) 1 aisle, sparse products b) 1 aisle, dense products c) 6 aisles, dense products

Figure 2. Layout of different virtual grocery store environments. Figures 2a and 2b are views of the front screen from a subjects' viewpoint; Figure 2c is a perspective view.

In each 10 m section of shelves, one of 4 different target products was placed. The four products were always presented in the same order throughout the study. Each product had a different color associated with it: white, yellow, red and purple. The products were chosen because they were grocery store objects that would most likely be unfamiliar to all of the subjects. By choosing unfamiliar objects, the authors were attempting to assure that no subject had an advantage of immediate product recognition during the testing. The distracting products were randomly chosen from among 21 other products, including products of the same color as the target. All 25 products were constructed from textures obtained from digital photographs of real products found in a grocery store. The textures were scaled and applied to an object that had consistent geometry throughout the store. Thus, a product could be identified only by its texture, and not by its size or shape.

Procedure

All subjects practiced moving through the 6 aisle virtual grocery store with the controller held in their dominant hand prior to the start of the experiment. Subjects performed 6 trials, each lasting 120 seconds. During the first trial, subjects moved through the 120 m, 1-aisle store without looking for products. On the next 2 trials, subjects moved through the 1-aisle store looking for the target products on the sparsely (trial 2) and densely (trial 3) populated shelves. On trial 4, subjects moved through the 20 m, 6-aisle store without looking for products. On the final trials, subjects moved through the 6-aisle store looking for the target products on the sparsely (trial 5) and densely (trial 6) populated shelves. Environments were presented in the same order because we assumed that patients would become more symptomatic with the scenes that required turning based on our clinical experience with people with vestibular dysfunction. Walking and turning has been reported to be difficult in persons with vestibular disorders.[1]

Initially, subjects were shown a picture of the first product that they needed to find on a card presented by the physical therapist. As they moved through the store, they were allowed to view the picture as many times as needed. Once the subjects found the target and pointed to it, or passed the product without locating it, they were shown the next product. Subjects were instructed to move at their comfortable speed through the scene. Within the 120 s trial duration, subjects attempted to find a maximum of 12 products.

After each 120 s trial, subjects sat in a chair outside of the BNAVE to have their blood pressure and heart rate recorded. Furthermore, all subjects reported their Subjective Units of Discomfort score (SUDs), which was rated as a score between 0 and 10 with 0 indicating no discomfort and 10 the most discomfort that they could imagine, and completed the Simulator Sickness Questionnaire (SSQ).[25] All measures were also recorded before the testing started.

Data Analysis

Several types of measures were recorded. Measures of subject tolerance included the SUDs and SSQ. Performance measures included the distance traveled, number of products correctly found, number of incorrect products found, and the number of correct products that were missed. The postural measure was the average speed of head yaw movements. Due to the limited sample size, individual data are presented.

Results

Clinical Characteristics

Subject demographics and clinical data are shown in Table 1. All subjects had balance confidence that is within normal limits for community ambulating adults. All subjects had negligible perceived dizziness handicap except for the 36 y.o. female who was continuing to compensate for a peripheral vestibular injury that occurred approximately 6 months ago. The Timed Up and Go scores were within the range of normal for all subjects, and unaffected by exposure to the virtual environments. Subjects performed the Dynamic Gait Index within a clinically normal range prior to the testing. However, both of the subjects with vestibular dysfunction had worse performance on the DGI after the testing.

Table 1. Subject demographics, self-report measures (ABC and DHI), and performance on functional balance tests before and after the exposure to the virtual environments.

Subject	Demography	ABC	DHI	TUG (s)		DGI	
				pre	post	pre	post
1	36 y.o. female UVH	93%	28%	7.3	7.6	22/24	21/24
2	69 y.o. male UVH	100%	6%	8.4	8.1	22/24	19/24
3	32 y.o. male CON	99%	0%	7.4	7.3	23/24	23/24
4	67 y.o. female CON	92%	0%	9.6	9.9	23/24	23/24
5	71 y.o. male CON	94%	6%	7.8	7.7	20/24	23/24

ABC: Activity-specific Balance Confidence score (100% = complete confidence in balance); CON: Control subject; DGI: Dynamic Gait Index (score < 20 indicates risk for falls); DHI: Dizziness Handicap Inventory (0% = no dizziness handicap); TUG: Timed Up and Go (score > 13.5 s indicates risk for falls); UVH: Unilateral Vestibular Hypofunction.

