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## Virtual Environments for the Induction of Action

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VIRTUAL ENVIRONMENTS FOR THE INDUCTION OF ACTION

BY

B. ADRIAN FLOWERS

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

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DOCTOR OF PHILOSOPHY DISSERTATION  
OF  
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## **ABSTRACT**

This dissertation is a study on the ways in which Virtual Reality can actively and reactively affect human physiology. The first manuscript describes the design of a highly generalized Virtual Reality biofeedback system. This system was developed such that, given proper design, it would be able to provide users with a highly responsive Virtual Environment to meet the criteria of embodiment, which will increase the user's responsiveness to stimuli. The system also functions as a biofeedback system that can be used for biomechanical as well as physiological feedback by using a generalized design paradigm.

The second manuscript describes a biofeedback game designed using the system from the first manuscript. This manuscript highlights the advantages of using the generalized multi-sensor design the system incorporates, and goes into detail on how the system processes sensor data for biofeedback.

The third manuscript discusses an experiment on using perspective to modulate the degree to which a participant responds to environmental stimuli. Unlike contemporary research, this study uses environmental stimuli rather than threat response to elicit a response in participants. The study proposes that while research in Virtual Reality generally focuses on increasing the feeling of immersion participants feel, there are potential advantages in decreasing the degree to which participants respond to stimuli as well. Particularly in the areas of Virtual Reality game development and film making, being able to reduce the degree of impact participants feel in response to negative stimuli would greatly increase the design options within these fields. While this study does not fully solve the problem of how to best design Virtual Environments within which to immerse participants, it does provide new and vital results that advance the field.

## ACKNOWLEDGMENTS

This dissertation is dedicated to all the colleagues and family that have assisted me throughout my academic career. Dr. Hervé has taught me over the years to look deeply at any problem before me, and not to merely accept what is visible at surface level without understanding. Unfortunately, he has yet to curb my love of ending sentences before completion. I must thank Dr. Katenka for always keeping me on track and teaching me to think beyond the state of the art.

I offer my heartfelt gratitude to Dr. Peckham and Dr. DiPippo for being there when I needed someone to consult regarding my career, research, and planning for the inevitability that is leaving graduate school. I owe my committee a great debt for the sacrifices they endured to their scheduling and their time, Dr. Daniels for his understanding, Dr. Boatright for her insight (and putting up with me meeting her after her class on so many occasions), and Dr. Comerford for his generosity.

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I especially want to thank my family. Beginning with the first engineer that I ever met, my grandfather, William Spaulding; while I may no longer be awed by his ability to construct toy car tracks as when I was a child, I am still touched by the depth of his heart. My grandmother, Delores Spaulding, for always making sure that I ate well. My sister, Felicia Garrido, for putting up with all of my complaints. My mother, Angelyn Flowers, who has always known what was in my best interest, even if I do not always listen. And finally, my father, Brian Flowers, the greatest hero that a growing child could ever wish to have. Hopefully, I can one day inspire others, the way that he has always inspired me.

## **PREFACE**

This dissertation is presented in a manuscript format with three manuscripts. The first manuscript describes the design of a generalized VR biofeedback system. It will be submitted to the International Journal of Human-Computer Studies. The second manuscript describes a biofeedback game for stress reduction that relies on the sensor redundancy provided by the system defined in the first manuscript for noise and failure resilience. It will be submitted to the 2018 IEEE Games, Entertainment, and Media Conference. The third manuscript discusses an experiment on the usage of perspective within Virtual Environments to modulate the impact a participant feels upon encountering environmental stimuli with Virtual Reality. It will be submitted to the 2018 IEEE Games, Entertainment, and Media Conference.

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**Manuscript 1:**

**BioPresence**

by

B. Adrian Flowers, Robert Tatomian, Natallia Katenka, and Jean-Yves Hervé

*The following manuscript will be submitted to the International Journal of Human-Computer Studies.*

## CHAPTER 1

### BioPresence

#### Manuscript 1:

### BioPresence

by

B. Adrian Flowers, Robert Tatoiian, Natallia Katenka, and Jean-Yves Hervé

#### 1.1 Abstract

Biofeedback therapy is the practice of providing users a visualization of a process within their body as a method of training the user in self-regulation. Contemporary research involves the usage of biofeedback games where the self-regulation of the player's physiological state is incorporated into the gameplay loop. Similarly, researchers are actively investigating the advantages and impact of using specialized Virtual Reality systems on human physiology and learning. This paper describes a biofeedback virtual reality system, as well as a selection of experiments built with the presented system system.

#### 1.2 Introduction

The definition of Virtual Reality systems (VRSs), as well as the research related to them, have an inherent degree of ambiguity. Dependent on the needs of the system, the VRS will abide by a standard set of constraints. The constraints built into the system will determine what assumptions can be made regarding the system, and the benefits of the system's usage. This is why it is important to start this article with the definition of VRS used in this research. We will use the term general VRS as an umbrella grouping for any VRS regardless of system constraints or design specifications. A VRS built for untethered mobile usage is a Mobile Virtual Reality system (mVRS). A VRS built around the constraints of the psychological phenomena known as body ownership will be referred to as an embodiment Virtual Reality system (eVRS). The BioPresence system proposed in this paper is an eVRS focused on biofeedback.

### **1.3 Background**

#### **1.3.1 Body Ownership and Embodiment**

Body ownership is a concept that finds its origin in a perceptual illusion known as the Rubber Hand Illusion (RHI). In the RHI, a participant has one arm hidden from view behind some type of covering. Placed next to this covering, the participant can see a rubber hand. Experimenters then simultaneously tactually stimulate the hidden true arm and the rubber arm. When the participant witnesses the rubber arm being touched along with the feeling of their own hand being stimulated, they will then respond to touch and threats directed towards the false hand as if it were the true hand [1].

Studies have shown that participants can incorporate entire false bodies as their own bodies given a similar methodology, resulting in what is referred to as the body swapping illusion [2]. For this illusion, a participant must see from the viewpoint of a false body. A false body in this context, being a body other than the participant's own, could be the body of an experimenter, a mannequin, or a virtual body. Generally, the participant will see through the eyes of the false body with a head-mounted display that is connected to a camera attached to the head of the false body. Once the participant sees from the false body's point of view, the participant must experience tactile stimulation and witness identical synchronous tactile input being performed on the false body. At this point, participants will take ownership of the false body and respond to threats and visually-perceived sensory input directed towards the false body in what is known as body ownership [2].

In the context of Virtual Reality, the elicitation of body ownership is often referred to as embodiment [3]. Studies suggest that embodiment requires that all motion between the participant's virtual body and true body be synchronized within 150 ms and that the virtual and true bodies be fully visuo-tactually matched. Given the above elicitation conditions [1], the participant will demonstrate a higher threat response to virtual visual stimuli.

#### **1.3.2 Biofeedback**

Biofeedback can be split into two overarching categories: Biomechanical Feedback and Physiological Feedback. Biomechanical Feedback provides feedback for physical phenomena such as motion and force. It is commonly applied for physical rehabilitation. Physiological Feedback is concerned with physiological processes within the body. Early uses of physiological biofeedback therapy focused on the treatment of migraines [4], muscular tension, skin conductance, heart rate, and/or breathing to reduce the onset and severity of migraine headaches [5]. Modern biofeed-

back therapy may also incorporate the usage of electroencephalography to leverage neurological feedback for the treatment of migraines [4].

### **Affective Feedback**

Biofeedback is also used to gain understanding of complex processes such as affect, which is defined as the experience of an emotion. In particular, affect represents an instantaneous reaction, often due to external stimuli. Researchers primarily define affective states along two axes: arousal and valence [6], where arousal corresponds to levels of physiological activation/focus and valence represents the subjective desirability of the state. Changes in arousal can be detected via physiological reactions, such as skin conductance, eye blink rate, and heart rate variability, whereas changes in valence have the highest correlation with a jaw-mounted electromyogram [6, 7]. As it is difficult to objectively measure an individual's affective state, and infeasible to attribute a meaning to it, feedback related to affective states (affective feedback) relies primarily on the relative change in an individual's physiological state, when compared against the previous measurement. A classical work in affective feedback literature is the biofeedback game *Relax to Win*, a racing game where players control the speed of their in-game avatar by increasing or decreasing their arousal level [8]. While there have been efforts to calculate objective multi-sensor measures of a participant's arousal, the usage of a single sensor approach can be considered more responsive and beneficial to participant training [9].

### **Biofeedback Games**

In part due to the applicability of biofeedback therapy towards children, a significant portion of contemporary physiological biofeedback research concerns the development of biofeedback games to teach children self-regulation. Classically, biofeedback is incorporated into the game play loop in one of three ways. The first approach involves using the participant's physiological state as the primary control biofeedback mechanism in the game [10]. The focus of these biofeedback-controlled games is primarily to teach the participants techniques to regulate their state. One of the most influential biofeedback controlled games is *The Journey to Wild Divine*, which is an exploration focused biofeedback game where player progress is controlled by the player's respiration. During the game, players are taught and practice breathing techniques. The game has been shown to result in a positive gain towards the management of Attention Deficit Hyperactivity Disorder symptoms in children [11].

The second approach to biofeedback games is to alter the in-game environment based on

the participant’s changing physiological state [10]. This approach is often used to train participants to manage their state within a specified environment. An example of this approach is the study by Chittaro and Sioni [9] on training players to remain calm in emergency and classroom environments. In one of the levels of this game, participants sit inside of a classroom and have to listen to a virtual lecturer, while filtering out unrelated ambient noise produced by virtual students. The volume of the distracting conversation by the nearby virtual students increase with the player’s stress.

The third approach to biofeedback games is to provide a reward to the player based on achieving and maintaining a goal state, independent of the underlying game. The purpose of this approach is to train participants choosing healthier options by providing a reward for healthy behavior, such as in the study by Ketheson et. al [12], in which participants were given power-ups by reaching and maintaining heart rate thresholds during the game. This third approach is popular within exergames.

### **Biofeedback in Exergaming**

Exergames are video games that use physical exercise as the main form of player input into the system [13]. An example is the *Paperdude* system by Bolton et. al [14], a VRS that required participants to pedal on a stationary bike, to virtually deliver papers to houses. An example of an early biofeedback exergame is the game *Pulse Masters Biathlon*, a game that directly mapped the users heart rate to the movement speed of the character in a game [15]. When not used as a direct control mechanism for exergames, biofeedback is used as a dynamic measure of wellness, such as in the *Cybercycle* system [16]. *Cybercycle* is a virtual cycling exergame that consists of users cycling through a virtual tour and is used to assist memory training in adults with dementia. Users in the *Cybercycle* game are shown their heart rate, and are instructed to maintain a minimum heart rate reserve as they play the game [16].

