

# 10 An Investigation into Physiological Responses in Virtual Environments: An Objective Measurement of Presence

Brenda K. WIEDERHOLD, Dong P. JANG, Mayumi KANEDA, Irene CABRAL, Yair LURIE, Todd MAY, In Y. KIM, Mark D. WIEDERHOLD, Sun I. KIM

**Abstract.** The purpose of this study was to investigate the relationship between subjective ratings of presence and physiological responses to a virtual environment. To measure subjective presence, Immersion, Presence, and Realism questionnaires were used. As measures of physiological response, heart rate and skin resistance readings were acquired. Seventy- two participants (36.4±15.5 years of age) were presented with a virtual environment depicting an airplane flight. The results show a correlation between Presence Questionnaire scores and both heart rate and skin resistance: -0.232 (95% confidence), -0.306 (99% confidence) respectively. In the study, heart rate and skin resistance appeared to indicate the participant's degree of immersion.

## Contents

10.1	Introduction .....	176
10.2	Method.....	176
10.3	Measures .....	177
10.4	Procedure .....	178
10.5	Analysis .....	178
10.6	Results .....	179
10.7	Conclusion.....	182
10.8	Acknowledgement .....	182
10.9	References .....	182

## 10.1 Introduction

Virtual Environments have been employed as tools for working applications in the mental health field for the past 8-10 years. One of the most important aspects of a virtual environment is to induce a state of "Presence," which is defined as "the observer's subjective sensation of 'being there' in a remote environment" [1]. The importance of the construct has generated multiple views for the quantitation and measurement of presence. These measurements can be broadly classified into two types: subjective and objective measures. Questionnaires that have previously been developed have been used as subjective measures in a majority of studies [2, 3, 4, 5]. They include such questions as: "How aware were you of events occurring in the real world around you?" or "How strong was your sense of presence, 'being there,' in the virtual environment?" While analyses of presence questionnaires may elucidate the phenomenology of immersive experiences, they largely remain post-test measures that are dependent on memory of the event. Presence has, also, been measured during the virtual experience by using a hand-held sliding scale [1, 6]. However, it is unclear exactly what participants were responding to and how responses were affected by the disruption of continuously assessing one's own experience.

Objective measures involve monitoring the impact of a virtual environment on physiologic processes such as heart rate, respiration rate, skin resistance, skin temperature and peripheral brain wave EEG activity. Unfortunately, there are only a few studies that examine the relationship between presence and physiological responses [7, 8, 9]. Meehan found a high and significant correlation between presence and skin conductance level with 10 participants exposed to a virtual height environment. The goal of the study was to investigate the relationship between subjective ratings of presence and physiological responses [13]. Heart rate and skin temperature did not prove to be good measures of presence and results of their correlation with presence were inconclusive. The results support the findings of presence by Wiederhold, Wiederhold, & Davis. Four non-phobic participants and one phobic participant had physiology measured while exposed to a virtual flight environment both in a head-mounted display and on a two-dimensional flat computer screen. Heart rate, respiration, skin resistance and peripheral skin temperature were measured during baseline, relaxed conditions, and during the virtual flight condition. Skin resistance seemed to correspond with self-report measures of anxiety. In addition, the more immersive and interactive experience of a head-mounted display increased physiological arousal and self-report scores of presence and immersion during the exposure. There was an obvious difference in arousal between the phobic participant and non-phobic participants.

## 10.2 Method

### 10.2.1 Participants

Seventy-two persons attending a local computer expo in August 1998 in San Diego served as participants. All participants had the study characteristics explained to them fully and gave written informed consent before the protocol began. Table 10.1 shows the characteristics of study participants (gender, ethnicity, and phobic/non-phobic status based on Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) criteria).

