EXPLORING HUMAN RESPONSES TO A VIRTUAL CHARACTER BUMP

by

Claudia Krogmeier

A Thesis

Submitted to the Faculty of Purdue University
In Partial Fulfillment of the Requirements for the degree of

Master of Science

Department of Computer Graphics Technology
West Lafayette, Indiana

May 2019

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. David Whittinghill, Chair

Department of Computer Graphics Technology

Dr. Christos Mousas

Department of Computer Graphics Technology

Dr. Tom Hummer

Indiana University School of Medicine

Approved by:

Dr. Nicoletta Adamo

Head of the Graduate Program

To my fabulous family and great friend, Brandon: Thank you for the support!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Author: Krogmeier, Claudia, M. MS
Institution: Purdue University
Degree Received: May 2019
Title: Exploring Human Responses to a Virtual Character Bump
Committee Chair: David Whittinghill

How does haptic feedback during human-virtual character interaction affect participant physiological responses in virtual reality? In this between-subjects study, haptic feedback and non-haptic feedback conditions in which virtual characters bump into the participant who is immersed in a virtual environment are compared. A questionnaire was developed to determine the influence of haptic feedback on presence, embodiment, positive and negative affect, interaction with virtual character, and haptic feedback realism, among other more exploratory concepts. These exploratory variables include engagement, flow, comfort with virtual characters, comfort with virtual characters' appearance, realism of virtual character interaction, realism of haptic feedback, and virtual reality sickness. Physiological data was collected using galvanic skin response (GSR) to investigate the influence of haptic feedback on physiological arousal during human-virtual character interaction. Five conditions were developed (no haptic feedback, full and half intensity, incorrect position, and delayed timing). Significant differences were found in embodiment, realism of virtual character interaction, haptic feedback realism, and GSR amplitude after the first interaction with the virtual character. These results may inform future virtual reality studies that investigate haptic feedback during human-virtual character interaction, arousal via GSR data, as well as advise studies that seek to correlate self-report responses with physiological data.

CHAPTER 1. INTRODUCTION

1.1 Statement of the Problem

Despite the increasing quantity of studies exploring virtual reality (VR) for mental health issues, there currently exists of lack of *quality studies* (defined as demonstrating the efficacy of various methods in virtual reality), as well as a deficit in studies exploring human interaction with virtual characters (Salamon, Grimm, Horack, & Newton, 2018). A large majority of virtual reality studies consist solely of self-report questionnaires, despite evidence that self-report data in virtual reality may neither correspond to expected nor obtained physiological measures (Wilhelm et al., 2005) (Bailey, Wise, & Bolls, 2009). Additionally, there is a need for more studies that explore affective responses in virtual reality (Parsons & Rizzo, 2008). Therefore, virtual reality studies which explore objective emotional responses in virtual reality, as well as studies that seek to correlate these physiological measures with subjective self-report measures are worth pursuing. To date, there exists little data concerning physiological emotional responses to virtual characters, especially concerning haptic feedback.

1.2 Research Question and Hypotheses

The primary variable in this study is quantity of event-related galvanic skin response (ER-GSR) to determine existence of physiological arousal, and ER-GSR peak amplitude, to determine intensity of physiological arousal. Primary, secondary and exploratory research questions and corresponding hypotheses are presented below.

Primary Research Questions:

- Does feeling haptic feedback increase physiological arousal during a virtual character interaction?
    - The researcher hypothesizes that haptic feedback will increase physiological arousal as compared to no haptic feedback. Specifically, the researcher hypothesized a higher ER-GSR peak count for the haptic feedback conditions as compared to the no haptic feedback condition, as well as higher ER-GSR peak

amplitude for haptic feedback conditions than for the no haptic feedback condition.

- How does physiological arousal reported objectively via GSR correlate with self-report positive and negative affect scores on our questionnaire?
    - The researcher hypothesizes that GSR will correlate with self-report positive affect scores, but possibly not with negative affect scores, as the experience is neutral/pleasing for participants interested in virtual reality.
- Do participants report higher levels of presence in virtual environments when they receive haptic feedback?
    - The researcher hypothesizes that participants will experience significantly higher levels of presence in the haptic feedback conditions.
- Do participants report higher levels of embodiment in virtual environments when they receive haptic feedback?
    - The researcher hypothesizes no differences in self-report embodiment between groups, as no steps to induce a body ownership illusion with the participant's self-avatar will be conducted, other than providing the participant with an opportunity to look down at an idle self-avatar body in the virtual environment.

<u>Secondary Research Questions:</u>

- Are there differences in physiological arousal based on participant sex, age, and/or weekly experience with video/computer games?
    - The researcher hypothesizes that experience with video/computer games may influence levels of physiological arousal in virtual reality.
- How might haptic feedback influence participant's perception of realism of virtual character interaction and haptic feedback?
    - The researcher hypothesizes that haptic feedback will be perceived as most realistic for the full intensity haptic feedback condition, while virtual character interaction will also be perceived most realistically with the full intensity haptic feedback condition.
- How does haptic feedback influence participant's comfort with the virtual characters?

Exploratory Research Questions:

- How might timing, position and intensity of haptic feedback influence participant physiological arousal and self-report measures of presence and embodiment?
    - The researcher hypothesizes that incorrect timing and incorrect position haptic feedback conditions may elicit less physiological arousal from the participant, as well as lower feelings of presence and embodiment, as the conditions are not logical, and therefore may take the participant out of the scene.
- How might the varying haptic feedback conditions compare to each other, and to the full intensity and no haptic feedback conditions?
    - The researcher hypothesizes that while there may be no significant differences found between the delayed haptic feedback, incorrect position, and half intensity haptic feedback conditions, significant differences in physiological arousal will be found between the no haptic feedback and full intensity haptic feedback conditions.
- Does haptic feedback influence participant engagement or flow within the virtual environment?
    - The researcher hypothesizes that higher levels of engagement and flow will be found in the logical haptic feedback conditions as compared to the no haptic feedback condition.

To summarize, the researcher hypothesizes that logical haptic feedback will elicit higher physiological arousal via ER-GSR than illogical haptic feedback or lack of haptic feedback. Additionally, it is thought that presence will be significantly higher in the logical haptic feedback conditions as compared to the no haptic feedback condition. The researcher hypothesizes that there will be no significant differences in embodiment, as the participant will only see a virtual self-avatar, rather than experience a body ownership conditioning to influence embodiment.

1.3 Significance of the Problem

Exploring physiological arousal responses in virtual reality is important as virtual reality is an effective tool concerning many mental health disorders, and necessitates more quality studies that demonstrate the efficacy of specific techniques (Salamon et al., 2018), and methods for improving presence. Investigating objective data concerning emotional arousal during virtual character interactions will be significant in its application to the creation of more immersive and thus effective virtual reality mental health treatments and entertainment.

One way in which Cognitive Behavioral Therapy (CBT) may decrease social anxiety levels in Social Anxiety Disorder (SAD) is through increasing emotion regulation skills (Goldin et al., 2014). Therefore, gaining a better understanding of emotional arousal responses in virtual reality would be practical for creating more immersive VR CBT paradigms for SAD, as well as for creating VR therapeutic paradigms for other disorders that may similarly benefit from increased knowledge concerning emotional arousal in VR. Multiple studies concerning emotional response to virtual reality therapy have demonstrated a need for additional studies focusing on presence, as well as a need to obtain more specific information concerning emotional responses (Parsons & Rizzo, 2008). Studies that compare general quality of user experience to objective measures such as heart rate and electro-dermal activity in virtual reality appear minimal. Studies that seek to relate physiological data with haptic feedback appear even uncommon (Egan et al., n.d.). This study will gather physiological data as well as explore correlations between physiological arousal and self-report positive and negative affect. Additionally, the study will investigate important theoretical concepts in virtual reality including presence and embodiment, while adding knowledge to a limited database concerning virtual character interactions, physiological arousal and haptic feedback in virtual reality.

This research has applications in all realms that strive to make virtual reality more effective via immersion and presence, such as the gaming industry and the field of psychology. As the researcher works to master the Unity game engine and learn methods inherent to physiological data collection, the thesis not only serves to enhance her technical skillset, but to address a gap in knowledge concerning objective data that may provide exciting insights in emotional arousal within virtual reality for a plethora of immersive VR applications.

1.4 Statement of Purpose/Scope

This study will explore physiological arousal during a virtual character interaction with varying haptic feedback conditions. The researcher will investigate how physiological arousal as seen via ER-GSR compares across different haptic feedback conditions. This study seeks to understand how and why differences in haptic feedback may influence physiological arousal; the purpose of this study is to investigate differences in physiological arousal due to varying haptic feedback during an interaction with a virtual character. This study will obtain physiological arousal data through ER-GSR, as well as collect data concerning self-report measures of emotional arousal via positive and negative affect, and self-report levels of presence and embodiment among other exploratory inquiries.

1.5 Definitions

Virtual Reality (VR): "A technology that can visually immerse the user in a simulated environment" (Da Costa & De Carvalho, 2004).

Avatar: A digital representation of one's physical self in a digital form (Waltemate, Gall, Roth, Botsch, & Latoschik, 2018).

Virtual Character (VC): A character in the world, controlled by artificial intelligence, with whom the user can interact.

Sense of Self-Location (SSL): "One's spatial experience of being inside of body," not including one's "spatial experience of being inside a world" (Kilteni, Groten, & Slater, n.d.).

Virtual Body Ownership (VBO): "Refers to one's self-attribution of a body…and implies that the body is the source of the experienced sensations" (Kilteni et al., n.d.), (Gallagher, 2000), (Tsakiris & Haggard, 2005).

Sense of Agency (SoA): The feeling of "having global motor control, intention, motor selection, and the conscious experience of will" (Blanke & Metzinger, 2009), (Kilteni et al., n.d.).
Sense of Embodiment (SoE): The ensemble of sensations that arise in conjunction with being inside, having, and controlling a body especially in relation to virtual reality applications" (Kilteni et al., n.d.). SoE consists of SSL, VBO, and SoA.

Presence: "The phenomenon of behaving and feeling as if we are in the virtual world…" (Sanchez-Vives & Slater, 2005).

Electrodermal Activity (EDA): “Term used for defining autonomic changes in the electrical properties of the skin” (Braithwaite, Watson, Robert, & Mickey, 2013). EDA is a technique in which to measure changes in emotional and cognitive states. EDA consists of tonic and phasic components, and is also known as Galvanic Skin Response (GSR).

Skin Conductance Level (SCL): The background tonic element of EDA, the SCL is the normal skin conductance level. It can be called a “moving baseline” of skin conductance (Braithwaite et al., 2013).

Skin Conductance Response (SCR): The rapid, phasic element of EDA. SCR is the change in the electrical conductivity of the skin, beyond the skin’s normal conductivity (Braithwaite et al., 2013).

Event-Related SCR (ER-SCR): “SCRs that can be attributed to a specific eliciting stimulus” (Braithwaite et al., 2013).

Emotional Arousal (EA): The amount of resources mobilized in the individual in response to a stimulus. EA is considered a key component in the first state of emotion regulation, which is stimulus detection. Differences in how individuals perceive stimuli may result in differences in emotional arousal (Dickstein & Leibenluft, 2006).

1.6 Key for Haptic Feedback Conditions

The abbreviations used for the five haptic feedback conditions discussed in the Chapter 3 are as follows: FIF: Full Intensity Haptic Feedback, NH: No Haptic Feedback, IPH: Incorrect Position Haptic Feedback, DH: Delayed Timing Haptic Feedback, and HIH: Half Intensity Haptic Feedback.

1.7 Assumptions

The researcher assumes subjects will be willing to participate in the study, as well as be willing to allow galvanic skin conductance (GSR) sensors, a virtual reality (VR) headset, and a haptic gaming vest to be attached throughout the duration of the study. Additionally, the researcher assumes that subjects will respond truthfully to questionnaires, and wear the haptic vest during the study. The researcher assumes that subjects respond appropriately to the call for research participants, and thus meet criteria for the study. The researcher assumes that iMotions will correctly capture GSR signal, and that there will be limited if any interruptions during the time of the study. The researcher assumes that most participants will be able to follow the short set of instructions for participating in the study. The researcher assumes participants will understand what "haptic feedback" refers to on the questionnaire.

1.8 Limitations

The study is limited in that it is a between-subjects study. Having each subject participate in all five conditions would be expected to skew results due to participants' familiarity with the virtual reality scene, and, due to time constraints for the project, a between-subjects study utilizing a single virtual reality scene will be implemented. Several potential weaknesses include differences in participant gender, age, mood at time of study, and differences in prior VR experience. Steps will be taken to ensure participants have comparable experience in VR. A brief preliminary phase of the actual study will include a short time in which participants can explore the scene to become at least slightly more aware of his or her surroundings within the virtual environment before data collection will occur within the second phase of the study.

While providing a wide range of adjustable haptic feedback, the bHaptics vest utilizes vibrotactile feedback, rather than mechanical actuators, which have been shown to be more realistic during virtual character interactions (Ahmed et al., 2016). Therefore, this study is limited in its realism of haptic feedback on virtual character interaction.

1.9 Delimitations

Subjects will be within the ages of 18 and 32, ideally with previous experience in VR prior to participating in the study. All subjects will be students at Purdue University in West Lafayette, Indiana. Participants will only experience one virtual reality scene (the same for every participant), and therefore will only experience one out of the five haptic feedback conditions.

1.10 Contributions

This study considered numerous concepts including presence and embodiment, self-report negative and positive affect, realism of haptic feedback, realism of virtual character interaction, and physiological arousal via GSR data. Previous studies have explored the influence of haptic feedback on presence and embodiment, but less research has investigated the influence of varying parameters of haptic feedback (such as timing, position and intensity), or the influence of haptic feedback during a virtual character interaction. Below are two publications that resulted from this work.

Krogmeier, C., Mousas, C.& Whittinghill, D. (2019). Human, Virtual Human, Bump! A Preliminary Study on Haptic Feedback. *IEEE Conference on Virtual Reality and 3D User Interfaces*.

Krogmeier, C., Mousas, C.& Whittinghill, D. (2019). Human-Virtual Character Interaction: Towards Understanding the Influence of Haptic Feedback. *Computer Animation and Virtual Worlds (Proc. of CASA 2019).*

CHAPTER 2. REVIEW OF LITERATURE

2.1 Implementation of Review of Literature

Conducted largely with IEEE Xplore and PubMed databases, the review of literature also includes data found through Google Scholar as well as the Purdue library search engine. Common searches include but are not limited to "virtual reality" AND "arousal," "virtual reality" AND "emotion" AND "skin conductance," "virtual reality" AND "cognitive behavioral therapy" AND "embodiment," or "virtual reality" AND "social anxiety disorder" AND "physiological."

2.2 Virtual Reality and Arousal Research

Investigating arousal in immersive virtual reality environments is a new concept, and the influence of haptic stimuli on arousal in virtual reality is so far underexplored (Koumaditis, Chinello, & Venckute, n.d.). A better understanding of arousal in virtual reality is necessary not only for making virtual reality more immersive, but for applications in which stress is present, such as virtual reality training scenarios (Koumaditis et al., n.d.). While emotional arousal in virtual reality significantly contributes to a user's experience within the virtual environment, it is often difficult to obtain objective measures of emotional arousal in such controlled settings such as virtual reality (Cavazza et al., 2014). Prior research has shown that giving a speech to a virtual audience in VR can effectively "elicit distress and physiological arousal in patients with (social anxiety disorder)," with VR exposure effectively treating fear of public speaking (Bouchard et al., 2017) (Owens & Beidel, 2015).

In a study conducted by Owens & Beidel, self-report measures of distress and feelings of presence as well as physiological measures (heart rate and electrodermal activity) were recorded in order to determine if a virtual audience in VR could elicit physiological arousal similar to that which is seen in reality during a public speaking task (2015). Both healthy individuals as well as those with SAD were included in the study. Results showed that VR had "some ability" to increase both physiological and self-report responses compared to baseline, thus, their research indicated that the virtual audience was not equivalent to an audience in the real world (Owens & Beidel, 2015). These findings are similar to other studies, in that VR as a public speech tool is able to elicit responses and presence, however not as fully as the real experience equivalent in reality (Slater, Pertaub, Barker, & Clark, 2006), (Kotlyar et al., 2008) .

It is clear that VR is useful for exposure therapies, despite not eliciting the same amount of emotional arousal and physiological engagement as compared to the real world. Interestingly, the Owens' study did not reveal differences in physiological responses between the SAD and healthy individuals. Researchers believe this may be due to the short nature of their experiment, as a study by Slater et al. showed significant differences in heart rate between "phobic and confident speakers" in a similar VR public speech scenario; additional studies are necessary (Owens & Beidel, 2015), (Slater et al., 2006). Studies promoting increased presence and emotional arousal are merited in the event that higher presence and engagement in virtual reality leads to VR therapies that are as or more effective than real world therapies which are costly, often avoided by patients, as well as difficult to conduct with a variety of environments. Looking at differences in "deceleration of arousal" following the task or event in order to determine the speed at which individuals return to baseline measures of arousal may also be of interest (Owens & Beidel, 2015).

Studies exploring psychological and physiological data in virtual reality include studies looking at cognitive behavioral therapy for emotion regulation as well as measuring self-criticism and self-compassion after different kinds of embodiment scenarios (Rodriguez et al., 2015), (Falconer et al., 2016). In Falconer's study, adults with self-compassion difficulties were embodied as adults in VR, and instructed to console a crying, virtual child in the environment. In the following scene, they were embodied as the child, and heard their own, comforting voice, which has been recorded in the first scenario, consoling themselves, now as the child. Increased levels of self-compassion, decreased levels of depression severity as well as increased levels of self-compassion were collected after the experiment (Falconer et al., 2016). In another experiment led by Dr. Anne-Marie Brouwer, EEG and ECG were recorded during stress-inducing VR scenarios in which subjects encountered a bomb simulation, as well as negative feedback regarding their performance on an assigned task in the environment (Brouwer, n.d.). This experiment, among others, has shown that VR can very effectively elicit stress in the subject.

VR is expected to greatly influence education in coming years, as cost decreases and VR studies in education continue to show that short-term knowledge retention in students increases as immersion increases; with high immersion, and positive emotional induction via a positive-expression virtual character providing the highest short-term knowledge retention (Olmos-Raya et al., 2018). Olmos-Raya et al. showed that positive emotions in VR cultivate higher levels of learning, and thus understanding ways in which emotional arousal might be influenced by haptics is a worthy pursuit when considering potential haptic advantages in the realm of VR education as well as VR mental health.

Avatar personalization has been shown to influence self-reported measures of presence, agency, and body ownership, as well as emotional response (Waltemate et al., 2018). Other studies have shown that while VR repeatedly elicits expected emotional states, electrodermal activity is not always significantly correlated with self-reported measures of presence, even while presence might be thought of as a precursor of emotion (Felnhofer et al., 2015).

Stress responses in heart rate as well as salivary cortisol measures based on varying features of the game such as manipulating innate fear, social and cognitive demand (judged by a virtual group of characters, and mental math) as well physical demands such as walking on a wooden plank have been seen in VR (Finseth, Barnett, Shirtcliff, Dorneich, & Keren, 2018). The researchers suggest that their study is limited in that they cannot detect stress responses based on a single game feature, and suggest future studies target specific game features in order to better understand user stress response in VR (Finseth et al., 2018).

2.3 Virtual Reality and Sense of Embodiment

Increasing sense of embodiment (SoE) in virtual reality can be achieved in many ways, including verifying avatar body movement with physical body movement as seen in a virtual mirror (Falconer et al., 2016), and having the user perform passive haptic feedback in the form of self-contact (Bovet, Debarba, Herbelin, Molla, & Boulic, 2018). Perhaps due to its immersive, ability-to-distract nature and ability the change perceptions, virtual reality is effective for alleviating pain during chronic pain treatment (Gromala, Tong, Choo, Karamnejad, & Shaw, n.d.). Studies have found that variations in SoE, such as changing avatar body size and viewpoint as well as enlarging or reducing self-avatar body sizes, as well as visually distorting body parts, can significantly change user perception of pain during in reality as well as in virtual reality (Romano, Llobera, & Blanke, 2016), (Mancini, Longo, Kammers, & Haggard, 2011). Interestingly, virtual body ownership (VBO) differences can cause cognitive perception changes in VR. In a study by Banakou, Groten, and Slater, embodying the user into the body of a child lead to overestimations of sizes of objects in the scene. Additionally, embodiment as a child lead participants to associate themselves with more child-like features (Banakou, Groten, & Slater, 2013). In another study, increasing Sense of Agency (SoA) resulted in a higher user virtual body ownership (VBO); when the user felt she could control the bat body, she felt more as if the bat body was her body (Andreasen, Nilsson, & Serafin, n.d.).

It is possible to manipulate VBO by varying visual feedback as it relates to embodiment, as demonstrated in a study that evaluated varying degrees of first person body avatar transparency (Martini, Kilteni, Maselli, & Sanchez-Vives, 2015). The researchers found that virtual body ownership decreased as transparency of the virtual body increased. Additionally, they found that, despite their hypotheses, a decrease in VBO did not result in a higher threshold for pain; therefore, utilizing a semi-transparent arm, for example, in virtual reality pain management would not be effective in reducing perception of pain.

In a study by Kilteni et al., it was found that "seeing a virtual body from first person perspective, and receiving spatiotemporally congruent multisensory and sensorimotor feedback with respect to the physical body entails an illusion of body ownership over that virtual body" (Kilteni, Bergstrom, & Slater, 2013). Caucasian subjects who saw their own virtual body in VR as dark-skinned had higher variations and frequency of body movement compared to seeing a light-skinned body or completely white hands, presumably based on cultural attributions for those with dark-skin to perform differently than light-skinned musicians.