### **Applications in Virtual Reality**

Virtual Reality Exposure Therapy is a common form of treatment for PTSD, allowing participants to re-experience the traumatic environment without risk of physical harm [17, 18]. Recent studies on embodiment, suggest that a participant embodying a virtual body will begin to evaluate and respond to conditions within the Virtual Environment from the perspective of the virtual body [19, 20]. One study of interest is the study by Banakou et. al [21], in which participants were tasked with moving objects from the perspective of a child’s body or from

the perspective of an shrunken adult’s body. The participants that were given the perspective of the child’s body overestimated the size of the objects they were instructed to interact with to a greater degree than those given the shrunken adult’s body. In another study of interest performed by Groom [22], Caucasian participants in a virtual environment were given the body of either a dark-skinned or light-skinned individual. Participants given the dark-skinned virtual body expressed a significantly lower racial bias in the post-experimental Implicit Association Test. The above research highlights what will likely become the largest advantage of biofeedback eVRSs, the ability to modulate user feedback within real-world environments from their own or alternative perspectives.

### 1.3.3 Existing Systems

The majority of existing biofeedback eVRSs are focused towards single-sensory input systems. An example of such a system is *DEEP*, a respiration control VR biofeedback game for children [23], in which the player explores an underwater world through deep breathing patterns. A system sharing similarities with the *BioPresence* system proposed in this paper is *PhysioVR*, a multi-sensor biofeedback VRS with built-in data recording [24]. Unlike *BioPresence*, *PhysioVR* is an mVRS with a focus towards biofeedback games that offers support for a set of proprietary sensors. As an eVRS, *BioPresence* is designed to support a large array of hardware/sensing tools to ensure the minimization of latency, leverages sensor fusion to minimize motion artifacts, and supports post experimental stimuli-response analysis. The generic design of the *BioPresence* system’s Sensor Interface (SI) also allows for greater variability in sensor usage and placement.

A second system related to this work is the component-based modular eVRS presented by Spanlang et. al [25]. Similar to our *BioPresence* system, Spanlang et al.’s system includes support for processing and recording physiological reactions in response to environmental stimuli. At the same time, the focus of that system is on measuring a participant’s reactions in relationship to the participant’s perceived level of immersion in the VE. As a biofeedback system, *BioPresence* by default sends all collected physiological data back into the system to modify the VE based on the participant’s physiological state.

## 1.4 BioPresence

The main functions of the proposed *BioPresence* system are sensor modularity and fusion, event-driven experiment modeling, and data replay and analysis.



### 1.4.1 System Overview

The system immerses a participant in a VE as dictated by a scenario, as well as a chronology of discrete events. The scenario is a script that defines the VE and a sequence of steps to be completed by a participant. Following a pre-selected scenario, multiple events can occur at various times and locations in the VE. An event is defined as any change in the VE that may result in a stimulus response from a participant. The system allows for the definition of scenario events and user events. A scenario event is an event that is driven by the pre-selected scenario. The participant does not have a direct control over the occurrence of a scenario event. A user event is an event that is triggered by an action performed by the participant. Throughout the scenario, the participant may have their physiological state recorded via external sensors. This information is fed back into the system as needed. All events, user positional and rotational information, and external sensing data are recorded to an external file. This external file can be fed into the system's playback engine to replay the iteration of the scenario. The generic modular design of the SI allows for rapid prototyping based on the evolving needs of the system.

The need for such a capability is highlighted by the experience of Sonne et. al [26], who designed the Chillfish biofeedback game. The Chillfish game was designed with respiration as the primary control modality. Unfortunately, the authors noted during usage of the system that the children participating in the study, would routinely break the system by shorting the circuitry with saliva. The children would also play with and rearrange the handworn physiological sensors [26]. While situations in which sensors are destroyed or invalidated due to motion are unavailable, the presented *BioPresence* system increased noise resilience over single sensor systems due to the usage of an independent multisensor paradigm.

### 1.4.2 System Architecture

The architecture of the *BioPresence* system, shown in Figure 1, consists of four components responsible for external sensor communication (Sensor Interface), event triggers (Event Interface), internal monitoring and decision-making (Manager), and Input-Output.

#### **Manager**

The Experiment Manager (EM) interprets incoming data and propagates the effect of events throughout the VE. All sensors, questionnaires, and event components included in the experiment must be registered through the EM during initialization. On launch, the EM generates a random ID for the experiment session to be used as the non-identifiable key to record data from the

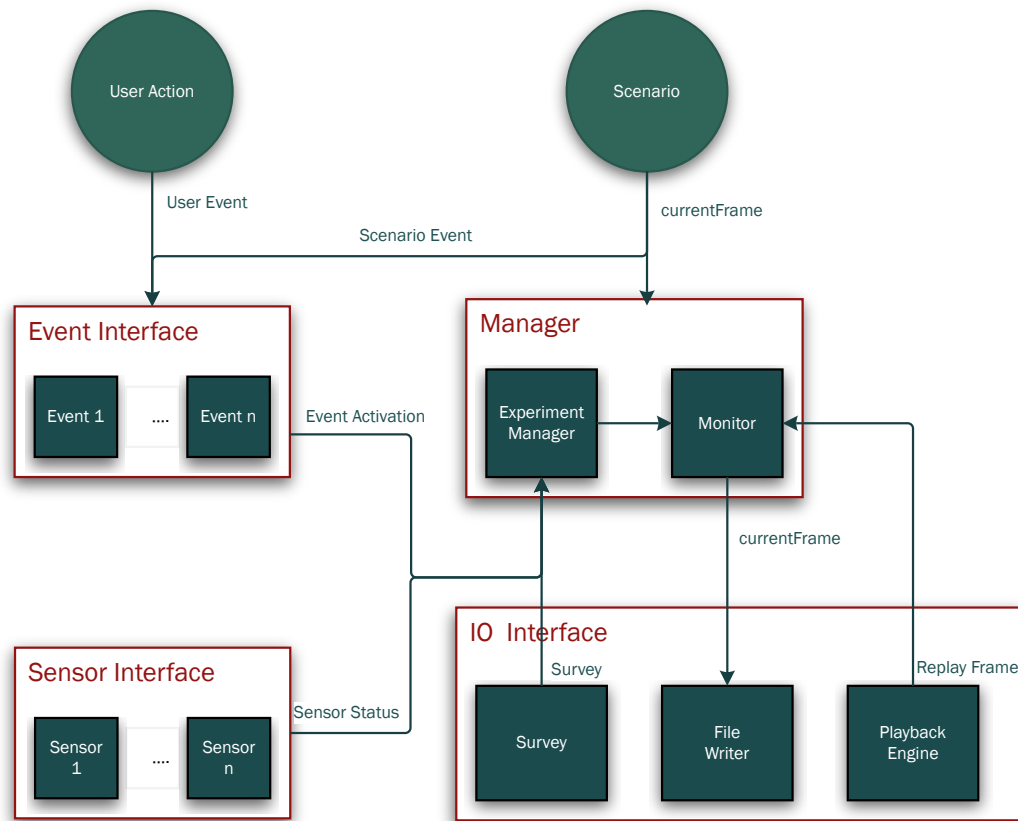


Figure 1. BioPresence Architecture

session. The Monitor is responsible for recording data during a scenario. The data recorded, provided through the EM, consists of user driven transforms, event, and sensor information.

### Event Interface

Event components are entities within the scenario to which an event is attached. When an event component is registered to the EM, it provides an ID for the attached event.

### Sensor Interface

Sensors are connected to the EM through a generic serial sensor interface. When a sensor registers to the EM it specifies the name (if any) of physiological attributes it represents. Upon registration to the EM, a sensor is provided a pollable data queue on the SI.

Physical motion is an integral part of many VRSs. Unfortunately, the introduction of noise caused by motion (motion artifacts) greatly reduces the reliability of body-worn sensors. However,

combining data from multiple sensors provides a degree of resilience to motion artifacts. The *BioPresence* system relies on polling to determine data accuracy. If multiple sensors have been registered for the same physiological attribute, the EM will poll the sensors for their belief on the relative change of the attribute since the previous request (Figure 2).

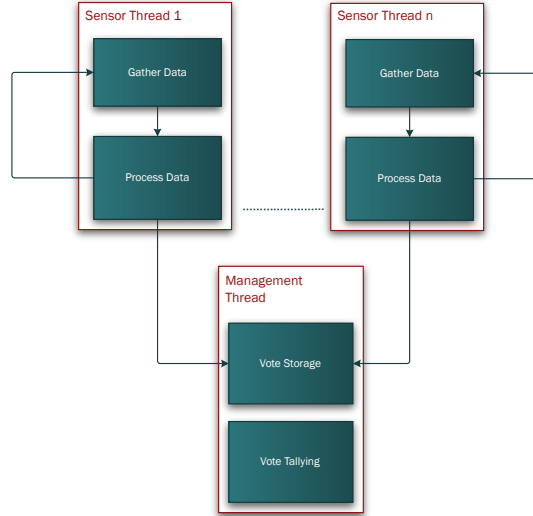


Figure 2. Vote Tallying

Each sensor connected to the SI registers with a sensor specific subclass that inherits from a generic interface class. Within the sensor specific implementation, the sensor specialized processing analyzes the changes in the participant’s physiological state. The EM accesses the trends in this data through an abstract function that returns a trinary response based on whether the representative physiological attribute measured by the sensor is decreasing, constant, or increasing, represented by -1, 0, and +1 respectively. The vote from each sensor is scaled by the sensor’s estimated reliability.

The general form for the function to vote on trends is shown below in Eqs. (1)–(3), where  $S$  is the sensor specific function to calculate the player’s arousal at time  $t$ . The function  $T_S$  calculates the relative trend in the player’s arousal state for a given sensor, because  $T_S$  is relative to the previous recording, the base case represents the sensor baseline with a trend of 0.  $R_S$  is the sensor specific reliability function.  $\varepsilon$  is an experimentally-calculated baseline threshold. The votes collected from all sensors are weighted by their reliability and divided by the total weighted vote count. This final average is used to decide the player’s overall arousal trend, represented by

the function  $T$ , for the given time frame.

$$T_S(0) = 0, \tag{1}$$

$$T_S(t) = \begin{cases} +1, & \text{if } S(t) - S(t-1) \geq \varepsilon, \\ -1, & \text{if } S(t) - S(t-1) \leq -\varepsilon, \\ 0, & \text{otherwise,} \end{cases} \tag{2}$$

$$T(t) = \frac{\sum_{k=1}^n R_{S_k}(t) T_{S_k}(t)}{\sum_{k=1}^n R_{S_k}(t)}. \tag{3}$$

This naive method allows the *BioPresence* system to take advantage of two generalizable sensor fusion methods of increasing motion artifact resilience: multi-site confirmation and sensor diversity. Multi-site confirmation leverages the ability to analogously collect specific physiological characteristics multiple sites on the human body, then compares trends across all collection sites. For example, skin conductance can be gathered from the fingertips, hands, and the bottoms of the soles [27]. Sensor diversity leverages differences between the expression of valid data across physiological sensors. Different sensors have different levels of sensitivity to noise and potential changes in the participant’s state. If the selected sensors disagree on what changes have occurred to the participant’s physiological state, it is likelihood that noise is affecting at least one of the sensors [28].

