Circumventing Side Effects of Immersive Virtual Environments

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1. INTRODUCTION

Making head movements during exposure to some forms of passive transport or when the visual feedback about one's movements is distorted has long been recognized as disorienting and nauseogenic (1, 2). Some of the most clear and dramatic results of space flight research came from the Skylab M-131 experiment in which astronauts experienced extreme disorientation and severe motion sickness while making head movements in a rotating chair pre-flight in a 1 g terrestrial force background but were free of symptoms and dizziness when first tested in 0 g on the sixth day in orbit (3). Understanding side effects of rotation is important because NASA is contemplating using a rotating space vehicle to generate artificial gravity for long duration space missions. The rotating vehicle is a gravitoinertial interface device to create a "virtual gravity" environment. Such a virtual environment may be adequate while the user is immobile but deviates from the normal terrestrial environment when voluntary movements, especially head movements, are made (4). Motion sickness, disorientation and motoric side effects are elicited when exposure to it begins, they abate during continued exposure if a sufficient number of movements are made on a suitable schedule (5) and there is a recurrence of motion sickness accompanied by negative orientational and motoric aftereffects upon return to the normal environment (6). Understanding the self-calibration mechanisms responsible for adaptive reduction of side-effects, negative aftereffects and reemergence of motion sickness requires a) analysis and measurement of the physical environment), b) consideration of specific sensory and effector systems and c) specialized sensorimotor subsystems such as the vestibuloocular reflex and cervical motor control.

We have applied this paradigm to understanding side effects of another important virtual environment interface - the helmet-mounted visual display (HMVD). A wide field of view (FOV) HMVD can immerse the user in a virtual environment. Scenes can be presented that generate a sense of self-motion and are nauseogenic even for an immobile user. Traditional visual flight simulators can do this too. We have been interested in problems uniquely related to HMVDs that arise when scenes are presented simulating a stationary world. Such scenes are not disruptive to an immobile observer but can become extremely nauseogenic and disorienting if head movements are made. Limitations in the displays themselves or computational difficulties in image generation make these situations analogous to, for example, moving the head while wearing prism spectacles which distort the visual feedback contingent on the vestibuloocular reflex.

The specific objectives of the research were a) to document motion sickness severity and other side effects in an immersive operational virtual environment utilizing a wide FOV HMVD as well as aftereffects when the HMVD is removed, b) to measure critical characteristics of the virtual environment system and c) to evaluate etiological factors in motion sickness and other side effects.

2. METHODS AND RESULTS

2.1 Apparatus and virtual environment

The HMVD we used was a LEEP Cyberface II with a nominal (see below) FOV 138° wide by 110° high, with aproximately 40° of binocular overlap. To achieve this FOV with standard liquid crystal display units (4 inch square, color, resolution=479 horizontal x 234 vertical), a lens system is used to create a non-uniform projection of the displayed images ontc the eye. The LEEP projection involves a radial expansion that results in minimal loss of resolution in the center of the field. A Polhemus 3SPACE FASTRAK was used to track position of the HMVD. Images were generated by a Silicon Graphics ONYX Reality Engine 2 with the multi-channel video output option. The scene presented was a harbor channel from the perspective of an observer in the sail of a stationary, surfaced submarine. The open ocean was straight ahead of the boat and shorelines to the right, left and rear. Maritime scenery included buoys, other surface craft and wave motion; the land scenery included buildings, trees, and hills. The normal graphics pipeline of the ONYX could not be utilized because of the LEEP projection which had to be computed with the main processor. The contents (number of polygons) of the virtual world were adjusted so that the frame rate for update of the visual image never fell below 30 Hz.

2.2. System characteristics

The only motion present in the displays resulted from voluntary head movements because the viewpoint was stationary. Tracking delays combined with the 30 Hz frame rate resulted in a characteristic delay between head movement and update of the visual display. Our first goal was to measure this delay. We measured the delay between motion onset of the HMVD and of a high contrast contour of the harbor scene. The ONYX received its information about HMVD motion from the Polhemus but we independently measured it with a zero-latency mechanical tracker; visual motion was registered by a photodiode placed directly on the liquid crystal display. The results indicated a minimal system delay of 67 ms between HMVD motion and update of the scene. Effective FOV was measured by adjusting an object in the virtual environment until it disappeared at the edges of the HMVD. This method indicated that the FOV was 126° wide by 74° high. The helmet and its counterpoise worn by the subject weighed 2.44 kg.