2.4 Virtual Reality and Presence

Currently, presence in virtual reality is measured primarily through self-report. Some level of presence in virtual reality is necessary in order for users to experience emotions; thus, research that explores relationships between presence and emotion in VR would be beneficial (Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015). One study found that having a self-avatar as opposed to having no body did not increase presence in a virtual reality scenario, however having a self-avatar body did significantly increase user's feelings that they could be hurt after a box fell over in the virtual world, suggesting increased embodiment due to having a virtual body (Steed et al., 2016).

Presence is necessary for users to experience emotions in virtual reality, and researchers stress the importance in more research that looks at the probable correlation between presence and emotion in VR (Diemer et al., 2015). In a study with snake phobics in VR, one group was told that there were snakes in the environment in real life, which produced greater feelings of anxiety in this group, as well as significantly higher ratings of presence as compared to those who were not told about snakes in the real world (Bouchard, 2008). In a similar study with height-phobics, within the higher-presence environment anxiety levels were significantly higher than in the lower presence environment, thus showing a "bi-directional relationship between presence and anxiety" (Klinger et al., 2005), (Bouchard et al., 2017). Klinger suggests utilizing this presence anxiety loop in order to foster effective VR encounters with virtual characters in order to treat social phobia. Improving presence in VR is essential for increasing user immersion in VR, especially when virtual body ownership is considered (Kilteni et al., 2013). Increasing presence in VR would be beneficial in order to create more effective VR therapy treatments as well as better VR training for stress-inducing tasks.

2.5 Virtual Characters in Virtual Reality

Within human-virtual character interaction in VR, several studies have shown that emotional effects based on these interactions is possible, with virtual characters more able to elicit negative emotions compared to positive emotions (Volante et al., 2016). In Volante et al.'s study, realistic and stylized virtual characters were created in order to test the emotional response of participants via galvanic skin conductance. They found that GSR responses vary greatly between males and females (as males have a higher GSR response, generally), with surprising results: the sketch and the cartoon rendered character elicited greater emotional responses than did the realistic character. The researchers hypothesize that their results were strongly influenced by the uncanny valley effect, as the users may have been more critical of the realistic character.

Previous research has shown that users prefer greater personal space in virtual reality when approached by an angry avatar as compared to a happy avatar (Onsch et al., n.d.). Additionally, when given the choice, users will not let a group of virtual characters approach as closely to themselves as they will an individual virtual character. In this study, gender as well as age of subjects influenced user personal space preferences in VR. Effective in its exploration of user behavior during a virtual character interaction, this study did not collect biometric data.

Similar to virtual character facial expression, virtual character personality affects users perceptions, in that VCs with more negative personalities induce more empathy, as well as higher concern for the VC than do VCs with more positive personalities (Zibrek, Kokkinara, & McDonnell, 2018). Subjects tasked with giving speeches in VR, despite being healthy or an SAD individual, have remarked that giving a speech to a virtual audience is not as scary as with a real audience, thus measures to make and test VCs with higher realism, different expressions and other measures to increase immersion are warranted (Owens & Beidel, 2015). Several studies have already shown that VC facial expression can influence anxiety and heart rate, thus showing that people can and do "react emotionally to virtual humans and their behaviors," with believability in VR being essential in creating reality-like emotional arousal responses (Klinger et al., 2005) (Bovet et al., 2018) (Herbelin, Riquier, Vexo, & Thalmann, n.d.). Further studies focusing on improved AI and more believable characters is necessary, especially considering VR's potential as a powerful tool in social disorder therapy. Moreover, studies that evaluate user group dynamics in VR would be useful, for team game play as well as social disorder group therapies (Salamon et al., 2018).

"It has been shown that perceiving emotional [virtual character] faces results in EMG activity in the same facial muscles as perceiving photographs of human faces," thus it is clear that the brain treats virtual characters similarly to real people (de Borst & de Gelder, 2015). Likewise, when interacting with virtual characters, people often behave as they would during a human interaction. Results from numerous studies indicate that VR stimuli can mimic simple as well as highly complex social situations, and influence user behavior (de Borst & de Gelder, 2015).

2.6 Virtual Reality and Haptic Feedback

According to Benko et al., "the capabilities of current devices to render meaningful haptics lag far behind their abilities to render highly realistic visual or audio content," with standard haptic feedback being built-in to controllers as vibrotactile feedback, which can vary in intensity and duration of sensation (Benko, Holz, Sinclair, & Ofek, 2016). While other forms of haptic feedback have been explored in VR, there is a need for more variety in the type of haptic response in addition to standard buzzing and rumblings on user's hands, as haptic feedback has been shown to increase levels of presence (Ahmed et al., 2016). In Ahmed et al.'s study, haptic feedback in the form of force feedback actuators were rated as more natural than haptic feedback in the form of vibrotactile touch during an interaction in which a virtual character touched the user (2016). Additionally, this study showed that touch intensity as well as naturalness of the virtual character response was influenced by the type of haptic feedback. Researchers found that users were most influenced when a virtual character had a happy expression, as well as felt more present during interactions with a smiling virtual character. Here it is seen that type and intensity of haptic feedback can influence virtual character's emotions, which in turn, affect users (Ahmed et al., 2016). Ahmed et al suggests mechanical force haptics over vibrotactile actuators for the purposes of affective virtual character interactions (2016).

Sense of touch is extremely important in real life social interactions, and can evoke strong negative and/or positive emotions, yet research beyond visual and auditory feedback in VR is comparatively limited (Haans & IJsselsteijn, 2006). According to multiple sources, social touch not only increases self-disclosure levels, but when one is touched briefly and discreetly, social touch has been shown to increase "compliance to a request (Haans & IJsselsteijn, 2006)." Studies involving user performance and haptics have found that objects with haptic feedback perform better and are perceived as more realistic than objects with no haptic feedback (Wu, Hsu, Lee, & Smith, 2017). During a conversation with a VC in VR in which users sat across from a VC at either a wobbly or non-wobbly table, the "subtle incidental movement" of the wobbly table led this group to feel significantly higher levels of presence than did the group that sat at a non-wobbly table (Lee et al., 2016). In a virtual reality phobia study, users who felt a virtual spider experienced more fear and presence than users who did not feel the spider, thus indicating the power of haptic feedback for user immersion (Hoffman,1998). The researchers did this with a toy spider, which they held out to the participant as he or she reached out to feel the virtual spider.

Important for VR simulations among other VR applications (Ryge et al., 2017), haptic feedback is thought, logically so, to influence perceived quality of experience. Ryge et al. showed that varying levels of haptic feedback during a VR baseball scenario influenced user perceived responsiveness of the virtual bat. In this study, haptic feedback led the virtual bat to be perceived as more responsive than with no haptic feedback, however differences in high or low fidelity of haptic feedback showed no significant differences in perceived responsiveness. The researchers suggest that this could be due to the short time period in which the user experienced the haptic feedback, as it was only felt during the brief moment in which the baseball hit the bat. Ryge et al. suggest exploring how varying duration of haptic feedback might alter user's perceptions of perceived responsiveness. One study did just that: finding that out of three trials (no vibration, constant vibration, and dynamic vibration), illusory self-motion and perceived realism during a VR sandboarding experience were highest during the constant vibration trials (Lind et al., 2016).

Preliminary research by Koumaditis et al. concerns stress and anxiety measures during virtual training scenarios (2018). The researchers would like to find ways to link arousal to task performance in order to improve virtual training for stressful scenarios (Koumaditis et al., 2018). The researchers plan to implement soft skin stretch and low frequency vibration haptic feedback in further stages of their research in order to understand the influence of haptic feedback on arousal. Additionally, haptics in virtual reality have been utilized in the study of perceptions of normal and overweight virtual characters. It was discovered that the duration and strength of the user hug varied based on the avatar weight and sex. Haptics proved useful as a way in which to measure the “anti-fat attitude,” which seems to translate to virtual characters in VR, based on this study (Tremblay et al., 2016).

With the ability to look closely at otherwise obscure anatomy, VR is a great tool for a wide variety of medical training in that it can provide haptic feedback that would be felt during the actual medical procedure. Commonly used in surgical as well as other medical simulations, VR simulations benefit from haptic feedback, in that haptic feedback provides significantly higher levels of realism for medical students, and thus potentially creating more effective, less costly training environments, as well as better surgeons (Wang et al., 2017). Additionally, Wang et al. showed that VR with haptic feedback is effective in showing differences among dental students and prosthodontics residents (2017). Specifically, they showed that students spent twice as long on the same task and had lower scores consisting of damaged teeth and other incorrect processes, thus demonstrating VR as a great tool for performance analysis as well as training. "Previous studies demonstrated that training with virtual simulators significantly improved students' manual skill compared with those students not trained on those systems” (Wang et al., 2017).

Sense of touch is not only essential for day to day life, but is needed in order to fully understand the environment as well as learn how one can interact with and within the environment (Robles-De-La-Torre, 2006). Haptic feedback in VR is currently used in virtual prototyping, scientific visualization, as well as assistive technology for users with visual deficiencies (Nam, Richard, Yamaguchi, & Bahn, 2014). VR haptic feedback has been found to be effective in improving user task performance, as well as in the enhancement of positive social effects, such as "increased perceived togetherness" during actions by a partner in VR (Nam et al., 2014). According to Nam et al., gaps in haptic technology research for VR primarily consist of a limited understanding of haptic effects on user behavior and perception (2014).

Haptic feedback in the form of haptic telecommunication has been shown to increase feelings of a shared experience between two people (Takahashi, Mitsuhashi, Murata, Norieda, & Watanabe, 2011). Takahashi et al. showed that haptic telecommunication "modulated the quality of the experience shared with another person as well as the impression of the other person (2011)," as well as increased sympathy for the other person. It is suggested that haptic feedback may be significant in influencing quality in interpersonal communications via technology, *and thus VR applications with haptic feedback could potentially increase the quality of the social interaction.*

2.7 Virtual Reality for Mental Health

VR has been around since the 1980s, with applications in mental health cropping up as early as 1995 (Riva, Wiederhold, & Mantovani, 2018). In a recent meta-analysis on VR clinical usage, it clear that VR has clinical potential in mental health disorder diagnosis and treatment, with VR therapies for SAD, eating disorders and pain management comparable to non-VR therapies, and consisting of therapeutic effects that are long-lasting and are "generalizable to the real world (Riva et al., 2018)." Riva et al. posits that VR's limits lie in its inability to allow users to experience simulations of the internal body, such as interoception, as users only experience simulations of the external body at this time. Psychosomatics, as defined by Riva et al., "is an interdisciplinary field that explores the relationships between psychosocial, behavioral factors, and bodily processes," and, accordingly, would be worth pursuing in VR in order to more fully immerse the user for the purposes of creating more embodied simulations, and "for enhancing homeostasis and well-being (Riva et al., 2018)."

Virtual reality is effective as a cognitive behavioral therapy as well as in affective research, as it allows for a high degree of stimulus control, precise stimulus measurement, and the ability to replicate experimental conditions with all subjects (Blascovich et al., 2016) (Purvis, 2016), with precise stimuli control being one of the main reasons VR was initially considered for use in therapy(Bohil, Alicea, & Biocca, 2011). Multiple studies have indicated that people respond to virtual realities just as they would to reality, with one study eliciting the same emotional response to food in virtual reality as compared to reality (Purvis, 2016). Several virtual reality therapies are currently in effect and successful in reducing patient symptoms such as pain management, eating disorders, reducing depressive symptoms, alleviating phobias, anxiety, PTSD, social recognition disabilities in individuals with autism, and hallucination management in schizophrenia among others (Salamon et al., 2018). Currently, there exists a dearth of objective measures in psychology for understanding emotional regulation behavior of patients, with self-report questionnaires being the primary source of information (Rodriguez et al., 2015).

Considering all VR therapies, exposure therapy is the most common for behavioral health (Riva et al., 2018). Safety, privacy, control and customization as well as an ideal setting for stimuli based on patient's progress are among some of the reasons that VR is so popular for clinical use, and is often described as being between real world and imagination therapies (Riva et al., 2018). While VR is effective in its simulation of the real external world in terms of vision and hearing, it is much less effective in recreating other senses such as touch and smell, as well as taste. In terms of haptic feedback, significantly underexplored is the use of Riva's sonoception technology: using vibrotactile transducers (proprioception – muscles), low bass sounds (over the chest for interoception – heart), and ultrasonic transducers (interoception – over the stomach) in order to mimic interoceptive/vestibular features of the body (2018). Perhaps before ideas such as sonoception are considered, a better understanding of the effects of haptic feedback on the external body are worth pursuing.

Numerous studies in VR have shown that psychosis in schizophrenics can be seen in various ways such as eye gaze, planning, perception of social emotional cues, as well as emotion recognition when compared to the subjects without schizophrenia, demonstrating that VR is safe as well as appropriate for assessment in psychosis (Rus-Calafell, Garety, Sason, Craig, & Valmaggia, 2017). Limitations include the need for physiological feedback provided to subjects, so that they might learn as they go within the therapy environment (Rus-Calafell, 2017), as "learning while experiencing" is common in many VR mindfulness paradigms for anxiety.

2.8 Virtual Reality and Emotion Regulation

Emotions involve subjective experiences, but also include the actions an individual may take as a result of his or her emotions (Gross, 2015). Emotions follow this pattern in the mind: Situation/Event > Attention > Appraisal/Analysis > Response, and can cycle rapidly through this pattern numerous times (Gross, 2015). The purpose of emotions is to guide sensory processing, enhance decision-making behavior, and provide additional information in order to determine the best response. When emotions last too long, are too intense or occur too frequently, they can be considered harmful rather than helpful. Emotion regulation (ER) refers to the ability to control the influence, intensity, and duration of emotions, which greatly affects an individual's behavior (Gross, 2015), (Rodriguez et al., 2015). Inadequate emotional regulation may lead to psychosocial and behavioral problems. Researchers would like to detect ER deficits before an individual experiences emotional/behavioral difficulties.

Mindfulness practices involve several emotion regulation techniques, which include increased attention as well as decreased expressive suppression of emotions (Gross, 2015). Studies have shown that mindfulness practices, such as concentration and meditation, in virtual reality have been effective in decreasing anxiety (Choo & May, 2015). Better emotion regulation involves more reappraisal, and less suppression of emotions (McRae, Rekshan, Williams, Cooper, & Gross, 2014). There is evidence that higher levels of reappraisal may contribute to a lower risk for cardiovascular diseases (Gross, 2015). Currently, emotion regulation strategies are limited, with reappraisal being the primary tool (Gross, 2015).

Healthy individuals use distraction for emotion regulation in higher emotional intensity situations more so than in lower emotional intensity situations (Hay, Sheppes, Gross, & Gruber, 2015). Because distraction may be more useful as an emotion regulation strategy in some individuals at different times and emotional intensities, it is logical to conclude that a variety of emotion regulation techniques would be beneficial for a variety of individuals. Research exploring the extent of emotion regulation techniques during various emotional encounters would be useful (Hay et al., 2015).

There are numerous ways to successfully regulate emotions, but the very best way in which to do so remains unknown (Gross, 2015). Additionally, there is a significant lack of understanding about the brain processes responsible for emotions (Gross, 2015). Researchers would like to explore new ways in which to measure emotion regulation deficits, in order to detect possible emotional and behavioral issues that an individual may have, before a problem arises (Rodriguez et al., 2015).

One study created a game system designed to collect ECG and psychological data during a cognitive reappraisal task in VR (Rodriguez et al., 2015). This study implemented two phases: a frustration phase, in which the patient becomes frustrated with a game that seems not to be working, followed by a training phase in which strategies to regulate this emotion are taught.

2.9 Virtual Reality and Social Anxiety Disorder

Not only is VR advantageous for use in social anxiety disorder (SAD) due its controllable, reproducible nature, but due to its limitless context variety, as well as due to its positive patient self-report, indicating less fear of virtual reality treatment compared to in vivo treatments, and thus less avoidance of therapy (Bouchard et al., 2017). In a study by Falconer et al., depressed patients expressed excitement at the VR treatment that allowed them to step outsides themselves and see a new perspective, and were better able to apply self-compassion techniques that they had learned in VR in the real world (Falconer et al., 2016). Furthermore, several studies have shown that virtual reality exposure for SAD paired with cognitive behavioral therapy is as effective or more effective for therapists than cognitive behavioral therapy without virtual reality exposure, with positive patient effects such as decreased self-report measures of social anxiety and social phobia, longer-lasting than without VR (Bouchard et al., 2017). However, in Bouchard's study, it was found that cognitive behavioral therapy conducted in vivo, as opposed to cognitive behavioral therapy conducted entirely in VR was more effective (2017), therefore, ways in which to make virtual reality scenarios more similar to reality would be beneficial in the pursuit of more effective treatments for social anxiety as well as for other disorders. The researchers hypothesize that VR CBT may generally be less effective than in vivo CBT, as the therapist is in a different room during the VR session; additionally, interactions with virtual characters such as dialogue may create technical difficulties.

It is essential that researchers pursue increased measures for improving "complex social interactions" in VR in order to better provide exposure therapies and better understand dysfunctional mental representations of social encounters in those with SAD (Bouchard et al., 2017). One way in which CBT may decrease social anxiety levels in SAD is through increasing emotion regulation skills (Goldin et al., 2014), and thus evaluating how to alter emotional arousal responses in social VR would be useful in increasing presence for improved VR CBT for SAD as well as other disorders with emotional processing issues such as depression.

2.10 Galvanic Skin Response (GSR)

Galvanic skin response (GSR), one form of electrodermal activity (EDA), is an electrical signal that detects changes in sweat gland activity, in which a higher skin conductance indicates higher arousal (*Galvanic Skin Response The Complete Pocket Guide*, 2017). While GSR measures intensity, it cannot be used to measure valence (positive/negative aspects) of emotions. Common measurements of GSR include latency and amplitude of signal, as well as quantity of "peaks;" places in the GSR waveform that are clear indicators of arousal (significant difference between baseline and phasic levels). Because there are numerous sweat glands found in the hands and feet, it is common and acceptable to place GSR sensors in these areas, often using the non-dominant hand if the hand is selected, so as not to add noise from subject movement (*Galvanic Skin Response The Complete Pocket Guide*, 2017). Skin conductance cannot be consciously controlled, and is, therefore, considered an accurate measure of arousal, however often researchers will add ionic gel and/or cleanse the skin with alcohol before applying sensors, in order to increase signal and/or remove noise from the signal, respectively. This choice must be consistent across subjects.

Common sample rates for GSR range from 1-10Hz (1 to 10 samples per second), but 100Hz can also be collected, and then later down sampled. Peak amplitude for GSR is the difference between onset of stimulus and the highest signal after this time (the peak). Rise time is considered the duration from onset up to the peak after stimulus, while recovery time is the time between peak to offset: a returning the baseline GSR level, which takes longer than rise time.

A typical skin conductance response (no arousing stimuli) can be between 10-50 μS (microSiemans). An event-related skin conductance response "can be attributed to a specific eliciting stimuli (Braithwaite et al., 2013)." Skin conductance response is phasic and changes quickly, while tonic signal changes slowly, and is attributed to normal conductance levels of the individual. ER-SCRs have a latency period of 1-3 seconds between stimulus onset and "first significant deviation in the signal," according to Braithwaite et al. (2013), and a latency of 1-5 seconds according to the *Galvanic Skin Response Complete Pocket Guide* (2017). This time interval is essential in concluding which peaks/responses are due to stimuli.

Noise in GSR signal can result due to bad sensor contact with skin, as well as subject interfering with the sensor. GSR is measured by two sensors that must remain in contact with the skin of the subject throughout the duration of the signal recording. When sensors are shifted, a 15 minute resettling period is necessary, as skin under the sensor contains more sweat than skin not in contact with the sensor (Bakker, Pechenizkiy, & Sidorova, 2011). Analysis of GSR data can include down sampling, as well as filtering. Filtering removes the tonic component of the of skin conductance, which is unrelated to arousal, in order to see only the increase in signal during arousal.

2.11 Virtual Reality and Galvanic Skin Response

Multiple studies have been conducted in VR with GSR. In a study by Hägni et al., in an unexpected stabbing of the user's virtual arm, GSR peaks were significantly higher for the subjects whom were first told to imagine the virtual arm was their arm, as opposed to the other group, whom just observed the virtual arm and the scene (2008). This study shows that humans can respond emotionally to virtual pain via self-report as well as physiological measures, and especially so when told to imagine the virtual body part is their own (2008). This study was conducted using a computer screen, and, therefore, testing within a virtual scenario might be worth the pursuit, as differences may be greater due to the immersive properties of VR. Although emotional arousal data differed significantly, there were no significant differences found between the two groups concerning VBO or presence, again raising the question as to how self-report measures of embodiment and presence are related or not related to objective measures of emotional arousal.

Just as it has been shown to increase pain threshold in real-life studies, it is equally possible to alter user pain perception due to changes in avatar body (Romano et al., 2016). Romano et al. showed that being aware of one's avatar in VR "affects the processing of painful stimuli with induction of different levels of pain responses for embodied virtual bodies of different sizes," and demonstrated a clear connection between pain perception and the self during embodied virtual body experiences in VR (2016). This study demonstrates that it is possible to induce analgesia (reduced pain sensation due to looking at one's body) as VBO increases. In this study, significant differences in GSR during noxious pain stimulation trials were found between the small and normal body, and small and large body, but no differences were between the normal and large body. The researchers believe this may be due to lack of realism, as the large body may have been more noticeably distinct, despite both small and big bodies being 30% smaller, or 30% larger, respectively (Romano et al., 2016). Manipulating body sizes in VR has been shown to alter pain perception when the user looks at his or her avatar (Mancini et al., 2011). Pain perception has been shown to increase in relation to perceived hand size, as seen in an experiment in real-life with a magnifying property of a mirror in a box, and would be worth testing in VR (Mancini et al., 2011).

2.12 Galvanic Skin Response Analysis

"The amplitude is the most frequently used measure to describe a single EDR" (Boucsein, 2012). After amplitude, the next most commonly measured aspect of electrodermal activity is the recovery period: the latency to offset after the galvanic skin response, otherwise called the peak.