**Table 10.1** Characteristics of Participants

Total ( <i>n</i> )	72		
Gender (Male/Female)	<i>N</i> 30/42		% 42/58
Age	<i>M</i> 36.4	<i>SD</i> 15.5	<i>Range</i> 18~73
Ethnicity (White/Hispanic/ African-American /other)	<i>N</i> 44/13/4/11		% 61/18/6/15
Non-Phobic/Phobic	<i>N</i> 62/10		% 86/14

### 10.2.2 Virtual Environments

The flying system being used was designed by Drs. Hodges and Rothbaum of Virtually Better, Inc. (Atlanta, Georgia) who have previously performed VR treatment for acrophobia and fear of flying [10, 11]. The system is run on a high-end Intel Processor-based personal computer and contains advanced audio and Diamond Monster-3D graphics cards, external multimedia speakers and subwoofer, a Polhemus INSIDETRAK position Tracker, and customized software. Audio was delivered to the participants through earphones on the head-mounted display. Vibratory sensations were delivered via a subwoofer mounted under the participant's chair.

## 10.3 Measures

### 10.3.1 Self-report questionnaires

The following questionnaires were administered to all participants:

- The Tellegen Absorption Scale (TAS) assesses a person's ability to become deeply absorbed into what one is doing or one's environment. Scores on the 34-item True/False inventory may range from 0-34 [12].
- The Dissociative Experiences Scale (DES) is a brief, self-report measure of one's frequency of dissociative experiences. All 28 items are scored from 0 to 100 according and an average score is determined by dividing the total score by 28 [13].
- The Simulator Sickness Questionnaire (SSQ) measures a participant's somatic response to the virtual environment [14, 15]. Each of the items is scored from 0 to 3.
- The Questionnaire on Presence and Realism rates the sense of presence and degree of realism [14, 7]. It is measured on a scale from 0 to 100.

### 10.3.2 Physiological measures

The following physiological parameters were measured:

- Skin Resistance (SR), which changes in relation to change in sweat gland activity-as sweat gland activity increases;
- Skin resistance decreases, and
- Heart Rate (HR), measured by electrocardiography.

SR was monitored with two silver/silver chloride electrodes placed on the ring and index fingers of the left hand. HR was collected with two sensors, one on each wrist. An I-330 C-2 computerized biofeedback system manufactured by J&J Engineering (Poulsbo, Washington) was used to collect physiological data.

## 10.4 Procedure

After signing an informed consent, the participant's two wrists, and left ring and index fingers were swabbed with a cotton ball soaked in to remove any dead skin cells and skin oils that might cause artifact and interfere with accurate readings. For SR, a small amount of electrode gel was placed on each electrode. The electrodes were attached to the ring and index fingers of the participant's left hand with Velcro tabs. For HR, a small amount of electrode gel was placed on each disposable electrode attached to the participant's right and left wrist. A 1-minute eyes closed baseline was then taken. The participant was then placed in a MRG4 Head-Mounted Display (HMD) by Liquid Image. The Polhemus head tracker allowed the participant to move his/her head and view various parts of the virtual environment. The virtual environment shows the participant seated in the left window seat over the wing in the passenger cabin of a commercial aircraft. The participant was instructed to look around the virtual plane to become oriented before beginning the flight sequence. During a 6-minute VR flight, the following sequence was performed: engines on, taxi, take-off, flying in good weather, and landing. After the plane landed, physiological recording was ended and the HMD was removed. Participants were then asked to fill out the self-report questionnaires previously described.

## 10.5 Analysis

Baseline physiology levels often vary widely between individuals so the percentage change from baseline was used for analyses rather than absolute values. Therefore, before comparing physiological recordings with presence measures, the percentage change of heart rate (%HR) was calculated as follows:

$$\%HR = (\text{MeanVR} - \text{MeanBaseline})/\text{MeanBaseline},$$

with:

MeanVR : Mean of Heart Rate during the VR exposure, and  
Mean Baseline: Mean of Heart Rate during baseline

Percentage change of skin resistance (%SR) was also obtained using the same method. A Spearman correlation was then used to evaluate the relationship among the various

presence measures (questionnaires, physiological parameters) due to its suitability for non-linear relationships.