### Input-Output Interface

At the end of each time frame the EM sends state information from the Scenario, alongside recordings from the Sensor and Event Interfaces to the Input-Output (IO) component as a data packet. This packet is then recorded in a participant’s unique file location.

#### 1.4.3 Data Recording

The Monitor is responsible for sensor synchronization and sampling the raw data collected from the SI to the global sampling rate specified by the EM. When a sensor registers with the SI, it provides its local start time. The sensor’s data is then interpolated into the global sampling rate through usage of linear interpolation. This process, shown below in Eq. 4- 7, is performed in post-processing. Given a sensor registered to the SI, the function  $S_t(x)$  is the native system time of the sensor at Index  $x$ , where  $x = 0$  represents the start time of the experiment, and  $x = n$  the end time of the experiment. The native system time of the sensor is the sensor’s local

time, for example, when using a sensor connected through an Arduino, the sensor’s native system time is the Arduino’s system time. The function  $EM_t(x)$  is the system time of the Experiment Manager at Index  $x$ . The variables  $S_d$  and  $EM_d$  are the time range of the experiment in the native system time of the sensor and the system time of the EM respectively. The ratio  $T_S$  is the difference in time scale between the sensor and the EM. The function  $S_{St}(x)$  converts the time of the sensor into standardized time (the system time of the EM). While the system’s design allows for alternative interpolation methods for the sensor and positional data, linear interpolation is the method used by default.

$$S_d = S_t(n) - S_t(0), \quad (4)$$

$$EM_d = EM_t(n) - EM_t(0), \quad (5)$$

$$T_S = \frac{EM_d}{S_d}, \quad (6)$$

$$S_{St}(x) = T_s * (S_t(x) - S_{kt}(0)) + EM_t(0). \quad (7)$$

Upon receiving the latest data packet from the Monitor, the EM checks that an event has not occurred since the previous data packet was received. If an event has occurred, the EM marks the corresponding event with an activation flag in the data packet for the current time frame.

## Replay System

Given a scenario, the scenario’s registered events, and the output from an experimental trial, the Replay System will regenerate a scenario iteration for post-experimental analysis. This is done by feeding the output transform and event data into the Experiment Manager. The Experiment Manager will then use the replay data as input for the system instead of live participant input.

### 1.5 Sequence Diagram

A sequence diagram detailing the life-cycle of the BioPresence system during an experiment is shown below in Figure 3. The Start function initializes the system by generating the participant’s participantID, then retrieving the list of registered sensors and event IDs for the experiment. Afterwards, inside the main loop, the Update function retrieves the participant’s current state (position and rotation) within the VE, and any trends that have been noted by the SI. The Update function then passes the participant’s state information, alongside any existing sensor trends, to the Event Interface to check if an event has been triggered. After checking the Event Interface, the Update function updates the VE as a result of changes in the sensor trends and/or

triggered events if necessary. Once the VE has been updated, the current data frame is sent to the IO Interface to be recorded.

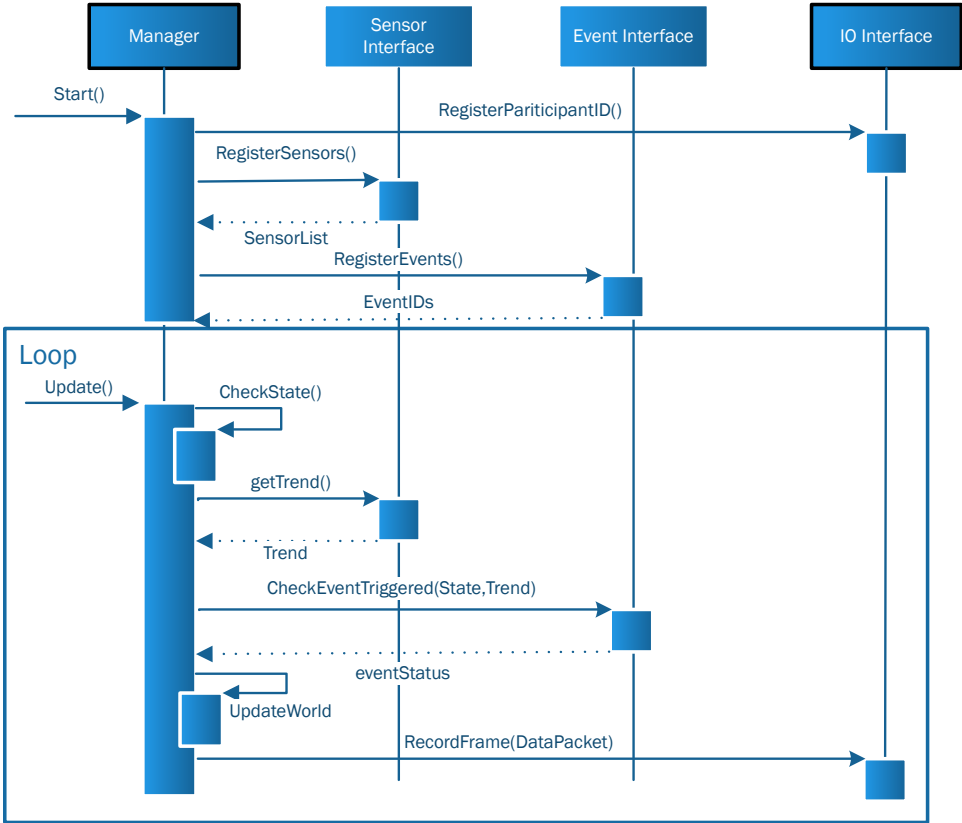


Figure 3. BioPresence Sequence Diagram

**1.6 Sample Studies**

This section presents a biofeedback game for stress reduction and two experiments that were built with the *BioPresence* system.

**1.6.1 Biofeedback Game**

The *BioPresence* system was used to develop a gesture controlled Virtual Reality Biofeedback game. The goal of the players in the game is to shoot a set of moving targets. When a player successfully hits a target, a multiplier bonus, determined by the player’s change in relaxation against their initial baseline, is applied to the point value the player receives for the target hit. The player’s current degree of relaxation is presented to the user via an on-screen meter, shown in Figure 4. Participants aim with their left hand, and shoot raising their left thumb. For every target hit, the participant is given a static score multiplied by a score multiplier, which is

determined by their arousal levels.

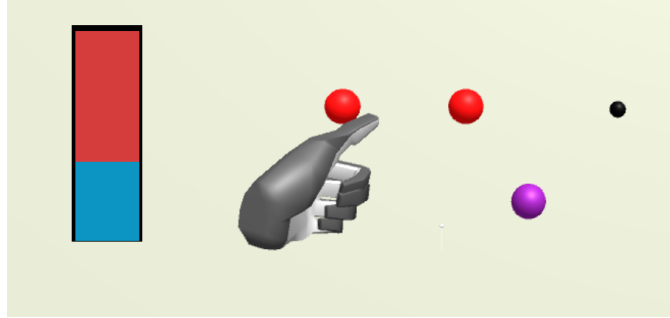


Figure 4. Biofeedback Shooting Gallery

### Equipment and Methodology

The game was developed in the Unity game engine. Participants have control of the camera through usage of an Oculus Rift. The game is controlled via gestures from a Leap Motion sensor. Players wear a skin conductance and blood volume pulse (BVP) sensor on their right hand. Skin conductance is considered a reliable measure of changing arousal in participants and offers robustness to noise. BVP, while being more prone to motion artifacts, is also a strong marker for changes in arousal.

The biofeedback game uses the sensor polling capabilities of the *BioPresence* system by combining multiple independently processed sensors. Each sensor is analyzed separately and provides a vote for what it perceives to be the relative change in a participant's arousal since the previous data recording. This relative change is reduced to a trinary statement, on a per sensor basis, based on whether the participant's arousal has decreased, remained constant, or increased, represented by -1, 0, and +1 respectively. Which of the three states received the most votes across all sensors is determined to be the true state for that time frame.

Using the independent multisensor voting paradigm of the *BioPresence* system offers two advantages. The first is increased resilience to noise through multisensor and multisite placement [27]. The second advantage is robustness. Physiological sensors require exact placement for proper performance. Unfortunately, in an applied usage, it can be difficult for participants to maintain proper sensor placement when playing biofeedback games, resulting in faulty readings or broken sensors [26]. As all sensors in the *BioPresence* system are evaluated independently, failure of a single sensor does equate to a failure in the system's performance.

### 1.6.2 Perspective on Control Loss within Virtual Environments

Studies on embodiment within VEs show a correlation between users having control over the head of a virtual avatar and feeling ownership over the avatar. This is most commonly tested by the magnitude of the threat response users feel towards threatening stimuli aimed at the virtual avatar. This threat response is measured through skin conductance response, heart rate variability, and self-survey responses [29]. This subsection presents an experiment on the impact of perspective on the removal of participant control within a VE. The experiment was event-focused and made use of *BioPresence* system’s post-experimental analytical capabilities.

#### Equipment and Methodology

In this preliminary experiment 16 participants between the ages of 18 and 35 wearing an Oculus Rift DK2 HMD explored a virtual environment using an Xbox controller. During the experiment, participants were equipped with hand-worn galvanic skin conductance and blood volume pulse sensors to measure for a threat response. While participants performed tasks such as visually tracking a moving ball (Figure 5), questionnaires designed to assess the participants’ comfort and perceived immersion levels would appear in front of them. The participants performed all tasks sequentially from a third-person perspective and from a first-person perspective.

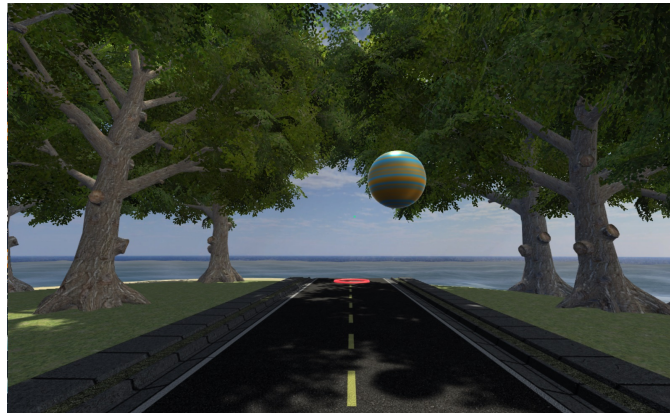


Figure 5. Ball Tracking Task

Unbeknownst to the participants, before the questionnaire would appear, the camera within the VE would freeze for 500 ms, removing the participants’ active control over the virtual avatar during this time. The scenario included differing types of freeze events depending on the type of motion the participant was performing at the time the camera was frozen. The metric of analysis was the magnitude of a participant’s response during the freeze events. Shown in Figure 6 is a



plot of a participant’s tonic skin conductance level (SCL) recorded during the experiment. The blue vertical lines mark automatically-tagged freeze events during the experiment.

