Perceived Anxiety and Simulator Sickness in a Virtual Grocery Store in Persons with and without Vestibular Dysfunction

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Introduction

People with vestibular disease often experience increased symptoms of dizziness and anxiety in visual environments that have complex textures and motion (e.g. grocery store). Visual motion and flow can cause patients with vestibular disorders to feel disoriented and nauseous. Anxiety is evident during virtual reality exposures with persons with vestibular disorders (Sparto, Whitney, Hodges, Furman, & Redfern, 2004; Whitney et al., 2005; Whitney et al., 2002; Whitney et al., 2006).

Patients with vestibular disorders who experience symptoms in supermarket aisles or moving visual surroundings demonstrate greater sway when exposed to full-field visual motion (Bronstein, 2004). Bronstein et al. demonstrated that five of 15 patients who had symptoms triggered in supermarket aisles or moving visual surroundings showed increased sway responses to full-field visual motion induced by a moving room. Bowman (Bowman, 2004) has also reported that persons with uncompensated or well-compensated unilateral vestibular hypofunction experience symptoms in a grocery store environment.

People with vestibular disorders may have greater reliance on visual cues, resulting in increased sway in visual provocative situations (Whitney et al., 2005). It has been reported that patients with vestibular disorders are sensitive to optic flow (Redfern & Furman, 1994), similar to what has been reported in persons with anxiety disorders who were sensitive to body sway during full-field visual motion from an optic flow stimulus (Redfern, Furman, & Jacob, 2006). One intervention strategy to decrease sway and anxiety is to attempt to have patients focus on proprioceptive cues to enhance postural stability, thus attempting to change their sensory weighting of postural cues (Whitney et al., 2005).

Habituation exercises (typically defined as repeated movement experiences that cause dizziness) in the form of visually provocative scenes have resulted in functional changes in patients with vestibular dysfunction (Pavlou, Lingeswaran, Davies, Gresty, & Bronstein, 2004; Vitte, Semont, & Berthoz, 1994). Vitte et al. (Vitte, Semont, & Berthoz, 1994) exposed patients with vestibular disorders to moving lights from a reflective ball with 2 horizontal bars on either side that were used as reference bars by the subjects. Subjects stood and experienced pitch and yaw flow in both directions while looking forward. The optic flow experience by Vitte et al. (Vitte, Semont, & Berthoz, 1994) is a similar visual experience to what is generated during virtual reality, i.e. the perception that the world is moving past the patient as they stand in a virtual environment. There is no immersion or true sense of reality involved in the optokinetic scenes generated by Vitte et al. (Vitte, Semont, & Berthoz, 1994) and Pavlou et al. (Pavlou, Lingeswaran, Davies, Gresty, & Bronstein, 2004). Both studies suggested that postural control improved and dizziness decreased as a result of the optokinetic exposure. Suarez (Suarez, Muse, Suarez, & Arocena, 2001) has suggested the optokinetic nystagmus may be related to falling in older adults with central vestibular disorders.

The ability of persons with vestibular disorders to tolerate visual environments is critical for the success of the virtual reality intervention. Therefore, the purpose of this study was to investigate how well persons with and without vestibular dysfunction tolerated moving through a virtual grocery store while they searched for products. In order to measure tolerance of the environment, we asked subjects to rate their perceived anxiety using the Subjective Units of Discomfort (SUD) and record their simulator sickness. The SUD scale has been used to quantify the magnitude of anxiety experienced in virtual experiences on a scale of 0 (no discomfort or anxiety) to 100 (the most discomfort or anxiety that the person could imagine) (B. Rothbaum & Hodges, 1993; B. O. Rothbaum, Hodges, & Kooper, 1997; B. O. Rothbaum & Hodges, 1999; B. O. Rothbaum et al., 1995). The SUD score has been shown to decrease over time after exposure to virtual scenes (B. O. Rothbaum, Hodges, & Kooper, 1997; B. O. Rothbaum & Hodges, 1999; B. O. Rothbaum et al., 1995; Sparto, Whitney, Hodges, Furman, & Redfern, 2004; Whitney et al., 2005). Kennedy et al. (Kennedy & Lane, 1993) developed a 16-item simulator sickness questionnaire (SSQ) to determine the degree of simulator sickness experienced during virtual reality exposures. The SSQ has been used in persons with vestibular disorders to determine their level of discomfort with the virtual experience (Whitney et al., 2005; Whitney et al., 2006).

