A "NATURAL" INDEPENDENT VISUAL BACKGROUND REDUCED SIMULATOR SICKNESS

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Several studies indicated that an independent visual background (IVB) reduced simulator sickness (SS) and balance disturbance associated with exposure to virtual environments (VEs) and motion simulators. A recent study showed that an IVB comprised of an earth-fixed grid was less effective in a complex driving simulator than in a simple VE. Subjects' post-experiment reports indicated that the VE motion "induced" motion of the earth-fixed grid IVB. This led to the suggestion that an IVB comprised of clouds would be less subject to induced motion and therefore would alleviate nausea more effectively than a grid IVB. Clouds are "natural" and are usually perceived as relatively stable, whereas a gird has no inherent stability. Twelve subjects were exposed to complex motion through a simulated environment in a driving simulator under 3 IVB conditions: grid, less clouds, and many clouds. They reported less nausea when the many-cloud IVB was used relative to the grid IVB condition.

INTRODUCTION

Prothero (1998) suggested that understanding of presence and motion sickness in virtual environments (VEs) and motion simulators could be facilitated by considering "rest frames." The rest frame can be defined as the particular reference frame used by an observer as the basis for spatial judgements, such as what should be regarded as "stationary." Based on this construct, Prothero proposed a procedure for reducing sickness and balance disturbance associated with exposure to motion simulators and VEs. A visual scene can be divided into components including one labeled the "content of interest" and another called the "independent visual background" (IVB). Based on the cue conflict approach to motion and simulator sickness (Griffin, 1990), an IVB could provide visual motion and orientation cues that match those from the vestibular receptors. Consequently, inclusion of an IVB in a VE should reduce VE sickness and simulator sickness (SS). Several previous studies, including one presented at the 2001 HFES meeting, supported the hypothesis that inclusion of an inertially stationary IVB in a fixed-base VE reduced SS and balance disturbance evoked by visual scene motion (Prothero et al., 1999; Duh 2001; Duh et al., 2001a; Duh et al., 2001b; Kim et al., 2001; Lin et al., 2001).

The previous studies revealed large differences between individual subjects with respect to IVB effectiveness, especially for reducing SS. Except for the one by Prothero et al., all of those studies used an earth-fixed grid for the IVB. The grid consisted of intersecting horizontal and vertical lines. The grid lines were stationary with respect to the subject and the reference frame provided by gravity. The number of grid lines varied across experiments. The grid was located in front of the virtual scene or behind it for different experiments. Further, the grid covered the entire visual scene or was placed at various locations in the visual field.

During the post experiment debriefings, some of the subjects in the previous experiments reported disturbing effects due to apparent grid IVB motion. A few subjects described experiences in a grid IVB exposure condition in following manner: "I guessed that the grid made me more dizzy and sick. It waved weirdly, and I couldn't understand why it moved that way." This disturbance may have been caused by induced motion.

When observers see a visual "frame," such as a rectangle, move to the right, they usually report that an earth-fixed ball inside the rectangle moves to the left. The illusory motion of the ball is called induced movement (Duncker, 1929). This basic phenomenon has been the subject of numerous studies. Motion induction is largest across a limited range of scene motion velocities (Mack, 1986). It is most pronounced when the frame and target are at the same distance

from the observer; relative location of the frame in the visual field (peripheral versus central) is another critical factor (Gogel et al., 1971).

Movement of an earth-fixed grid IVB induced by visual movement has been noticed, but not systematically examined, in several previous experiments (e.g., Prothero et al., 1999; Duh et al., 2001a; Duh et al., 2001b). Illusory IVB motion has been induced by visual scenes composed of black and white patterns (bars, radial patterns) as well as by a low-resolution cartoon scene. Induced IVB motion was greater when the moving scene was a complex cartoon environment (Crayolaland) presented in a driving simulator that included a full-size Saturn car. In this situation, subjects apparently tended to select the Crayolaland scene as the rest frame.

Motion induction was most pronounced when the grid IVB was perceived as part of the car, as something pasted on the windshield. Most subjects have extensive experience driving about in moving cars; they expect cars to move relative to a fixed background. Consequently, any visual scene component perceived as part of the car would be perceived as moving with it. Of course, the car and grid IVB were earth-fixed; only the Crayolaland scene was moving with respect to the inertial reference frame provided by the earth.