In the post experimental analysis it was noted that the participants’ heart-rate response, during scene transition and when the camera was frozen during translational motion, was greater from a third-person perspective than from a first-person perspective.

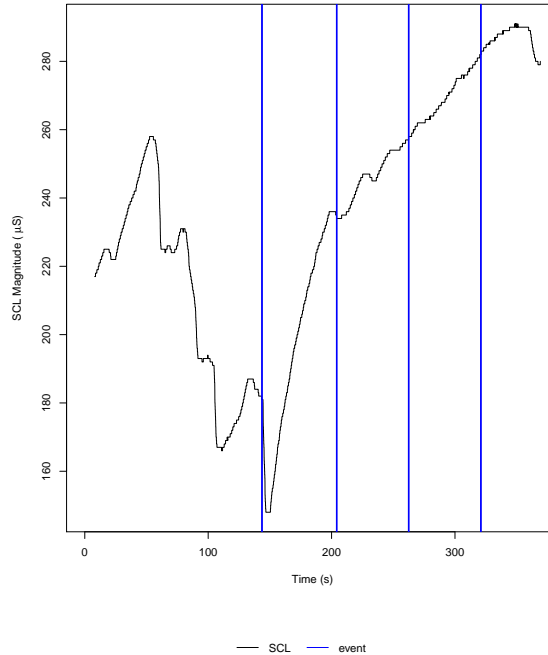


Figure 6. Sample Skin Conductance Level

### 1.6.3 Dynamic Environments for Physical Activity

This experiment under development built with the *BioPresence* system is an exergame for testing the induction of action within VEs. For this experiment, a participant rides a virtual bike through a VE. The conditions within the VE are modified based on the participant’s heart rate with the goal of instructing the participant to modulate their speed, until a desired heart rate is achieved. This exergame has been designed both to use the environment to modulate a participant’s intensity of exercise without providing numerical feedback of their heart rate, and as an experiment to analyze how users react to different environments under the effects of the Body Ownership Illusion. Figure 7 shows the experimental setup and the VE viewed by the participant.



Figure 7. Bike Experiment

### Equipment and Methodology

The criteria for the body ownership illusion are met by giving the participant one-to-one control of the virtual bike. This is performed by controlling the virtual bike through biomechanical feedback from a Hall effect sensor attached to the wheels of a stationary bike. During the experiment, participants are also equipped with a blood volume pulse sensor to track their heart rate. The generalized nature of the SI allows the *BioPresence* system to meet a large number of development goals, interchangeably supporting both physiological and biomechanical feedback.

#### 1.7 Discussion

Biofeedback therapy is a proven method to teach individuals vital skills for self-regulation. The presented *BioPresence* system offers a versatile eVRS featuring a modular design paradigm that allows for noise resilience, robustness to sensor movement, and features a fully integrated pipeline for data recording, analysis, and post-experimental replay.

#### 1.8 Future Work

There are three areas of focus for the future work. The first is to gather the participants for the biomechanical biofeedback experiment on the induction of user action. Using the biofeedback game, on multiple participants, one can test the perceived performance gain or loss in terms of participant satisfaction and relaxation as a result of the multisensor voting paradigm on the user experience. Finally, the documentation of the system should be further developed and

templates for common sensors should be made available to increase the usage and viability of the *BioPresence* system.

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**Manuscript 2:**

**Independent Sensory Decision Making for Resilient Biofeedback Game Design**

by

B. Adrian Flowers, Robert Tatoian, Ashley Witkowski, Natallia Katenka, and Jean-Yves Hervé

*The following manuscript will be submitted to the IEEE Games Entertainment and Media (GEM) conference on April 20th, 2018.*

## CHAPTER 2

### BioFeedback Game

#### 2.1 Abstract

Biofeedback games are often developed to teach self-management skills to children. Unfortunately, the underlying system for many of these games are designed for laboratory environments and are not built to accommodate sensor movement and noise that are common in an applied setting. This paper describes a gesture controlled biofeedback virtual reality game designed to train participants to lower their physiological arousal that incorporates sensor fusion for increased system resilience.

#### 2.2 Introduction

Biofeedback therapy is the practice of providing users a visualization of a process within their body as a method of training the user in self-regulation [1]. In order to increase engagement, biofeedback therapy is often embedded into biofeedback-controlled games. When selecting the sensors to be used for the game, developers must decide what is the optimal sensor for the physiological attribute for which they want to provide feedback [1]. The developers must also consider the sensors' reliability, and the limitations imposed by the sensors placement on the design of the game. The proposed multi-sensor approach attempts to increase the reliability of sensors through the usage of redundancy.

#### 2.3 Background

Biofeedback can be split into two overarching categories: biomechanical feedback and physiological feedback. Biomechanical feedback provides feedback for physical phenomena such as motion and force. Physiological feedback is concerned with physiological processes within the body such as heart rate variability [2]. Early uses of physiological biofeedback therapy focused on the treatment of migraines. Participants were taught to regulate their body temperature, muscular tension, skin conductance, heart rate, and/or breathing to reduce the onset and severity of migraine headaches [2]. In addition to the above sensors, modern biofeedback therapy may also incorporate the usage of electroencephalography and functional near-infrared spectroscopy to leverage neurological feedback for the treatment of migraines. Biofeedback therapy is also commonly used to train children with autism and/or to regulate their anger and stress [3].

## Biofeedback Games

In part due to the applicability of biofeedback therapy towards children, a significant portion of contemporary physiological biofeedback research concerns the development of biofeedback games to teach children self-regulation. Classically, biofeedback is incorporated into the game play loop in one of three ways. The first approach involves using the participant’s physiological state as the primary control biofeedback mechanism in the game [1]. The focus of these biofeedback controlled games is primarily to teach the participant techniques to regulate their state. One of the most influential biofeedback controlled games is *The Journey to Wild Divine*, which is an exploration focused biofeedback game where player progress is controlled by the player’s respiration. During the game, players are taught and practice breathing techniques. The game has been shown to result in a positive gain towards the management of Attention Deficit Hyperactivity Disorder symptoms in children [4].

The second approach to biofeedback games is to alter the in-game environment based on the participant’s changing physiological state [1]. This approach is often used to train participants to manage their state within a specified environment. An example of this approach is the study by Chittaro and Sioni [5] on training players to remain calm in emergency and classroom environments. In one of the levels of this game, participants sit inside of a classroom and have to listen to a virtual lecturer, while filtering out unrelated ambient noise produced by virtual students. The volume of the distracting conversation by the nearby virtual students increase with the player’s stress.

The third approach to biofeedback games is to provide a reward to the player based on achieving and maintaining a goal state, independent of the underlying game. The purpose of this approach is to train participants choosing healthier options by providing a reward for healthy behavior, such as in the study by Ketheson et. al [6], in which participants were given power-ups by reaching and maintaining heart rate thresholds during the game. This third approach is popular within exergames, which are video games that use exercise as the player input into the system.

### 2.3.1 Affective Feedback

Biofeedback is also used to gain understanding of complex processes such as affect, which is defined as the experience of an emotion. In particular, affect represents an instantaneous reaction, often due to external stimuli. Researchers primarily define affective states along two axes: arousal



and valence [7], where arousal corresponds to levels of physiological activation/focus, and valence represents the subjective desirability of the state. Changes in arousal can be detected via physiological reactions, such as: skin conductance, eye blink rate, and heart rate variability, whereas changes in valence have the highest correlation with a jaw mounted electromyogram [7, 8]. As it is difficult to objectively measure an individual’s affective state, and infeasible to attribute a meaning to it, feedback related to affective states (affective feedback) relies primarily on the relative change in an individual’s physiological state, when compared against the previous measurement. A classical work in affective feedback literature is the biofeedback game *Relax to Win*, a racing game where players control the speed of their in-game avatar by increasing or decreasing their arousal level [9].

Physiological measures and baselines will vary from person to person and throughout the course of the day. Because of this volatility, it is difficult to objectively measure an individual’s affective state based on physiological measures. What is more common is to track an aspect of the user’s physiology and measure how it changes in response to emotionally charged stimuli, thus providing a comparative metric on how the participant’s physiology is impacted by changes in the participant’s affective state. For example, an increase in a participant’s arousal is positively correlated with an increase in the participant’s skin conductance level.

Research has been conducted to use multi-sensor metrics to calculate an objective rating of a participant’s arousal [10], however it is considered preferable to use the classic single sensor comparative metric for biofeedback games. The reason for this is because there is considered to be little tangible benefit in using a combined multi-sensory metric. In a study by Chittaro and Sioni [5] participants playing a biofeedback game controlled by arousal were split into three groups. The first group only used a skin conductance sensor to control the game. The second group used a combined metric generated from skin conductance, heart rate, and electromyogram sensors. The third group was a placebo group which were provided a pseudo-random feedback signal. In the analysis of this study, no significant difference was found in the post experimental performance between the combined metric and the placebo group, while an improvement was noted between the skin-conductance only and placebo group. Participants in the skin-conductance only group also reported feeling a greater sense of control over the game than the group that used the combined metric.

### 2.3.2 Virtual Reality Biofeedback

In recent years, researchers have begun to explore the usage of virtual reality systems for biofeedback therapy. An example of such a system is *DEEP*, a respiration controlled virtual reality biofeedback game for children [11], in which the player explores an underwater world through deep breathing patterns. Studies on a designing virtual environments such that participants feel as if they embody their given virtual avatars suggest that the participants will begin to evaluate and respond to conditions within the Virtual Environment from the perspective of the given virtual avatar [12, 13], expressing a higher magnitude of response to specific environmental stimuli. One study of interest, is the study by Banakou et. al [14], in which participants were tasked with moving objects from the perspective of a child’s body or from the perspective of an shrunken adult’s body. The participants that were given the perspective of the child’s body overestimated the size of the objects they were instructed to interact with to a greater degree than those given the shrunken adult’s body. In another study of interest performed by Groom [15], Caucasian participants in a virtual environment were given the body of either a dark-skinned or light-skinned individual. Participants given the dark-skinned virtual body expressed a significantly lower racial bias in the post-experimental Implicit Association Test.