2.13 Galvanic Skin Response Sex Differences

Women have shown greater "sensitivity and vulnerability" to stressful events as seen through GSR, as well as differences in startle reflex amplitude during emotional response tests that involve pleasant, neutral, and unpleasant images from the International Affective Picture System (Bianchin & Angrilli, 2012). Women have shown an overall heightened response to unpleasant stimuli, in this case, unpleasant images. Men elicit greater GSR during positively-charged images such as erotic images, while women exhibit greater responses during negatively-charged unpleasant images, such as mutilation (Brown & Macefield, 2014).

Studies that do not involve emotionally charged stimuli have not shown difference in GSR responses between men and women.

2.14 Summary of Review of Literature

Further studies focusing on believable virtual characters is necessary, as virtual reality has numerous potential benefits within the realm of social disorder therapies and other mental health applications. Moreover, studies that pursue objective emotional responses in virtual reality will contribute knowledge concerning self-report accuracy as it relates to physiological data and player experiences in entertainment applications.

CHAPTER 3. METHODOLOGY

3.1 Participants

Participants were students 18-32 years old, most with at least some prior experience in virtual reality. Participants were obtained through flier and email announcements, as well as through word of mouth, and announcements made in undergraduate classrooms. Participants had the chance to experience the virtual reality scene, as well as try the bHaptics gaming vest, but were not compensated otherwise. Many participants came from the computer graphics technology department at Purdue, and therefore had experience in digital media creation. Participants were assigned an avatar that best matched their sex and skin tone, in order to embody the participants more strongly in the self-avatar that they received in the virtual environment.

3.2 Research Type and Framework

This thesis was a quantitative research experiment, with the primary variable of interest being event-related galvanic skin response. The goal of this research was to determine if haptic feedback provided greater physiological arousal in users during a virtual character interaction than no haptic feedback. Additionally, the study explored if self-reported levels of presence and embodiment increased with the presence of haptic feedback. Furthermore, the study included three haptic feedback conditions in addition to full-intensity haptic feedback, and no haptic feedback, which will be discussed in more depth below.

3.3 Questionnaire

Upon arriving, participants were first asked to answer a short demographic questionnaire. After completing the experiment, he or she completed the full questionnaire. The questionnaire consisted of 20 items in total, and allowed for participant comments if they wished to express any additional thoughts. The first four questions corresponded to presence, and are nearly identical to the questions from a gold standard virtual reality presence questionnaire, designed and used by Slater, Usoh and Steed (1994). The next four questions corresponded to embodiment, and are based on standard questions concerning embodiment and virtual body ownership (Slater, Perez Marcos, Ehrsson & Sanchez-Vives, 2008). The following two questions were used to determine self-report affect, while the next two questions were used to determine self-report negative affect and are taken from the Positive and Negative Affect Schedule, a standard self-report questionnaire used to measure positive and negative emotion (Watson, Clark, & Tellegen, 1988).

Next were five exploratory questions, not based on standard questions, used primarily to determine general feelings of participants concerning the virtual characters and haptic feedback. Questions addressing the realism of virtual characters and haptic feedback, as well as virtual character interaction were explored. Following these five questions is Question 18, which was used to determine if any participant experienced any physical discomfort, or VR sickness. The last two questions were taken from standard questionnaires concerning flow and engagement, as an added exploratory variable. Below please find the questions used on both the demographic questionnaire, and full questionnaire.

Table 1: Demographic Questionnaire Items

Question 1	Question 2	Question 3	Question 4
What is your age?	What is your sex?	How much time do you spend playing video games every week?	Have you experienced virtual reality before?
Enter number	M, F, Prefer not to say	None, Less than an hour, 1-2 hours, 2-5 hours, more than 5 hours	Never, 1-2 times, 3-10 times, Frequently

Table 2: Full Questionnaire Items

Q1	Please rate your *sense of being in the* virtual environment, on a scale of 1-7, where 7 represents your *normal experience of being in a place.*
Q2	To what extent were there times during the experience when the virtual environment was reality for you? (1 indicates being in the real world, while 7 indicates being in the virtual environment)
Q3	When you think back to the experience, do you think of the virtual environment more as *images that you saw* or more as *somewhere that you visited*? (1 indicates images, while 7 indicates somewhere visited)
Q4	During the time of the experience, which feeling was strongest: your sense of being in the virtual environment, or your sense of being elsewhere? (1 indicates virtual environment, while 7 indicates being elsewhere)
Q5	How strong was the feeling that the body you saw was your own? (1 indicates not at all, 7 indicates very strong)
Q6	When you looked at the body, how strong was the feeling that you were looking at your own body? (1 is not at all strong, 7 is very strong)
Q7	How strong was the feeling that your body was becoming the virtual body? (1 is not all strong, 7 is very strong)
Q8	How strong was the feeling that the virtual body was beginning to look like your real body? (1 is not at all strong, 7 is very strong)
Q9	How enthusiastic did you feel during your time in the virtual environment? (1 is not at all, 7 is extremely)
Q10	How interested did you feel during your time in the virtual environment? (1 is not at all, 7 is extremely)
Q11	How upset did you feel during your time in the virtual environment? (1 is not at all, 7 is extremely)
Q12	How distressed did you feel during your time in the virtual environment? (1 is not at all, 7 is extremely)
Q13	How realistic did you find the virtual characters? (1 is not at all, 7 is extremely)
Q14	Did the appearance of the virtual characters make you feel uncomfortable? (1 is not at all, 7 is extremely)
Q15	Did you feel comfortable when the virtual characters walked past you? (1 is not at all, 7 is extremely)
Q16	How realistic were your interactions with the virtual characters? (1 is not at all, 7 is extremely)
Q17	How realistic was the haptic feedback that you felt? (1 is not at all, 7 is very realistic). If you did not receive haptic feedback, please write "NA".
Q18	Were you dizzy, nauseous or did you feel poor physically during the virtual experience? (1 is not at all, 7 is extremely)
Q19	Did you feel involved in the virtual environment experience? (1 is not at all, 7 is extremely)
Q20	Did you feel you were losing your sense of time during the virtual environment experience? (1 is not at all, 7 is extremely)

3.4 Galvanic Skin Response Collection

A Shimmer sensor was attached to the wrist of the participant's non-dominant hand, in addition to two electrodes on the underside of the participant's index and middle fingers of the same hand. The Shimmer sensor sent the data via Bluetooth to the iMotions software on the same PC used to display the virtual reality scene to the participant. The entire experimental session was recorded in iMotions, about 2 minutes before the stimulus presentation began.

While iMotions uses an internal algorithm for peak detection, and therefore does not necessitate a baseline recording to determine tonic levels for each participant, a baseline recording was collected nonetheless. Additionally, iMotions recommends a resting period for the user, prior to data collection, to allow the user to become relaxed in the situation (*Galvanic Skin Response The Complete Pocket Guide*, 2017). This study used the default signal processing settings within iMotions, which are supported by literature concerning electrodermal activity.

3.5 Galvanic Skin Response Analysis

GSR data was assessed for number of responses across the entire stimulus period, which is called the total GSR. Event-related (ER) GSR was analyzed as well, as it is best to focus on ER-GSR in order to obtain accurate measures of physiological arousal that are due to the stimuli being tested (*Galvanic Skin Response The Complete Pocket Guide*, 2017). In addition to Total GSR and ER-GSR, the researcher explored peak amplitude of both Total GSR and ER-GSR.

3.6 Overview of Participant Experience

Upon arriving, participants were briefly introduced to the project and the purpose of the equipment. Next, the experimental procedure was explained. While the participant completed the demographic questionnaire, the experimenter adjusted the self-avatar to most closely match the participant's skin tone, as the researcher wanted to provide participants with a higher body ownership experience (Waltemate et al., 2018). Then, the participant was fitted with the bHaptics "Tactsuit," a haptic gaming vest which allows precise control of haptic feedback, and is controlled with a Unity3D plugin. Next, a Shimmer GSR sensor was attached to the participant's non-dominant hand, with the two electrode sensors fit securely on the index and middle finger. The participant with all necessary equipment can be seen in Figure 5. The participant was instructed to relax, try not to talk or move, and breathe normally, as these are the recommended instructions for minimizing muscular artifacts (*Galvanic Skin Response The Complete Pocket Guide*, 2017), (Boucsein, 2012). The sensors were connected to iMotions biometrics recording and analysis software via Bluetooth.

Within iMotions, the screen output of the virtual reality scene was captured and observable by the experimenter throughout the study. The experimenter used a timer to verify that the 2-minute baseline recordings had been obtained, and then started the VR scenario. After the VR scenario was complete, the Shimmer sensor, electrodes, haptic vest, and head-mounted display were removed, and the participant completed the 20-item questionnaire. Afterwards, he or she was invited to ask any questions, and express any verbal feedback in addition to the written feedback on the questionnaire.

Figure 1: Participant with Sensor, Vest, and Headset

3.7 Virtual Reality Scene Creation

The VR scenario was created in Unity, using free assets taken from a combination of Turbosquid, the Unity store, and CGTrader. Virtual characters were created with the use of Adobe Fuse, and animated in Mixamo. The virtual crosswalk environment was created in 3Ds Max by a third party artist, and imported and rescaled in Unity. To incorporate the haptic vest into the Unity scene, the bHaptics Unity plugin was utilized. Images of the Virtual Reality environment can be seen in the figures below.

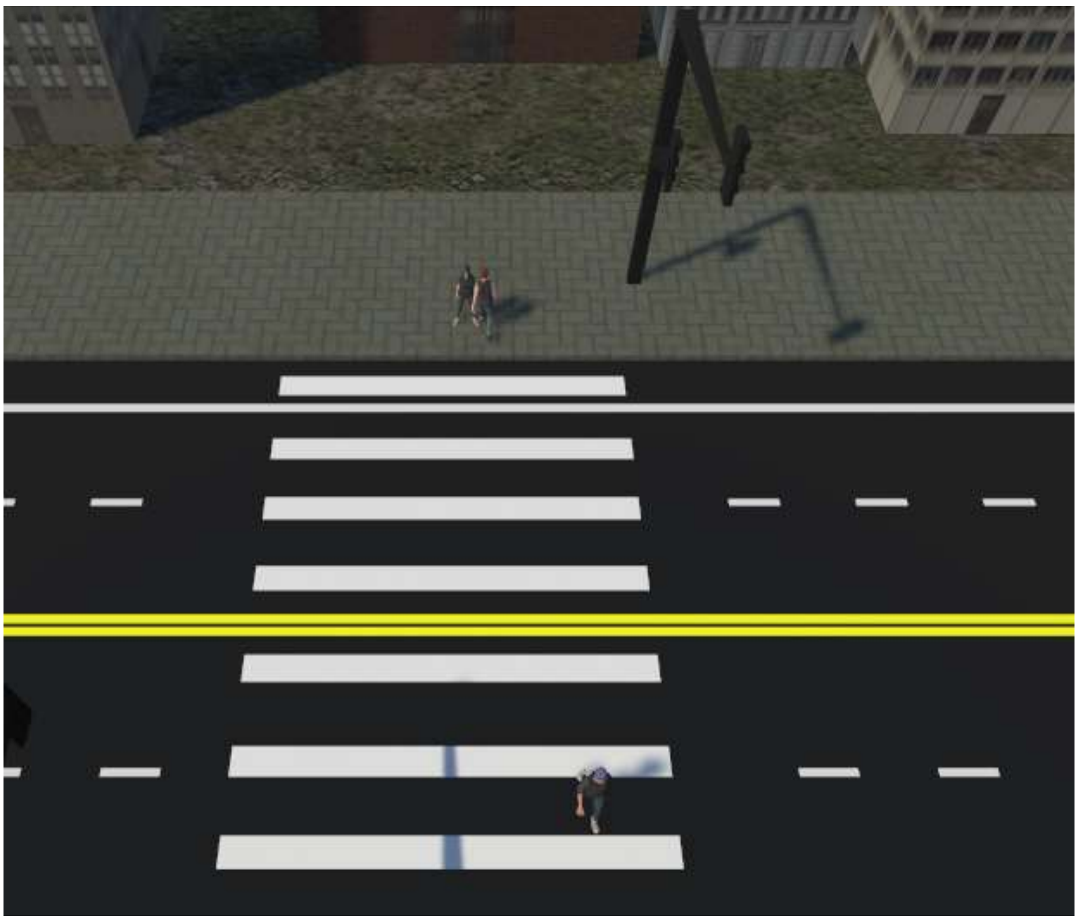

Figure 2: Bird's Eye View of Virtual Scene

Figure 3: Side View of Virtual Scene

Figure 4: Bird’s Eye View of Virtual Character Bump

Figure 5: Participant's Perspective as Virtual Character Approaches

3.8 Introduction to the Three Phases of the Study

The experiment consisted of 3 total phases: the baseline/relaxation phase (2 minutes), the virtual reality exploratory phase (30 seconds), and finally, the experimental phase in virtual reality (2 minutes). The total time of the experiment was 4 minutes and 30 seconds for every participant. This is time in which iMotions recorded GSR, and the participant experienced virtual reality, wearing all equipment. This time did not include the time needed to explain the study to the participant nor the time allotted for filling out the demographic questionnaire and full questionnaire after the experiment was complete. Below, the three experimental phases are explained in more detail. Before the start of the baseline/relaxing phase, all equipment was attached and explained to the participant. The first experimental phase began after the participant had all questions answered, and was comfortably set up for the study.

3.9 Experimental Phase: Baseline

In order to conduct the baseline/relaxing phase, the participant was first instructed to relax, breathe normally, try not to move or talk too much, while he or she stood with the headset, vest and sensors attached, within the virtual reality Oculus home screen. This scene was relaxing, with cheery music, and had a view of a cozy living area overlooking the wilderness. Therefore, it was decided that this waiting screen would be ideal for users to habituate to the scenario in a relaxing way, and at the same time, provide a simple, low interaction scene for capturing a neutral baseline skin conductance.

3.10 Experimental Phase: Exploratory

After the 2-minute baseline/resting phase in which the participant wore all necessary equipment, the virtual reality scenario created for the study began. All participants experienced the same virtual environment: a busy crosswalk. During the virtual scenario, virtual humans walked by on sidewalks, crossed from behind the participant and walked towards the participant as they crossed the street. Before haptic stimuli conditions commenced, participants received text instructions within the virtual environment that instructed them to “Feel free to look left, right and down at your body.” In this 30-second exploratory phase, the participant saw his or her self-avatar, as well as virtual humans walking on sidewalks and crossing the street. After 25 seconds, participants again received text instructions to “Please face forward and remain still,” in order to minimize movement artifacts in GSR. At the 30-second mark, participants were facing forward, having explored the scene briefly.

3.11 Experimental Phase: Stimulus Timeframe

During the next 2-minute period, participants were collided with, or bumped into by virtual humans. These collisions occurred six times total for each participant, at 20-second intervals, as other virtual humans continued to pass by. Participants received one of five conditions: FIF, NH, IPH, DH or HIH. After the 2-minute experimental phase of the study, the virtual scene terminated, and participants then filled out the 20 item questionnaire.

3.12 Haptic Feedback Conditions

Haptic feedback conditions included: FIF (Full Intensity Haptic Feedback), NH (No haptic feedback), IPH (Incorrect Position Haptic Feedback), DH (Delayed Timing haptic feedback), and HIH (Half intensity haptic feedback), described in more detail below.

- FIF. The full intensity haptic feedback condition could be considered the most accurate haptic feedback condition, in that it could be considered the most believable bump felt upon colliding with a virtual character. However, it is important not to call this condition the accurate haptic feedback condition, as accuracy of haptic feedback on collision did not consist of extensive testing. The FIF condition consisted of haptic feedback at 100% intensity (set within a Unity parameter).

- NH. In this condition, the participant wore the haptic vest, but the button to pair the haptic vest with the bHaptics software downloaded onto the research PC was not turned on, and therefore there was no possibility that the participant would accidentally receive haptic feedback. In this condition, the participant received zero haptic feedback.

- IPH. In this condition, the participant received haptic feedback that was at full intensity, but on the incorrect side of the body. For example, if the virtual character bumped the participant on the left side of his or her body, the participant would feel the haptic feedback on the right side of his or her body, and vice versa.

- DH. In this condition, the haptic feedback was at full intensity, but would be felt one second later than was logical; it was felt one second later than all other haptic feedback conditions.

- HIH. In this condition, haptic feedback was again correct in position and timing, such as it was in the FIF condition, however, it was set to 50% intensity (adjusted in Unity).

3.13 Haptic Feedback Vest

The haptic vest used in this experiment is made by bHaptics, and it allows for precise control in intensity and position within their online designer platform (bHaptics designer), as well as within Unity, as it is adjustable within Unity parameters seen in the Inspector window. This vest has 40 vibration points, and fits most users. It can be used for feeling gunshots, paint splatters and snakes coiling around the body, among other examples. In this study, the vest was used to provide physical feedback (haptic feedback) as the virtual character bumped the subject.

3.14 Timeline for Experiment

The study duration was 15 minutes per participant, and varied slightly depending on participant's time used to complete the questionnaires, and any time needed in order to answer participant's questions upon completion of the study. Below is a timeline for the study.

- Introduction to the study, consent forms, demographic questionnaire completion (2 minutes)
- Attachment and explanation of equipment (5 minutes)
- Experiment (4 minutes and 30 seconds)
- Post-Experiment Questionnaire and Wrap-up (5 minutes)

3.15 Summary of Methodology

Upon arriving, participants were briefly introduced to the project and completed a demographics questionnaire (concerning sex, age, and prior VR experience). Next, the experimenter adjusted the self-avatar to most closely match the participant's skin tone. Then, the participant was fitted with the bHaptics gaming vest. Next, the Shimmer sensor and electrodes, as well as the vest and headset were adjusted and put on the participant. The experimenter used a timer to verify that the 2-minute baseline recordings had been obtained, and then started the VR scenario. For this experiment, all participants experienced the same virtual environment during both phases: a busy crosswalk. During the virtual scenario, virtual humans walked by on sidewalks, crossed from behind the participant and walked towards the participant as they crossed the street. Before haptic stimuli conditions commenced, participants received text instructions within the virtual environment that instructed them to "Feel free to look left, right and down at your body." In this

30-second exploratory phase, the participant saw his or her self-avatar, as well as saw virtual humans walking on sidewalks and crossing the street. Next, participants again received text instructions to “Please face forward and remain still,” in order to minimize movement artifacts in GSR signal. During the next 2-minute period, participants were collided with, or bumped into by virtual humans. These collisions occurred six times total for each participant, at 20-second intervals, as other virtual humans continued to pass by. Participants received one of five conditions, as described previously in the methodology: FIH, NH, IPH, DH or HIH. After the 2-minute experimental phase of the study, the virtual scene terminated. Participants then answered a post-experiment questionnaire to determine levels of presence, embodiment, and self-report emotional arousal. Participants were encouraged to express any additional thoughts either on the questionnaire or verbally after the study had terminated.

CHAPTER 4. RESULTS

4.1 Data Analysis

Q-Q plot residuals were used to verify the normality of the data. A one-way analysis of variance (ANOVA) was used in order to determine significant differences between all haptic feedback conditions, with post hoc comparisons completed with Bonferroni corrections. The analysis was conducted in SPSS. Additionally, a Pearson correlation was used to investigate possible correlations between the subjective questionnaire data and the more objective physiological data of GSR. Below, the data is presented and visualized with box plots.

4.2 Questionnaire Results Overview

This study consisted of 60 total participants, with 12 participants in each haptic feedback condition. In summary, no significant differences were found between any haptic feedback groups when looking at presence, positive affect, negative affect, virtual reality sickness, flow and engagement. Significant differences were found between haptic feedback groups in terms of embodiment, realism of virtual character interaction and realism of haptic feedback. Below are the statistical analyses of the data obtained from the questionnaire completed by the participant post-experiment.

4.3 Presence

Presence was scored by taking the mean value of the 4-item measures of presence. No significant differences were found at the $p<0.05$ level concerning presence [F (4,55) =.304, p=.874].

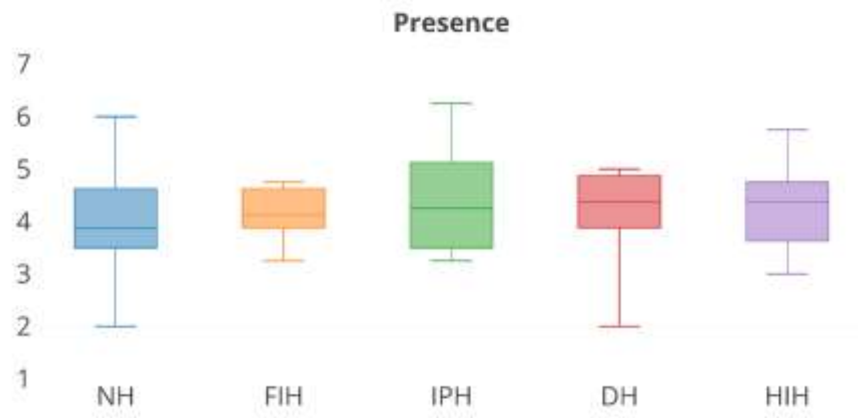

Figure 6: Presence

4.4 Embodiment

Embodiment was scored by taking the mean value of the 4-item measures of embodiment. A significant effect of haptic feedback on embodiment [F (4, 55) =5.353, p=.001] was found across the five conditions. Post hoc comparisons show the mean score for the no haptic feedback condition (M=1.81, SD-.87) was significantly lower than the mean score for the incorrect position haptic feedback condition (M=3.33, SD=1.59), delayed haptic feedback condition (M=3.63, SD=1.09), and the half intensity haptic feedback condition (M=3.81, SD-1.31). There were no significant differences found between the full intensity haptic feedback condition (M=2.65, SD=1.16) and the other haptic feedback conditions.