Induced motion of the IVB may increase SS for some subjects. In this case, the IVB may be perceived as another "moving object" in the scene rather than a "stationary background," and this "moving object" covers a very wide field of view (FOV), the whole scene. Subjects sometimes reported that the grid IVB moved strangely relative to Crayolaland objects (as well as the reference axes of subjects) and this probably disturbed subjects' vection (visually-induced self-motion) evoked by the Crayolaland motion.

Purpose. The above observations indicate that, apparently due to induced motion, a grid IVB may not be effective for reducing SS in realistic, wide FOV motion simulators. That led to the following question. Is a "natural" IVB, one composed of "meaningful" objects such as clouds, more effective than a grid for alleviating SS?

METHOD

Subjects. 4 women and 8 men, ages 20 to 40 were recruited from the Human Interface Technology Laboratory subject pool. No subjects reported a history of auditory disturbance, balance disorders, back problems, or high susceptibility to motion sickness. Subjects were paid $15/ hour. The University of Washington Human Subjects Review Committee approved the protocol.

Apparatus. We used a Real Drive driving simulator (Illusion Technologies International, Inc.) including a full-size Saturn car (General Motors Company), 3 800 x 600 pixel Sony Superdata Multiscan VPH-1252Q projectors, and 3 230 x 175 cm screens. A virtual world (Crayolaland) was generated by the CAVE software library (developed at the EVL, University of Illinois, Chicago) using a Silicon Graphics Onyx2 system. Crayolaland is a cartoon world that includes a cabin, pond, flowerbeds, and a forest. Additional software permitted inputs from a controller and replay of prerecorded trajectories through Crayolaland. In addition to the Crayolaland scene, an IVB composed of 8 horizontal and 35 vertical grid lines, an IVB composed of 7 clouds, or an IVB composed of 28 clouds was presented behind the Crayolaland mountains. The computer-generated images were presented on the 3 screens as a panoramic scene and subtended a 220° horizontal FOV. The scene was presented in stereo using CrystalEyes stereo glasses (StereoGraphics Inc.) that alternatively masked the left and right lenses.

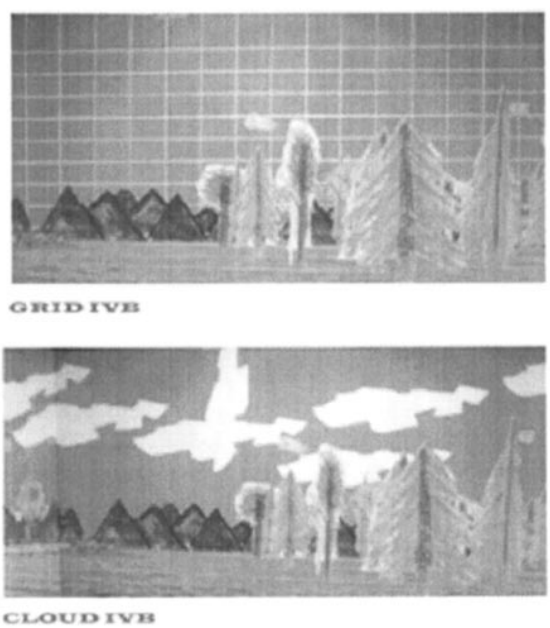

Figure 1. Crayolaland scene with grid IVB (top) and cloud IVB (bottom).

Procedure. The independent variable was IVB condition: Grid (G); Less clouds (L); Many clouds

(M). Using a within-subjects experimental design, each subject was exposed to each of the 3 IVB conditions. 2 subjects were randomly assigned to each of the 6 orders of IVB condition. Instructions were as follows:

> Welcome to the driving simulator! You are participating in a virtual environment experiment. We are investigating whether the virtual environment gives you a sense of presence, how strongly the virtual environment evokes a sense of "being there." This experiment includes 3 trials. During each trial, you will experience 2 minutes following a pre-recorded path through a virtual environment called Crayolaland. There will be slight differences in the virtual environment between trials. If you notice the differences, please let me know after each trial. After each trial, we will ask you several questions regarding your sense of presence. Since simulator sickness is a side effect of exposure to virtual environments, we will also ask you to tell us about any simulator sickness symptoms.