## 10.6 Results

As was predicted, the TAS and DES were highly correlated, as were the SSQ and DES. The expected significant relationship between the Presence questionnaire and Realism questionnaire was also shown, with both also showing a high degree of correlation with the DES (Table 10.2).

**Table 10.2** Spearman Correlation of Dissociative Experiences Scale (DES) to other questionnaires

Measurements	Spearman Correlation
Tellegen Absorption Scale & DES	.353 ( p < 0.01 )
Simulator Sickness Questionnaire & DES	.289 ( p < 0.05 )
Presence & DES	.293 ( p < 0.05 )
Realism & DES	.271 ( p < 0.05 )

Also noted were changes in physiology based on degree of immersion. Table 10.3 shows the relationship among the presence, absorption, and dissociation measures.

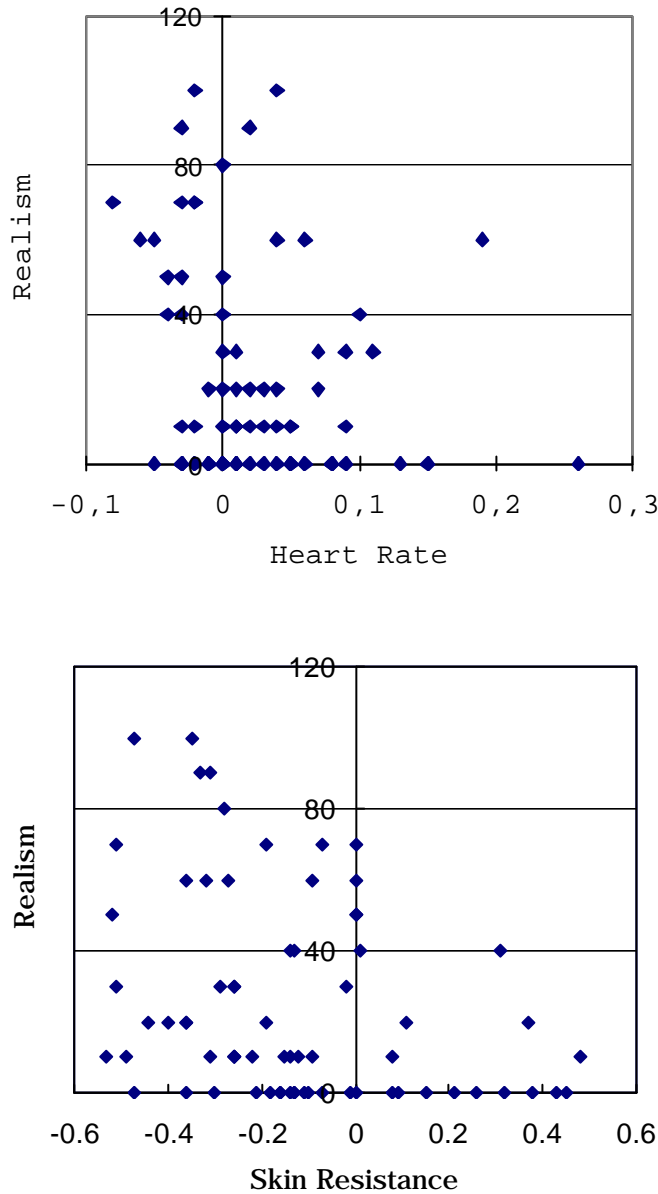
**Table 10.3** Spearman Correlation among the presence measures and physiology( Correlation / Sig.)

	PRESENCE	REALISM	TAS	? SR	? HR
PRESENCE		.813 (.000)**	.229 (.053)	-.306 (.009)**	-.232(.050)*
REALISM	.813 (.000)**		.255 (.031)*	-.307 (.009)**	-.250(.034)*
TAS	.229 (.053)	.255 (.031)*		.061 (.612)	-.264(.025)*
%SR	-.306 (.009)*	-.307 (.009)**	.061 (.612)		.004 (.973)
%HR	-.232 (.050)*	-.250 (.034)*	-.264 (.025)*	.004 (.973)	

\*\* : Correlation is significant at the 0.01 level (2-tailed).