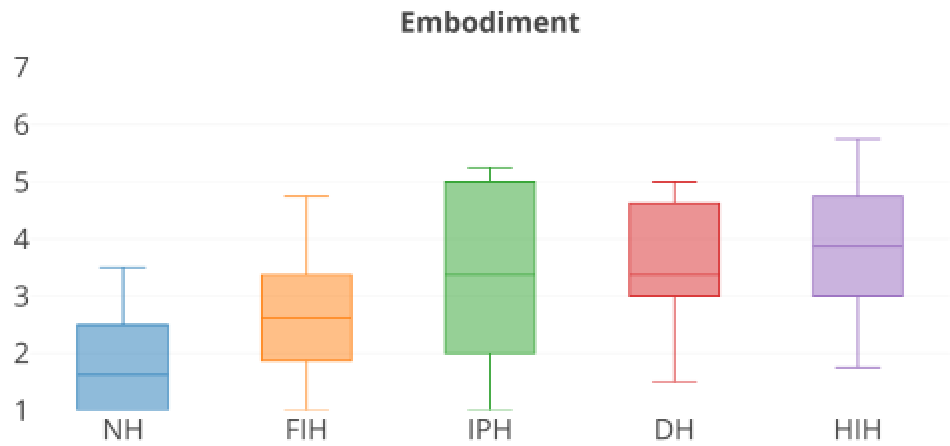

Figure 7: Embodiment

4.5 Positive Affect

Positive Affect was scored by taking the mean value of the 2-item measures. No significant differences were found at the $p<0.05$ level concerning positive affect [$F(4,55) = .806$, $p=.527$].

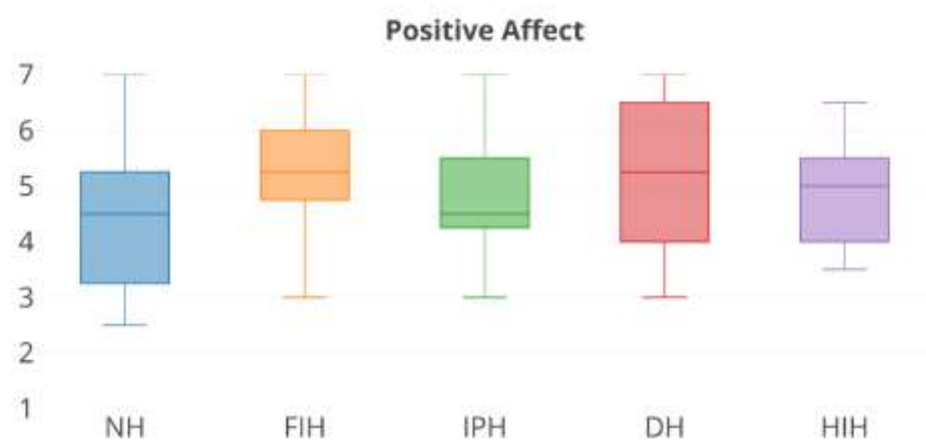

Figure 8: Positive Affect

4.6 Negative Affect

Negative affect was scored by taking the mean value of the 2-item measures. No significant differences were found at the $p<0.05$ level concerning negative affect [$F(4,55) = .695$, $p=.599$].

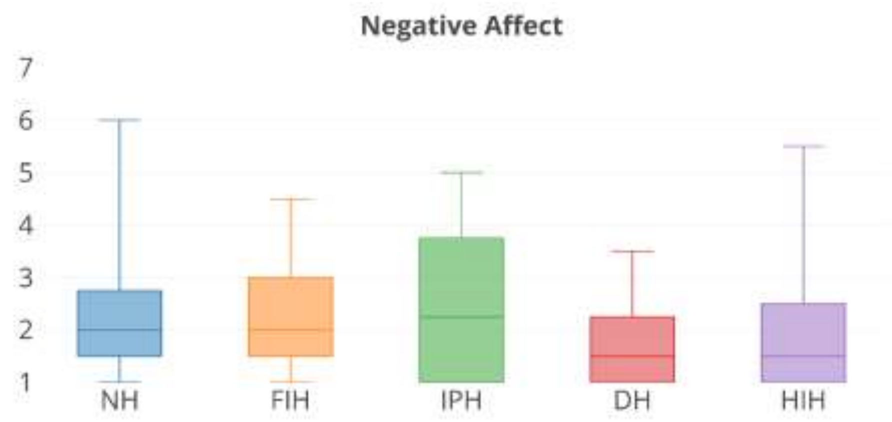

Figure 9: Negative Affect

4.7 Realism of Virtual Character Interaction

A significant effect of haptic feedback on realism of virtual character interaction was found across the five haptic feedback conditions [$F(4,55) = 3.779$, $p=.009$]. Post hoc comparisons show that the mean score for the no haptic feedback condition ($M=2.5$, $SD=1.45$) was significantly lower than the mean score for the delayed haptic feedback condition ($M=4.25$, $SD=1.06$). No other significant differences were found among the other haptic feedback conditions.

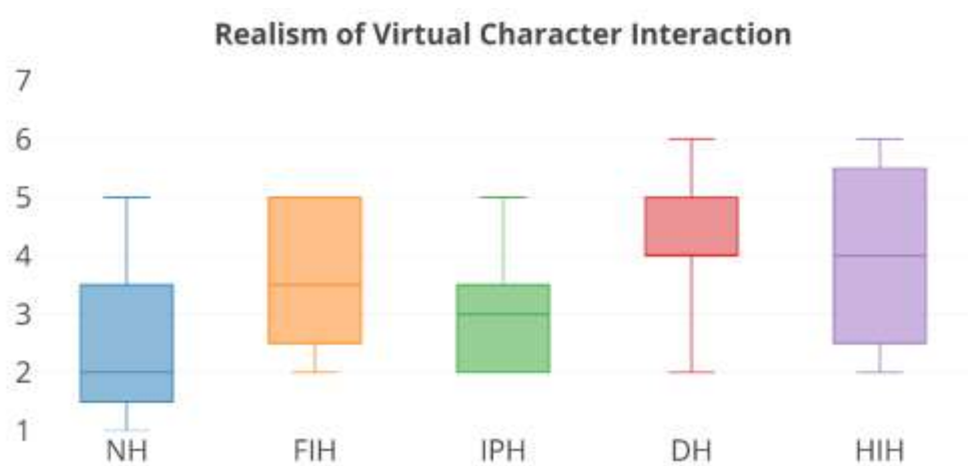

Figure 10: Realism of Virtual Character Interaction

4.8 Realism of Haptic Feedback

The no haptic feedback condition is not included in this analysis, as there was no haptic feedback in this condition, and participants were instructed to write "NA," for this question if they had been assigned to this group. Significant differences in the realism of haptic feedback were found across the four other haptic feedback conditions [F (3,44) =4.708, p=.006). Post hoc comparisons showed that the mean score for the half intensity haptic feedback condition (M=4.50, SD=1.31) was significantly higher than the mean score for the incorrect position haptic feedback condition (M=2.67, SD=1.16). Post hoc comparisons also showed that the realism of the full intensity haptic feedback condition mean score (M=4.08, SD=1.56) was significantly higher than the mean score of the incorrect position haptic feedback condition (M=2.67, SD=1.16). No other significant differences were found between any other haptic feedback conditions.

Figure 11: Realism of Haptic Feedback

4.9 Virtual Reality Sickness

No significant differences were found at the $p<0.05$ level concerning virtual reality sickness [F (4,55) =.627, p=.645].

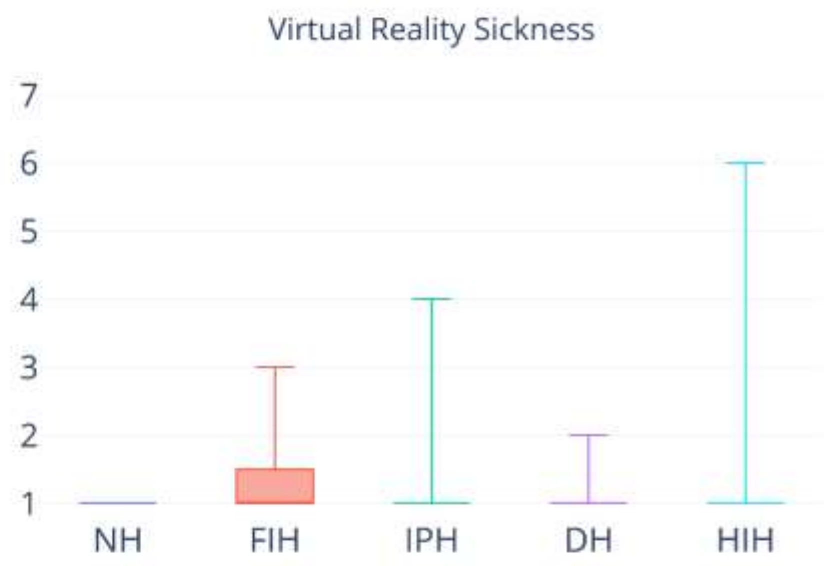

Figure 12: Virtual Reality Sickness

4.10 Engagement

No significant differences were found at the $p<0.05$ level concerning engagement [$F(4,55) = 1.679$, $p=.168$].

Figure 13: Engagement

4.11 Flow

No significant differences were found at the $p<0.05$ level concerning flow [$F(4,55) = .438$, $p = .780$].

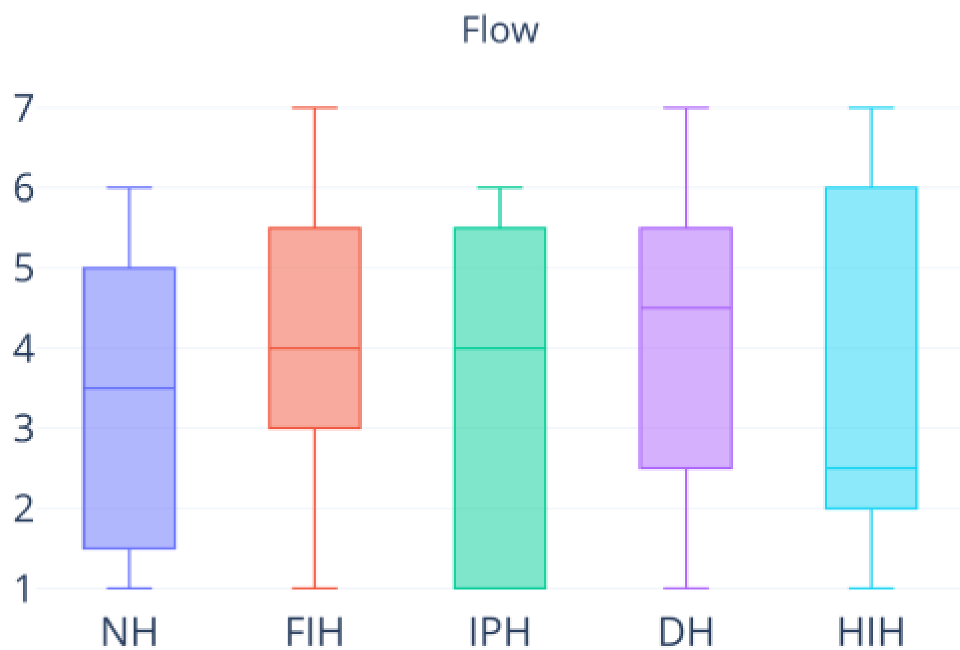

Figure 14: Flow

4.12 Comfort with Virtual Characters

No significant differences were found at the $p<0.05$ level concerning participant's comfort level with the virtual characters [$F(4,55)=1.155$, $p=.341$].

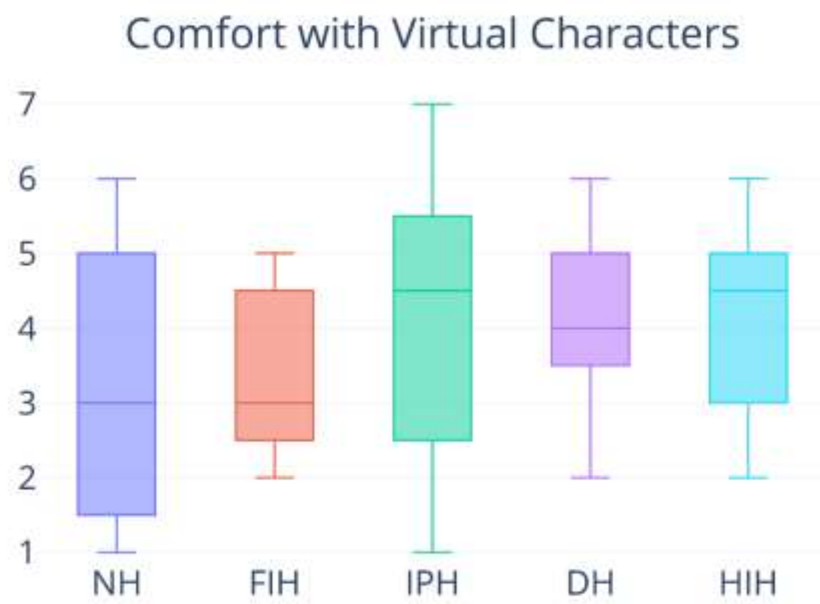

Figure 15: Comfort with Virtual Characters

4.13 Comfort with Appearance of Virtual Characters

No significant differences were found at the $p<0.05$ level concerning participant's comfort level with the appearance of the virtual characters [$F(4,55) = 1.073$, $p=.379$].

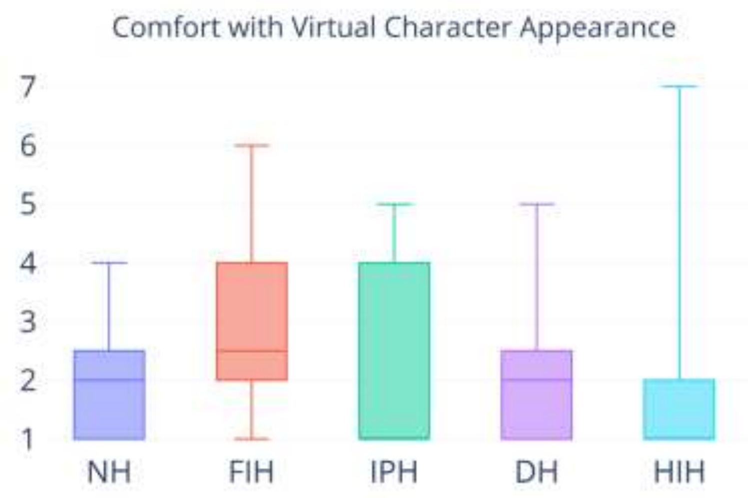

Figure 16: Comfort with Virtual Character Appearance

4.14 Realism of Virtual Characters

No significant differences were found at the $p<0.05$ level concerning realism of virtual characters [$F (4,55) =.549$, $p=.701$].

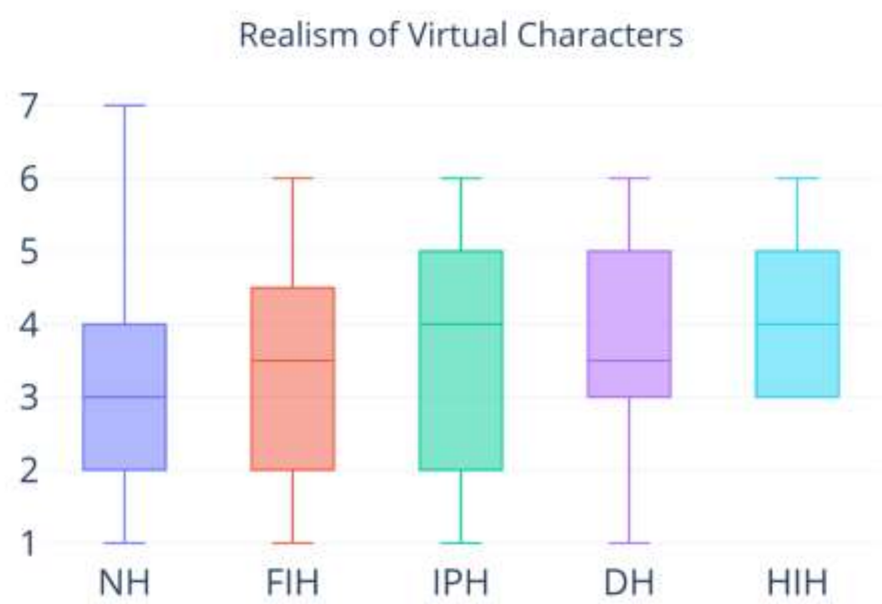

Figure 17: Realism of Virtual Characters

4.15 GSR Results Overview

No significant differences were found at the $p<.05$ level across the five haptic feedback conditions for either total GSR (all GSR during the stimulus period), total event-related GSR (all event-related GSR), or GSR amplitude (of both total GSR and event-related GSR). Prompted by numerous participant verbal and written comments concerning the predictability of the haptic feedback after the first virtual character interaction, the researcher decided to compare the very first instance of event-related GSR amplitude across the five haptic feedback conditions. Significant differences in event-related GSR amplitude were found across the haptic feedback conditions. After finding a significant difference in first event-related GSR amplitude, recovery time of the first event-related GSR was explored, but not significant differences were found.

4.16 Total GSR Peak Count

No significant differences were found at the $p<0.05$ level concerning the total amount of galvanic skin responses during the 2-minute stimulus window [$F(4,55) = .243$, $p = .913$].

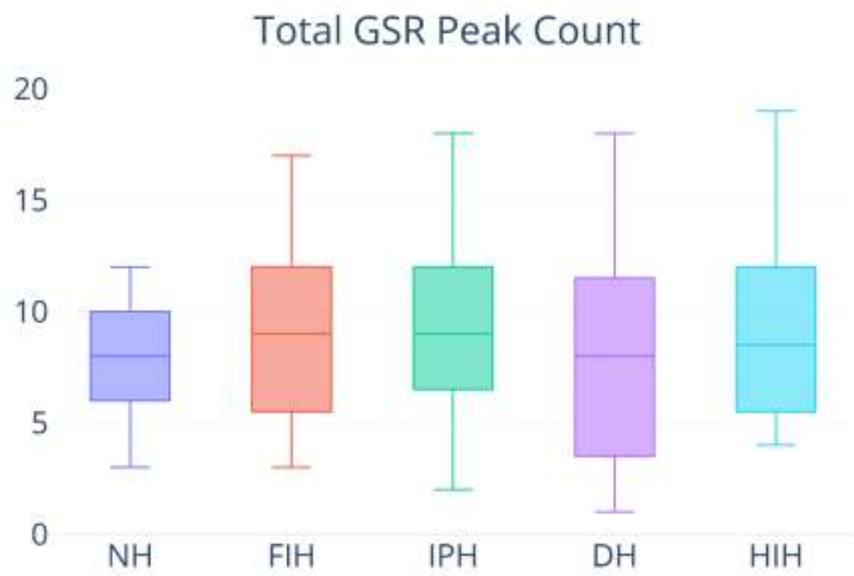

Figure 18: Total GSR Peak Count

4.18 Total Event-Related GSR Peak Count

No significant differences were found at the $p<0.05$ level concerning the total amount of event-related galvanic skin responses during the 2-minute stimulus window [$F(4,55) = 1.635$, $p=.179$].

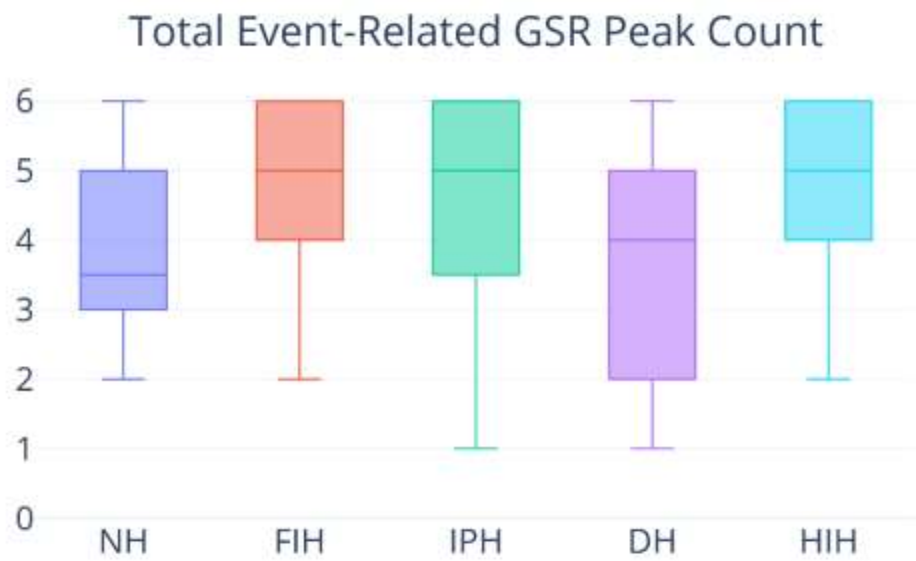

Figure 19: Total Event-Related GSR Peak Count

4.19 Total GSR Peak Amplitude

No significant differences were found at the $p<0.05$ level concerning the total amplitude of event-related galvanic skin responses during the 2-minute stimulus window [$F(4,55) = 1.728$, $p = .157$].