Methods

Twenty healthy subjects with no evidence of neurological disease (10 female, mean age 45 y, range 21 to 79 y) and 10 patients with unilateral vestibular hypofunction, UVH (4 female, mean age 58 y, range 37 to 69 y) participated. All healthy subjects had undergone a neurologic screening and had a normal vestibular test battery that included electronystagmography (positional testing, calorics and oculomotor), rotational chair, and computerized dynamic posturography. Patients underwent the same test battery and all were diagnosed with unilateral peripheral vestibular hypofunction.

A single-aisle virtual grocery store was displayed in a full field-of-view CAVE-like virtual environment (2.4 m high, 2.4 m wide, 1.5 m deep, Figure 1) (Sparto, Whitney, Hodges, Furman, & Redfern, 2004). 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^{o} 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 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 30 frames per second. Perspective was not updated based on head location.

On each of 2 separate visits, subjects navigated down the aisle by: a) standing and pushing forward on a joystick, or b) walking on a custom-made treadmill placed within the environment. Subjects performed 6 trials divided into 2 blocks: a walking block and a standing block of trials; the order was counterbalanced across visits. During two of the 6 trials (i.e. one in each block), subjects were asked to search for common cereal boxes (Frosted Flakes and Cheerios) that had been pseudo-randomly placed 20 times along the length of a 120 m aisle. The aisle was a repeating pattern of shelves that were 5 m long with a 2 m inter-shelf break. The other parts of the aisle were completely filled with 30 other brands of products. The ratio of the number of “target” products to the number of “distractor” products was approximately 8% (Search Full condition). During two more of the trials, subjects again searched for the 2 target products, but half of the shelf space was empty, resulting in a target-to-distractor product ratio of approximately 16% (Search Half condition). On the other 2 trials, subjects locomoted down the aisle without searching for any products (No Search condition).

Prior to the testing on each visit, products were displayed on a standard computer screen to ensure that the subjects would be able to recognize the products in the virtual grocery store. Once the investigator was comfortable that the subjects could recognize the targets, subjects were trained how to move through the store using the treadmill and joystick.

The speed of the treadmill was controlled by the amount of force subjects exerted on an instrumented shopping cart. The speed of movement through the store was matched to the treadmill speed during the walking trials. During the standing trials, the speed of movement was controlled by pushing forward on the joystick. The maximum speed of movement on the treadmill and in the store was 1.2 m/s. Each visit, subjects underwent several practice trials to ensure that they were comfortable with the equipment and procedures. All subjects were secured to an overhead harness to ensure that they were safe on the treadmill.

Figure 1. Subject walking through virtual grocery store while pushing on physical grocery cart instrumented with force transducers. The speed of the treadmill and movement through the store is proportional to the amount of force applied to the cart handle. Speed is limited to 1.2 m/s.

Perceived anxiety was measured prior to testing and after each trial using the SUD scale, in which 0 corresponded to no anxiety and 100 to the worst-possible anxiety. In addition, prior to testing and after each trial, subjects completed the Kennedy Simulator Sickness Questionnaire (SSQ), in which subjects rated the intensity of 16 symptoms from 0 (none) to 3 (severe). The number of symptoms that had an intensity greater than 0 for the SSQ was computed for each trial.

The scores from both measures were not normally distributed; in particular, there were a large number of trials in which the SUD was 0, and no symptoms were reported on the SSQ. Therefore, differences in SUD and SSQ between healthy controls and subjects with UVH were examined with the non-parametric Mann-Whitney U test, using the median of each subject's scores as the estimate of central tendency. Between-visit and between-trial differences were tested using the non-parametric Friedman test, again using the median of each subject's scores.

Results

SUD

The prevalence of SUD ratings that were greater than zero during the testing demonstrate a large difference between controls and subjects with UVH (Table 1). After 81% of the trials, subjects with UVH had a SUD score greater than zero, compared with 39% of the trials in controls.

Table 1. Percentage of trials in which controls (CON) and subjects with unilateral vestibular hypofunction (UVH) reported Subjective Units of Discomfort (SUD) greater than zero, or reported at least one symptom on the Simulator Sickness Questionnaire (SSQ).