Before each trial, subjects filled out the Revised Simulator Sickness Questionnaire (RSSQ; Kim, 1999) to measure their baseline simulator sickness symptoms. (The RSSQ uses many items from the widely-known Simulator Sickness Questionnaire, SSQ -Kennedy et al., 1993, employs a slightly different scoring procedure and adds a Strain/ Confusion subscale.) Subjects were then exposed to a motion trajectory through Crayolaland for 2 min. After each exposure, they filled out the RSSQ and the presence and enjoyment sections from the E^2I (Lin et al., 2002). Between trials, subjects rested for at least 5 min or until any SS symptoms associated with the previous trial had returned to baseline. Total experiment time was about 1 h.

RESULTS

RSSQ scores (Total, Nausea subscale, Disorientation subscale) are illustrated in Figures 1 and 2. The trend was for lower RSSQ scores (less sickness) when a natural IVB was used rather than a grid, except for the Oculomotor and Strain/Confusion subscales.

Specific directional hypotheses were developed prior to data collection based on detailed graphical models. (This permitted analysis using one-tailed statistical tests.) The hypotheses were: (1) SS would be greater for the grid IVB condition than the many clouds condition; (2) SS would be greater for the grid IVB condition than for the average of the less clouds and many clouds conditions, and (3) SS would be greater for the less clouds condition than the many clouds condition.

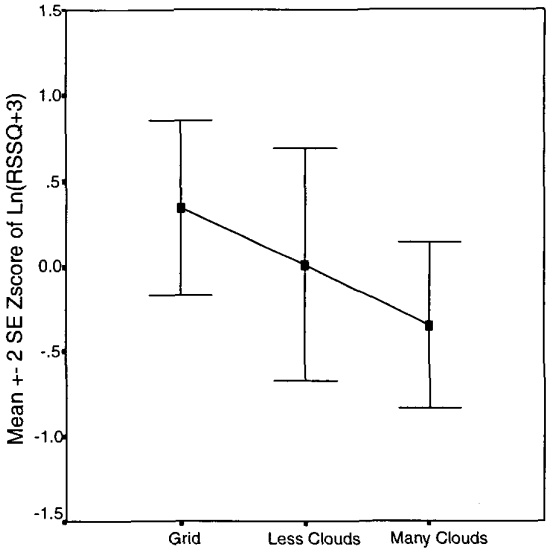

Figure 2. Total RSSQ scores as a function of IVB condition. Less SS was reported in the many-clouds IVB condition than the grid IVB condition.

Paired-t tests were calculated to examine the hypotheses. Diagnostics were performed to examine the normality and equal variance assumptions for the RSSQ and E^2I data. Based on normal quantile-quantile plots, residual plots, and the Bartlett test of homogeneity of variances, logarithmic transformations of the RSSQ Total score and subscales were performed to satisfy the assumptions of the analyses.

For the RSSQ scores, the resulting one-tailed paired t-tests show that hypothesis 1 was supported for the Total and Nausea subscale scores [$t(11)=1.89$, $p=0.043$; $t(11)=3.19$, $p=0.004$, respectively]. Hypothesis 2 was supported for the Nausea subscale scores [$t(11)=3.09$, $p=0.005$]; but not for the Total scores [$t(11)=1.43$, $p=0.090$]. Neither the Total nor subscale data supported hypothesis 3; however, the Nausea subscale scores approached significance [$t(11)=1.54$, $p=0.076$]. Scores on the Nausea subscale were highly significant for both hypotheses 1 and 2: subjects reported significantly less nausea symptoms when a natural IVB was presented rather than a grid IVB.

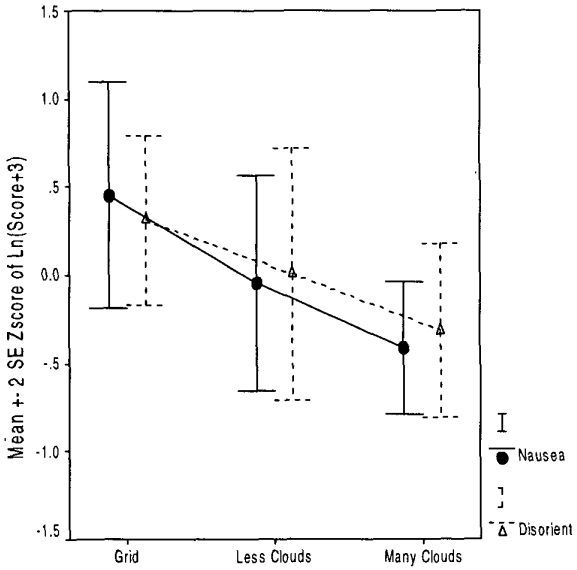

Figure 3. RSSQ Nausea and Disorientation subscale scores as a function of IVB condition. The results illustrated in Figure 2 are due primarily to Nausea and Disorientation subscale .

