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

SUSAN L. WHITNEY, Ph.D.,[1,2] PATRICK J. SPARTO, Ph.D.,[1–3] LARRY F. HODGES, Ph.D.,[4] SABARISH V. BABU, M.S.,[4] JOSEPH M. FURMAN, M.D., Ph.D.,[1–3] and MARK S. REDFERN, Ph.D.[1–3]

ABSTRACT

People with vestibular dysfunction often complain of having difficulty walking in visually complex environments. Virtual reality (VR) 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 VR grocery stores while finding products. Perceived discomfort, simulator sickness symptoms, distance traveled, and speed of head movement were recorded. Symptoms and discomfort increased in one subject with vestibular dysfunction. The older subjects traveled a shorter 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 a shorter 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] A subset of patients with vestibular dysfunction reports that they have increased symptoms in visually complex environments, such as in grocery stores, crowds, and buildings that have high walls.[2,3] Jacob et al.[4] have labeled this symptom complex "space-and-motion discomfort" (SMD). Bronstein[3] reported that patients with vestibular disorders who experienced symptoms in supermarket aisles or in 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.[5] There is mounting evidence that habituation exercises in the form of visually provocative scenes can cause functional improvement in patients with vestibular dysfunction.[6–8]

If habituation exercises are helpful in the treatment of persons who become symptomatic in complex visual environments, virtual reality (VR) could be an ideal method for delivery of these exercises. The advantage of VR 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.[9,10] Viirre[11] and Kramer et al.[12] were the first to discuss the use of VR for persons with

[1]Department of Physical Therapy, University of Pittsburgh, Pittsburgh, Pennsylvania.
[2]Department of Otolaryngology, University of Pittsburgh, Pittsburgh, Pennsylvania.
[3]Department of BioEngineering, University of Pittsburgh, Pittsburgh, Pennsylvania.
[4]Department of Computer Science, University of North Carolina–Charlotte, Charlotte, North Carolina.

vestibular dysfunction. It has been demonstrated that VR can be used to induce adaptations in the vestibulo-ocular reflex (VOR) and reduce dizziness.[8] However, VR 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 VR grocery store environment and to examine head movement strategies that are used to locate products while shopping within the store.

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

METHODS

Two adults (36 years old [y.o.] female, 69 y.o. male) with a history of a unilateral vestibular loss (UVL) 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. The older male with UVL had complete unilateral loss subsequent to a vestibular nerve section 8 years prior to assessment. The young female with UVL had a 54% loss subsequent to a peripheral vestibular injury 6 months before the assessement. All subjects completed the Dizziness Handicap Inventory (DHI)[13] and the Activities-Specific Balance Confidence scale (ABC),[14] self-report questionnaires that assessed their perceived dizziness handicap (DHI) and provided information about fear of falling (ABC). All subjects performed the Dynamic Gait Index (DGI)[15] and the Timed Up and Go (TUG)[16] before and after the virtual reality experience.

Instrumentation

The Balance NAVE Automatic Virtual Environment (BNAVE; <www.mvrc.pitt.edu>), a wide field of view projection-based display system, was developed to investigate multi-sensory interactions in postural control.[10] Three 2.4 m $\times$ 1.8 m (vertical $\times$ horizontal) back-projected screens are arranged as shown in Figure 1. The side screens make an included angle of 110 degrees 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.

The images are displayed using Epson 810p PowerLite LCD monoscopic projectors, with a pixel resolution of 1024 $\times$ 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 images on the three PCs are synchronized and controlled by a server with an image update rate of at least 20 frames/sec.

An Airstick (Macally) game controller was used to navigate in the environment. Users could move forward, back, right and left with push-buttons. The maximum speed of movement was approximately 1.2 m/sec and the speed of rotation was approximately 12 degree/sec.

Subjects stood on a modified Neurotest force platform (Neurocom International). 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.

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 (Fig. 2A,B). The other two environments consisted of a store containing six 20-m-long aisles with either sparsely or densely populated shelves (Fig. 2C). Products covered 6.7% and 50% of the shelf space in the sparsely and densely populated shelves, respectively. For each environment, the aisle width was 3 m, and the height of the shelves was 2 m.

In each 10-m section of shelves, one of four different target products was placed. The four target products were always presented in the same order. The authors chose unfamiliar products to assure that no subject had an advantage of immediate

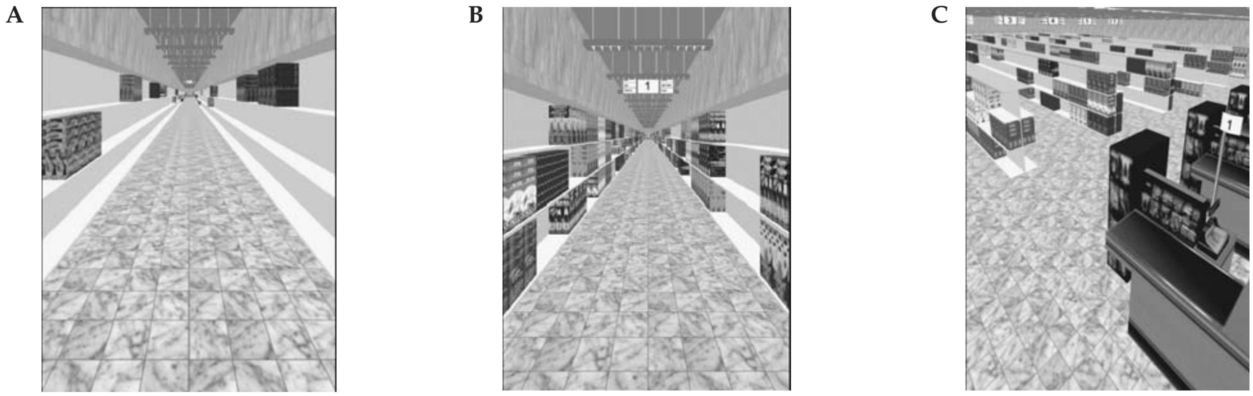

FIG. 2. Layout of virtual grocery stores. (**A**) One aisle, sparse products. (**B**) One aisle, dense products. (**C**) Six aisles, dense products.

