Peripheral responses to a mental-stress inducing virtual environment experience

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ABSTRACT

Virtual environments (VEs) are used increasingly in the education and training of people with disabilities. When utilizing these VEs, it is important to know 1) whether they are effective in the manner desired and 2) whether there are side effects from them. This exploratory study looks at both issues. This paper describes a study in which we observe a predictable pattern of both stress related to the content of the VE and a pattern of relaxation over time (30 minutes – 1 hour) in the VE.

1. INTRODUCTION

When using a virtual environment (VE) for the education and training of people with disabilities, it is important to know whether the VE is effective and whether it produces undesired side effects. This paper discusses a study that looks at both issues: Are there noticeable side effects from the virtual environment, and can a VE produce a predictable physiological stress response?

Since the mid 1980's, researchers have been laboring to make virtual environments work well and to reduce the side effects from VEs. One of the keys to making virtual environments work well is engaging the user in the content of the VE. The key to reducing the side effects of VEs is presenting to the user the information that they expect: proper visual information, low movement lag, high frame rate, etc…

In this study we look at whether the content of the VE can evoke predictable physiological stress response. We also look for a stress response produced by simply engaging in the VE. Sixteen subjects were instructed to navigate the ARCANA virtual environment – a VE version of the Wisconsin Card Sorting Test. The environment became more difficult to navigate after each room (via the introduction of visual fog in the VE), and incorrect navigation triggered additional fog and the sound of a gunshot accompanying a virtual soccer-ball in the face (see figures 1 and 2).

We found that the content of the VE evokes a predictable stress response in the participants of the study. We interpret this predictable pattern of stress response as the subjects engaging in the content of the virtual environment – the VE is effective. The ability to produce a predictable stress response and the fact that users can be engaged in the virtual environment for a long period of time without physiological side effects (other than the stress response evoked by the content) gives us confidence that physiological response can be used to monitor reaction to the content of a VE.

Since we can monitor physiological reaction to the content of a virtual environment, it might be possible to use physiological reaction to gauge how believable a virtual environment is for a user: how *present* a user is in the virtual environment.

These findings provide a basis for the research direction: "Can physiological response be used to measure presence in virtual environments?" This serves as a cornerstone for this research by showing that physiological response can be used to measure reaction to the content of a virtual environment and that users do not have a confounding physiological reaction to simply engaging in the VE for a long period of time (30 minutes – 1 hour).

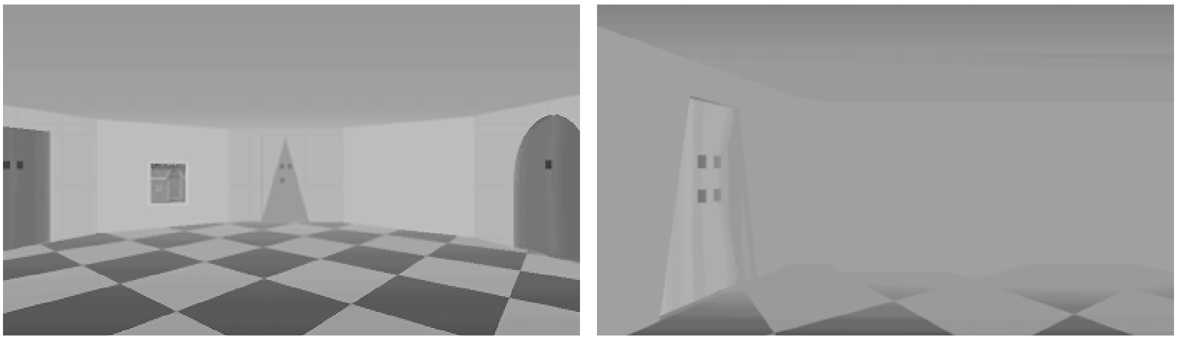

Figure 1. *The environment with little fog (left) and with debilitating fog (right).*

Figure 2. *Soccer ball in the face is accompanied by the sound of a gunshot. Occurs when a user makes an incorrect door choice.*

2. THE ENVIRONMENT

As in (Pugnetti et al, 1995), our VE was an electronic version of the Wisconsin Card Sorting Test (WCST). It was built using Superscape's Virtual Reality Toolkit and ran under Superscape Visualiser version 5.60 on an Intel Pentium II 400 MHz processor running Microsoft Windows 98. A Neuroscan 32 system was used to monitor neurological and physiological responses. A joystick was used for navigation, and the image was projected at 640x480 to (approximately 1 meter x 1.35 meter).

We had 16 users navigate a virtual building in as short a time as possible. Participants moved from room to room by selecting an exit door. Before selecting an exit door, subjects position themselves in the center of the room and face the entrance door. This closes the entrance door and "unlocks" the exit doors. The cue for selecting the correct exit door is obtained by looking at the entrance door. There are three potential categories for correct door choice – matching the color, shape, or pattern of the exit door to that of the entrance. There are 32 rooms.