### 2.4 The Game

The game presented is a gesture controlled first-person shooter that uses a generalized multi-sensor approach to biofeedback wherein players must shoot a set of targets. The final score players are given is determined by the degree to which they have relaxed since the start of the game. The player’s current degree of relaxation is presented to the player via an on-screen meter, as shown in Figure 8. Players aim with their left hand and shoot by raising their left thumb. For every target hit, players are given a static score multiplied by a score multiplier, which is determined by their arousal levels.

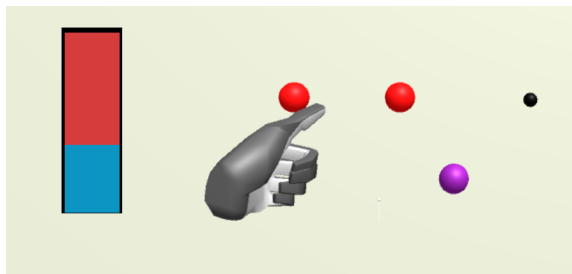


Figure 8. Biofeedback Shooting Gallery

Successfully hitting a target is expected to result in an increase in the players' arousal. In order to maximize their score, the players must then lower their arousal further to increase their score multiplier.

#### **2.4.1 Equipment**

The game was developed with the Unity game engine. Players have control of the camera through usage of an Oculus rift. The game is controlled with gestures detected by a Leap Motion sensor. Players wear a skin conductance and blood volume pulse (BVP) sensor on their right hand. SCR is considered a reliable measure of change in arousal and is somewhat resilient to noise caused by motion. BVP, while being more prone to motion artifacts, is also a strong marker for increases in player arousal.

#### **2.4.2 Methodology**

Contrary to related works [11, 9], the virtual reality biofeedback game presented here uses a multi-sensor design. The reason for this is to build redundancy into the system in case of sensor failure. The design proposed and implemented in the game uses an independent sensor paradigm, where all sensors vote separately on how they estimate the player's physiological state to be changing. The votes are all tallied, and the relative change in the player's arousal is estimated from that tally.

This independent approach to sensor fusion offers two advantages. The first is increased resilience to noise through multisensor and multisite placement [16]. Although the biofeedback game presented only makes use of a single skin conductance and BVP sensor, the underlying system supports the usage of duplicate sensors as necessary. If it is expected to be difficult for the player to keep the recording sensors stationary, duplicate sensors can be placed at alternate sites (such as the sole of the foot or an earlobe in the case of skin conductance and BVP respectively) as a redundancy measure. The second advantage is robustness. Physiological sensors can require exact placement for proper performance. Unfortunately, in an applied setting, it can be difficult for players to maintain proper sensor placement when playing biofeedback games, resulting in improper readings or broken sensors [17]. The proposed multi-sensor approach can continue to function in the event of sensor failure if the majority of sensors are still functioning properly. Towards this resilience to failure, the vote of each sensor is scaled by a sensor-specific reliability function which computes how reliable the sensor is believed to be at the given time.

## Skin Conductance

The changes in a player's arousal level can be detected with a skin conductance sensor by measuring the player's skin conductance level (SCL). A player's raw skin conductance consists of two signals, the SCL/tonic skin conductance and the skin conductance response (SCR)/phasic skin conductance. The SCL is the player's overall skin conductance. The SCR is an impulse response to stimuli. In order to extract the SCL, which is positively correlated with arousal, from the raw signal, the SCR must be removed. The game presented here uses a simplistic method to quickly calculate an estimate of the SCL, taking the mean of the raw skin conductance signal over a specified time windows. Performing the extraction of the SCL with a mean-filter provides only a rough estimate of the true SCL, however it is fast-enough to perform online during run-time. The described function to use a Galvanic Skin Response sensor to estimate the player's arousal from their SCL,  $S_{SCL}$ , is shown below in Eq. 8.  $GSR$  in the context of the below function is the raw GSR signal.  $M$  is the window size for the mean filter.

$$S_{SCL}(t) = \frac{1}{M} \sum_{j=0}^{M-1} GSR((t-1) + j). \quad (8)$$

SCL is a reliable measure of the changes in a player's arousal and has a constant reliability function

$$R_{SCL}(t) = 1.$$

## Blood Volume Pulse

Heart rate acceleration is correlated with increases in arousal [18]. The changes in a player's arousal level are detected on the BVP sensor by measuring the change in the player's heart-rate. A handworn BVP sensor uses infrared light to measure the blood flow through the finger. Heartbeats are expressed as peaks in the resultant signal, as seen in Figure 9.

These heartbeats are extracted from the BVP signal through a windowed filter to extract local maxima. The times between heartbeats, known as the interbeat intervals (IBIs), are calculated from the differences between the time index of successive heartbeats. If the IBI interval between consecutive heartbeats is decreasing it represents an acceleration in the player's heart rate. The IBI intervals from the data represented in Figure 9 is shown in Figure 10. Because the interbeat intervals can only be measured when a heartbeat occurs, linear interpolation was used to create the continuous IBI plot in Figure 10.

The described function to estimate the player's arousal with a BVP sensor,  $S_{BVP}$  is shown

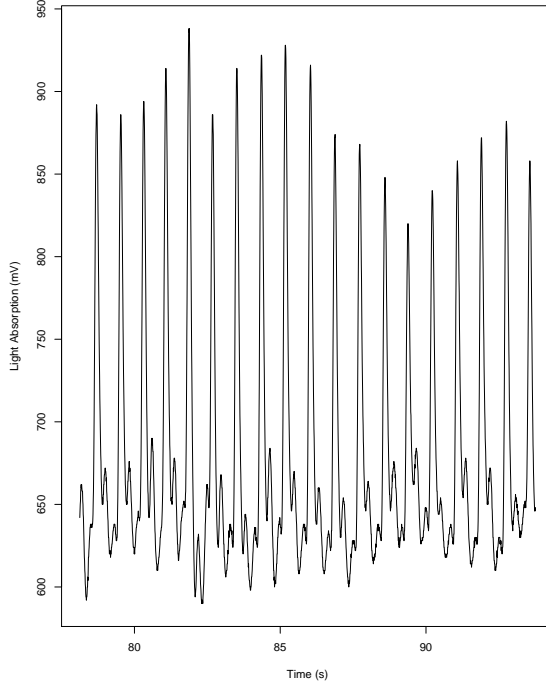


Figure 9. Blood-Volume Pulse Signal

below in Eq. 9 and 10. This function detects whether the player’s heart rate is accelerating, deceleration, or remaining constant during the given time period.

$$S_{\text{BVP}}(0) = 0 \quad (9)$$

$$S_{\text{BVP}}(t) = \text{IBI}(t) - \text{IBI}(t - 1) \quad (10)$$

It is important to note that HR is only an accurate detector of arousal stimuli when the stimuli exceeds a certain threshold. HR is not an accurate measure for small increases in arousal, and does not accurately detect decreasing arousal [19]. While heart rate deceleration is often considered a detector of changes in valence, it is unreliable as a measure of arousal. As such, the BVP sensor is only reliable as a detector of arousing stimuli. Unless the BVP sensor detects heart-rate acceleration, the BVP sensor’s vote should be discarded. The reliability function,  $R_{\text{BVP}}$ , is shown below in Eq. 11. The  $\varepsilon$  parameter in Eq. 11 is an experimentally-decided minimum threshold for a significant change in the player’s heart-rate acceleration.

$$R_{\text{BVP}}(t) = \begin{cases} 1, & \text{if } S_{\text{BVP}}(t) - S_{\text{BVP}}(t - 1) \geq \varepsilon, \\ 0, & \text{otherwise.} \end{cases} \quad (11)$$

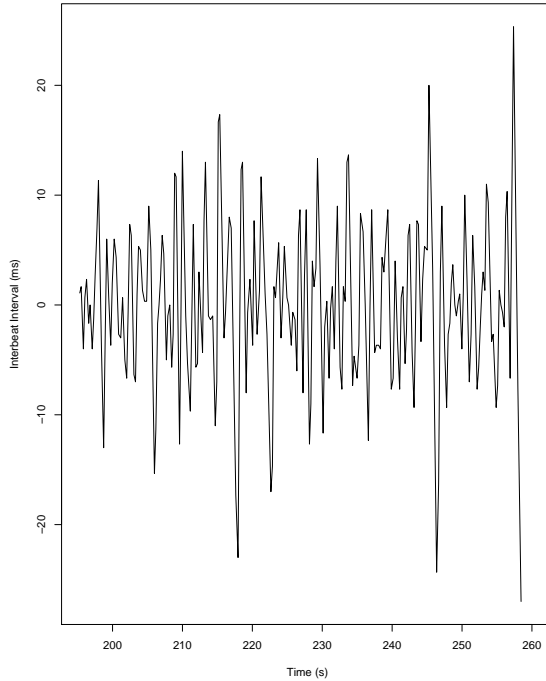


Figure 10. Interbeat Interval Plot

### Independent Polling

The approach used in the described biofeedback game is for each sensor to independently analyze the player’s change in arousal, then vote on the observed trend. The trend in the player’s arousal is described as a trinary statement, based on whether the player’s arousal has decreased, remained stationary, or increased, represented by -1, 0, and +1 respectively. The vote from each sensor is scaled by the sensor’s estimated reliability.

The general form for the function to vote on trends is shown below in Eqs. (12)–(14), where  $S$  is the sensor specific function to calculate the player’s arousal at time  $t$ . The function  $T_{S_k}$  calculates the relative trend in the player’s arousal state for a given sensor  $k$ . Because  $T_{S_k}$  is relative to the previous recording, the base case represents the sensor baseline with a trend of 0.  $\varepsilon$  is an experimentally-calculated baseline threshold. Eq. (14) collects a weighted vote collected from all  $n$  sensors then divides them by the sum of the weights. This final average is used to

decide the player’s overall arousal trend, represented by the function  $T$ , for the given time frame.

$$T_S(0) = 0, \tag{12}$$

$$T_S(t) = \begin{cases} +1, & \text{if } S(t) - S(t-1) \geq \varepsilon, \\ -1, & \text{if } S(t) - S(t-1) \leq -\varepsilon, \\ 0, & \text{otherwise,} \end{cases} \tag{13}$$

$$T(t) = \frac{\sum_{k=1}^n R_{S_k}(t) T_{S_k}(t)}{\sum_{k=1}^n R_{S_k}(t)}. \tag{14}$$

## 2.5 Discussion

Biofeedback therapy is a proven method to teach individuals vital skills for self-regulation. Unfortunately, there is a challenge in bridging the gap from biofeedback therapy in a controlled environment, and the development of reliable and resilient biofeedback games. This paper presents an approach to increasing the reliability of the sensors used in biofeedback games by increasing the quantity of sensors used, avoiding the situation where the loss of single sensor results in a single point of failure. All of the sensors in the presented biofeedback game are evaluated independently, using a sensor specific approach to estimate the player’s arousal level. The estimate from each sensor is then weighted against the sensor’s estimated reliability at that time. A poll is then taken over each voting sensor, each vote weighted by the sensor’s reliability function. In the game presented, players dedicate one hand to shooting moving targets, while the other hand remains stationary for physiological data collection. This does not have to be the limitation for biofeedback games; with careful multisite sensor placement, combined with movement aware sensors, it is possible to dynamically reweight a sensor’s reliability function based on its level of movement, providing higher weights to the most stationary and natively resilient sensors.