For further analysis of total RSSQ scores, subjects were segregated into susceptible and non-susceptible groups using the cluster analysis procedure of partitioning around mediods. Subsequent repeated-measures analyses of variance (ANOVAs) revealed no differences across IVB conditions for the non-susceptible subjects. For susceptible subjects, hypothesis 2 was supported [$F(1,5)=7.26$, $p=0.043$] and hypotheses 1 and 3 approached statistical significance [$F(1,5)=6.32$, $p=0.054$] and [$F(1,5)=5.15$, $p=0.073$], respectively.

In terms of the E^2I data, the mean scores for the Presence Subscale dropped slightly across the gird, less clouds, and many clouds conditions; whereas the mean scores for the Enjoyment subscale increased slightly across the 3 conditions. However, neither the Total E^2I scale scores nor the Presence and Enjoyment subscale scores differed significantly across conditions based on the repeated measured ANOVA [E^2I: $F(2,22)=0.08$, $p=0.908$; Presence: $F(2,22)=0.41$, $p=0.612$; Enjoyment: $F(2,22)=0.46$, $p=0.633$]. Even the paired t-tests for the 3 pairs of conditions used in the SS hypotheses failed to reveal any significant differences on E^2I and its subscales.

DISCUSSION

Results from this study indicate that a "natural" IVB composed of "meaningful" objects (clouds) is more effective than a grid for alleviating SS. The data did not clearly support the suggestion that numerous clouds would be more effective than scattered ones.

Motion induction appears to be the basic problem for using a grid IVB. This problem is likely to be encountered in large, realistic motion simulators; consequently, the results from this study are likely to generalize most readily to that type of simulator rather than one that uses a small FOV or a head-mounted display.

Highly significant differences were found for the Nausea RSSQ subscale data. This finding is quite impressive given the variability across subjects, as indicated by the error bars in Figures 2 and 3, and the fact that 2 of the 12 subjects reported no SS. None of the analyses for the other subscale scores approached significance, which may account for the lower effect size for the RSSQ Total Score analyses.

For the purposes of alleviating disturbance in a VE or motion simulator, it is appropriate to consider primarily the Nausea subscale scores. This subscale is composed of items, including increased salivation, sweating, difficulty concentrating, burping, general discomfort, stomach awareness, and nausea, that are correlated with true motion sickness. The Oculo-motor and Strain/ Confusion subscales are more indicative of inappropriate VE optics and difficulty in performing the tasks in the VE. IVBs were not intended to resolve oculomotor and strain/ confusion problems.

The absence of significant differences for the E^2I scores and the Presence and Enjoyment subscale scores suggests that different types of IVBs do not significantly influence subjects' presence and enjoyment levels. The distribution of mean scores for the Presence subscale implies a positive correlation between presence and SS in the low SS range; whereas the distribution of mean scores for the Enjoyment subscale hints at a negative correlation between enjoyment and SS. A significant negative correlation between Enjoyment subscale scores and the RSSQ Total score was found [Pearson's R =-0.486, p = 0.003]. This finding is consistent with the results from a previous study (Lin et al., 2002).

IVB luminance and brightness are possible confounding variables in the present study. The total IVB luminance was greatest in the many-clouds condition, lower in the less-clouds condition, and least in the grid condition. Several previous studies have demonstrated that reduction of postural disturbance by an IVB was positively correlated with IVB luminance (see Duh et al., 2001). It is possible that luminance differences contributed to the effects reported here.

In a previous study, effects of subjects' expectations were demonstrated (Kim et al., 2001). The instructions used in this study were similar to those for a "non-expectations group" in the Kim et al. study. In this study, quite clear results were obtained despite the fact that the instructions were designed to misdirect the subjects regarding the purpose of the experiment and expected effects of the IVBs.

In conclusion, the "natural" IVB comprised of clouds more effectively alleviated nausea than the less natural, more ambiguous grid IVB.

ACKNOWLEDGEMENTS

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