Once an exit door is chosen, it opens onto a hallway at the end of which is an unmarked door. If the choice is correct, the unmarked door opens to the next room. If the door is incorrect, the participants hear a gunshot and see a virtual soccer ball come directly at them as they entered another hallway (see figure 2). Participants are instructed to press the joystick's trigger upon seeing the ball.

At some point for each subject, the fog becomes *debilitating* - they can no longer see the entrance door (or any other door) from the center of the room. Before the fog becomes debilitating, a correct exit choice increases the fog slightly, and an incorrect exit choice increases the fog greatly. After the fog becomes debilitating a correct choice decreases the fog slightly, and an incorrect choice increases the fog. The fog only increases to the point where the subject can see a virtual arm's length. Once the fog reaches the point of debilitation, it never recedes beyond that point - regardless of the number of correct door choices. Debilitating fog is reached at 9-15 incorrect door choices. Figure 1 depicts a low fog and a debilitating fog situation. In figure 2, both views have no fog.

3. RESULTS AND DISCUSSION

We monitored subjects' physiological and neurological responses while in the environment. This paper discusses the physiological responses: heart rate (EKG) and skin potential. A companion paper, (Pugnetti et al, 2000) discusses the neurological responses. We monitor heart rate (via EKG) and electrodermal activity (via skin potential level and skin potential reactions). These measures have been seen to vary due to fear: heart rate increases, and skin potential increases. (Weiderhold et al, 1998), (Andreassi, 1995) For general information on measuring and interpreting skin potential and heart rate, please see (Andreassi, 1995).

1. *There is a significant decrease in the percentage change skin potential level (%ΔSPL) predicted by the number of rooms traversed and there is a significant increase in %ΔSPL predicted by the number of incorrect door choices. Additionally, there is a reduction in the predicted effect of number of incorrect rooms on %ΔSPL once the virtual fog is thick enough that the subject can not see the doors from the center of the room.*

We measure skin potential level (SPL) as the average skin potential level recorded in the first minute of each room. Percentage change skin potential level (%ΔSPL) is calculated as the percentage change of SPL as compared to the first room. The corrected model is constructed using SPSS 10.0.1 for Windows with 5% as the entry cutoff for variables and 10% as the removal cutoff. The cutoff for model significance is 5%. The resulting model is then analyzed using SPSS's univariate GLM with parameter estimation. Table 1 is a reduced version of the generated tables.

Table 1. *Tests of Between-Subjects Effects: Percentage change skin potential level.*

Source	**Parameter Estimate**	**F**	**Sig.**
Corrected Model		4.381	.000
Intercept	-382.656	13.877	.000
SUBJ	(Different for each: +134..+411)	4.876	.000
# room traversed (#R)	-4.962	2.879	.091
# incorrect choices (#IC)	16.759	3.659	.057
#incorrect choices * (0=less fog, 1=debilitating fog) (#IC*FD)	-8.528	4.096	.044

Table 1 shows that the corrected model is significant at <0.1%. The parameter estimates suggest that, after correcting for between-subject differences in intercept, %ΔSPL decreases with number of rooms traversed (#R) and increases as subjects make incorrect choices (#IC). Additionally, the effect of number of incorrect choices on %ΔSPL decreases after the fog in the environment has reached the point where the subject can no longer see the doors from the center of the room (FD – fog is debilitating).

We interpret the decrease in %ΔSPL with #R as a subject's ability to relax in the environment. This is an interesting finding since the subjects were not only subjected to a virtual environment for an extended period (between 30 minutes and 1 hour), but because they were covered with physiological and neurological monitoring equipment. We believe that this finding supports the theory that virtual environments and physiological monitoring equipment are not overly stress producing. That is, subjects who do not regularly use virtual environments can show signs of relaxation over time when exposed to the environment even when they have an ostensibly uncomfortable arrangement of wires are connected to them. Before the experiment, we recognized that either discomfort from the monitoring equipment or the novelty of the virtual environment might be stressful for the participants or otherwise impair our results. We believe these data support a theory that subjects are able to relax in spite of the monitoring equipment and the novelty of the virtual environment.

We interpret the increase in %ΔSPL with #IC as the subject reacting to the content of the virtual environment. This supports the theory that the environment is engaging and that the engagement evokes physiological stress response that follows patterns predicted by reactions to similar real situations.

The interaction between #IC and FD suggests that there is a decrease in physiological reaction to incorrect choices once the task becomes difficult. The subjects need to stand in the center of the room to close the entrance door. Once they can no longer see the doors from the center of the room, it is easy to become disoriented (little to no feed back on position from the center of the room) and frustrated (makes it difficult to close the entrance door). Figure 1 illustrates low and debilitating fog. Also, with much fog, subjects loose the ability to see the entrance door, which they use to determine the correct exit door. This makes the task more difficult because they must memorize the original door and navigate the room in order to make a decision. We interpret the decrease in #IC's effect on %ΔSPL once the fog becomes debilitating as a sign that subjects become less concerned about correct choices once navigation becomes sufficiently difficult and simply try to traverse the rooms as best they can.