## 2.6 Future Work

The goal of development was to create a robust biofeedback game that leverages a generalizable sensor paradigm. While we were successful in this regard, it is important that future works study how the usage of an independent multi-sensor design impacts the player’s perceived control over the game, and the impact this design has on the player’s arousal levels after playing the game. This will require two future experiments. Participants in the first experiment will be split between an experimental group, in which players will play the game as it currently is,

and a control group, wherein the players will play the game without being provided a meter to alert them to the status of their score multiplier. The main variable of analysis will be the players' scores. The scores are not Gaussian normal, unless a minimum sample size is reached for the scores to be considered approximately normal under the Central Limit Theorem. If this minimum sample size is reached for each group, a parametric t-test can be used for analysis. If this minimum sample size is not reached, the nonparametric Wilcoxon Ranked Sum test should be used [20]. The second experiment will be a repeated-measure experiment with two trials, one in which players will play the game with a single sensor, and a second in which the game will be played with a multi-sensor implementation, because this is a repeated measure experiment, the order in which participants perform each trial will be randomized. After each trial the participants will be asked to rank the degree of control they felt over the game. If the participant sample size exceeds the minimum size required for the Central Limit Theorem, the difference in ranks can be considered approximately Gaussian normal and a paired t-test will be used to test for a difference between the multi-sensor and single sensor paradigms. If the sample size is too small, then the nonparametric Wilcoxon Signed Rank test should be used [20].

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**Manuscript 3:**

**Using Perspective to Reduce Stimuli Response in Virtual Reality**

by

B. Adrian Flowers, Robert Tatoian, Natallia Katenka, and Jean-Yves Hervé

*The following manuscript will be submitted to the IEEE Games Entertainment and Media (GEM) conference on April 20th, 2018.*

## CHAPTER 3

### Using Perspective to Reduce Stimuli Response in Virtual Reality

#### Manuscript 3:

### Using Perspective to Reduce Stimuli Response in Virtual Reality

by

B. Adrian Flowers, Robert Tatoian, Natallia Katenka, and Jean-Yves Hervé

#### 3.1 Abstract

Research shows that the method used to immerse someone within Virtual Reality has an impact on the way in which they physiologically respond to environmental stimuli. Existing literature is primarily concerned with maximizing a participant's response to stimuli. This has been shown to correspond to higher user self-reported degrees of immersion, positively affect learning, and impact participant behavior. This study is concerned with using a participant's perspective to reduce the degree to which the participant responds to stimuli within a Virtual Environment. This can be beneficial when a participant is exposed to a stimulus that is expected to result in an undesirable response. As part of this study an experiment on the effect of changing perspectives was performed. It is necessary to note that the participants of this experiment primarily controlled the motion of the player avatar through the usage of an analog controller and used an Oculus Rift DK2 for head/camera control.



Figure 11. Perspective Experiment

### 3.2 Introduction

It is important to start the paper with the definition of Virtual Reality Systems (VRSs) used in this research. We will refer to a VRS with no constraints as a general VRS. This is an open category with no constraints on either the input medium to the system nor the output display. Due to the lack of consistency across general VRS experiments, the most consistent metric of analysis is Presence. Presence is the general feeling of being immersed in virtual reality; it exists as an intrinsic characteristic of experiencing a virtual environment. Given the subjective nature of presence, the degree to which presence is felt is primarily measured with self-survey responses [1, 2]. In order to better understand the impact of presence, comparative studies are used to test which components of virtual environments most contribute to a user’s self-evaluated degree of presence.

A more constrained subcategory of VRSs are systems built around the psychological phenomenon known as body ownership; such VRSs will be referred to as embodiment Virtual Reality systems (eVRSs). Body ownership is a concept that originated in a perceptual illusion known as the Rubber Hand Illusion (RHI). In the RHI, a participant has one arm hidden from view behind some covering. Placed next to this covering, the participant can see a rubber hand. Experimenters then simultaneously tactually stimulate the hidden true arm and the rubber arm. When the participant witnesses the rubber arm being touched along with the feeling of their own hand being stimulated, they will then respond to touch and threats directed towards the false hand as if it were the true hand [3].

### 3.3 Background

Studies have shown that participants can incorporate entire false bodies as their own bodies given a similar methodology, resulting in what is referred to as the body swapping illusion [4]. For this illusion, a participant must see from the viewpoint of a false body. A false body in this context, being a body other than the participant’s own, could be the body of an experimenter, a mannequin, or a virtual body. Generally, the participant will see through the eyes of the false body with a head-mounted display that is connected to a camera attached to the head of the false body. Once the participant sees from the false body’s point of view, the participant must experience tactile stimulation and witness identical synchronous tactile input being performed on the false body. At this point, participants will take ownership of the false body and respond to threats and visually-perceived sensory input directed towards the false body in what is known

as body ownership [4].

In the context of Virtual Reality, the elicitation of body ownership is often referred to as embodiment [5]. Studies suggest that embodiment requires that all motion between the participant’s virtual body and true body be synchronized within 150 ms and that the virtual and true bodies be fully visuo-tactually matched. Given the above elicitation conditions [3], the participant will demonstrate a higher threat response to virtual visual stimuli. Other studies suggest that a participant embodying a virtual body will begin to evaluate and respond to conditions within the Virtual Environment from the perspective of the virtual body [6, 7, 8, 9]. These benefits make eVRs of particular interest to research on context-sensitive training and rehabilitation.

The strict timing and visuotactile requirements of eVRs can make it difficult for such systems to be leveraged commercially either due to cost constraints or physical system limitations. A study of particular interest to this work is the work of Slater et. al [10]. The experiment at the basis of this study granted users simultaneous visuomotor stimuli by allowing them to control their virtual avatar’s head within the experiment by leveraging a head-mounted display with head tracking. The participants’ threat-response during this experiment suggested that when simultaneous visuotactile stimulation is lacking, if simultaneous visuomotor stimulation exists, participants will still express an increased average skin conductance response to visually threatening stimuli. This study also noted that when participants viewed their virtual avatar experience visually threatening stimuli from a third person perspective, the participants expressed a lower threat response than those whom experienced the threatening stimuli from a first person perspective.

Along this line of inquiry, an experiment performed by [11] further investigated the impact of perspective on threat response in relationship to body-ownership. The referenced experiment had participants use an HMD to look at their own body from a third-person perspective. An experimenter would stand next to the participant. The experimenter would synchronize the third-person camera to the participant’s body, by visually touching where the participant would expect their chest to be if looking from the camera, while simultaneously touching the participant’s chest (which was out of view of the camera). Participants were split into two groups. A “synchronous group” followed the simultaneous visuotactile stimulation needed to induce the illusion. For an “asynchronous group,” the experimenter stimulated the camera’s chest and the participant’s chest asynchronously. The asynchronous group acted as the control group. After synchronous or

asynchronous visuotactile stimulation was performed, the participant would see the experimenter threaten their back with a knife. Interestingly, the participants in the synchronous group with the camera displayed a lower average skin conductance response to seeing their body threatened with a knife than the participants that were part of the asynchronous control group. This result suggests that using body ownership to induce an out-of-body experience lowers a participant's threat response to visually threatening stimuli.

### 3.4 Design of Study

The present study hypothesizes that within a virtual environment, participants will express a lesser response to environmental stimuli if they view their virtual avatar from a third-person perspective as opposed to a first-person perspective. This claim differs from current knowledge in two ways. The stated hypothesis is that perspective affects not only a participant's response to physically-threatening stimuli but a wider variety of environmental stimuli expected to result in a physiological response. Furthermore, the results suggest that change in a participant's response to environmental stimuli will occur when elicited within general VRSs that do not meet the strict requirements of the body-ownership illusion as opposed to the eVRSs that have been the focus of previous studies.

A preliminary experiment was performed to test participant response to two forms of stimuli within a VRS. Participants experienced the stimuli from both a first-person and third-person perspective, shown below in Figure 12. A repeated measure design was used for this experiment, with all participants completing both the first-person, and third-person, trials in randomized order. The benefit of randomizing the order of the trials is to remove any bias that may occur within the data due to trial order.

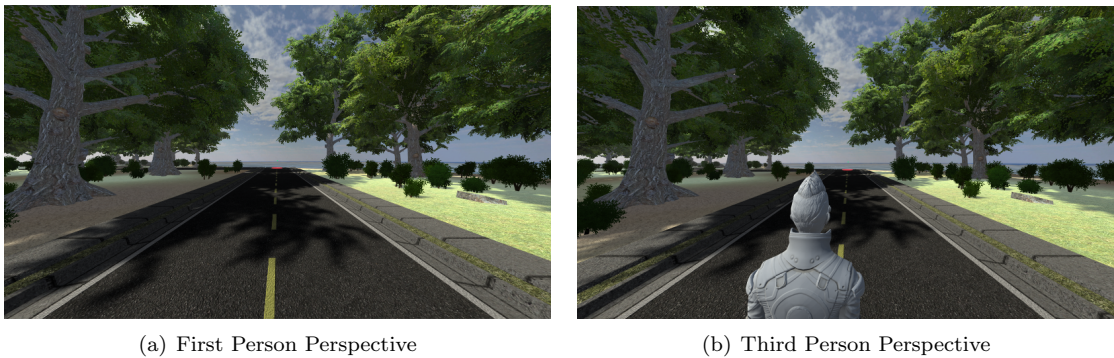


Figure 12. Perspectives of Interest

### 3.4.1 Control and Perspective

Participants wore an Oculus Rift DK2 HMD and controlled avatar locomotion using an Xbox 360 controller. The left joystick was used for translation of the player avatar and the right joystick for rotation. This control scheme was selected for its ubiquitous use in non-virtual reality video games. This control scheme is commercially considered a suboptimal control method for locomotion in Virtual Reality because it is thought to induce cybersickness (CS) in players.

Participants controlled the camera through the Oculus Rift's built in head tracking. From a first-person perspective, participants saw through the eyes of the virtual avatar. From a third-person perspective, the camera was located a fixed distance behind the virtual avatar's head. When participants rotated their head from a third-person perspective, this would cause the camera to rotate, remaining a fixed distance behind the participant. This differs from other studies on the effect of perspective on Body-ownership in that the participant retained active control of the camera from a third-person perspective in this study, wherein the camera from a third-person perspective remains stationary in other studies on perspective.