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.

Procedure

All subjects practiced moving through the six aisle virtual grocery store with the controller held in their dominant hand prior to the start of the experiment. Subjects performed six trials in the same order, each lasting 120 sec. During the first trial, subjects moved through the 120-m, one-aisle store without looking for products. On the next two trials, subjects moved through the one-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, six-aisle store without looking for products. Subjects then moved through the six-aisle store looking for the target products on the sparsely (trial 5) and densely (trial 6) populated shelves. Initially, subjects were shown a picture on a card of the first product that they needed to find and 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 a comfortable speed while they attempted to find a maximum of 12 products per trial.

After each 120-sec trial, subjects had their blood pressure and heart rate recorded. Furthermore, all subjects reported their Subjective Units of Discomfort score (SUDs), which was rated as a score of 0–10, with 0 indicating no discomfort and 10 the most discomfort that they could imagine, and completed the Simulator Sickness Questionnaire (SSQ).[17] 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 average speed of yaw head movements was computed from the head position.

RESULTS

The older subject with a UVL had balance confidence that was within normal limits for community ambulating adults and had negligible perceived dizziness handicap; the 36 y.o. female with UVL had a DHI score of 28 at rest. The Timed "Up & Go" scores were within the range of normal for both UVL subjects both before and after exposure to the virtual environments. Both people with UVL performed the Dynamic Gait Index within a clinically normal range prior to the testing. However, both subjects with UVL had worse performance on the DGI after the testing (a loss of 1 and 3 points on the DGI).

The younger female with UVH had changes in the SUDs and SSQ during testing. She reported SUDs of 0, 0, 1, 2, 2, and 3 across trials 1–6. She reported no symptoms on the SSQ during trials 1 and 2, 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. The older male with UVL reported no symptoms during or following virtual reality exposure.

Subjects were generally able to locate the targets without difficulty. Across all trials, subject 1 missed 0 products, S3 and S4 missed one product, S5

TABLE 1. TOTAL DISTANCE TRAVELED IN METERS AND PRODUCTS MISSED FOR EACH OF THE VIRTUAL GROCERY STORE TRIALS

	Trial					
Subject/patient	*1*	*2*	*3*	*4*	*5*	*6*
1. 36 y.o. female UVL	120 (0)	89 (0)	77 (0)	81 (0)	62 (0)	69 (0)
2. 69 y.o. male UVL	120 (0)	67 (0)	57 (3)	46 (0)	39 (0)	41 (2)
3. 32 y.o. male CON	120 (0)	89 (0)	76 (1)	100 (0)	80 (0)	70 (0)
4. 67 y.o. female CON	120 (0)	64 (0)	52 (0)	63 (0)	65 (0)	43 (1)
5. 71 y.o. male CON	120 (0)	70 (1)	39 (1)	60 (0)	45 (0)	20 (0)

Turns at the end of aisles in trials 4–6 were not included in the computation.
y.o., years old; UVL, unilateral vestibular loss; CON, control.

missed two products, and S2 was not able to locate five products. Consequently, overall performance in the task was correlated with the distance traveled through the environment (Table 1). Several trends were evident in the distance traveled. First, the subjects with vestibular dysfunction traveled as far as the controls. However, older subjects did not move as far as the young 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 six-aisle store. Also, subjects were not able to go as far in the environments with the densely populated shelves compared with the sparsely populated shelves.

The average velocity of yaw head movements while searching for products was computed (Table 2). In general, subjects with UVL 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 two components to the speed 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.

DISCUSSION

In general, movement through the VR grocery stores was well tolerated by the control subjects and by one of the patients in this study. The young female with UVL who had increased symptoms during the progression of the experiment, reported that shopping in an actual grocery was difficult for her. She reported that the VR grocery store gave her similar symptoms as when she was in an actual grocery store, including head fullness during trial 6.

The appearance of an age effect was interesting and somewhat unexpected. 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 lo-

TABLE 2. AVERAGE SPEED OF YAW HEAD MOVEMENTS (DEGREE/SEC) FOR EACH OF THE TRIALS REQUIRING SUBJECTS TO FIND THE GROCERY PRODUCTS

	Trial					
Subject/patient	*1*	*2*	*3*	*4*	*5*	*6*
1. 36 y.o. female UVL	N/A	13	15	N/A	6	5
2. 69 y.o. male UVL	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

y.o., years old; UVL, unilateral vestibular loss; CON, control.

cate them much further away while still on the front screen. These observed differences could be the result of normal age-related differences in scanning strategies. Additional studies will substantiate whether age is a factor in the strategies used during grocery shopping in a virtual environment.

CONCLUSION

This pilot study suggests that movement through a VR 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 VR for rehabilitation of persons with balance and vestibular disorders.

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Address reprint requests to:
Dr. Susan L. Whitney
Department of Physical Therapy
University of Pittsburgh
6035 Forbes Tower
Pittsburgh, PA 15260

E-mail: whitney@pitt.edu