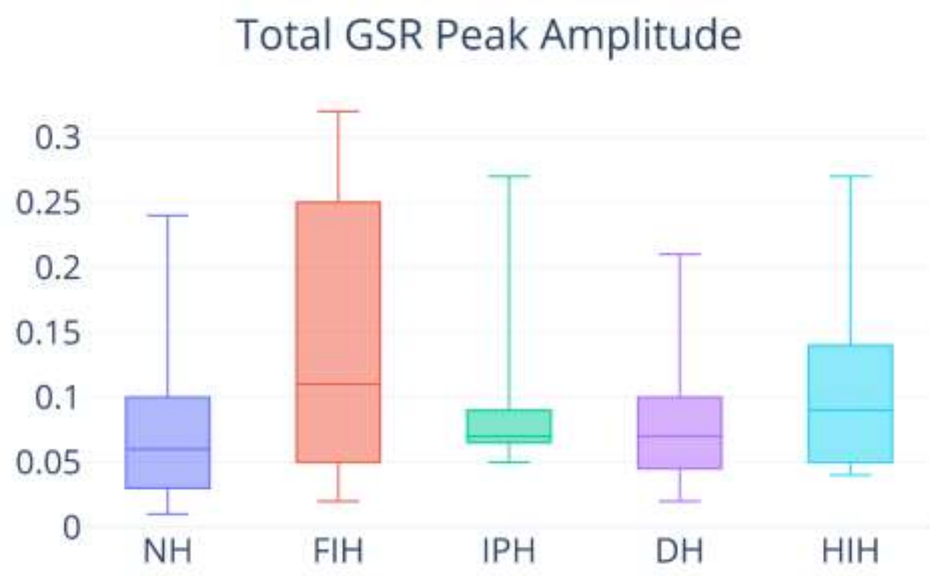

Figure 20: Total GSR Peak Amplitude

4.20 Event-Related GSR Amplitude

No significant differences were found at the $p<0.05$ level concerning the average GSR amplitude of event-related galvanic skin responses during the 2-minute stimulus window [$F(4,55) = 1.722$, $p = .158$].

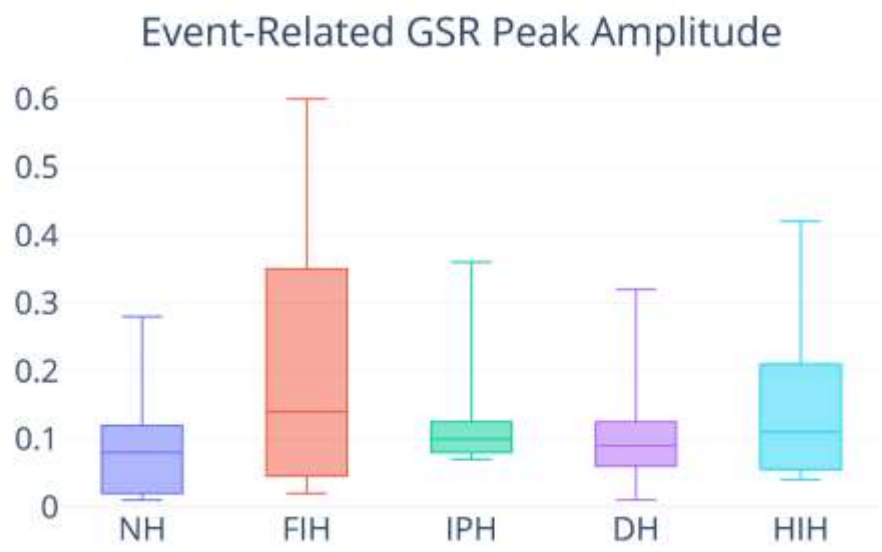

Figure 21: Event-Related GSR Peak Amplitude

4.21 First Event-Related GSR Amplitude

Significant differences in GSR amplitude after the first virtual character interaction were found across the five haptic feedback conditions [F (4,55) =3.731, p=.009). Post hoc comparisons showed that the mean score for the full intensity haptic feedback condition (M=.3510, SD=.31481) was significantly higher than the mean score for the no haptic feedback condition (M=.0807, SD=.07891). No other significant differences were found across the other conditions.

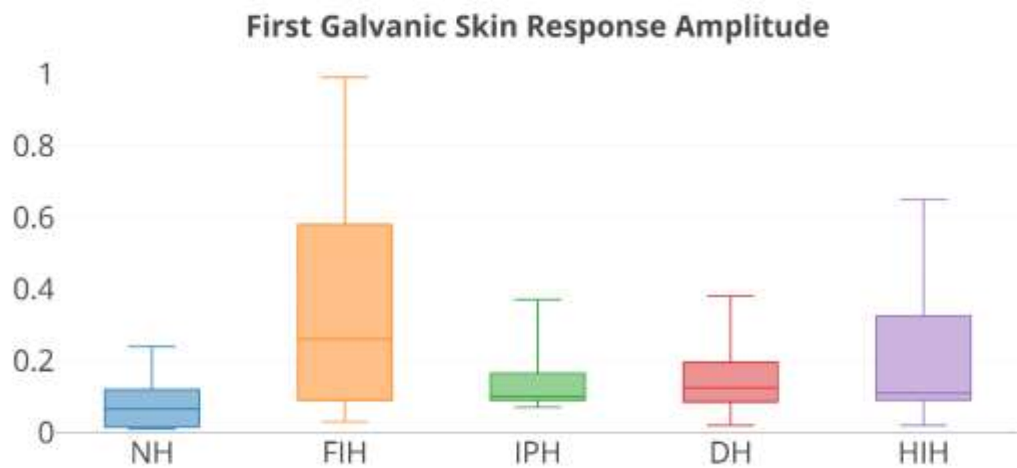

Figure 22: First Galvanic Skin Response Amplitude

4.22 Correlations

Correlations were explored across all combinations of GSR data and questionnaire data, by using a Pearson correlation coefficient. A noticeable positive correlation [r=.329, n=48, p=.023] was discovered between the realism of the haptic feedback and first event-related GSR amplitude (GSR amplitude after the first virtual character interaction). Additionally, a positive correlation [r= .415, n=48, p=.003] was found between the realism of haptic feedback and the total event-related GSR average amplitude. No other combinations revealed significant correlations. Below, please see the correlations explored in this study. A one way ANCOVA was conducted in order to determine a statistically significant difference between haptic feedback condition on embodiment controlling for prior experience in VR. Additionally, a way ANCOVA was conducted in order to determine a statistically significant difference between haptic feedback condition on presence controlling for prior experience in VR. With both the embodiment and presence ANCOVAs, tests were conducted for each covariate (age, sex, prior experience in VR, and weekly time spent playing games). No significant differences were found. Below is a summary of bivariate Pearson correlations between all examined subjective (questionnaire) and objective (GSR) measures.

Table 3: Correlations

	GSR Peaks Count	**Average GSR Amplitude of All Peaks**	**First Interaction GSR Amplitude**
Presence	.202	-.014	.010
Embodiment	.173	.148	.137
Positive Affect	.085	.153	.197
Negative Affect	-.062	-.055	-.094
Character Interaction Realism	.186	.205	.192
Haptic Feedback Realism	.033	.415**	.329*

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

4.23 Descriptive Statistics

Descriptive statistics (Mean [M], Standard Deviation [SD], Minimum [Min] and Maximum [Max] value) of variables of primary interest obtained from the objective measures from questionnaire across experimental conditions (N = 60), and patterns of differences. NH: No Haptic Feedback, FIH: Full Intensity Haptic Feedback, HIH: Half Intensity Haptic Feedback, DH: Delayed Haptic Feedback, and IPH: Incorrect Position Haptic Feedback.

Table 4: Descriptive Statistics (Questionnaire)

Variable	Condition	M	SD	Min	Max	Pattern of Differences
Presence	NH	4.00	.98	2.00	6.00	NH = IPH = DH = HIH
	FIH	4.15	.49	3.25	4.75	= FIH
	HIH	4.27	.78	3.00	5.75	
	DH	4.17	.91	2.00	5.00	
	IPH	4.35	.95	3.25	6.25	
Embodiment	NH	1.81	.87	1.00	3.50	NH < IPH = DH = HIH
	FIH	2.65	1.16	1.00	4.75	
	HIH	3.81	1.31	1.75	5.75	
	DH	3.63	1.09	1.50	5.00	
	IPH	3.33	1.59	1.00	5.25	
Positive Affect	NH	4.41	1.29	2.50	7.00	NH = IPH = DH = HIH
	FIH	5.21	1.29	3.00	7.00	= FIH
	HIH	4.92	.97	3.50	6.50	
	DH	5.21	1.47	3.00	7.00	
	IPH	4.83	1.23	3.00	7.00	
Negative Affect	NH	2.38	1.43	1.00	6.00	NH = IPH = DH = HIH
	FIH	2.33	1.13	1.00	4.50	= FIH
	HIH	2.13	1.48	1.00	5.50	
	DH	1.71	.78	1.00	3.50	
	IPH	2.50	1.48	1.00	5.00	
Character Interaction Realism	NH	2.50	1.45	1.00	5.00	NH < DH
	FIH	3.58	1.24	2.00	5.00	
	HIH	3.92	1.56	2.00	6.00	
	DH	4.25	1.06	2.00	6.00	
	IPH	2.92	1.00	2.00	5.00	
Haptic Feedback Realism	FIH	4.08	1.57	2.00	6.00	IPH < FIH
	HIH	4.50	1.31	2.00	6.00	IPH < HIH
	DH	3.67	.89	2.00	5.00	

Table 5: Descriptive Statistics (GSR)

IPH 2.67 1.16 1.00 5.00

Descriptive statistics (Mean [M], Standard Deviation [SD], Minimum [Min] and Maximum [Max] value) of variables of interest obtained from the objective measures from GSR across experimental conditions (N = 60), and patterns of differences. NH: No Haptic Feedback, FIH: Full Intensity Haptic Feedback, HIH: Half Intensity Haptic Feedback, DH: Delayed Haptic Feedback, and IPH: Incorrect Position Haptic Feedback.

Variable	**Condition**	**M**	**SD**	**Min**	**Max**	**Pattern of Differences**
GSR Peaks Count	NH	3.83	1.39	2.00	6.00	NH = IPH = DH = HIH = FIH
	FIH	4.83	1.34	2.00	6.00	
	HIH	4.75	1.29	2.00	6.00	
	DH	3.58	1.78	1.00	6.00	
	IPH	4.50	1.73	1.00	6.00	
Average GSR Amplitude of All Peaks	NH	.09	.08	.01	.28	NH = IPH = DH = HIH = FIH
	FIH	.21	.19	.02	.60	
	HIH	.16	.14	.04	.42	
	DH	.11	.08	.01	.32	
	IPH	.12	.08	.07	.36	
First Interaction GSR Amplitude	NH	.08	.08	.01	.24	NH < FIH
	FIH	.35	.31	.03	.99	
	HIH	.22	.19	.02	.65	
	DH	.15	.11	.02	.38	
	IPH	.15	.10	.07	.37	

4.24 Summary of Results

While finding no significant differences in presence across the haptic feedback conditions was surprising, also surprising to the researcher was finding significant differences in embodiment across the five haptic feedback conditions. Finding no significant differences in positive and negative affect was disappointing, but may make sense, as the content of the scene was purposefully kept emotionally neutral (See Chapter 5 for more information).

CHAPTER 5. DISCUSSION

5.1 Introduction to Discussion

This study aimed to explore the effect of five haptic feedback conditions on multiple variables, including both subjective measures in the self-report data from the questionnaires, and objective measures in the GSR recordings. A virtual environment in which virtual characters bump into the participant while she stands at a virtual crosswalk was developed. From the data analysis as seen in the results section, significant differences were surprising and unexpected, primarily in that there were no significant differences in presence, but significant differences in embodiment. There were minimal significant differences seen in GSR across participants, perhaps due to the stationary and/or predictable nature of the experiment. Significant differences were not found across all concepts and across all five conditions. Significant differences that were found will be further discussed in this section.

5.2 Presence

In this experiment, participants were instructed to remain still in order to minimize muscular artifacts in GSR data. This ultimately limited their ability to explore and move, which may be one reason for decreased presence across all conditions. Additionally, lack of movement meant that the participant was not able to control his self-avatar, or engage in the environment in any way besides looking forward. Slater and Steed have suggested that presence may depend on participant's active involvement in the environment (Singer & Witmer, 1999), which may explain the results obtained in this experiment: no significant differences in presence across all conditions. Additionally, presence may be extremely difficult to measure for a variety of reasons: terminology on questionnaires is confusing for participants, its meaning may depend and vary moment-to-moment, and participants may only consider presence as they *interact with* the environment, rather than how they perceive the environment (Singer & Witmer, 1999). Evidence for the participants' confusion concerning presence on the questionnaire was plentiful, with one participant stating "the elsewhere question is confusing," and numerous participants asking the researcher, while they were filling out the questionnaire, how various presence questions should be interpreted and what they meant. Despite the gold standard presence questionnaire used in the experiment, as well as the steps taken to clarify its phrasing (based on confusion from a preliminary test using the same questions), the results may indicate potential confusion that remained concerning presence on the questionnaire. Not only is presence difficult to measure via self-report, but the participant's inability to truly interact in the environment may have contributed to finding no significant differences in presence across all conditions.

5.3 Embodiment

While embodiment was not hypothesized to be significantly different across different haptic feedback conditions, several significant differences in embodiment were found. Participants in the no haptic feedback condition rated their feelings of embodiment significantly lower than did participants in the half intensity, delayed and incorrect position haptic feedback conditions. There was no significant difference in embodiment seen between the no haptic and the full intensity haptic feedback condition, which was also surprising. The researcher hypothesized that embodiment would not be significantly different across any groups because the participant would not be able to control the self-avatar, and would only be able to look briefly at the body. The researcher did not think that embodiment would even be a factor in the study, since the self-avatar had such a limited role for the participant, however, results of this study indicate that differences in embodiment are possible even when agency, the ability to control the self-avatar, is not a factor. Perhaps the full intensity haptic feedback condition was less believable for participants, and therefore embodiment was significantly lower than in other conditions, and thus more similar to the low level of embodiment felt by the no haptic condition group.

Because embodiment was significantly greater for those who felt the half intensity haptic feedback than for those in the other haptic feedback conditions, this result may indicate that embodiment may increase with plausibility of haptic feedback, in that more logical/believable haptic feedback can increase embodiment. For example, haptic feedback that is incorrectly positioned or incorrectly timed, in this study, is shown to elicit lower feelings of embodiment than haptic feedback that occurs at a logical position, and occurs at a logical time. Therefore, embodiment may be less during an illogical interaction, such as feeling a bump long after the virtual human has passed by. As the delayed haptic feedback group experienced higher levels of embodiment than did the group that experienced the incorrect position haptic feedback group, it is possible that logical positioning of haptic feedback is more essential in increasing participant embodiment than logical timing. Additionally, the incorrect position haptic feedback group experienced higher embodiment than did the no haptic feedback group, perhaps suggesting that accuracy of position is less important than other parameters such as timing and intensity, when considering embodiment. While these results are both interesting and surprising, they may also be due to flaws in experimental design and, therefore, future studies that similarly test haptic feedback will be essential in better untangling results such as these.

5.4 Virtual Character Interaction Realism

One significant difference in virtual character realism across haptic feedback groups was found: Those in the delayed haptic feedback condition reported significantly higher virtual character realism than did the no haptic feedback group. No significant differences were found across any other haptic feedback conditions. It could be argued that, based on this result, even when haptic feedback does not align with other visual information (such as the character walking past), it can increase realism of the interaction, as compared to having no haptic feedback at all. It could perhaps also be argued here that accurate/logical timing of haptic feedback is less important than position and intensity when virtual character realism is concerned, as no other haptic feedback condition besides the delayed condition was significantly different than the no haptic feedback condition. It was expected that more logical haptic feedback conditions, such as the half and full intensity haptic feedback condition would elicit higher virtual character realism over illogical conditions such as delayed timing and incorrect position. Again, future studies may be necessary to determine why no other significant differences were seen amongst the other haptic feedback groups. Numerous participants mentioned verbally and in the comments section of the questionnaire that the haptic feedback did not seem like a person was bumping into them, as it was more like a vibration than a person *bumping* into the body. Therefore, the bHaptics vest may not be the most appropriate form of virtual human haptic feedback.

5.5 Haptic Feedback Realism

The researcher hoped to determine which of the four conditions that included haptic feedback (all but the no haptic feedback condition) was perceived as most realistic by the participant. Results indicate that participants who experienced half intensity haptic feedback perceived significantly higher levels of haptic feedback realism than those that were in the incorrect position group. Additionally, those in the full intensity haptic feedback group perceived the haptic feedback as significantly more realistic than the incorrect position haptic feedback group. Could this indicate a similarity between half and full intensity haptic feedback? The results suggest that they may be similar in realism in that they both show significantly higher realism than no haptic feedback, and in that they are not significantly different from each other. Additionally, these results may indicate that realism of haptic feedback is more influenced by position than timing, as the delayed haptic feedback condition was not significantly different than any other conditions. It can be stated that haptic feedback at a logical position may be important in increasing the realism of haptic feedback. Also, it appears that realism may not be related to intensity of haptic feedback, or, the intensities tested in this study are not significantly different enough from each other where realism of haptic feedback is concerned.

5.6 Positive and Negative Affect

It was hoped that this study could shed light on participant's emotional arousal by finding correlations between positive and negative affect from self-report data on the questionnaire with physiological arousal from the GSR data, however no significant differences were found. Two questions to determine positive affect, and two questions to determine negative affect were provided on the questionnaire. Some participants expressed confusion concerning negative affect questions, in that the two provided negative affect questions were too similar. One question asked, "How upset did you feel...?" while the other question asked "How distressed did you feel…?" both in order to determine negative affect. Some participants asked how they were to interpret distressed as different from upset, indicating that they did not understand why the same question (basically) was on the questionnaire twice. Perhaps using only one question for negative affect and one question for positive affect would have led to less confusion, and perhaps self-report answers that more closely corresponded to participant's emotional state at the time of study.

Additionally, questions such as these, that deal with emotion, might do well to be included within the environment. If these questions were administered within the headset immediately following the VR scenario, perhaps participants could more accurately report feelings. Future studies might consider using a visual analogue scale (VAS), rather than a Likert scale, as a VAS has been shown to include more sensitivity/accuracy of response. As suggested in the previous paragraph, future studies might also seek to use one-item measures, as this has been shown to accurately measure anxiety (Davey, Barratt, Butow, & Deeks, 2007). Because no significant differences were found concerning positive/negative affect, nor concerning correlations with GSR, the researcher can only make conclusions about physiological arousal, as data concerning emotional arousal was not found.

5.7 Virtual Reality Sickness

No significant differences were found across the five conditions concerning virtual reality sickness. It should be noted that a handful of participants reported higher scores on this question, indicating virtual reality sickness, and are considered outliers. No participant reported any feelings of discomfort, illness, or pain of any kind either verbally or in the comments section of the question, and therefore it is possible that the question was misinterpreted on the questionnaire. It may be important to verbally confirm physical feelings of comfort or discomfort with participants immediately following the headset removable, in order to confirm their responses.

5.8 Engagement

No significant differences were found across the five conditions concerning engagement. This was an exploratory variable, added to the questionnaire as a means to explore possible relations between engagement and haptic feedback, with the plan being that, if found, other studies could be designed in order to more effectively study the influence of haptic feedback on engagement. It is likely that no differences were found in engagement across groups for the same reasons that no differences were found in presence: it may be important for the user to be actively involved in the scene, moving, responding, and interacting fully, rather than simply standing and observing the scene.

5.9 Flow

No significant differences were found in flow state across the five groups. In addition to engagement, the question about flow was added as an exploratory variable. While the flow question comes from a validated flow state scale (Jackson & Marsh, 2016), it is also primarily used in *activities*, in that the participant is *doing something*, either a physical action that requires some level of skill and challenge. As the participant in this study had no tasks, utilizing a flow state question is perhaps nonsensical, beyond exploratory purposes. Therefore, not obtaining flow data is neither surprising nor unexpected.

5.10 Comfort with Virtual Characters

No significant differences were found concerning comfort with virtual characters. Written comments include participant feelings such as: characters were creepy, characters are not realistic, etc. It is thought that perhaps by including primarily students within the Computer Graphics Technology department at Purdue University, many of the self-report responses may have been influenced by the fact that many participants had some experience creating digital environments either in games, VR, or in modelling and animating characters. This may have made them more critical when evaluating the scene, as they may have been thinking about it from a creator's perspective, rather than from a player's perspective.

5.11 Comfort with Virtual Character Appearance

No significant differences were found concerning comfort with virtual character appearance. This question appears to have been redundant, and may have served only to increase the work load on the participant in finishing questionnaire. As mentioned above, those that are very familiar with digital characters in VR or simply in games, may have critiqued the virtual character appearance beyond the level of a normal/non-digital creator perspective.

5.12 Realism of Virtual Characters

No significant differences were found across groups concerning the realism of the virtual characters. One participant mentioned that the characters looked nothing like real people, for example. Future studies with access to appropriate technology should create similar studies in which body-scanned real humans are used on top of virtual character models, in order to achieve the most realism possible.

5.13 GSR

Numerous GSR data was analyzed in order to determine significant differences across all five conditions, and one significant difference was found in GSR peak amplitude between the no haptic feedback group and the full intensity haptic feedback group after the first interaction (bump) with the virtual character. Other GSR data that was analyzed includes the following:

- Total number of peaks during the stimulus time frame over the entire 2-minute period in which virtual characters walk by and bump the participant. No significant differences were found.
- Number of event-related peaks: GSR in response to virtual character bump over each 1-5 second time period immediately following the bump. No significant differences were found
- GSR average amplitude of total peaks. No significant differences were found.
- GSR average amplitude of event-related peaks. No significant differences were found.
- GSR amplitude of first event-related peak: GSR amplitude following the first interaction with the virtual character. *A significant difference was found between the no haptic feedback group and the full intensity haptic feedback group.*

As seen above, the full intensity haptic feedback group had a significantly higher GSR amplitude than the no haptic feedback group following the first interaction with the virtual character. These results were surprising, as it was expected that the event-related GSR count and event-related GSR amplitudes would be significantly higher for the full intensity haptic feedback group than the delayed, incorrect position and half intensity haptic feedback group. It was also expected that the delayed, incorrect position and half intensity haptic feedback group might be significantly different from the no haptic feedback group, but results indicate no significant differences.

Results indicate that haptic feedback may be able to influence participant physiological arousal, however not all haptic feedback conditions are able to influence arousal. Because only full intensity and no haptic feedback conditions were significantly different, it is possible that participants are simply more sensitive to logical/more believable haptic feedback where physiological arousal is concerned.

