AFTEREFFECTS FROM VIRTUAL ENVIRONMENT EXPOSURE: HOW LONG DO THEY LAST?

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The duration of the aftereffects from virtual environment (VE) exposure are not well characterized to date. Yet information concerning the incidence and enduring nature of these effects is essential to delimit the effective and safe use of VE technology. This study examined the aftereffects from VE exposure after three different exposure periods ranging from 15 to 45 minutes. Sixty participants were randomly assigned to one of the exposure periods, twenty to each condition. Sickness symptomatology, eye-hand coordination, and postural stability were measured before and after exposure. There were five measurements taken after exposure at 15 minute intervals. The results from the sickness symptomatology have been analyzed to date and show significantly higher symptomatology that persists for the entire post-exposure period in which measurements were taken. One hour after exposure the Total Severity of symptoms were 12 times higher than pre-exposure levels. Examining the three sub-dimensions of these symptoms indicated that one hour after exposure Nausea symptoms were 10x's higher, Oculomotor disturbances were 7x's higher and Disorientation was 95x's higher than pre-exposure levels. The very high levels of reported Disorientation are consistent with other studies that indicate that VE systems engender high levels of dizziness and vertigo upon post-exposure. The tangible and persistent aftereffects raise concerns for the safety and well being of VE system users and suggest that their activities should be monitored upon post exposure.

INTRODUCTION

When users complete their interaction with a virtual environment (VE) and return to their natural environment they are likely unaware that their interaction with the VE has potentially changed their ability to interact with their normal physical environment. There are, however, several different kinds of aftereffects that may persist after a participant has returned to the physical world (Welch, 1997). For example, perceptual-motor disturbances that could affect hand-eye coordination have been observed after relatively short duration exposures (20 to 40 minutes) to VE devices (Kennedy, Dunlap, Jones, & Stanney, 1996; Kennedy, Jones, Stanney, Ritter, & Drexler, 1996; Kennedy, Stanney, Dunlap, & Jones, 1996; Kennedy, Stanney, Ordy, & Dunlap, 1997; Rolland, Biocca, Barlow, & Kancherla, 1995). Postural sway, similar to that experienced by an inebriated individual, has also been observed upon post VE exposure (Kennedy & Stanney, 1996). Changes in the vestibulo-ocular reflex (VOR), or one's ability to stabilize an image on the retina, have also been detected (Draper, Prothero, & Viirre, 1997; Draper, Viirre, Furness, & Parker, 1997).

These aftereffects are due to adaptation that occurs when an individual interacts with a VE that is not sensorily veridical to their natural environment. This adaptation is the natural and automatic response to an intersensorily imperfect VE and is elicited due to the plasticity of the human nervous system (Welch, 1978). Due to technological flaws (e.g., slow update rate, sluggish trackers), users of VE systems may be confronted with one or more intersensory discordances (e.g., a disparity between seen and felt limb position). In order to perform effectively in the VE, they must compensate for these discordances by adapting their psychomotor behavior. Once they discontinue their interaction with the VE, however, these compensations persist for some time after exposure.

One of the most commonly asked questions from VE developers once they learn of these issues, is how long do the aftereffects last? Today there is limited research to answer this question. While the recovery time course for simulator systems (Ungs, 1987) and space flight (Paloski, Reschke, Black, Doxey, & Harm, 1992) are known to be potentially lengthy, the nature of VE aftereffects is not clear. There are also fundamental differences between simulators, space flight, and VE systems that indicate that their recovery time courses may be different (Stanney, Kennedy, & Drexler, 1997). It is thus of fundamental importance to determine how long these aftereffects last. Understanding that there is not one direct answer to this question is also important, as the term of the aftereffects may be related to the exposure duration (Kennedy, Stanney, & Dunlap, in press). This study focused on determining the time course of readaptation for several different exposure periods.

METHOD

Participants

The participants were 60 University of Central Florida students, mostly from engineering and psychology classes. Participants volunteered to participate in experimental sessions and were rewarded by earning extra credit in current classes or receiving monetary compensation.

Task

The participants were asked to interact with a VE for either 15, 30, or 45 minutes. During interaction the participants traversed throughout the VE performing several different tasks along the way. The battery of tasks used included locomotion, manipulation, tracking, reaction time, and recognition tasks, which are based on the Virtual Environment Performance Assessment Battery (VEPAB) (Lampton, Knerr, Goldberg, Bliss, Moshell, & Blau, 1994). These tasks were performed in a virtual environment shaped like a maze that consists of 29 rooms and 3 long corridors. Each room is 4x4 feet.