\* : Correlation is significant at the 0.05 level (2-tailed).

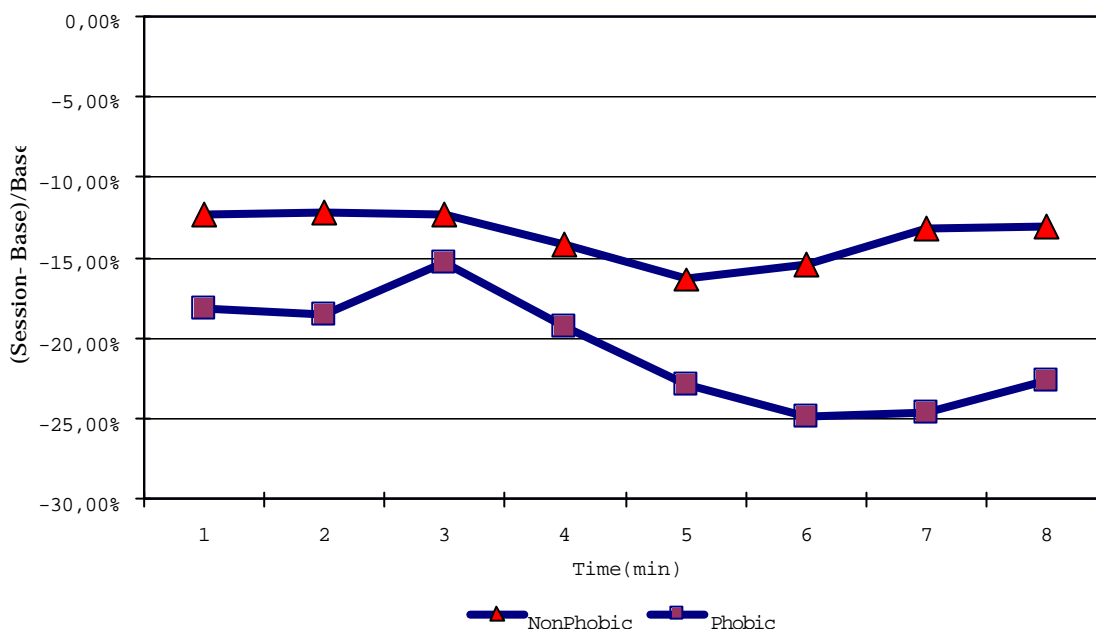
Percentage change of skin resistance (%SR) and heart rate (%HR) both had a high correlation with the Presence questionnaire and Realism questionnaire. When placed in a virtual environment, a new and novel stimulus, skin resistance levels decreased, indicating some physiological arousal. In 1907, Carl Jung discovered that skin resistance was a means to objectify emotional tones previously thought to be invisible. Skin resistance, unlike EMG and skin temperature, tends to reflect mental events more quickly and with more resolution than other physiological measures [16]. Before the experiment, it was predicted that heart rate would also increase to reflect arousal when the participant experiences the virtual environment. However, contrary to this expectation, heart rate had a negative correlation with the realism questionnaire as shown in Table 10.3. That is, heart rate decreased as the participant felt the virtual environment was more realistic. Figure 10.1 illustrates the scatter plot of heart rate and realism.



**Figure 10.1** Scatter plot : Realism and Heart Rate (% HR), Realism and Skin Resistance (%SR)

From previous work on experiences to novel situations, two types of reactions are described: an orientation reaction (OR) that was automatically elicited by novel stimuli, and a defense reaction (DR) that was evoked by high-intensity stimulation and had the opposite effect on stimulus discrimination [17]. Previous research shows some of these reactions (i.e., the skin conductance response) are common to both reactions but HR and general motor activity distinguish between the reactions [18]. That is, in reaction to unexpected stimuli, heart rate deceleration has been correlated with the orienting response to novelty and accelerations with defensive responses such as fear and anxiety [19, 20]. Therefore, the well-immersed participants who had no fear of flying react to the virtual environment as an unexpected, novel stimulus. This results in an increase in parasympathetic activity and resulting in a decrease in heart rate. It may be that a relaxed and focused physiological tone allows for more careful and full exploration of a new experience, such as that seen with intense but enjoyable concentration. Analysis of heart rate was not significantly different between phobics and non-phobics, however, it is clear