2.3. Etiological factors for motion sickness

Six experimental conditions were employed to evaluate system delay, FOV and effective weight of the HMVD as etiological factors. The conditions were: 1) minimum system update delay (67 ms), full FOV and helmet weight counterbalanced by elastic cords; 2) same with a 100 ms delay added by software; 3) same with a 200 ms added delay, 4) same with a 300 ms added delay; 5) 200 ms added delay with the linear dimensions of the FOV reduced by half; 6) 200 ms added delay, full FOV, subject bearing full weight of the HMVD.

Twenty one subjects gave their informed consent to participate in six experimental sessions scheduled at least a week apart, in random order. We did not admit subjects who had a history of high susceptibility to motion sickness. The first procedure in each session was to measure baseline motion sickness symptomatology using the Graybiel categorization system (7). After being shown a bird's eye view of the harbor "environment" on paper to learn landmarks, subjects put on the HMVD. Then, they stood at a hand rail and made paced voluntary head and eye movements to a series of landmarks called out on a tape recording. Head movements were unrestrained except for the elastic cord relieving the weight of the HMVD. Over a two minute interval, 24 head movements 12° to 180° in amplitude were made at five second intervals. This sequence was repeated five times with one minute breaks between. During the breaks we recorded motion sickness symptoms while subjects stood quietly, wearing the HMVD. After the fifth session subjects sat quietly for 15 minutes without the HMVD and then donned it again for a final sequence of head movements. Motion sickness was rated before and after this final sequence.

The highest motion sickness ratings in the first five sessions (15 minutes) were averaged across subjects and compared across conditions. A broad range of motion sickness symptoms, including nausea occurred during the 15 minute exposure. Significant sickness was elicited at the shortest update delay , with some subjects in the moderately sick category according to the Graybiel criteria and two subjects withdrawing before the session was complete. Sickness severity increased monotonically up to the maximum delay, with six subjects withdrawing. Halving the linear dimensions of the FOV with the 200 ms added delay cut motion sickness severity in half. Increasing the loading of the head and neck with the supplementary 200 ms delay did not alter motion sickness severity. After 15 minutes rest, symptoms had almost completely disappeared but returned again to their maximum level in a subsequent two minute period of scanning the virtual environment with voluntary head movements.

2.4. Postural disturbances and aftereffects

Five of the subjects who participated in the motion sickness evaluations agreed to return for another session in which postural stability was measured. Sway of the center of pressure on a Kistler force platform was measured while subjects stood on it for 25 seconds in the standard Romberg posture with normal vision. Baseline measurements were made before exposure to a virtual environment. Then subjects completed five sessions with 200 ms added to the minimal delay, full FOV, and no support of the HMVD weight, following the procedure described above. After each two minute sequence, the subjects stood quietly on the force platform, wearing the HMVD. After the fifth sequence the helmet was removed and sway was measured immediately and then at five minute intervals up to fifteen minutes.

The average amplitude of sway in the medial-lateral direction doubled compared to baseline in the five tests performed with the HMVD worn, and the mean total power of sway increased fivefold. When subjects were tested without the HMVD immediately after the fifteen minute exposure, sway amplitude and power were significantly greater than baseline. Both measures returned exponentially to baseline in the subsequent tests at five minute intervals.

3. CONCLUSIONS

Exposure of only 15 minutes to a stationary virtual environment displayed via wide a FOV HMVD can elicit motion sickness symptoms severe enough for subjects to withdraw from the exposure. Motion sickness induced by the HMVD in this circumstance is not directly analogous to simulator sickness because it is only generated by the HMVD when the head moves. Delays between head movement and visual motion caused by tracking latency, computation times and other sources are a unique etiological factor in motion sickness in virtual environments that utilize wide FOV HMVDs. Motion sickness severity increases monotonically with the delay. Decreasing the FOV greatly reduces the effect of visual update delays. The weight of the HMVD does not appear to be an important factor but future studies should evaluate the inertial loading of the head. Motion sickness symptoms may decay to a negligible level rapidly after departure from the virtual environment if the user is not exposed to additional provocative stimulation, but subjects appear nevertheless to be sensitized so that a very brief exposure to provocative stimulation raises the symptom level to its previous peak. Posture is destabilized while a HMVD is worn and for a period after it is removed.

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