Tolerance measures

Only 1 subject (36 y.o. female with UVH) had a change in SUDs or SSQ during the testing. This subject reported SUDs of 0, 0, 1, 2, 2, 3 across trials 1 – 6. In addition, she reported no symptoms on the SSQ during trials 1 and 2. She reported mild head fullness during trial 3, with additional mild dizziness on trials 4 and 5. On the final trial, she reported mild dizziness and medium head fullness.

Performance measures

Subjects were able to locate the targets without difficulty. Across all trials, S1 missed 0 products, S3 and S4 missed 1 product, S5 missed 2 products, and S2 was not able to locate 5 products. Consequently, overall performance in the task was correlated with the distance traveled through the environment (Table 2). Several trends were evident in the distance traveled. First, regarding demographic factors, the subjects with vestibular dysfunction traveled as far as the controls. However, older subjects did not move as far as the young adult subjects. Environmental factors also played a role in the distance traveled. Due to the time spent turning at the end of the aisles, subjects found fewer products and traveled less distance in the 6-aisle store. In addition, subjects were not able to go as far in the environments with the densely populated shelves compared with the sparsely populated shelves.

Table 2. Total distance traveled (m) for each of the trials. Turns at the end of aisles in trials 4 – 6 not included in computation.

Subject	Demography	Trial					
		1	2	3	4	5	6
1	36 y.o. female UVH	120	89	77	81	62	69
2	69 y.o. male UVH	120	67	57	46	39	41
3	32 y.o. male CON	120	89	76	100	80	70
4	67 y.o. female CON	120	64	52	63	65	43
5	71 y.o. male CON	120	70	39	60	45	20

Head movements

The average velocity of head yaw movements during the location of products was computed (Table 3). Subjects with UVH had the same speed of head movements as the control subjects. The older adult subjects moved their head faster than the young adult subjects, on average. There were 2 components to the greater amount of head movements: searching for the products, and referring back to the picture of the product that they needed to locate. Searching for products in the densely-populated store resulted in greater velocity of head movements compared with the sparsely-populated stores.

Table 3. Average speed of head yaw movements (deg/s) for each of the trials requiring subjects to find the products.

Subject	Demography	Trial					
		1	2	3	4	5	6
1	36 y.o. female UVH	N/A	13	15	N/A	6	5
2	69 y.o. male UVH	N/A	23	43	N/A	20	34
3	32 y.o. male CON	N/A	17	25	N/A	7	15
4	67 y.o. female CON	N/A	16	18	N/A	11	19
5	71 y.o. male CON	N/A	20	36	N/A	23	29

Discussion

In general, the virtual grocery stores were well tolerated by the control subjects and one of the patients in this study. Subject 1, the woman with UVH who had increased symptoms during the progression of the experiment, reported that shopping in an actual grocery was difficult for her. She also reported that the virtual grocery store gave her similar symptoms as when she was in an actual grocery store, including head fullness during trial 6 (6 aisles, dense products). Had the 2 patients been more acute (both had greater than 6 months of symptoms), the differences might have been greater between the control subjects and the patients. Ongoing studies are investigating the degree to which current symptoms affect the tolerance to virtual environments in the BNAVE.

The appearance of an age affect was interesting and somewhat unexpected as 4 out of 5 subjects reported that they regularly grocery shop. The investigator who observed the subjects reported that the older adults seemed to locate the objects only after they appeared on the side screens, whereas the younger subjects appeared to recognize the objects and locate them much further away while still on the front screen. Additional work will substantiate whether age is a factor in the strategies used during grocery shopping in a virtual environment. These differences in strategies could also have an impact on head-movement therapy across age.

Conclusion

This pilot study suggests that a virtual reality grocery store can be tolerated by persons with and without vestibular dysfunction. However, some symptoms can be elicited by these environments. Ongoing work will further define the utility of virtual reality for rehabilitation of persons with balance and vestibular disorders.

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