that heart rate measures are probably not sensitive enough to discriminate between groups, or sensitive enough to illustrate differences. For this reason, other measures of cardiovascular reactivity must be used, and are currently being measured at the Virtual Reality Medical Center. We are currently measuring systolic and diastolic blood pressure, heart rate variability, and cardiac output. Skin resistance levels, however, delineate the phobic and non-phobic participants (see Figure 10.2).



**Figure 10.2** The average display of Skin Resistance in non-phobic and phobic participants

This has been found also in previous work comparing phobic and non-phobic participants [9, 20, 21-24].

Another interesting finding, although not significant, is that non-phobics did not rate the virtual environment as realistic as phobics (Table 10.4).

We need to bear in mind when constructing new virtual reality environments for additional mental health applications that patients with disorders may have unexpected reactions to novel virtual worlds. Results obtained with normal participants can be a useful guide for predicting of how patients might react, but graded exposure of patients to new environments is prudent.

**Table 10.4** Summary of results obtained from both non-phobics' and phobic's measurements

Measurement	Phobic	Non-Phobic
Presence & Realism	M=28.5 (SD=24.7)	M=23.1 (SD=25.4)
Simulator Sickness Questionnaire	M=11.3 (SD= 8.4)	M=7.2, (SD= 8.2)
Tellegen Absorption Scale	M=7.10 (SD=2.42)	M=6.29 (SD=2.51)
Dissociation Experiences Scale	M=19.2 (SD=11.5)	M=18.3 (SD=19.2)
skin Resistance (%)	M=-23.6 (SD=29.9)	M=-12.8 (SD=24.8)
heart Rate (%)	M=-0.1 (SD=2.8)	M=2.85 (SD=6.15)

## 10.7 Conclusion

This study revealed that percentage change in heart rate and skin resistance had a high level of correlation with presence, degree of realism, and immersiveness. The two physiological parameters may therefore be useful as an objective measure of presence and real-time measure of immersiveness. In future work, other physiological measures such as, EEG, blood pressure, heart rate variability, and cardiac output could provide additional important indicators of responses to virtual worlds. In addition, presence questionnaires need to be modified for use in clinical practice. We have as yet incomplete understanding of how those with mental health disorders fully perceive, react, and interact within virtual environments.

## 10.8 Acknowledgement

Partial support was provided by a grant from the National Research Laboratory Program ( 2000-N-NL-01-C-159 ).