### 3.4.2 Environmental Stimuli

The first type of stimuli tested were Breaks in Presence (BiPs). A break in presence occurs when the virtual environment a participant is immersed in disappears. The impact of BiPs on a participants skin conductance and heart rate within a CAVE environment was studied by [12]. In that study, participants walked through a virtual environment while wearing hand-worn skin conductance and blood volume pulse sensors. At a set periodicity, the virtual environment displayed on the walls of the CAVE would be removed, and the participants would see themselves in an all-white environment. When the virtual environment was removed, participants would express a response noted by a change in the interbeat interval of the participants' heart-rates. The participants also showed a response to the BiPs during the experiment in a frequency domain of their skin conductance.

The second type of stimuli tested was a loss of user-control through breaks in camera synchronization. Loss of control within a Virtual Environment is considered to be a factor that can result in a feeling of cybersickness (CS). Through taking away the users control at key moments during the experiment, the study was designed to test the impact of perspective change on the frequency of self-reported rates of CS.

### 3.4.3 Equipment and Methodology

In this preliminary experiment, 16 participants between the ages of 18 and 35 wearing an Oculus Rift DK2 HMD explored a virtual environment built in the Unity Engine using an Xbox controller. Participants wore hand-worn galvanic skin conductance response (GSR) and blood volume pulse sensors (BVP) to measure threat and event response. The experiment was divided into five segments: a training phase, the preliminary survey, the first trial, the second trial, and the post-experimental survey. During the training phase of the experiment, participants were placed on a virtual island in a first-person perspective and trained on the protocol for the experiment. The preliminary survey segment of the experiment presented the participant with a questionnaire to ask demographic information. For the two trials, participants walked through an environment and performed a series of tasks from a first and third-person perspective. The post-experimental survey presented participants with a questionnaire related to perceived immersion levels and discomfort within the environment. After each segment of the experiment would end, the virtual world would be replaced with a black screen as the next segment of the experiment loaded. The transitions after each segment of the experiment were the BiPs stimuli.

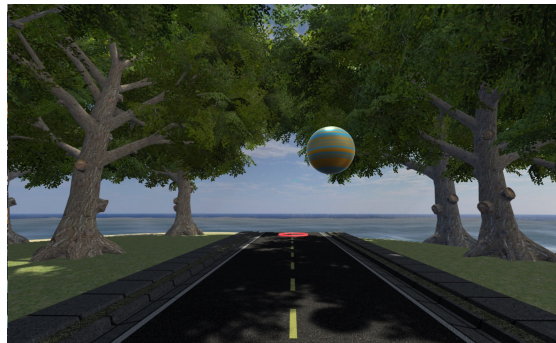


Figure 13. Ball Tracking Task

Each of the two experimental trials consisted of three sets of two alternating tasks. The first task was a lateral motion task, where participants were instructed to walk along a straight path until reaching a mark point in the environment. Upon reaching this point, participants would perform the second task, a rotational motion task. For this second task, a striped ball would appear before the participants. The participant was to follow the ball, keeping it in the center of their vision, until it disappeared (Figure 13). During the second lateral motion task, and the third rotational motion task of each trial the participants were given a mid-trial survey to answer. Unbeknownst to participants, before the survey would appear, control was removed



from the participants' HMD for 500ms, freezing the virtual environment during that time. This removal of control, disguised by the appearance of the mid-trial surveys, were the loss of user-control stimuli. Participants would undergo one trial from a first-person perspective and the other trial from a third-person perspective. The perspective each participant underwent for their first trial was randomized.

### **3.5 Limitations**

There were four limitations and constraints encountered during the study. The first constraint is that the timing for the occurrence of events was not synchronized across participants. Participants were allowed to complete and progress through the trials at their own pace. For this reason, the primary method of analysis for the study is based on the participants' responses to stimuli events.

The second limitation encountered concerns the frame rate within the experiment. The version of the Oculus Rift SDK required for the experiment introduced stuttering and latency into the system. The stuttering was constant and persistent throughout the experiment. It is possible that the stuttering ambiguated the loss-of-control events, as participants would have been unable to differentiate between the loss of control events and frame rate inconsistencies.

The third limitation of the study is the quality and placement of the physiological sensors used for analysis. The skin conductance and blood-volume pulse sensors were low-cost sensors integrated into the system and mounted to an Arduino microcontroller. Two days of testing had to be canceled and rescheduled after participants broke the sensors. In addition, the sensors used during the experiment were hand-worn. It is feasible that the usage hand-worn sensors in conjunction with a handheld game controller for locomotion may have introduced additional noise into the system. Furthermore, conductance gel was not used for the experiment.

The fourth limitation of this study was the small sample size. This preliminary study only had a sample size of 16 participants. The data for three of these participants had to be discarded due to violations of the experimental protocol. Seven of the remaining participants experienced the first-person perspective trial first, and the other six experienced the third-person perspective trial first.

### **3.6 Data Collection**

The stimuli response metrics used for the GSR and BVP sensors respectively were Event Reponse Skin Conductance Response (ER-SCR) and the difference in magnitude of the mean

Interbeat Interval (IBI) before and after event induction. ER-SCR is the impulse skin conductance response to stimuli. The average time for an individual's ER-SCR to reach it's peak after event elicitation is within a one to three second time window [13], in order to allow for additional variance, the ER-SCR for the experiment was taken from a window one-five seconds after the event elicitation. The amplitude of the (ER-SCR) was estimated as the difference between the participants' minimum and maximum skin conductance response taken within this one to five second window. IBI is the time between consecutive heartbeats. Guger et. al noted that a participant's average interbeat interval would be affected by BiPs[12], for this reason, we use the difference between average IBIs before and after event stimuli to measure the impact of the event on participants. Similarly to Guger et. al's experiment, we found the highest degree of variance using a two second window before and after the event induction from which to extract a participant's mean IBIs. An example plot of a participant's changing IBI interval is show below in Figure 14.

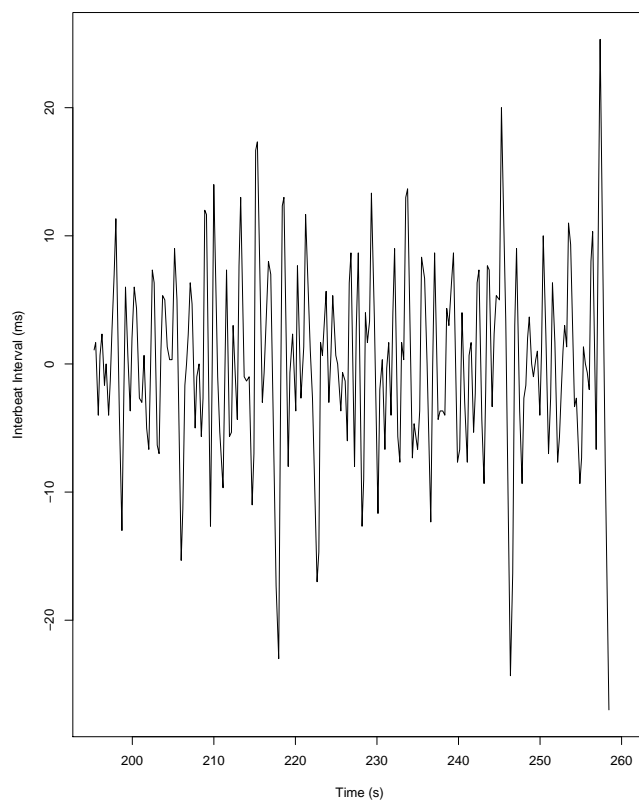


Figure 14. Interbeat Interval Plot

The ER-SCR was standardized across participants by dividing each participant’s skin conductance readings by the magnitude of the participant’s maximum skin conductance response, this scales each participant’s skin conductance values between zero to one. Afterwards, the participant’s ER-SCR was normalized through usage of a square-root transformation [14]. The participant’s mean IBI values were used without standardization or normalization. Due to the lack of normality for the mean IBI data, and the small sample size, the nonparametric Wilcoxon Ranked Sum test was used for the data analysis [15].

### **3.7 Results**

The results were analyzed from the central claim of this paper, that participants of the experiment in third person would have a lower response to environmental stimuli than those in first person.

#### **3.7.1 Does 1PP have a greater response than 3PP?**

The following hypothesis was analyzed using the Wilcoxon Ranked-Sum Test, “Participants will experience a higher response to environmental stimuli from 1PP than from 3PP.” The three events of interest for this hypothesis were the translational motion freeze, the rotational freeze, and the BiPs. When possible, the impact of each event was tested for each sensor. The BVP boxplot for each of the three event types in shown in Figure 15.

Contrary to expectations, it was found that participants experienced a greater BVP response to the translational motion freeze event during the 3PP trial than during the 1PP trial with a p-value of 0.086. The differences in ER-SCR were non-significant. No significant difference in response was noted on either the ER-SCR or mean IBI for the rotational motion freeze event. Similarly to the Translational Motion Freeze events, participants’ experienced a greater response to BiPs after the 3PP than during the 1PP trial with a p-value of 0.025 for the BVP sensor. The differences in ER-SCR magnitudes during the BiPs were non-significant.

#### **3.7.2 Does Perspective Impact Future Event Response?**

Based on the results of the previous analysis, the following hypothesis was analyzed using the Wolcoxon Ranked-Sum Test, “Participants that take the 3PP followed by the 1PP (3PP→1PP) will express a greater decrease in response to environmental stimuli than participants who began in 1PP followed by 3PP (1PP→3PP).” This was tested by comparing the difference in response between a participant’s two trials. The BVP boxplot for each of the three event types in shown

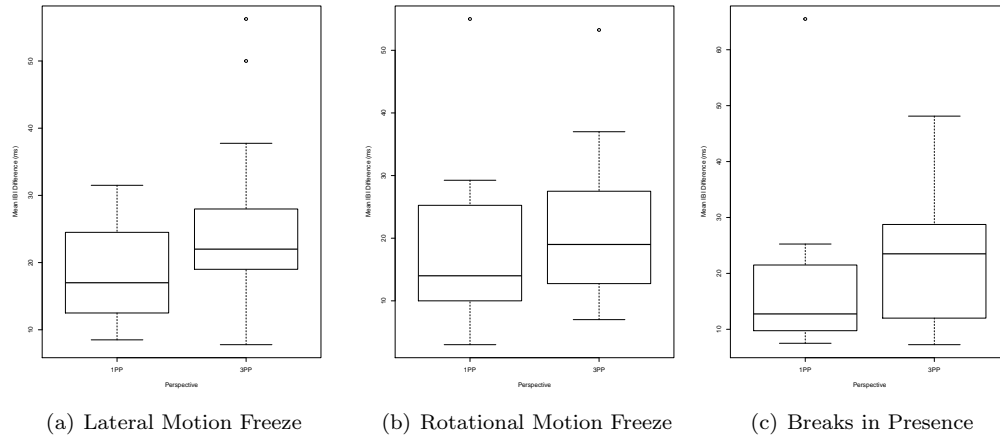


Figure 15. 1PP Compared Against 3PP

in Figure 16.