It appears that the predictable nature of all haptic feedback conditions may have influenced arousal, in that participants may not have been as aroused as they would have been, had they not been able to predict when the haptic feedback would occur. Multiple participants stated that the haptic feedback was predictable. One participant wrote, “After the first bump, you know what to expect.” A participant in the no haptic feedback group wondered “why didn’t I feel anything?” indicating that perhaps those in the no haptic feedback group experienced higher physiological arousal generally, because they were anticipating haptic feedback, as they were wearing a haptic vest and told that they were participating in study about haptic feedback. Another no haptic feedback participant wrote “I kept waiting for something to happen…but nothing occurred,” again suggesting a feeling of anticipation and impatience. Because impatience is a state of increased arousal, the no haptic feedback group may have generally been more aroused than they would have, had they not been anticipating anything (Naveteur et al., 2013).

It is believed that perhaps not telling participants anything about potential haptic feedback they might receive prior to the experiment might generate different results in future studies. The fact that a significant difference was found in GSR amplitude between the no haptic feedback and full intensity haptic feedback groups *only* after the first virtual character interaction supports the idea that predictability may be the cause for lesser arousal than expected for the following instances of virtual character interactions across all groups. If participants could not so easily predict haptic feedback after the first bump, and if the no haptic feedback group was not anticipating haptic feedback, perhaps GSR results would be closer to what was expected: total peak quantity and total GSR peak amplitude of the full intensity haptic feedback condition as significantly higher than the no haptic feedback group, and possibly significantly different than the other haptic feedback conditions. It is a stretch with the current results, however, the findings suggest a future ability to predict realism of haptic feedback with GSR data, but additional studies are necessary to validate and expand upon these findings.

5.14 Correlation: GSR Amplitude and Realism of Haptic Feedback

A moderate positive correlation was found between haptic feedback realism and first event-related GSR peak amplitude, so perhaps GSR peak amplitude could indicate haptic feedback realism, especially in future studies, which should take the limitations of this study into consideration.

5.15 Future Work

Improvements to this study include but are not limited to using a visual analogue scale rather than a Likert scale, facilitating the post-experiment questionnaire within the HMD, using one-item questions concerning positive and negative affect, and exploring better paradigms for conducing physiological research within an environment that is best experienced through action and user movement. It may be important for future studies to incorporate unpredictability and variety into each haptic feedback condition as well, in addition to the previously mentioned suggestions. Perhaps more pretesting with the questionnaire is important in order to confirm participant's understanding of all questions.

While the virtual scene was adequate for research, even "wowing" several participants, it lacked the finesses that can be produced by many of the participants also involved in the creation of dynamic digital content such as the research virtual reality environment, and it lacked the realism that could be needed to elicit emotion and arousal. For example, the virtual characters turned at harsh 90-degree pivot points upon every corner, and sometimes their feet did not touch the ground at all points. Animation was far from perfect, and may have influenced participant feelings of realism. Future studies by the research might work to improve animation and other essential aspects of the environment, so as to more fully suspend belief for the participants in the creation of a more realistic virtual world.

Although this study could not correlate subjective emotional response with objective physiological arousal in order to determine emotional status, future studies should strive to correlate subjective and objective measures in order to better understand how people interact with virtual characters, and how haptic feedback may influence changes in participant emotional and physiological arousal. Also, it will be important for future virtual reality studies to target better ways in which physiological data can be captured in a medium that calls for user interaction through movement, which adds noise to physiological signals such as GSR. In future research, the researcher would like to continue to pursue physiological and brain activity data, as well as find ways in which to more accurately collect self-report data, so that correlations between the two might be possible.

REFERENCES

Ahmed, I., Harjunen, V., Jacucci, G., Hoggan, E., Ravaja, N., & Spapé, M. M. (2016). Reach out and touch me: effects of four distinct haptic technologies on affective touch in virtual reality. In *Proceedings of the 18th ACM International Conference on Multimodal Interaction - ICMI 2016*. https://doi.org/10.1145/2993148.2993171

Andreasen, A., Nilsson, N. C., & Serafin, S. (n.d.). *Agency Enhances Body Ownership Illusion of Being a Virtual Bat*.

Bailey, R., Wise, K., & Bolls, P. (2009). How Avatar Customizability Affects Children's Arousal and Subjective Presence During Junk Food–Sponsored Online Video Games. *CyberPsychology & Behavior*. https://doi.org/10.1089/cpb.2008.0292

Bakker, J., Pechenizkiy, M., & Sidorova, N. (2011). What's your current stress level? Detection of stress patterns from GSR sensor data. In *Proceedings - IEEE International Conference on Data Mining, ICDM* (pp. 573–580). https://doi.org/10.1109/ICDMW.2011.178

Banakou, D., Groten, R., & Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences*. https://doi.org/10.1073/pnas.1306779110

Benko, H., Holz, C., Sinclair, M., & Ofek, E. (2016). NormalTouch and TextureTouch. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology - UIST '16*. https://doi.org/10.1145/2984511.2984526

Bianchin, M., & Angrilli, A. (2012). Gender differences in emotional responses: A psychophysiological study. *Physiology and Behavior*. https://doi.org/10.1016/j.physbeh.2011.10.031

Blanke, O., & Metzinger, T. (2009). Full-body illusions and minimal phenomenal selfhood. *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2008.10.003

Blascovich, J., Loomis, J., Beall, A. C., Swinth, K. R., Crystal, L., Inquiry, S. P., … Bailenson, J. N. (2016). Immersive Virtual Environment Technology as a Methodological Tool for Social Psychology Hoyt and Jeremy N . Bailenson Stable URL : http://www.jstor.org/stable/1449167 REFERENCES Linked references are available on JSTOR for this article : You may need to l, *13*(2), 103–124.

Bohil, C. J., Alicea, B., & Biocca, F. A. (2011). Virtual reality in neuroscience research and therapy. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn3122

Boucsein, W. *Electrodermal Activity.* Springer Science & Business Media, 2012.

Bouchard. (2008). *Sté phane Anxiety Increases the Feeling of Presence in Virtual Reality*. *Outaouais Presence* (Vol. 17).

Bouchard, S., Dumoulin, S., Robillard, G., Guitard, T., Klinger, E., Forget, H., … Roucaut, F. X. (2017). Virtual reality compared with in vivo exposure in the treatment of social anxiety disorder: A three-arm randomised controlled trial. *British Journal of Psychiatry*. https://doi.org/10.1192/bjp.bp.116.184234

Bovet, S., Debarba, H. G., Herbelin, B., Molla, E., & Boulic, R. (2018). The critical role of self-contact for embodiment in virtual reality. *IEEE Transactions on Visualization and Computer Graphics*. https://doi.org/10.1109/TVCG.2018.2794658

Braithwaite, J., Watson, D., Robert, J., & Mickey, R. (2013). A Guide for Analysing Electrodermal Activity (EDA) & Skin Conductance Responses (SCRs) for Psychological Experiments. …, 1–42. https://doi.org/10.1017.S0142716405050034

Brouwer, A.-M. (n.d.). *EEG alpha asymmetry, heart rate variability and cortisol in response to Virtual Reality induced stress SleepCare: Persuasive technology for personalized sleep coaching View project*. Retrieved from https://www.researchgate.net/publication/239522474

Brown, R., & Macefield, V. G. (2014). Skin sympathetic nerve activity in humans during exposure to emotionally-charged images: Sex differences. *Frontiers in Physiology*. https://doi.org/10.3389/fphys.2014.00111

Cavazza, M., Jacob, Y., Soreq, E., Klovatch, I., Hendler, T., Charles, F., … Jackont, G. (2014). Towards emotional regulation through neurofeedback. In *Proceedings of the 5th Augmented Human International Conference on - AH '14*. https://doi.org/10.1145/2582051.2582093

Choo, A., & May, A. (2015). Virtual mindfulness meditation: Virtual reality and electroencephalography for health gamification. In *Conference Proceedings - 2014 IEEE Games, Media, Entertainment Conference, IEEE GEM 2014*. https://doi.org/10.1109/GEM.2014.7048076

Da Costa, R. M. E. M., & De Carvalho, L. A. V. (2004). The acceptance of virtual reality devices for cognitive rehabilitation: A report of positive results with schizophrenia. *Computer Methods and Programs in Biomedicine*. https://doi.org/10.1016/S0169-2607(03)00066-X

Davey, H. M., Barratt, A. L., Butow, P. N., & Deeks, J. J. (2007). A one-item question with a Likert or Visual Analog Scale adequately measured current anxiety. *Journal of Clinical Epidemiology*. https://doi.org/10.1016/j.jclinepi.2006.07.015

de Borst, A. W., & de Gelder, B. (2015). Is it the real deal? Perception of virtual characters versus humans: An affective cognitive neuroscience perspective. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2015.00576

Dickstein, D. P., & Leibenluft, E. (2006). *Emotion regulation in children and adolescents: Boundaries between normalcy and bipolar disorder*.

Diemer, J., Alpers, G. W., Peperkorn, H. M., Shiban, Y., & Mühlberger, A. (2015). The impact of perception and presence on emotional reactions: A review of research in virtual reality. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2015.00026

Egan, D., Brennan, S., Barrett, J., Qiao, Y., Timmerer, C., & Murray, N. (n.d.). *An evaluation of Heart Rate and Electrodermal Activity as an Objective QoE Evaluation method for Immersive Virtual Reality Environments*.

Falconer, C. J., Rovira, A., King, J. A., Gilbert, P., Antley, A., Fearon, P., … Brewin, C. R. (2016). Embodying self-compassion within virtual reality and its effects on patients with depression. *British Journal of Psychiatry Open*. https://doi.org/10.1192/bjpo.bp.115.002147

Felnhofer, A., Kothgassner, O. D., Schmidt, M., Heinzle, A. K., Beutl, L., Hlavacs, H., & Kryspin-Exner, I. (2015). Is virtual reality emotionally arousing? Investigating five emotion inducing virtual park scenarios. *International Journal of Human Computer Studies*. https://doi.org/10.1016/j.ijhcs.2015.05.004

Finseth, T., Barnett, N., Shirtcliff, E. A., Dorneich, M. C., & Keren, N. (n.d.). STRESS INDUCING DEMANDS IN VIRTUAL ENVIRONMENTS. https://doi.org/10.1177/1541931218621466

Gallagher, S. (2000). Philosophical conceptions of the self: Implications for cognitive science. *Trends in Cognitive Sciences*. https://doi.org/10.1016/S1364-6613(99)01417-5

Galvanic Skin Response The Complete Pocket Guide. (2017).

Goldin, P. R., Lee, I., Ziv, M., Jazaieri, H., Heimberg, R. G., & Gross, J. J. (2014). Trajectories of change in emotion regulation and social anxiety during cognitive-behavioral therapy for social anxiety disorder. *Behaviour Research and Therapy*. https://doi.org/10.1016/j.brat.2014.02.005

Gromala, D., Tong, X., Choo, A., Karamnejad, M., & Shaw, C. D. (n.d.). The Virtual Meditative Walk: Virtual Reality Therapy for Chronic Pain Management. https://doi.org/10.1145/2702123.2702344

Gross, J. J. (2015). Emotion Regulation: Current Status and Future Prospects. *Psychological Inquiry*. https://doi.org/10.1080/1047840X.2014.940781

Haans, A., & IJsselsteijn, W. (2006). Mediated social touch: A review of current research and future directions. *Virtual Reality*. https://doi.org/10.1007/s10055-005-0014-2

Hägni, K., Eng, K., Hepp-Reymond, M. C., Holper, L., Keisker, B., Siekierka, E., & Kiper, D. C. (2008). Observing virtual arms that you imagine are yours increases the galvanic skin response to an unexpected threat. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0003082

Hay, A. C., Sheppes, G., Gross, J. J., & Gruber, J. (2015). Choosing how to feel: emotion regulation choice in bipolar disorder. *Emotion (Washington, D.C.)*. https://doi.org/10.1037/emo0000024

Herbelin, B., Riquier, F., Vexo, F., & Thalmann, D. (n.d.). *Virtual Reality in Cognitive Behavioral Therapy : a Study on Social Anxiety Disorder*.

Hoffman, H. G. (n.d.). Physically touching virtual objects using tactile augmentation enhances the realism of virtual environments. In *Proceedings. IEEE 1998 Virtual Reality Annual International Symposium (Cat. No.98CB36180)*. https://doi.org/10.1109/VRAIS.1998.658423

Jackson, S. A., & Marsh, H. W. (2016). Development and Validation of a Scale to Measure Optimal Experience: The Flow State Scale. *Journal of Sport and Exercise Psychology*. https://doi.org/10.1123/jsep.18.1.17

Kilteni, K., Bergstrom, I., & Slater, M. (2013). Drumming in immersive virtual reality: the body shapes the way\nwe play. *IEEE Trans. Vis. Comput. Graph.*, *19*(4), 597–605. Retrieved from http://dx.doi.org/10.1109/TVCG.2013.29

Kilteni, K., Groten, R., & Slater, M. (n.d.). *The Sense of Embodiment in Virtual Reality*.

Klinger, E., Bouchard, S., Légeron, P., Roy, S. D., Lauer, F., Chemin, I., & Nugues, P. (2005). *Virtual Reality Therapy Versus Cognitive Behavior Therapy for Social Phobia: A Preliminary Controlled Study*. *CYBERPSYCHOLOGY & BEHAVIOR* (Vol. 8).

Kotlyar, M., Donahue, C., Thuras, P., Kushner, M. G., O'Gorman, N., Smith, E. A., & Adson, D. E. (2008). Physiological response to a speech stressor presented in a virtual reality environment. *Psychophysiology*. https://doi.org/10.1111/j.1469-8986.2008.00690.x

Koumaditis, K., Chinello, F., & Venckute, S. (n.d.). *Design of a Virtual Reality and Haptic Setup Linking Arousals to Training Scenarios: a Preliminary Stage*. Retrieved from https://humansystems.arc.nasa.gov/

Lee, M., Kim, K., Daher, S., Raij, A., Schubert, R., Bailenson, J., & Welch, G. (2016). The Wobbly Table: Increased Social Presence via Subtle Incidental Movement of a Real-Virtual Table. In *Proceedings - IEEE Virtual Reality*. https://doi.org/10.1109/VR.2016.7504683

Lind, S., Thomsen, L., Egeberg, M., Nilsson, N., Nordahl, R., & Serafin, S. (2016). Effects of vibrotactile stimulation during virtual sandboarding. In *Proceedings - IEEE Virtual Reality*. https://doi.org/10.1109/VR.2016.7504732

Mancini, F., Longo, M. R., Kammers, M. P. M., & Haggard, P. (2011). Visual distortion of body size modulates pain perception. *Psychological Science*. https://doi.org/10.1177/0956797611398496

Martini, M., Kilteni, K., Maselli, A., & Sanchez-Vives, M. V. (2015). The body fades away: Investigating the effects of transparency of an embodied virtual body on pain threshold and body ownership. *Scientific Reports*. https://doi.org/10.1038/srep13948

McRae, K., Rekshan, W., Williams, L. M., Cooper, N., & Gross, J. J. (2014). Effects of antidepressant medication on emotion regulation in depressed patients: An iSPOT-D report. *Journal of Affective Disorders*. https://doi.org/10.1016/j.jad.2013.12.037

Nam, C. S., Richard, P., Yamaguchi, T., & Bahn, S. (2014). Does Touch Matter?: The Effects of Haptic Visualization on Human Performance, Behavior and Perception. *International Journal of Human-Computer Interaction*. https://doi.org/10.1080/10447318.2014.941270

Naveteur, J., Coeugnet, S., Charron, C., Dorn, L., Anceaux, F. Impatience and Time Pressure: Subjective Reactions of Drivers in Situations Forcing Them To Stop Their Car in the Road. *Transportation Research Part F: Traffic Psychology and Behaviour,* 18:58-71, 2013.

Olmos-Raya, E., Ferreira-Cavalcanti, J., Contero, M., Castellanos, M. C., Giglioli, I. A. C., & Alcañiz, M. (2018). Mobile virtual reality as an educational platform: A pilot study on the impact of immersion and positive emotion induction in the learning process. *Eurasia Journal of Mathematics, Science and Technology Education*. https://doi.org/10.29333/ejmste/85874

Onsch, A. B. ¨, Radke, S., Overath, H., Asché, L. M., Asché, A., Wendt, J., … Kuhlen, T. W. (n.d.). *Social VR: How Personal Space is Affected by Virtual Agents' Emotions*.

Owens, M. E., & Beidel, D. C. (2015). Can Virtual Reality Effectively Elicit Distress Associated with Social Anxiety Disorder? *Journal of Psychopathology and Behavioral Assessment*. https://doi.org/10.1007/s10862-014-9454-x

Parsons, T. D., & Rizzo, A. A. (2008). Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry*. https://doi.org/10.1016/j.jbtep.2007.07.007

Purvis, C. K. (2016). *Virtual Reality and Body Image: An Exploration of Behavioral and Self-report Correlates of Body Satisfaction in Immersive Virtual Environments*. *ProQuest Dissertations and Theses*. Retrieved from http://elib.tcd.ie/login?url=https://search.proquest.com/docview/1937583235?accountid=14404%0Ahttp://linksource.ebsco.com/linking.aspx?sid=ProQuest+Dissertations+%26+Theses+A%26I&fmt=dissertation&genre=dissertations+%26+theses&issn=&volume=&issue=&date=20

Riva, G., Wiederhold, B. K., & Mantovani, F. (2018). Neuroscience of Virtual Reality: From Virtual Exposure to Embodied Medicine. *Cyberpsychology, Behavior, and Social Networking*. https://doi.org/10.1089/cyber.2017.29099.gri

Robles-De-La-Torre, G. (2006). The Importance of the sense of touch in virtual and real environments. *IEEE Multimedia*. https://doi.org/10.1109/MMUL.2006.69

Rodriguez, A., Rey, B., Vara, M. D., Wrzesien, M., Alcaniz, M., Banos, R. M., & Perez-Lopez, D. (2015). A VR-based serious game for studying emotional regulation in adolescents. *IEEE Computer Graphics and Applications*. https://doi.org/10.1109/MCG.2015.8

Romano, D., Llobera, J., & Blanke, O. (2016). Size and viewpoint of an embodied virtual body affect the processing of painful stimuli. *Journal of Pain*. https://doi.org/10.1016/j.jpain.2015.11.005

Rus-Calafell, M., Garety, P., Sason, E., Craig, T. J. K., & Valmaggia, L. R. (2017). Virtual reality in the assessment and treatment of psychosis: a systematic review of its utility, acceptability and effectiveness. *Psychological Medicine*. https://doi.org/10.1017/S0033291717001945

Ryge, A., Thomsen, L., Berthelsen, T., Hvass, J. S., Koreska, L., Vollmers, C., … Serafin, S. (2017). Effect on high versus low fidelity haptic feedback in a virtual reality baseball simulation. In *Proceedings - IEEE Virtual Reality*. https://doi.org/10.1109/VR.2017.7892328

Salamon, N., Grimm, J. M., Horack, J. M., & Newton, E. K. (2018). Application of virtual reality for crew mental health in extended-duration space missions. *Acta Astronautica*. https://doi.org/10.1016/j.actaastro.2018.02.034

Sanchez-Vives, M. V., & Slater, M. (2005). Opinion: From presence to consciousness through virtual reality. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn1651

Singer, M. J., & Witmer, B. G. (1999). On selecting the right yardstick. *Presence: Teleoperators and Virtual Environments*. https://doi.org/10.1162/105474699566486

Slater, M., Pertaub, D.-P., Barker, C., & Clark, D. M. (2006). An Experimental Study on Fear of Public Speaking Using a Virtual Environment. *CyberPsychology & Behavior*. https://doi.org/10.1089/cpb.2006.9.627

M. Slater, D. P´erez Marcos, H. Ehrsson, and M. V. Sanchez-Vives. Towards a digital body: the virtual arm illusion. Frontiers in human neuroscience, 2:6, 2008.

Steed, A., Frlston, S., Lopez, M. M., Drummond, J., Pan, Y., & Swapp, D. (2016). An “In the Wild” Experiment on Presence and Embodiment using Consumer Virtual Reality Equipment. *IEEE Transactions on Visualization and Computer Graphics*. https://doi.org/10.1109/TVCG.2016.2518135

Takahashi, K., Mitsuhashi, H., Murata, K., Norieda, S., & Watanabe, K. (2011). Improving shared experiences by haptic telecommunication. In *Proceedings - 2011 International Conference on Biometrics and Kansei Engineering, ICBAKE 2011*. https://doi.org/10.1109/ICBAKE.2011.19

Tremblay, L., Roy-Vaillancourt, M., Chebbi, B., Bouchard, S., Daoust, M., Dénommée, J., & Thorpe, M. (2016). Body Image and Anti-Fat Attitudes: An Experimental Study Using a Haptic Virtual Reality Environment to Replicate Human Touch. *Cyberpsychology, Behavior, and Social Networking*, *19*(2), 100–106. https://doi.org/10.1089/cyber.2015.0226

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance*. https://doi.org/10.1037/0096-1523.31.1.80

Volante, M., Babu, S. V., Chaturvedi, H., Newsome, N., Ebrahimi, E., Roy, T., … Fasolino, T. (2016). Effects of Virtual Human Appearance Fidelity on Emotion Contagion in Affective Inter-Personal Simulations. *IEEE Transactions on Visualization and Computer Graphics*. https://doi.org/10.1109/TVCG.2016.2518158

Waltemate, T., Gall, D., Roth, D., Botsch, M., & Latoschik, M. E. (2018). The impact of avatar personalization and immersion on virtual body ownership, presence, and emotional response. *IEEE Transactions on Visualization and Computer Graphics*. https://doi.org/10.1109/TVCG.2018.2794629

Wang, R., Yao, J., Wang, L., Liu, X., Wang, H., & Zheng, L. (2017). *A Surgical Training System for Four Medical Punctures Based on Virtual Reality and Haptic Feedback*.