Apparatus

A 200Mhz Pentium MMX computer with 64MB of RAM and an Elsa Winner Pro 2000/X with 8 MB RAM graphics board was used to generate the virtual environments. A Logitech Cordless Mouseman Pro was used as the input device. A helmet-mounted display (Virtual Research V6), equipped with a Virtual iO! Tracker was used to generate the graphics and track the movements of the user. RenderWare software was used to develop the virtual environments. A Summagraphics SummaSketch FX digitizing tablet with a cordless stylus was used to measure proprioceptive aftereffects (i.e., eye-hand coordination) from VE exposure. Video equipment was used to assess postural stability (i.e., ataxia) before and after VE exposure. The Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993) was used to assess subjective aftereffects. The SSQ consists of a checklist of 26 symptoms, each of which is related in terms of degree of severity (none, slight, moderate, severe), with the highest possible total score (most severe) being 300. A weighted scoring procedure is used to obtain a global score reflecting the overall discomfort level known as the Total Severity (TS) score. The SSQ also provides scores on three subscales representing separable but somewhat correlated dimensions of simulator sickness (i.e., Nausea [N], Oculomotor Disturbances [O], and Disorientation[D]).

Procedure

Prior to the experimental session all subjects filled out a subject consent and demographics form. Prior to exposure to the VE, baseline measures of the SSQ, eye-hand coordination and postural stability were obtained. Participants were randomly assigned to one of the treatment conditions (i.e., 15, 30, or 45 minutes of exposure). During exposure, the subjects maintained a seated position while wearing the HMD and traversed through the maze completing the battery of tasks described above. Immediately following the exposure period, measures of all dependent variables were taken. Repeated measures were taken every 15 minutes for 1-hour post-exposure.

Experimental Design

A nested two factor General Linear Model was used for the experimental design. The between subjects independent variable was exposure duration (15, 30, or 45 minutes) and the within subject independent variable was time after VE exposure (0, 15, 30, 45, or 60 minutes). Twenty subjects were randomly assigned to each treatment condition.

The dependent variables included the SSQ measures as well as objective measures of the aftereffects from VE exposure. These later included measurements of ataxia obtained using the procedures specified in Kennedy and Stanney (1996) and eye-hand coordination, which was measured according to the procedure specified in (Stanney, Kennedy, Drexler, & Harm, in press). Post hoc analysis of significant variables included Fisher's method of multiple comparisons.

RESULTS

The experimental design was unbalanced because some participants had to be removed from the data set due to high pre-exposure SSQ scores. To date the data from the SSQ have been analyzed and show significant subjective symptomatology upon post VE exposure. For Total Severity, there was a significant effect for the time after exposure ($F(15,270)=2.18$, $p<0.007$). Fisher's pairwise comparisons indicated that the mean pre-exposure TS ($\bar{X}=1.95$, $s=2.44$) was significantly ($p<0.01$) less than all post-exposure mean levels (see Table 1). For Nausea, there was a significant effect for the time after exposure ($F(15,270)=2.53$, $p<0.002$). Fisher's pairwise comparisons indicated that the mean pre-exposure Nausea ($\bar{X}=1.59$, $s=4.10$) was significantly ($p<0.01$) less than all post-exposure mean levels (see Table 1). For Oculomotor disturbances, there was a significant effect for the time after exposure ($F(15,270)=1.79$, $p<0.036$). Fisher's pairwise comparisons indicated that the mean pre-exposure Oculomotor disturbances ($\bar{X}=2.68$, $s=3.98$) was significantly ($p<0.01$) less than all post-exposure mean levels (see Table 1).

Only for Disorientation was there a significant length of exposure effect ($F(2,270)=3.39$, $p<0.035$) and a significant effect for the time after exposure ($F(15,270)=1.70$, $p<0.05$). Fisher's pairwise comparisons indicated that the mean Disorientation was significantly ($p<0.05$) greater after 15 minutes of exposure as compared to 30 and 45 minutes of exposure (see Table 2). Fisher's pairwise comparisons indicated that mean pre-exposure Disorientation ($\overline{X}=0.29$, $s=2.01$) was significantly ($p<0.01$) less than all post-exposure mean levels (see Table 1). The objective measures of aftereffects have not yet been analyzed.

Table 1. Mean SSQ scores at different times post VE exposure.