It was found that participants in the 3PP→1PP group experienced a greater reduction in event response during the Translational Motion Freeze than participants in the 1PP→3PP with a p-value of 0.03 for the BVP sensor. The boxplot for each of the three event types is shown in Figure 16. No significant difference in response was noted for the rotational motion freeze event. It was found that participants in the 3PP→1PP group experienced a greater reduction in event response to BiPs than participants in the 1PP→3PP with a p-value of 0.03 for both the BVP and ER-SCR.

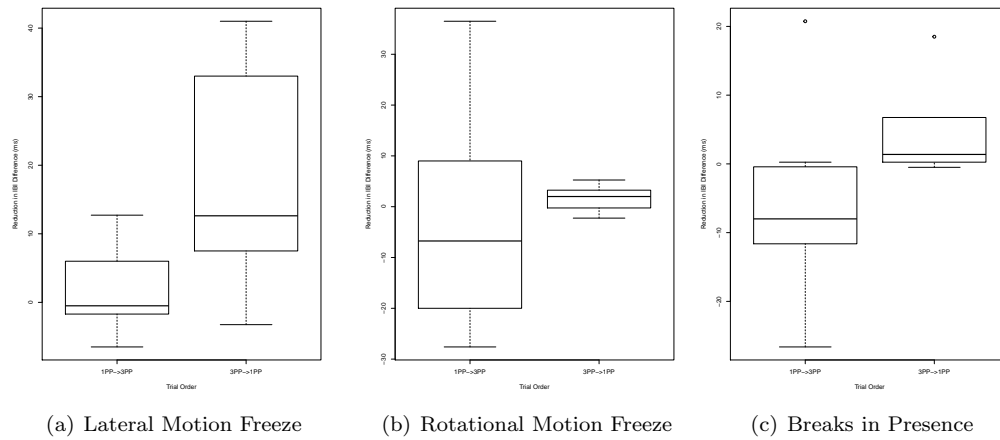


Figure 16. Successive Event Reduction

### 3.7.3 Does Perspective Impact Reported Feelings of Cybersickness?

Too few of our participants reported feelings of discomfort or sickness to study the impact of perspective on CS.

## 3.8 Discussion

Participants in this preliminary experiment expressed a higher response to stimuli from 3PP than from 1PP. Furthermore, there were three findings of interest in the experiment to be investigated in follow-up works. The first is that the magnitude of a participant's response to camera freeze and BiP events varied based on the participant's perspective. This is encouraging towards the usage of perspective to mitigate feelings of discomfort in Virtual Environments. The second finding is that the participants that when a participant experienced the 3PP first, it resulted in a reduced impact to event stimuli for the following perspective. This is suggestive of a phenomenon commonly referred to as "VR legs," wherein users of Virtual Reality report that repeated exposure to Virtual Reality reduces their feelings of discomfort over time. It is recommended that a more extensive repeated trial study be performed to investigate the long term impact that perspective has on repeated VR induction to investigate whether this can be used to train people to gain resilience against discomfort and/or CS. The third finding is that participants expressed a greater event response from a third-person perspective than from a first-person perspective, counter to similar studies. The two most likely explanations for this are that the training phase of the experiment took place from a first-person perspective, which may have reduced the participants' impact to the first-person trial, and that unlike other studies, this one gave participants active-control over the third person camera, rather than fixing it in a stationary position.

## 3.9 Future Work

The results of this study are encouraging towards the usage of changing perspectives to mitigate a participant's response to stimuli within a virtual environment. Unfortunately, few participants reported CS during this preliminary study. In order to investigate the possibility that changing perspectives can be used to mitigate CS in participants, a follow-up study is necessary.

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**APPENDIX**  
**Perspective Materials**

**A.1 Surveys**

**A.1.1 Preliminary Survey**

Question 1: Are you or could you potentially be pregnant

**Yes**

**No**

**Not Sure**

Question 2: What age range do you fall within

**≤ 18**

**18-24**

**25-34**

**≥ 45**

Question 3: How often do you play video games

**No Experience**

**Very little** (I have played them before)

**Occasionally** (Multiple times a year)

**Frequent** (Multiple times a month)

**Often** (Multiple times a week)

Question 4: How often do you play first person games

**No Experience**

**Very little** (I have played them before)

**Occasionally** (Multiple times a year)

·**Frequent** (Multiple times a month)

·**Often** (Multiple times a week)

Question 5: How prone are you to motion sickness

·**No Experience**

·**Very little** (I have played them before)

·**Occasionally** (Multiple times a year)

·**Frequent** (Multiple times a month)

·**Often** (Multiple times a week)

#### **A.1.2 Mid-trial Survey**

Question 1: I felt that the virtual body was my body

·**Strongly Disagree**

·**Disagree**

·**Somewhat Disagree**

·**Neither agree nor disagree**

·**Somewhat Agree**

·**Agree**

·**Strongly Agree**

Question 2: I felt as though the virtual avatars eyes were my eyes

·**Strongly Disagree**

·**Disagree**

·**Somewhat Disagree**

·**Neither agree nor disagree**

·**Somewhat Agree**



·Agree

·Strongly Agree

Question 3: I felt that I was in control of the virtual avatar

·Strongly Disagree

·Disagree

·Somewhat Disagree

·Neither agree nor disagree

·Somewhat Agree

·Agree

·Strongly Agree

Question 4: I felt that I was in control of the head

·Strongly Disagree

·Disagree

·Somewhat Disagree

·Neither agree nor disagree

·Somewhat Agree

·Agree

·Strongly Agree

Question 5: I felt discomfort during the experiment

·Strongly Disagree

·Disagree

·Somewhat Disagree

·Neither agree nor disagree

·Somewhat Agree

·Agree

·Strongly Agree

Question 6: I found it difficult to navigate the environment

·Strongly Disagree

·Disagree

·Somewhat Disagree

·Neither agree nor disagree

·Somewhat Agree

·Agree

·Strongly Agree

Question 7: The targets were easy to locate

·Strongly Disagree

·Disagree

·Somewhat Disagree

·Neither agree nor disagree

·Somewhat Agree

·Agree

·Strongly Agree

### A.1.3 Post-experimental Survey

Question 1: Did you feel any discomfort during the experiment?

·Yes

·No

Question 2: What type of discomfort did you feel strongest?

·Disorientation

·Nausea

·Headache

·Neck Pain

·Eye Strain

Question 3: What triggered the discomfort?

·Not Sure

·The discomfort was constant

·Moving

·Rotating

·Stopping

Question 4: Was the discomfort lower depending on the perspective?

·The discomfort was lessened with a first person perspective

·The discomfort was lessened with a third person perspective

·No difference

Question 5: Did you feel more in control of the virtual body depending on perspective?

·I had more control over the body from a 1PP

·No difference

·I had more control over the body from a 3PP

Question 6: Did the amount the virtual body felt like your body vary based on perspective?

·A first-person perspective felt more like my own body

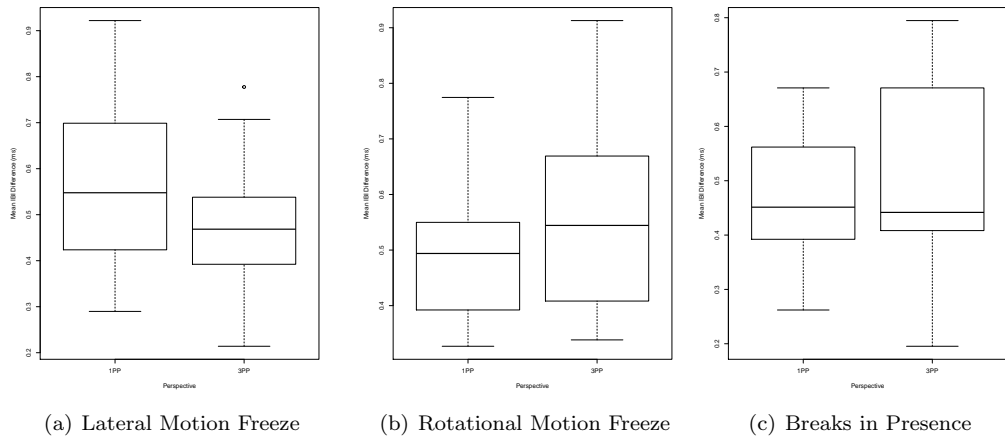
·No difference

·A third-person perspective felt more like my own body

## A.2 SCR Box Plots

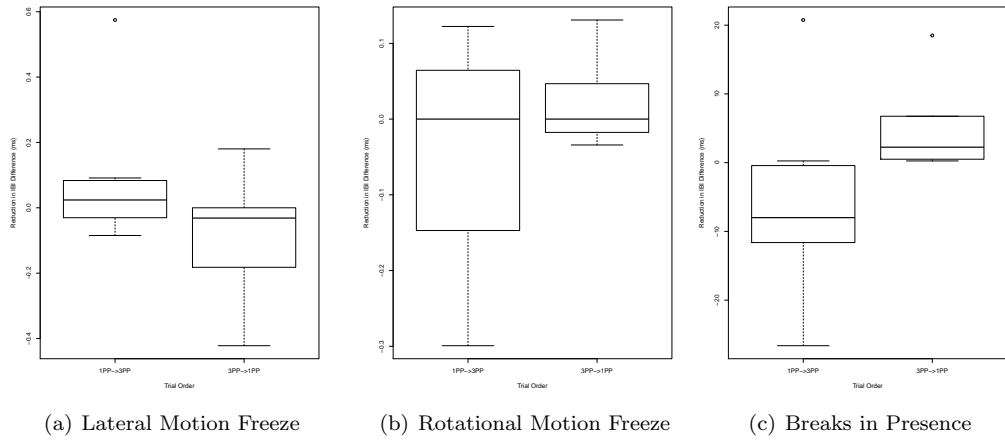
### A.2.1 1PP Compared Against 3PP

### A.2.2 Successive Event Reduction



(a) Lateral Motion Freeze (b) Rotational Motion Freeze (c) Breaks in Presence

Figure A.1. 1PP Compared Against 3PP



(a) Lateral Motion Freeze (b) Rotational Motion Freeze (c) Breaks in Presence

Figure A.2. Successive Event Reduction

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