Watson, D., Clark, L. A., & Tellegen, A. (1988). *Development and Validation of Brief Measures of Positive and Negative Affect: The PANAS Scales*. *Journal of Personality and Social Psychology* (Vol. 54).

Wilhelm, F. H., Pfaltz, M. C., Gross, J. J., Mauss, I. B., Kim, S. I., & Wiederhold, B. K. (2005). Mechanisms of virtual reality exposure therapy: The role of the behavioral activation and behavioral inhibition systems. *Applied Psychophysiology Biofeedback*. https://doi.org/10.1007/s10484-005-6383-1

Wu, C. M., Hsu, C. W., Lee, T. K., & Smith, S. (2017). A virtual reality keyboard with realistic haptic feedback in a fully immersive virtual environment. *Virtual Reality*. https://doi.org/10.1007/s10055-016-0296-6

Zibrek, K., Kokkinara, E., & McDonnell, R. (2018). The effect of realistic appearance of virtual characters in immersive environments - Does the character’s personality play a role? *IEEE Transactions on Visualization and Computer Graphics*. https://doi.org/10.1109/TVCG.2018.2794638

PUBLICATIONS

Human, Virtual Human, Bump! A Preliminary Study on Haptic Feedback

Claudia Krogmeier* Purdue University
Christos Mousas† Purdue University
David Whittinghill‡ Purdue University

Figure 1: The virtual crosswalk environment (left) and the participant equipped with GSR sensor, haptic vest, and VR headset (right).

ABSTRACT

How does haptic feedback during a human-virtual human interaction affect emotional arousal in virtual reality? In this between-subjects study, we compare haptic feedback and no haptic feedback conditions in which a virtual human "bumps" into the participant in order to determine the influence of haptic feedback on emotional arousal, sense of presence, and embodiment in virtual reality, as well as compare self-report measures of emotional arousal to those objectively collected via event-related galvanic skin response (GSR) recordings. We plan to extend the current preliminary study by adding three more conditions as described in the future work section. Participants are students age 18-32 with at least moderate experience in virtual reality. Preliminary results indicate significant differences in presence and embodiment between haptic feedback and no haptic feedback groups. With our small sample size at the current time, GSR does not show significant differences between haptic and no haptic feedback conditions.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality

1 INTRODUCTION

Virtual reality has high potential for psychosocial research [4]. Therefore, a better understanding of the influences and potentially required realism of haptics on emotional arousal and presence may aid in the creation of more believable human-virtual human interactions in virtual reality. Haptic feedback is present in many virtual reality games and experiences, but specific factors such as timing, intensity, and position accuracy remain underexplored. Furthermore, emotional arousal, which may or may not be associated with presence, appears lesser explored.

Previous studies have shown that haptic feedback in virtual reality can increase sense of presence. In the wobbly table study [2], participants who experienced slight movements of a physical table during their interaction with a virtual human experienced significantly higher self-report levels of presence than did those who felt no physical movements of the table. Additionally, Ryge et al. [3] found that higher fidelity haptic feedback felt from baseballs in virtual reality increased the perceived realism of the baseball. But how might haptic feedback influence emotional arousal, and how does more realistic haptic feedback compare to illogical or inaccurate haptic feedback? This study seeks to link emotional arousal recorded objectively via galvanic skin response (GSR) with subjective self-report emotional arousal, presence, and embodiment.

*e-mail: ckrogmei@purdue.edu
†e-mail: cmousas@purdue.edu
‡e-mail: dmwhittinghill@purdue.edu

2 METHODOLOGY

Upon arriving, participants are briefly introduced to the project, and the purpose of the equipment as well as the experimental procedure are explained. While the participant completes a pre-questionnaire (concerning sex, age, and prior VR experience), the experimenter adjusts the self-avatar to most closely match the participant's skin tone, as we wanted to provide participants with a higher body ownership experience [8]. Then, the participant is fitted with the bHaptics "Tactsuit," a haptic gaming vest which allows precise control of haptic feedback, and is controlled with a Unity3D plugin. Next, a Shimmer GSR sensor is attached to the participant's non-dominant hand, with the two electrode sensors fit securely on the index and middle finger. The participant with all necessary equipment can be seen in Figure 1.

The participant is instructed to relax, try not to talk or move, and breathe normally, as these are the recommended instructions for minimizing muscular artifacts [1] [7]. The sensors are connected to iMotions biometrics recording and analysis software via Bluetooth. Within iMotions, the screen output of the virtual reality scene is captured and observable by the experimenter throughout the study (see Figure 2). The experimenter uses a timer to verify that the 2-minute baseline recordings have been obtained, and then starts the VR scenario.

2.1 Event-Related GSR

Once the participant confirms that he or she feels comfortable and is ready to begin, he or she is instructed to relax for 2 minutes, while baseline GSR is recorded. After this 2-minute period, the experimenter starts the virtual reality scenario that consists of 2 phases: exploratory, and experimental. In the exploratory phase,

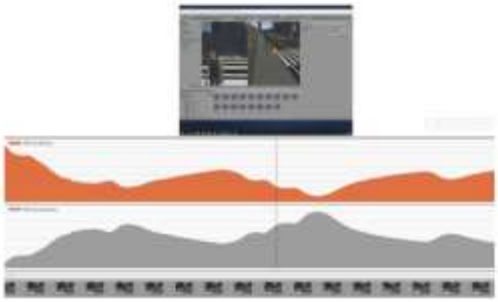

Figure 2: iMotions screen capture during experiment. The virtual environment in Unity3D (top) and the GSR data (bottom).

the participant is made aware of his or her self-avatar and virtual environment. In the experimental phase, the participant experiences one of the developed conditions.

2.2 VR Environment and Haptic Stimuli

For our experiment, all participants experience the same virtual environment during both phases: a busy crosswalk. The virtual environment was created in Autodesk 3ds Max and imported into the Unity3D game engine. Virtual humans were created in Adobe Fuse and animated with Mixamo. During the virtual scenario, virtual humans walk by on sidewalks, cross from behind the participant and walk towards the participant as they cross the street. Before haptic stimuli conditions commence, participants receive text instructions within the virtual environment that instruct them to "Feel free to look left, right and down at your body." In this 30-second exploratory phase, the participant sees his or her self-avatar, as well as sees virtual humans walking on sidewalks and crossing the street. Next, participants again receive text instructions to "Please face forward and remain still," in order to minimize movement artifacts in GSR signal.

During the next 2-minute period, participants are collided with, or "bumped into" by virtual humans. These collisions occur six times total for each participant, at 20-second intervals, as other virtual humans continue to pass by. Participants receive one of two conditions: haptic feedback or no haptic feedback. After the 2-minute experimental phase of the study, the virtual scene terminates. Participants then answer a post-experiment questionnaire to determine levels of presence, embodiment, and self-report emotional arousal. Our questionnaire is based on standard presence questions from the Slater-Usoh-Steed (SUS) questionnaire [6] and on standard questions concerning body-ownership illusion [5]. A comments section is provided at the end of the questionnaire for participants to express any additional thoughts.

3 Results

The current preliminary study examined two conditions: haptic versus no haptic feedback, with a sample size of eight thus far: four in the haptic feedback condition, and four in the control. A preliminary analysis of the presence and embodiment scores for these two groups looks promising, with a statistically significant difference seen between those who receive haptic feedback and those who receive no haptic feedback. For the results presented in this section, we have used a paired samples T-test. There was a significant difference in the embodiment scores for haptic feedback (M= 4.03, $SD = 0.61$) and no haptic feedback ($M = 1.94$, $SD = 0.52$) conditions; $t(3) = 35.34$, $p = 0.005$. Scores for presence also suggest a statistically significant difference for haptic feedback ($M = 5.31$, $SD = 0.85$) and no haptic feedback ($M = 3.31$, $SD = 0.52$) conditions; $t(3) = 8.0$, $p = 0.004$.

To analyze emotional arousal from event-related GSR, we looked at the 1-5 second time window immediately following the onset of the stimulus [1], in this case, the onset of virtual human collision, which occurs 6 times at 20-second intervals, starting at 161 seconds into the recording for every participant. For example, for the 161-second stimulus onset time, the time window 162-167 seconds was analyzed for the existence of GSR. While our current analytic approach involves simply "more" or "less" emotional arousal between participants in different conditions based on quantity of peaks, it may be interesting to consider GSR latency to onset of peak (the time is takes to reach the peak response), especially as the data from the more nuanced haptic feedback conditions (described in Section 4) is collected. Our results for event-related GSR indicate non-significance in this early stage of the study between haptic feedback ($M = 3.75$, $SD = 1.85$) and no haptic feedback ($M = 3.12$, $SD = 1.89$) conditions; $t(3) = 0.404$, $p = 0.713$. As we continue the study, an appropriate N may show significant differences in GSR between haptic feedback and no haptic feedback groups.

4 Conclusion and Next Steps

An overview of our experiment for investigating emotional arousal, presence and embodiment in haptic feedback and no haptic feedback conditions during human-virtual human interactions in virtual reality is presented. In this work, the methodology, technical set-up, as well as descriptions of the experimental procedure and specific virtual reality scene are presented.

As data collection continues, we plan to add the following conditions to the experiment: haptic feedback with inaccurate position (feeling the bump on the wrong side of the body: felt on the left side of the body, as the virtual human collides with the right side of the participant's body), haptic feedback with inaccurate intensity (50% increase from accurate haptic feedback), and haptic feedback with inaccurate timing (1 second delay between haptic feedback and human-virtual human collision). Preliminary data suggests a more engaging experience in virtual reality with the addition of haptic feedback, and paves the way for the continuation of our data collection and analysis concerning all five haptic feedback conditions.

References

[1] Imotions: Biometric Research Platform. Galvanic skin response: The complete pocket guide, 2017.

[2] M. Lee, K. Kim, S. Daher, A. Raij, R. Schubert, J. Bailenson, and G. Welch. The wobbly table: Increased social presence via subtle incidental movement of a real-virtual table. In *Virtual Reality (VR), 2016 IEEE*, pp. 11–17. IEEE, 2016.

[3] A. Ryge, L. Thomsen, T. Berthelsen, J. S. Hvass, L. Koreska, C. Vollmers, N. C. Nilsson, R. Nordahl, and S. Serafin. Effect on high versus low fidelity haptic feedback in a virtual reality baseball simulation. In *Virtual Reality (VR), 2017 IEEE*, pp. 365–366. IEEE, 2017.

[4] N. Salamon, J. M. Grimm, J. M. Horack, and E. K. Newton. Application of virtual reality for crew mental health in extended-duration space missions. *Acta Astronautica*, 2018.

[5] M. Slater, D. Pérez Marcos, H. Ehrsson, and M. V. Sanchez-Vives. Towards a digital body: the virtual arm illusion. *Frontiers in human neuroscience*, 2:6, 2008.

[6] M. Slater, M. Usoh, and A. Steed. Depth of presence in virtual environments. *Presence: Teleoperators & Virtual Environments*, 3(2):130–144, 1994.

[7] G. Turpin and T. Grandfield. Electrodermal activity. *Encyclopedia of Stress*, 2007.

[8] T. Waltemate, D. Gall, D. Roth, M. Botsch, and M. E. Latoschik. The impact of avatar personalization and immersion on virtual body ownership, presence, and emotional response. *IEEE transactions on visualization and computer graphics*, 24(4):1643–1652, 2018.

Human-Virtual Character Interaction: Towards Understanding the Influence of Haptic Feedback

Claudia Krogmeier
Purdue University
ckrogmei@purdue.edu

Christos Mousas
Purdue University
cmousas@purdue.edu

David Whittinghill
Purdue University
dmwhittinghill@purdue.edu

Abstract

In this study, we compare haptic feedback and non-haptic feedback conditions in which virtual characters bump into the participant who is immersed in a virtual environment. A questionnaire was developed to determine the influence of haptic feedback on a number of concepts (presence, embodiment, positive and negative affect, interaction realism with virtual character, and haptic feedback realism). Physiological data was also collected using galvanic skin response (GSR) to investigate the influence of haptic feedback on physiological arousal during human-virtual character interaction. Five conditions were developed (no haptic feedback, full and half intensity, incorrect position, and delayed timing) to determine which aspects of haptic feedback are most important in influencing participant responses. Significant differences were found in embodiment, realism of virtual character interaction, and haptic feedback realism. In addition, significant differences were found in GSR amplitude after the first interaction with the virtual character. Implications for further research are discussed.

Keywords: haptic feedback, haptic vest, virtual characters, virtual bump, virtual reality, galvanic skin response

1 Introduction

In order to provide highly immersive experiences for virtual reality users, a number of interfaces and devices were developed over the past year. Among them were those designed to provide haptic feedback in order to recreate the sense of touch by applying forces, vibrations, or motions to the user [1]. Haptic feedback is present in many virtual reality experiences and games, but specific factors such as timing, intensity, and position accuracy remain underexplored. In addition, the literature is not yet conclusive regarding human perception of haptic feedback, especially in virtual reality scenarios in which humans closely interact with virtual characters [2]. Considering that virtual reality has great potential for inclusion in human behavior research [3], a better understanding of the influences and potential realism of haptics on a variety of cognitive and social interaction concepts may aid in the creation of more believable human-virtual character interactions in virtual reality.

This study aims to understand human-virtual character interaction through haptic feedback by considering presence, embodiment, positive and negative affect, interaction realism, and haptic feedback realism. To this end, subjective data was collected by asking participants to self-report their sensations in relation to the above-mentioned concepts, and objective data was collected by using a galvanic skin response (GSR) sensor.

This experiment was considered based on the assumption that feeling the bump with a haptic vest would elicit greater arousal than would simply watching the virtual character walk by, without the sensation of interaction with the virtual character due to haptic feedback. This study may cultivate a better understanding of human perception and physiological arousal as influenced by variations in haptic feedback by answering the following research questions:

- **RQ1:** Are there perceptual and physiological differences across the five experimental conditions?
- **RQ2:** How does more realistic haptic feedback compare to illogical or inaccurate haptic feedback?
- **RQ3:** Can we use GSR to predict self-report responses?

2 Related Work

Considering that virtual characters transfer information to humans on both a cognitive-analytic and emotional processing level [4], it can be said that humans are able to understand an interaction with a virtual character and that the virtual characters may even evoke a sense of social presence [5], especially when represented in an anthropomorphic way [4]. However, when examining human emotion and behavior during human-virtual character interaction scenarios, we relied mainly on visual and auditory information without considering other senses that might influence the interaction process. For this reason, we decided to examine how haptic feedback may affect the perception and arousal of participants when they closely interact with a virtual character.

Multiple studies have explored how humans perceive haptic feedback. In general, the literature includes a variety of studies regarding the design, development, and testing of haptic feedback devices that target improvement of haptic stimulus [6]. Some of these platforms [7] and haptic surfaces [8] are quite useful for virtual reality interaction.

Various studies were conducted demonstrating that haptic feedback improves the performance of participants within virtual environments [9, 10] and that participants perceive the virtual environment as more realistic because they are able to touch and feel [11]. Lee et al. [9] found that providing additional stimuli (aural or haptic) associated with the virtual environment had the result of improving realism because more of the user's senses were engaged. Another study investigated the benefits of multimodal interaction (including haptic feedback), demonstrating that it can be used to enhance the learning performance levels of participants compared to unimodal environments [12].

Most studies exploring haptic vest usage have either focused on the development process of the equipment or the development of applications relating to the use of haptic feedback for the navigation and guidance of users in unknown environments using vibrotactile stimulation or thermal actuators [13]. Haptic vests have been used in a number of different training scenarios, including tactical training [14], medicine [15], rehabilitation [16], and serious games used in learning environments [17].

It is believed that the appropriate haptic pattern of a vibration produced by a haptic vest may be an important factor in improving the level of realism provided for the user [18]. In addition, it has been found that the pattern of the haptic feedback can be quite useful for transmitting information [19]. However, it appears that researchers have focused less on how various parameters (duration, intensity, position, etc.) of haptic feedback may influence the emotion and behavior of participants when they are immersed in a virtual environment. Unlike a previous study that concern haptic feedback patterns [19], the objective of this study is to generate conditions of varying haptic feedback parameters in order to understand how participants' arousal and perception is altered within a virtual reality environment.

In the current study, we considered different concepts, including presence and embodiment, as well as self-report negative and positive affect. Previous studies have shown that haptic feedback in virtual reality can increase sense of presence [20] and embodiment [21] as well as influence positive and negative affect [22]. To the best of our knowledge, no recent study has explored: 1) the use of a haptic vest, 2) variations of the haptic feedback stimuli, or 3) the alteration of these two concepts during human-virtual character interaction. The investigation of these three issues is our main contribution.

3 Experiment Overview

This section describes the basic methodology and implementation of the study.

3.1 Participants

For this experiment, 60 volunteers participated, including undergraduate and graduate students at a Midwest U.S. university. Of the sample, 15 participants were female (age $M = 22.54$, $SD = 3.64$) and 45 were male (age $M = 21.78$, $SD = 2.97$). Because the experiment was conducted within the Computer Graphics Technology department, 93% of subjects had experienced virtual reality prior to the study. Approval for this study was granted by the Institutional Review Board of Purdue University. All participants gave written consent before the beginning of the study. Note that this study had a between-group design, with twelve participants in each group.

3.2 Hardware Setup and the Virtual Environment

An experimental application was developed for the purpose of this study using the Unity3D game engine version 2018.2.12. The Oculus Rift head-mounted display (HMD) was used to immerse participants in the virtual environment, and the bHaptics gaming vest with its associated Software Development Kit (SDK) was used to deliver the necessary haptic feedback to participants. Lastly, a Shimmer GSR sensor was used to capture arousal state.

In the virtual environment, the participant stood at a busy crosswalk. Virtual characters were pre-scripted to walk by on sidewalks across the street, to walk towards the participant at the crosswalk, and to cross the street behind the participant. Figure 1 shows the virtual environment used for the purpose of this experiment. The scene was lit with afternoon sunlight and audio was added to increase the feeling of being outdoors in a busy city. Sound relating to the virtual content was expected to enhance the participant's presence in the virtual reality scenario [23]. A few cars drove past as pedestrians walked by, crossing the street. The virtual environment was created in Autodesk 3ds Max and imported into the Unity3D game engine. The virtual characters in the scene were designed in Adobe Fuse and animation was provided by Adobe Mixamo. In order to ensure that the participant had at least a minimum form of self-representation in virtual reality, we included a self-avatar body. We decided to assign gender to the self-avatar, based on which gender was selected by the participant on the demographic section of the questionnaire. We wanted to provide an embodied experience and make the participants feel that the body that represented them was their own. Thus, we decided to assign a self-avatar that most closely represented the participant's skin tone as well. To do this, we designed three male and three female avatars with variations in skin color (light, medium, and dark).

3.3 Experimental Conditions

Five experimental conditions were developed for the purpose of the experiment. The same visual information was received by all groups, as all participants experienced the same virtual environment.

- **No haptic feedback (NH):** In this condition, the participant did not feel any haptic feedback during the entire experiment.
- **Full intensity haptic feedback (FIH):** The haptic feedback in this condition was set to 100% intensity, with no other adjustments.
- **Half (50%) intensity haptic feedback (HIH):** The haptic feedback in this condition was adjusted to 50% intensity.
- **Delayed haptic feedback (DH):** The haptic feedback in this condition was delayed by one second; therefore, the participant felt the bump one second after seeing the virtual character bump into them. This haptic feedback was set to full intensity.

Figure 1: The virtual reality scenario developed for this study.

- **Incorrect position haptic feedback (IPH):** The haptic feedback in this condition was felt on the opposite side of the body. For example, if the virtual character approached and bumped into the participant on the right side, the haptic feedback would be felt on the left side of the body, and vice versa. This haptic feedback was set to full intensity.

3.4 Experimental Procedure

Once participants arrived at the lab, they were asked to complete a demographics questionnaire concerning age, sex, and prior virtual reality experience. Next, they were fitted with the haptic vest. The Shimmer sensor, which sits on a wrist strap, was then placed on the wrist of the participant's non-dominant hand, with the two electrodes placed on the index and middle finger of each participant. A participant wearing all the equipment and observing the virtual reality scenario is shown in Figure 2.

Before fitting the HMD to the participant, the experimenter relayed instructions for the participant to follow as closely as possible. Participants were told that they would first experience a baseline GSR period, which would last for two minutes. They were also told that, after two minutes, the virtual reality scene would start. Participants were informed that they would receive two sets of text instructions within the headset: the first telling them to feel free to explore to their left and right and look down at their body. After 30 seconds, a second set of text instruction would be provided, which instructed the participant to face forward and remain still. They were informed that this was when it was important to relax, remain still, try not to talk or move too much, and breathe normally. They were also informed that there would be no user interaction, so there would be nothing for them to do except relax and experience the scene.

Next, the experimenter started the GSR data capture and the timer. At the two-minute mark, the virtual reality scene was started. As explained by the experimenter, the participant saw instructions to explore. Participants looked on either side of themselves and down at their virtual body. When they saw the second set of instructions, participants relaxed in a stationary position, facing forward.

During the final two-minute time period (the stimulus window in which haptic feedback was present), the participant saw numerous virtual characters walking past him or her. At evenly spaced 15-20 second intervals, a virtual character walked too close and bumped into the participant, for a total of six bumps (instances of stimuli) per participant. The participant received one of five haptic feedback conditions (see the Section 3.3). All six bumps adhered to their condition, in that one participant would, for example, feel all the bumps with delayed haptic feedback, or feel no haptic feedback at all. Note that all participants wore the haptic vest, but no participant knew which haptic feedback condition he or she would receive in the virtual environment.

