RELATIONSHIPS BETWEEN HEAD-SHOULDER DIVERGENCES AND SICKNESS IN A VIRTUAL ENVIRONMENT

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Sickness is often experienced during exposure to virtual environments (VEs). Optical flow patterns may influence this VE sickness. We investigated the relationship between VE sickness and head-shoulder divergence angles while moving through a VE. The VE experience induced some level of VE sickness in all participants. Those not completing the study evidenced significantly more severe VE sickness symptoms than those completing it did. No relationships between head-shoulder divergence and sickness were revealed for experimental dropouts. However, significant correlations were found between several sickness measures and head-shoulder divergences for those completing the study. An interaction between head-shoulder divergence and time on task may exist.

INTRODUCTION

Varying levels of sickness are often experienced during or after exposure to computer generated Virtual Environments (VEs) (Kolasinski, 1995). Although originally developed for use with traditional simulators, Kennedy, Lane, Berbaum and Lilienthal's (1993) self-report Simulator Sickness Questionnaire (SSQ) is often used in the study of VE sickness. Kennedy et al, have identified three sets of symptoms associated with such sickness: Nausea, Oculomotor Discomfort, and Disorientation. A Total Severity score is also calculated.

The most prevalent theory of simulator sickness is the sensory conflict theory, which is borrowed from motion sickness research. This theory states that when information from one sense is inconsistent with another, sickness occurs. Conflict within a sense may also produce sickness (Kolasinski, 1995).

Problems associated with optical flow are considered to be important factors in VE sickness (Kolasinski, 1995). Optical flow is the amount of visual information moving across the retina during periods of self- or environmentally- induced motion. There are two general types of optical flow patterns: radial and linear. When, for example, the individual is fixated on the point to which he or she is moving, the flow vectors radiate outward from that "anchor" towards the observer, and spread around the observer and into the periphery as they come closer (Sekular & Blake, 1990), hence the term radial. When the individual is facing perpendicular to the direction of motion the flow pattern moves sideways across the visual scene

(Gibson, 1950), and is therefore linear in nature. If the individual is not looking parallel or perpendicular to the direction of motion, the flow in the visual field will be a combination of these two flow patterns. Thus, optical flow simultaneously indicates direction of movement and direction of gaze.

However, the visual perceptual system does not work in isolation. Although we can speak of optical flow, the individual who is moving is also receiving vestibular feedback. This vestibular feedback also includes both linear and rotational components from the statcoyst organ and semi-circular canals, respectively.

Traditionally in VEs optical flow and vestibular information are in conflict. Although the vestibular system indicates no motion because the user is typically sitting or walking in place (even on a treadmill, there is no actual forward motion), the optical flow of the visual scene indicates forward motion. Thus, the grounds for sensory conflict are present.

VE hardware and software have become more sophisticated and multiple position sensors are now available. By using sensors on both the HMD and shoulders, a system can be configured that allows the user to look in one direction and move in another. In addition, this promotes more natural movement in the VE as no joysticks or unidirectional treadmills are needed. In this way, more proprioceptive feedback for body movement is afforded, (e.g., the user's body is moving rather than movement being mediated through a joystick, and the body can turn to move in any direction rather than being limited to the direction of the treadmill). Thus, the user receives proprioceptive information about body position and movement. From a data collection point of view, using separate position sensors to determine gaze and movement direction enables better independent tracking of these positions.

The current paper examines the relationship between head movements made while walking in a multi-sensor VE and VE sickness based on data from a recent experiment conducted by the U.S. Army Research Institute's Simulator Systems Research Unit (ARI SSRU). We investigated the average angle of divergence between head and shoulders and the variance in this divergence as those values relate to VE sickness. The greater the divergence between the direction of movement and head position, the more the individual is looking in one direction while walking in another. It therefore also indicates the type of optical flow pattern experienced. The variance of this divergence takes into account the spread of this difference over time, (i.e., how much someone looks around). As this experiment had one of the highest dropout rates in any experiment in the research program at ARI SSRU (approximately 25%), we also examined this phenomenon by comparing those who completed the study (finishers) and those who dropped out due to sickness (dropouts).

METHOD

Participants

18 females and 24 males, ranging in age from 18 to 44 years, with a mean age of 22.2 years participated in this study. All participants had normal or corrected to normal vision with no color blindness, and no history of seizures or severe motion sickness. Four females and six males terminated the experiment due to VE sickness.