% non-zero events	SUD	SSQ
CON	39%	29%
UVH	81%	81%

Subjects with UVH had greater median SUD scores compared with controls during both the pre-test assessment and virtual reality exposure (Table 2, $p = 0.002$). However, there was no difference in the change in SUD from pre-test to virtual reality exposure between the two subject groups. None of the experimental factors had a significant effect on SUD score, including: visit 1 vs. visit 2, standing vs. walking, searching vs. not searching, or order of trial.

Table 2: Range of median Subjective Units of Discomfort (SUD) scores reported before and during exposure to virtual grocery store. Median scores for "Pre-Test" computed from 2 trials (2 visits X 1 trial). Median scores for "Test" computed from all 12 trials (2 visits X 6 trials). SUD values from one control subject were missing.

SUD	Pre-Test	Test
CON	0 for 11 subjects	0 for 11 subjects
	2.5, 3.5, 4, 4, 5, 9, 12.5, 30	1, 2.5, 4, 4, 6.5 10, 10.5, 20
UVH	0 for 1 subject	0 for 2 subjects
	1, 9, 10.5, 12.5, 15, 25, 25, 30, 30	10, 11.5, 17.5, 22.5, 22.5, 27, 29, 60

SSQ

The prevalence of SSQ ratings that were greater than zero during the testing also show group differences (Table 1). After 81% of the trials, subjects with UVH reported at least one symptom, compared with 29% of the trials in controls.

During the pre-test and exposure to the grocery store, subjects had greater number of symptoms reported on the SSQ than controls (Table 3, $p<0.002$). The range of median number of symptoms reported by the subjects with UVH was 0 to 12 out of 16. The range of median number of symptoms reported by control subjects was 0 to 2 out of 16. The change in number of SSQ symptoms reported from pre-test to virtual reality exposure did not differ between the groups. As with the SUD, no experimental factors affected the number of symptoms reported on the SSQ. For the control subjects, the median SSQ score was 0 for the Pre-Test and Test; for the subjects with UVH, the median SUD score was 14 for the Pre-Test and 20 for the Test.

Among the subjects with UVH, a significant correlation existed between the median SUD and median number of symptoms reported on the SSQ (Spearman rho = 0.850, p = 0.002). No such relationship existed for the control subjects (Spearman rho = -0.09, p = 0.72), probably due to the large number of scores equal to zero.

Table 3: Range of median Simulator Sickness Questionnaire (SSQ) scores reported before and during exposure to virtual grocery store. Median scores for "Pre-Test" computed from 2 trials (2 visits X 1 trial). Median scores for "Test" computed from all 12 trials (2 visits X 6 trials).

SSQ	Pre-Test	Test
CON	0 for 15 subjects	0 for 14 subjects
	0.5, 0.5, 0.5, 0.5, 1	0.5, 1, 1, 1, 2, 2
UVH	0 for 2 subjects	0 for 2 subjects
	0.5, 1, 2, 4, 4.5, 6, 8, 9	1, 1.5, 2, 2, 4, 9, 9.5, 12

Discussion/Conclusion

Subjects with and without vestibular abnormalities were able to complete all trials when navigating through a virtual grocery store, except for one patient. She was unable to complete the final trial on her second visit due to nausea. Patients with vestibular disorders reported more symptoms during the pre-test than the control subjects. These remained relatively stable over the 6 trials, suggesting that subjects in both groups tolerated exposure to the virtual grocery store. Thus future studies of the use of a virtual grocery store for rehabilitation of persons with vestibular disorders are warranted.

It was surprising that there was not an effect noted between the walking and standing trials. It had been expected that patients would have more difficulty with the standing trials because of the conflict created between the lower extremity sensation of static posture and the strong visual perception of movement. Patients and control subjects seem to be equally able to manage this somatosensory-visual conflict and resolve it, as no patients fell or reported problems with the visual scene.

Subjective measures recorded after virtual reality exposure suggest that there were no differences between visits, making changes demonstrated from virtual reality exposure more likely to be a change in perceived health status versus learning of the virtual reality task. These data suggest that subjective measures recorded after exposure to the virtual reality grocery store are stable over time.

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