2. *There is a significant decrease in the percentage change heart rate (%ΔHR) predicted by the number of rooms traversed and there is a significant increase in %ΔSPL predicted by the number of incorrect door choices when the fog is not debilitating.*

Heart rate (HR) is measured as the average HR recorded in the first minute of each room. Percentage change heart rate (%ΔHR) is calculated as the percentage change of HR as compared to the first room. The corrected model is constructed using SPSS 10.0.1 for Windows using the method described above. Table 2 is a reduced version of the generated tables.

Table 2. *Tests of Between-Subjects Effects: Percentage change heart rate.*

Source	Parameter Estimate	F	Sig.
Corrected Model		3.658	.028
Intercept	-2.056	3.492	.063
# rooms traversed (#R)	-.182	7.173	.008
#incorrect choices * (1=debilitating fog, 0 otherwise) (#IC*FD)	.170	3.162	.077

Table 2 shows that the corrected model is significant at <5%. The parameter estimates suggest that %ΔHR decreases with #R and increases with #IC when the fog is not debilitating. The addition of subject to the model approached significance.

As with %ΔSPL, we interpret the decrease in %ΔHR with #R as a subject's ability to relax in the environment. This further confirms our theory that virtual environments and physiological monitoring equipment are not overly intimidating or stress producing. Subjects who do not regularly use virtual environments can show signs of relaxation over time when exposed to the environment even when they have an ostensibly uncomfortable arrangement of wires are connected to them.

We interpret the increase in %ΔHR with #IC when not FD as the subject reacting to the content of the virtual environment. As with %ΔSPL, this supports the theory that the environment is engaging and that the engagement evoked physiological stress response that follows a predictable pattern.

The significance of the interaction between #IC and FD suggests that there is little to no physiological reaction once the task becomes difficult. As described above, when the fog becomes debilitating, the task becomes difficult enough that subject may no longer be concerned with finding the correct choice, but only interested in completing the task.

3. *The amplitude of skin potential reactions significantly increased with number of incorrect choices.*

Skin potential (SP) is measured as the difference between the negative and positive components of the skin potential reaction when an incorrect door was chosen. An SPR generally occurs within 2-5 seconds of stimulus and is characterized as a wave with a negative and positive component. A typical SPR is illustrated in figure 3.

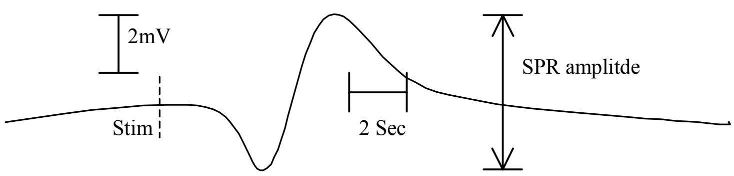

Figure 3. *A typical skin conductance reaction.*

Percentage change skin potential reaction (%ΔSPR) is calculated as the percentage change of the amplitude of the SPR as compared to that of the first incorrect choice. The corrected model is constructed using SPSS 10.0.1 for Windows using the method described above. Table 3 is a reduced version of the generated tables.

Table 3. *Tests of Between-Subjects Effects: Percentage change skin potential reaction.*

Source	**Parameter Estimates**	**F**	**Sig.**
Corrected Model		3.544	.000
Intercept	15.462	11.715	.001
# incorrect choices (#IC)	5.508	4.998	.028
SUBJ	(Different for each: -33..181)	3.314	.001

The corrected model is significant at <0.1%. After correcting for between-subject differences in intercept, there was a significant increase in %ΔSPR as subjects made more incorrect choices. We interpret this finding as subjects becoming more frustrated (more SPR reaction) as they make more incorrect choices. This further supports the theory that the environment was engaging and can evoke physiological response in a pattern predictable by real-world reaction.

4. CONCLUSIONS

Overall, these finding suggest that the content of a virtual environment can evoke physiological response in a predictable pattern. It also supports the belief that the technology associated with the VE and the physiological and neurological monitoring equipment neither impedes the understanding of the content nor confounds the results of content-based stress production.

5. FUTURE WORK

This study provides the base for four studies (three have been completed; one will soon be conducted) that investigate the use of physiological response to assess presence in virtual environments. Presence has been defined as the user feeling that *the experience is more like a place visited and not just a series of pictures seen* (Slater et al, 1995). In these follow-up experiments, the VE passively evokes a stress response. Physiological reactions and other measures of presence are used as metrics to determine what technological advances in virtual environments are important in making a virtual environment engaging. System factors under investigation include better frame rate and use of near-field static haptics. The firsts of these follow-up studies was presented at Presence 2000 in Delft, the Netherlands. (Meehan, 2000) This is the focus of the first author's Ph.D. dissertation work.

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