Materials

The University of Central Florida's Institute for Simulation and Training developed the VE graphical environment and data output software. The experimental environment was generated on a Silicon Graphics ONYX^{tm}, which also captured the data output. Participants viewed the VE through a Virtual Research Corporation VR4 HMD. The HMD had a 48°(H) X 36°(V) field of view with a resolution of 3.88 arcmin/pixel. The position of the participant's head, shoulder, feet, right arm, and right hand were tracked independently of one another by an Ascension Flock-of-Birds^{tm} magnetic tracker.

The experimental task required participants to search for and acquire target briefcases in a series of VE rooms. Twelve office building rooms were constructed and arranged in six different series of six rooms. Each series comprised one experimental trial and all six series were presented in a counterbalanced order. Participants moved through the VE by walking in place. Each time the sensors on the legs registered a vertical separation of 4 inches between them, the participant moved forward one step. The participant could stop to look around or continue moving as he or she desired. The participant moved in the direction of shoulder orientation. Because the head and shoulder position trackers were independent of one another, the participant was able to move in one direction while looking in another. Head and shoulder yaw was recorded approximately every 0.75 seconds.

Four SSQ's were administered: before the first trial (pre-SSQ), after the third trial (mid-SSQ), after the sixth trial (post-SSQ), and 30 minutes after the end of the sixth trial (recovery SSQ). Several other questionnaires were also administered before and after immersion in the VE.

Procedure

Participants read a summary of the experimental purpose, tasks, risk of VE sickness, and their right to withdraw from the study at any time without penalty. After signing a consent form, several pre-exposure questionnaires including the pre-SSQ were administered. The answers to these questions determined participants' eligibility for the study.

Once accepted into the study, participants watched a video showing how sensors would be attached, and demonstrating experimental procedures, movement techniques and target acquisition. Participants then "suited up" and entered the VE. After following a scripted training session in a practice room, they completed three experimental trials with a mandatory 5-minute break between trials during which the HMD was removed. For each trial, the participants were instructed to complete the task as quickly and accurately as possible. There was no time limit for the trials. After the third trial they removed all the VE equipment and took a 15-minute break during which they completed the mid-SSQ. Participants then completed the last three trials with the same mandatory 5-minute break between trials. After the sixth trial, they filled out the post-SSQ and several other questionnaires not related to this study. All participants remained at the experimental site for approximately 30 minutes after their exposure to the VE to allow any possible aftereffects of VE exposure to diminish. A recovery-SSQ was administered to record symptom levels after the recovery period.

RESULTS

Those who completed the study (finishers) were in the VE significantly longer than those who did not (dropouts), $F(1, 41) = 52.10$, $p < .001$. Table 1 presents the average, minimum, and maximum time in the VE for finishers and dropouts.

Table 1
Time (minutes) spent in the VE by Group

Group	Minimum	Maximum	Mean
Finishers	42.58	104.05	67.45
Dropouts	10.76	56.73	31.65

A paired t-test revealed significant differences between Total Severity scores for the pre- (PreTot) and post- (PstTot) SSQs for both finishers and dropouts (see Table 2). Thus, both groups developed significant symptoms during the experiment—a common finding in our research program.

Table 2
Comparison of Pre- and Post- SSQ Total Severity Scores by Group

Group	PreTot	PstTot	Df	t	Signif.
Finishers	3.51	19.08	31	-4.562	0.001
Dropouts	5.23	76.22	9	-6.974	0.001

An ANOVA also revealed a significant difference between the PstTot sickness scores of finishers and dropouts ($F(1, 41) = 49.293$, $p < 0.001$). Finishers reported less severe symptoms than dropouts. Table 3 presents the average SSQ post-exposure subscale scores for each group.

Table 3
Average Post-Exposure Subscale Scores by Group

Group	Naus.	Oculomo.	Disorien	Total
Finishers	14.91	15.40	21.75	19.28
Dropout	73.14	43.79	86.61	73.56

The difference between head and shoulder yaw angles (in degrees) was sampled approximately every 0.75 seconds. A large value means a greater difference (measured in degrees) between the direction the participant was looking and the direction he or she was walking. Thus, this divergence is a measure of the head shoulder (H/S) offset or deviation. Dropouts had a significantly greater average H/S divergence angle than finishers $F(1, 41) = 4.171$, $p < 0.048$. Table 4 presents the minimum, maximum and means of each group.

Table 4
Head-Shoulder Divergences while Walking by Group

	Minimum	Maximum	Mean
Finishers	5.81°	15.29°	10.62°
Dropouts	4.78°	19.40°	12.95°

Although the mean divergence angle indicates on average how many degrees away from movement direction the individual looked, it does not provide the best measure of how much the individual actually looked around. For example, two people could both average 15° of divergence. However, one person could have steadily maintained a 15° divergence, while the other actually looked around a great deal. Therefore, the variance in the amount of H/S divergence was examined.