## 10.9 References

- [1] Freeman, J., Avons, S.E., Pearson, D.E., & Ijsselsteijn, W.A. (1999). Effects of sensory information and prior experience on direct subjective ratings of presence. *Presence: Teleoperators and Virtual Environments*, 8(1), 1-13.
- [2] Regenbrecht, H., Schubert, T. (1998). Measuring the sense of presence and its relations to fear of heights in virtual environments. *International Journal of Human-Computer Interaction*, 10(3), 230-250.
- [3] Slater, M., Usoh, M. (1994). Depth of presence in virtual environments. *Presence: Teleoperators and Virtual Environments*, 3(2), 130-144.
- [4] Usoh, M., Catena, E., Arman, S., & Slatore, M. (2000). Using Presence Questionnaire in Reality. *Presence: Teleoperators and Virtual Environments*, 9(5), 497-503.
- [5] Witmer, B.G., & Singer, M.M. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*, 7(3), 224-240.
- [6] Ijsselsteijn, W., Ridder, R.H., Hamberg, R., Bouwhuis, D., & Freeman, J. (1998). Perceived depth and the feeling of presence in 3DTV. *Displays*, 18, 207-214.
- [7] Dillon, C., Keogh, E., Freeman, J., & Davidoff, J. (2000). Aroused and immersed: the psychophysiology of presence. *Presence 2000 - 3rd International Workshop on Presence*.
- [8] Meehan, M. (2000). An Objective Surrogate for Presence: Physiological Response. *Presence 2000-3<sup>rd</sup> International Workshop on Presence*. [online]. Available: <http://www.presence-research.org> (May 29,2001)
- [9] Wiederhold, B.K., Davis, R., & Wiederhold, M.D. (1998). The effect of immersiveness on physiology. In Riva, G., & Wiederhold, M.D. (Eds.), (1998). *Virtual environments in clinical psychology and neuroscience*. Amsterdam: IOS Press.
- [10] Hodges, L.F., Kooper, R., Rothbaum, B.O., Opdyke, D., de Graaff, D.D., Williford, J.S., & North, M.M. (1995). Virtual Environments for treating the fear of heights. *Computer Innovative Technology for Computer Professionals*, 28(7), 27-34
- [11] Rothbaum, B.O., Hodges, L.F., Watson, B.A., Kessler, G.D., & Opdyke, D. (1996). Virtual reality exposure therapy in the treatment of fear of flying: A case report. *Behavior Research & Therapy*, 34(5), 477-481
- [12] Tellegen, A. & Atkinson, G. (1974). Openness to absorbing and self-altering experiences ("absorption"), a trait related to hypnotic susceptibility. *Journal of Abnormal Psychology*, 83, 268-277
- [13] Carlson, E.B., & Putnam, F.W. (1993). An update on the dissociative experiences scale. *Dissociation*, 6(1), 16-27
- [14] Parent, A. Unpublished questionnaires. [online]. Available: <http://www.trytel.com/~aparent> (May 29, 2001)

- [15] Kennedy, R.S., Lane, N.E., Berbaum, K.S. & Lilienthal (1993). A simulator sickness questionnaire (SSQ): A method for quantifying simulator sickness. *International Journal of Aviation Psychology*, 3(3), 203-220
- [16] Schwartz, M.S. (Eds.) (1995). *Biofeedback: A Practitioner's Guide*. New York: Guilford Press
- [17] Sokolov, E.N. (1963). *Perception and the conditioned reflex*. New York: MacMillan
- [18] Graham, F.K., & Hackley, S.A. (1991). Passive and active attention to input. In J.R. Jennings & M.G.H. Coles (Eds.), *Handbook of cognitive psychophysiology* (pp. 251). Sussex, England: Wiley
- [19] Graham, F.K. (1992). Attention: The heartbeat, the blink and the brain. In Campell, B.A., Hayne, H., & Richardson, R. (Eds.), *Attention and information processing in infants and adults: Perspectives from human and animal research*. Hilldale, New Jersey: Lawrence Erlbau Associates.
- [20] Wiederhold, B.K., & Wiederhold, M.D. (1999). Clinical Observations During Virtual Reality Therapy for Specific Phobias. *CyberPsychology & Behavior*, 2(2), 161-168
- [21] Wiederhold, B.K. (1999). A comparison of imaginal exposure and virtual reality exposure for the treatment of fear of flying. (Doctoral dissertation, California School of Professional Psychology, May, 1999). *Dissertations Abstracts International*.
- [22] Wiederhold, B.K. & Wiederhold, M.D. (2000). Lessons learned from 600 virtual reality sessions. *CyberPsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, 3(3), 393-400.
- [23] Wiederhold, B.K., Gevirtz, R., & Wiederhold, M.D. (1998). Fear of flying: A case report using virtual reality therapy with physiological monitoring. *CyberPsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, 1(2), 97-104.
- [24] Wiederhold, B.K., Gevirtz, R.G., & Spira, J.L. (2000). *A controlled study comparing imaginal exposure and virtual reality exposure for the treatment of fear of flying*. Manuscript submitted for publication.