	Mean SSQ Score*			
Time Post Exposure (minutes)	TS	N	O	D
Pre-Exposure	1.95 (2.44)+	1.59 (4.10)+	2.68 (3.98)+	0.29 (2.01)+
0	35.69 (32.38)	30.21 (29.21)	25.74 (24.36)	41.47 (47.57)
15	30.23 (36.62)	23.85 (29.19)	22.11 (28.14)	37.12 (51.07)
30	28.83 (39.63)	20.27 (27.52)	22.58 (31.10)	36.25 (57.91)
45	25.25 (36.89)	17.89 (28.76)	19.90 (27.51)	31.32 (53.30)
60	23.06 (32.03)	16.30 (25.20)	18.79 (23.87)	27.55 (47.31)

*Standard deviation in parenthesis. + Mean significantly different than others in column ($p<0.01$).

Table 2. Mean SSQ scores per exposure time.

	Mean SSQ Score*			
Exposure Time (minutes)	TS	N	O	D
15	29.44 (41.03)	22.35 (31.58)	20.88 (31.79)	38.76 (56.22)+
30	20.57 (27.23)	15.79 (24.65)	16.84 (19.28)	22.58 (42.84)
45	21.93 (30.96)	16.50 (22.93)	17.92 (23.77)	24.65 (43.62)

*Standard deviation in parenthesis. + Mean significantly different than others in column ($p<0.05$).

DISCUSSION AND CONCLUSIONS

The results indicate that the subjective symptomatology experienced by users after VE exposure is substantial, persistent (see Figure 1), and statistically significant ($p<.01$). By collapsing data across the mostly non-significant exposure duration, one can see that the overall TS levels are approximately 18x's higher than pre-exposure levels immediately after exposure and still approximately 12x's higher 60 minutes post-exposure. The immediate post-exposure Nausea levels are approximately 19x's higher than pre-exposure and approximately 10x's higher 60 minutes post-exposure. Oculomotor disturbances are nearly 10x's higher immediately upon post-exposure and approximately 7x's higher at 60 minutes post-exposure. The highest level of aftereffects are those of Disorientation, which are approximately 143x's higher immediately after exposure and still approximately 95x's higher 60 minutes post-exposure. These results clearly indicate that the subjective symptomatology does not quickly dissipate upon post VE-exposure but lingers on for a significant period of time.

The exposure duration results indicated that Disorientation was significantly greater for the 15 minute exposure as compared to the 30 and 45 minute exposures (see Table 2). A similar trend was found across the other sickness dimensions (TS, N, and O), however, these effects were not significant. This outcome is interesting and indicates that subjective symptomatology may actually lessen with protracted exposures. If, as the literature suggests (Welch, 1978), this lessening is due to physiological adaptation (i.e., as the user adapts they become less ill), then one would expect to see greater ataxia and degraded eye-hand coordination in those who endured longer exposures. This relationship will be examined when the data from the objective aftereffects measures are analyzed.

Based on the results from the SSQ, it is quite noteworthy that approximately 66.7% of the participants in this study experienced drowsiness after VE exposure. This may be an indication of the sopite syndrome, which is characterized by lowered arousal or mood during or after VE use (Lawson, Rupert, Guedry, Grissett, & Mead, 1997). If the sopite syndrome occurs among VE users, it would be likely to affect performance without being fully detected by the afflicted person (Lawson & Mead, 1997). In addition, approximately 31.3% experienced falshbacks, a symptom which in most literature has been classified as 'rare' (Baltzley, Kennedy, Berbaum, Lilienthal, & Gower, 1989). Also, while the pathognomonic signs of vomiting are rare, one of the participants in this study did have an emetic response.

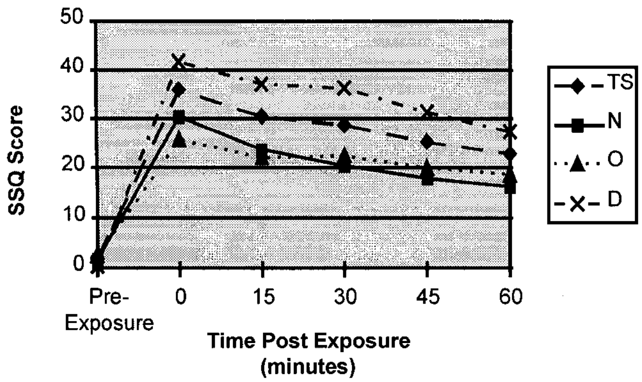

Figure 1. SSQ scores per exposure time

The objective measures of eye-hand coordination and postural stability will be analyzed next to determine if they last as long as the subjective aftereffects and if they intensify with increased exposure duration. If the objectively measured aftereffects are also substantial and persistent, this will imply that users may undergo a significant loss in their functional capacities after VE exposure. The implication being that VE users' activities should be closely monitored for a considerable period of time upon post-exposure to avoid personal injury or harm.

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