After the two-minute haptic feedback stimulus window ended, the experimenter stopped the GSR recording in iMotions and stopped the Unity3D application. The participant was instructed to remove the headset. Then, the experimenter helped remove the GSR wristband and the haptic vest. Finally, the participant completed the questionnaire, with the opportunity

Figure 2: The virtual environment that was used for the purpose of this study (left), participant wearing HMD, haptic vest, and GSR sensor (right).

to add any comments or feedback at the end of the questionnaire. Each participant spent four minutes and thirty seconds in the virtual reality environment. The total time that each participant spent during the experiment was roughly 20 minutes.

3.5 Measurements

In order to determine changes in participant perception and physiological arousal in our virtual environment, we used both subjective and objective measurements: questionnaire and GSR recordings respectively. Both are discussed in more detail below.

3.5.1 Subjective Measurements

Our questionnaire included a total of fourteen questions intended to explore the following concepts: presence, embodiment, positive and negative affect, realism of virtual character interaction, and realism of haptic feedback. Four presence questions were based on the Slater-Usoh-Steed (SUS) questionnaire [24], and four embodiment questions were based on body ownership illusion questions [25]. Four questions were based on the PANAS (positive and negative affect schedule) [26] in order to determine the subjective positive affect (2 questions) and negative affect (2 questions) experienced during the virtual scenario. The questions about the realism of character interaction and the realism of the haptic feedback were developed by the authors of this paper. The questionnaire was paper-based and administered immediately following removal of the HMD. The questionnaire used in this study is provided as supplementary material.

3.5.2 Objective Measurements

We used GSR as a means to determine alterations in arousal across the five experimental conditions. While GSR cannot determine the valence of emotion, it can determine increases in physiological arousal [27], here defined as a "necessary condition for the elicitation of an emotional state" [26]. To determine GSR count, we measured the number of GSR peaks within the appropriate one to five second post-stimulus time frame to determine event-related GSR, as this is the best way in which to determine direct measurements of arousal [27]. In our case, the stimulus was the virtual character bump. We also computed the average GSR amplitude of all peaks during virtual character interaction in order to determine intensity of physiological arousal. Additionally, we explored intensity of arousal upon the first virtual character interaction across all groups, as multiple participants expressed that the virtual scenario was predictable after experiencing the first virtual character interaction.

4 Results

To analyze our data, we used a one-way analysis of variance (ANOVA), using the five developed conditions as our independent variables, and the self-report results and the GSR measurements as dependent variables. The analyses of the subjective and objective data were performed individually. Before analyzing the data, the normality assumption was evaluated graphically using Q-Q plots of the residuals. We found that the collected data fulfilled the normality assumption. The post hoc comparisons were performed using Bonferroni corrected estimates. The self-report data and GSR results for each examined concept of this experiment are presented in Figure 3 and Figure 4 respectively. Descriptive statistics are provided as supplementary material.

4.1 Self-Reported Results

We compared the effect of haptic feedback on participants across the five experimental conditions (no haptic feedback, full and half intensity haptic feedback, delayed haptic feedback, and incorrect position haptic feedback). No significant effects were found at the $p < .05$ level regarding presence $[F(4,55) = .304, p = .874]$, positive affect $[F(4,55) = .806, p = .527]$, or negative affect $[F(4,55) = .695, p = .599]$.

After analyzing the data concerning embodiment, we found a significant effect of haptic feedback across the five conditions $[F(4,55) = 5.353, p = .001]$. Post hoc comparisons indicated that the mean score for the no haptic feedback condition ($M = 1.81, SD = .87$) was significantly lower than that for the incorrect position haptic feedback condition ($M = 3.33, SD = 1.59$) at the $p < .05$ level, delayed haptic feedback condition ($M = 3.63, SD = 1.09$) at the $p < .01$ level, and half intensity feedback condition ($M = 3.81, SD = 1.31$) at the $p < .01$ level. However, no significant differences were found between the full intensity haptic feedback condition ($M = 2.65, SD = 1.16$) and any other haptic feedback conditions.

The results concerning the realism of the interaction with the virtual character also indicated a significant effect of haptic feedback across the five experimental conditions $[F(4,55) = 3.779, p = .009]$. Post hoc comparisons show that the mean score for the no haptic feedback condition ($M = 2.5, SD = 1.45$) was significantly lower than that for the delayed haptic feedback condition ($M = 4.25, SD = 1.06$) at the $p < .05$ level. There were no other significant differences found between any of the conditions.

Finally, we were also able to identify significant differences in the realism of the haptic feedback across the four experimental conditions $[F(3,44) = 4.708, p = .006]$. Note that the no haptic feedback condition was omitted from this consideration. Post hoc comparisons indicated that the mean score for the half intensity haptic feedback condition ($M = 4.50, SD = 1.31$) was significantly higher than that for the incorrect position haptic feedback condition ($M = 2.67, SD = 1.16$) at the $p < .05$ level. Moreover, post hoc comparisons indicated that the realism of the full intensity haptic feedback condition ($M = 4.08, SD = 1.56$) was significantly higher than that of the incorrect position haptic feedback condition ($M = 2.67, SD = 1.16$) at the $p < .01$ level. There were no other significant differences found between any of the conditions.

4.2 Results from the GSR Data

We analyzed the number of event-related GSR peaks, the average GSR amplitude of these peaks, and the amplitude of the first GSR peak in response to the first virtual character interaction. From our data analysis, we were not able to identify significant differences at the $p < .05$ level across the five conditions for either the number of peaks $[F(4,55) = 1.635, p = .179]$ or the average amplitude of peaks $[F(4,55) = 1.722, p = .158]$. However, a significant difference in GSR amplitude was found across the five experimental conditions $[F(4,55) = 3.731, p = .009]$ when analyzing the GSR after the first virtual character bump. Post hoc comparisons indicated that the mean score for the no haptic feedback condition ($M = .0807, SD = .07891$) was significantly lower than that for the full intensity haptic feedback condition ($M = .3510, SD = .31481$) at the $p < .01$ level.

4.3 Subjective-Objective Correlations

Because both questionnaire responses and GSR data were collected, we decided to explore possible correlations between the datasets and, more specifically, between the six concepts examined in this paper. In total, we examined 18 combinations between the questionnaire and the

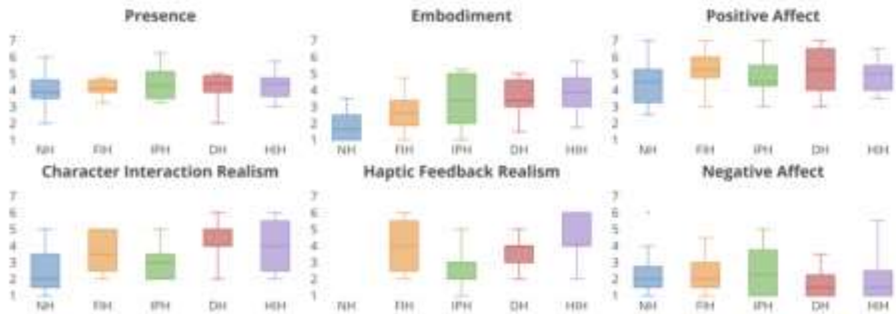

Figure 3: The questionnaire data for all the examined concepts.

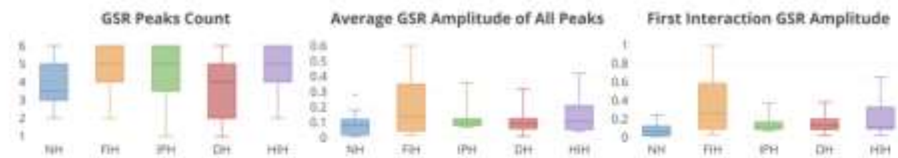

Figure 4: The results obtained from the GSR analysis.

GSR measurements (six components from the questionnaire and three GSR measurements) using a Pearson product-moment correlation coefficient. We found a moderate positive correlation [$r = .415$, $n = 48$, $p = .003$] between the realism of haptic feedback and the average GSR peak amplitude, and a moderate positive correlation [$r = .329$, $n = 48$, $p = .023$] between the realism of haptic feedback and the GSR peak amplitude after the first virtual character interaction.

5 Discussion

This study aimed to explore the effect of haptic feedback conditions on both subjective and objective measurements based on the analysis of collected GSR data. A simple scenario in which virtual characters bump into the self-avatar representing the participant in the virtual environment was developed. In response to our **RQ1**, from our data analysis, we were not able to identify differences for all examined concepts across the five developed conditions.

No significant differences were found between the five conditions when examining participants' presence. In the experiment, the participants were instructed to remain stationary in order to minimize muscular artifacts, so as to obtain clean, more accurate GSR data. Therefore, they were unable to control the self-avatar representing them or engage otherwise in the virtual environment. According to Slater and Steed [28], it may be necessary for the participant to act within an environment in order to elicit feelings of presence, therefore, perhaps our participants felt lower presence than expected across all groups because they had no actions to carry out within the environment. An important consideration, however, is that presence may generally be too difficult to capture with current questionnaires, perhaps because the concept of presence is loosely interpreted and highly dependent upon the moment, with its meaning most likely formed through actions and interactions, rather than the way the environment looks and feels [28].

One of the participants, after the experiment, commented that "the elsewhere question (concerning presence) is confusing." In addition to subjects "bracing themselves," as one participant stated, it is also possible that no differences in presence were found due to the fact that the participants were told to stay still. Participants in other studies have likewise admitted confusion concerning "presence," because participants do not necessarily share the same mindset and understanding of the concept of presence as do researchers [29].

Participants' sense of embodiment was also examined. Our results indicate that participants who experienced the no haptic feedback condition rated their sense of embodiment lower that the groups that experienced the half intensity, delayed, and incorrect position haptic feedback. However, it should be noted that the group assigned the full intensity haptic feedback condition experienced lower than expected levels of embodiment. Because embodiment was significantly greater for those who felt the half intensity haptic feedback than for those who felt any other haptic feedback, it is possible that embodiment may depend partially on the logical interactions of the environment and, thus, embodiment would be less for an interaction that did not make sense, such as feeling a person bump into you with a delay. Another finding that should be discussed is that those in the delayed haptic feedback group experienced higher embodiment than those in the wrong position haptic feedback group, perhaps suggesting that logical timing is more influential in increasing embodiment than is logical position. To answer our **RQ2**, further research is necessary in order to replicate our results as well as to pursue why certain haptic feedback parameters appear to take priority over others, where embodiment is concerned.

We found that the delayed haptic feedback group reported significantly higher realism of virtual character interaction than did the no haptic feedback group. This result suggests that a haptic feedback condition, even if it is delayed and, therefore, may not align with perceived visual feedback, can enhance the realism of a virtual character interaction. However, the remainder of the results concerning the realism of virtual character interaction were highly unsatisfactory. We expected that at least one of the correct timing and correct position haptic feedback conditions (either the full intensity or half intensity) would alter the realism of the interaction during the virtual bump. We interpret our results as follows: when one human bumps into another, not only is there a touch sensation due to physical contact, but also a physical sensation due to a shift in balance felt by the person who is bumped. In our experiment, physical sensations in addition to the brush of physical contact were not considered. Further studies that work to incorporate additional simulated physical sensations inherent to being bumped are needed to fully assess the realism of this kind of interaction.

The final question that participants were asked concerned the realism of the haptic feedback itself. With this question, we hoped to determine the perceived realism of each of the five developed conditions. Participants in the half intensity haptic feedback group reported significantly higher levels of perceived haptic feedback realism than the participants in the incorrect position haptic feedback group. Additionally, participants in the full intensity haptic feedback group also reported significantly higher levels of haptic feedback realism than participants did in the incorrect position group. Based on these results, it can be stated that haptic feedback at the correct position is important in making participants feel that the haptic feedback they received is realistic. Moreover, since no significant differences were found between the haptic conditions, realism of this haptic feedback might not be related to its intensity.

We were able to identify a significant difference in GSR peak amplitude between the no haptic feedback group and the full intensity haptic feedback group upon the first virtual character interaction. Additionally, we investigated the total number of peaks and the average amplitude of all peaks but were unable to identify significant differences in the existence or intensity of physiological arousal. The results concerning the collected GSR data were mixed since we expected to find significant differences for GSR count and total GSR amplitude as well. The obtained results indicate that haptic feedback might be able to alter the physiological arousal of participants, but that not all haptic conditions are able to do so, or that predictability of the scenario may critically influence arousal. In our case, since the only difference was between the full intensity haptic feedback condition and the no haptic feedback condition, participants might be more sensitive to logical and accurate haptic feedback than that which is illogical or inaccurate.

A participant from the full intensity haptic feedback group commented, "After the first bump, you know what to expect." Therefore, we argue that participants may have been less influenced by the following instances (bumps) of the haptic feedback due to their predictability after the first bump has happened. This might be the reason that the only difference we found in the GSR amplitude was found immediately following the first human-virtual character interaction. In the no haptic feedback condition, participants commented "Why didn't I feel anything?" and "Is the vest supposed to do anything?" upon removing the vest after the virtual scene had ended. Numerous participants in this group were confused as to why they did not feel anything, and one wrote "I kept waiting for something to happen... but nothing occurred," suggesting a feeling of anticipation, and impatience. As others expressed similar sentiments, it is likely numerous participants in the no haptic feedback condition were equally impatient. Impatience is a state of increased arousal [30], therefore, this feeling may have altered participants' arousal levels and prevented us from identifying the expected differences in the examined conditions. Future studies might consider including a condition in which no vest is worn. Our data analysis and the participants' comments suggest that experiencing haptic feedback could induce greater changes in arousal as compared to not receiving haptic feedback in virtual reality, perhaps if participants are unable to so easily predict when such feedback might occur.

Our findings suggest an ability to determine realism of haptic feedback with GSR data, as well as that haptic feedback can, in fact, trigger physiological responses that can be used to determine parameters of realistic haptic feedback during human-virtual character interaction. Additional studies may benefit from improved methods in order to assess emotional state. Perhaps this could be done with the inclusion of a questionnaire within the HMD, or including more than two questions that correspond to negative and positive affect, or with the use of the visual analogue scale, rather than a Likert scale. Also note that while GSR data can measure changes in arousal [27], it is highly affected by muscular artifacts such as limb movements and head turns [31], which are normally essential for virtual reality interaction. Considering that a moderate correlation was found between haptic feedback realism and GSR peak amplitude, perhaps GSR peak amplitude could function as an indicator of haptic feedback realism, especially in studies which take our limitations into consideration. Given that this was an exploratory study regarding the effects of varying parameters of haptic feedback on human-virtual character interaction, we would like to reiterate that more extensive research is required in order to obtain more reliable, conclusive results. To respond to **RQ3**, we might say that based on our findings, there is evidence that GSR could be used to determine optimal parameters of haptic feedback.

6 Conclusions and Future Work

For this study, a haptic vest was used to understand whether the haptic feedback delivered to virtual reality users during interactions with virtual characters alters their perception and physiological arousal within the virtual environment. As our research concerning the half intensity, delayed timing, and incorrect position haptic feedback was exploratory, future research might focus on these conditions in more depth, as well as consider our findings concerning embodiment in order to better determine why delayed haptic feedback, for example, might elicit higher feelings of embodiment than incorrect position haptic feedback. We also suggest exploring the possibility that each participant experiences several instances of every haptic feedback within the same environment. In addition to incorporating variety for the participant, it may be necessary to incorporate unpredictability, as mentioned previously.

We believe that an extensive investigation of the correlation between subjective and objective data is important in order to more effectively understand the way in which users perceive interaction with virtual characters. For this reason, we plan to further investigate the effects of haptic feedback during close interaction (bumps, virtual hugs, collision avoidance, etc.) with virtual characters. In addition to adding variety and unpredictability to our haptic feedback conditions, it may be necessary to explore ways in which physiological data can accurately and realistically be obtained in virtual reality, a medium that is often interactive in the form of user movement. Lastly, the inclusion of participants with specific characteristics (e.g., students with phobias, anxiety, depression, etc.) in our future studies may provide new insights into physiological arousal, human emotion, and perception where haptic feedback is concerned.

References

[1] G. Robles-De-La-Torre. International society for haptics: Haptic technology, an animated explanation. Isfh.org, 2010.

[2] L. Goedschalk, T. Bosse, and M. Otte. Get your virtual hands off me!–developing threatening IVAs using haptic feedback. In *Benelux Conference on Artificial Intelligence*, pages 61–75, 2017.

[3] N. Salamon, J. M. Grimm, J. M. Horack, and E. K. Newton. Application of virtual reality for crew mental health in extended-duration space missions. *Acta Astronautica*, 146:117–122, 2018.

[4] A. M. von der Pütten, N. C. Krämer, J. Gratch, and S.-H. Kang. "it doesn't matter what you are!" explaining social effects of agents and avatars. *Computers in Human Behavior*, 26(6):1641–1650, 2010.

[5] J. Fox, S. Joo Ahn, J. H. Janssen, L. Yeykelis, K. Y. Segovia, and J. N. Bailenson. Avatars versus agents: A meta-analysis quantifying the effect of agency on social influence. *Human-Computer Interaction*, 30(5):401–432, 2015.

[6] G. García-Valle, M. Ferre, J. Breñosa, and D. Vargas. Evaluation of presence in virtual environments: Haptic vest and user's haptic skills. *IEEE Access*, 6:7224–7233, 2018.

[7] P. Ramsamy, A. Haffegee, R. Jamieson, and V. Alexandrov. Using haptics to improve immersion in virtual environments. In *International Conference on Computational Science*, pages 603–609, 2006.

[8] M. A. Otaduy, A. Okamura, and S. Subramanian. Haptic technologies for direct touch in virtual reality. In *ACM SIGGRAPH 2016 Courses*, page 13, 2016.

[9] J. Lee, Y. Kim, and G. J. Kim. Effects of visual feedback on out-of-body illusory tactile sensation when interacting with augmented virtual objects. *IEEE Transactions on Human-Machine Systems*, 47(1):101–112, 2017.

[10] E. Giannopoulos, Z. Wang, A. Peer, M. Buss, and M. Slater. Comparison of people's responses to real and virtual handshakes within a virtual environment. *Brain research bulletin*, 85(5):276–282, 2011.

[11] A. M. L. Kappers. Human perception of shape from touch. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366(1581):3106–3114, 2011.

[12] J. Moll, Y. Huang, and E.-L. Sallnäs. Audio makes a difference in haptic collaborative virtual environments. *Interacting with Computers*, 22(6):544–555, 2010.

[13] L. A. Jones, M. Nakamura, and B. Lockyer. Development of a tactile vest. In *International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pages 82–89, 2004.

[14] C. McGregor, B. Bonnis, B. Stanfield, and M. Stanfield. Design of the ARAIG haptic garment for enhanced resilience assessment and development in tactical training serious games. In *IEEE International Conference on Consumer Electronics*, pages 214–217, 2016.

[15] E. van der Meulen, M.-A. Cidotă, S. G. Lukosch, P. J. M. Bank, A. J. C. van der Helm, and V. T. Visch. A haptic serious augmented reality game for motor assessment of parkinson's disease patients. In *IEEE International Symposium on Mixed and Augmented Reality*, pages 102–104, 2016.

[16] S. C. Gobron, N. Zannini, N. Wenk, C. Schmitt, Y. Charrotton, A. Fauquex, M. Lauria, F. Degache, and

R. Frischknecht. Serious games for rehabilitation using head-mounted display and haptic devices. In *Augmented and Virtual Reality*, pages 199–219, 2015.

[17] X. Hou, O. Sourina, and S. V. Klimenko. Haptic-based serious games. In *International Conference on Cyberworlds*, pages 39–46, 2014.

[18] A. Israr, S. Zhao, K. Schwalje, R. L. Klatzky, and J. F. Lehman. Feel effects: Enriching storytelling with haptic feedback. *ACM Transactions on Applied Perception*, 11(3):Article No. 11, 2014.

[19] S. Zhao, J. F. Lehman, A. Israr, and R. L. Klatzky. Using haptic inputs to enrich story listening for young children. In *International Conference on Interaction Design and Children*, pages 239–242, 2015.

[20] B. G. Witmer and M. J. Singer. Measuring presence in virtual environments: A presence questionnaire. *Presence*, 7(3):225–240, 1998.

[21] J. Frohner, G. Salvietti, P. Beckerle, and D. Prattichizzo. Can wearable haptic devices foster the embodiment of virtual limbs? *IEEE Transactions on Haptics*, 2019.

[22] M. Y. Tsalamlal, N. Ouarti, J.-.C. Martin, and M. Ammi. Haptic communication of dimensions of emotions using air jet based tactile stimulation. *Journal of Multimodal User Interfaces*, 9(1):69–77, 2015.

[23] G. Serafin and S. Serafin. Sound design to enhance presence in photorealistic virtual reality. Georgia Institute of Technology, 2004.

[24] M. Slater, M. Usoh, and A. Steed. Depth of presence in virtual environments. *Presence*, 3(2):130–144, 1994.

[25] M. Slater, D. Pérez Marcos, H. Ehrsson, and M. V. Sanchez-Vives. Towards a digital body: the virtual arm illusion. *Frontiers in Human Neuroscience*, 2:6, 2008.

[26] W. Boucsein. *Electrodermal activity*. Springer Science & Business Media, 2012.

[27] Imotions: Biometric Research Platform. Galvanic skin response: The complete pocket guide, 2017.

[28] M. J. Singer and B. G. Witmer. On selecting the right yardstick. *Presence*, 8(5):566–573, 1999.

[29] C. D. Murray, P. Arnold, and B. Thornton. Presence accompanying induced hearing loss: Implications for immersive virtual environments. *Presence*, 9(2):137–148, 2000.

[30] J. Naveteur, S. Cœugnet, C. Charron, L. Dorn, and F. Anceaux. Impatience and time pressure: Subjective reactions of drivers in situations forcing them to stop their car in the road. *Transportation research part F: traffic psychology and behaviour*, 18:58–71, 2013.

[31] M Lazzaro. *Game usability: advice from the experts for advancing the player experience*. CRC Press, 2008.