The variance in head and shoulder directional divergences for intervals during which the participant moved for two or more seconds was derived for each participant for each trial, the two 3-trial "segments," and the entire experiment. The head-shoulder divergence variances were used in the following analyses. An ANOVA revealed no significant difference in the average variance of H/S divergences while walking between finishers and dropouts ($F(1, 41) = 0.38$, $p < 0.846$). Table 5 presents the minimum, maximum and average variances for these divergences across the total experiment.

Table 5.
Head-Shoulder Divergence Variances (in degrees^2) by Group while Walking

Group	Minimum	Maximum	Mean
Finishers	717.33	7946.34	2409.67
Dropouts	497.74	4951.34	2303.57

Using the Bonferonni correction for multiple comparisons analyses (i.e., 0.05/5 = 0.01), significant positive correlations between several SSQ subscales and the H/S divergence variances were revealed for the finishers. A significant correlation was found between the mid-SSQ Nausea scale and the variance in head-shoulder divergences over the first three-trial segment ($r = 0.457$, $p < 0.009$). In addition, significant correlations between the H/S divergence variance across all 6 trials and the post-SSQ subscales were also found: Nausea ($r = 0.482$, $p < 0.005$), Oculomotor Discomfort ($r = 0.455$, $p < 0.009$), and Total Severity ($r = 0.478$, $p < .006$).

However, no significant correlations were revealed between the H/S divergence variance and any SSQ scores for dropouts.

DISCUSSION

Analyses revealed a significant difference in sickness after exposure to the VE for all participants. Thus, the task induced some level of VE sickness in all participants. In addition, there was a significant difference in sickness scores between finishers and dropouts. Dropouts evidenced significantly more severe VE sickness symptoms than did finishers. These results are not surprising. Research indicates VEs tend to cause sickness, and it is reasonable that those feeling particularly ill would choose to terminate their VE exposure.

However, there were several intriguing differences between the two groups in terms of head-shoulder divergence angles. Given that the average head-shoulder divergence angle was greater for dropouts (12.95° vs. 10.62°), the different optical flow pattern between the two groups might have been a key factor in increasing sickness. Because neither group on average was looking either parallel or perpendicular to the direction of motion, a critical combination level of radial and linear flow that induces sickness might have been revealed here in the significant difference in the average divergence angle between the two groups

The variance in head-shoulder rotational angle divergences was calculated for continuous movement intervals. The higher this value the more the participant tended to look around while moving.

There was no significant difference in the variances for finishers vs. dropouts.

On the other hand, for finishers, H/S divergence variance values significantly correlated with several SSQ sickness measures. H/S divergence variances correlated significantly with the Nausea subscale of the mid-SSQ. As the study continued, the H/S divergence variance correlated significantly with more facets of VE sickness. The Nausea, Oculomotor Discomfort, and Total Severity scores from the post-SSQ correlated significantly with the total H/S divergence variance. Thus, there may be an interaction between H/S divergence variances and time on task in relation to sickness.

However, there was no significant correlation with Disorientation for either group. It seems reasonable that head movement would be associated with disorientation measures (e.g., vertigo, dizziness). Sensory conflict was present in this study in that the visual scene contained rotational and linear elements, but walking in place only allowed rotational vestibular input as no linear progress was made. It is possible that these facets may be unrelated to Disorientation, or that any vestibular stimulation (linear or rotational) while walking helps reduce Disorientation. Alternatively, the more direct movement paradigm and increased proprioceptive feedback possible in a system that does not use joysticks or even treadmills may reduce Disorientation. Further research into these possibilities is warranted.

Several hypotheses exist to explain the lack of correlations for the dropouts. There may be some people who will feel poorly in a VE no matter how much or how little they move about. Alternative factors to explain the rapid and significantly higher symptom levels must be investigated, including individual, task, or hardware/software configurations and their interactions. As noted above, the grounds for sickness were present according to the sensory conflict theory. Although visually the optical flow pattern contained linear and rotational information, only rotational vestibular information was available, because the user did not actually move forward. The dropouts may simply be more sensitive to this disjunct, which made them more uncomfortable and did so relatively quickly. However, the significant correlations with H/S divergence variances and sickness for the finishers may indicate over time this conflict becomes a problem for most people. Finally, the lack of significant correlations may be an artifact of the smaller n for the dropouts (10) compared to the finishers (32). There simply may not have been enough data points to find significant correlations.

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