The Virtual Heart Illusion:
An investigation into the effect of representing the heart in VR over the Sense of Embodiment, Interoceptive Sensitivity, and activity of the real heart

by

Cristian Patras
Mantas Cibulskis

Supervised by Niels Christian Nilsson

Department of Architecture,
Design, and Media Technology

Aalborg University

Copenhagen, Denmark

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Aalborg University Copenhagen
Frederikskaj 12,
DK-2450 Copenhagen SV
Semester Coordinator:
Secretary: Lisbeth Nykjær

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Supervisor(s): Niels Christian Nilsson

Students: Cristian Patras
Mantas Cibulskis

Abstract:

Representing the human body within Virtual Reality Environments represents an area which is still unexplored. However, its powerful immersive capabilities highlight the potential for building exceptional experiences, or aiding the the human body via processes that are still being explored.

Starting from the previous studies which focused on representing the activity of the body internal processes (e.g., Monti et al. (2020)), and considering studies focused on other technologies (e.g., AR – Suzuki et al. (2013) the current work focuses on investigating the effects of representing the heart within a Virtual Environment over the Sense of Ownership, Interoceptive Sensitivity, as well as activity of the real heart. Three conditions are employed: (1) synchronized, (2) manipulated, and (3) random heart activities.

The study was conducted on 19 people, who took part in a within subject experiment, where each participant was exposed to all three conditions. The results suggest that the condition where the heart was synchronized yielded the highest scores for the SoE, while lowering the virtual heart rate leads to a reduction of the subject's real heart rate.

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CHAPTER 1

Introduction

Humans have always been able to freely visualize their body in real life in great details. This, however, starts to become an issue when one joins a Virtual Environment, as the representation of the human body in Virtual Reality is still an unexplored area. However, the extent to which it is unexplored is proportional to its potential to be applied in various areas (e.g., education, art). At the same time, the continuously improving software, and hardware used to run VR applications allow for highly realistic environments, as well as the elements they include.

There have been previous attempts at representing the human body in different conditions (e.g., including vs. not including breathing [49]), which demonstrated that, due to the high reliance on vision while perceiving the world around, manipulating the way the body is represented within VR can affect the sense of ownership over the virtual avatar to a certain extent. At the same time, similar ways of representing the body parts were discovered via other media [92], mainly for artistic purposes. Suzuki et al. [73], on the other hand, employeed another technology - Augmented Reality - to investigate how representing the activity of the human heart can affect the sense of ownership over the virtual hand. Another famous experiment, The Rubber Hand Illusion [15], revealed that, given a certain extent of visuo-tactile stimulation, one can get a sense of ownership over an object that is foreign to the body.

To the best of the knowledge of the research group, no experiment has investigated the influence of representing the human heart within VR, to examine its influence over the Sense of Embodiment, Interoceptive Sensitivity, as well as how the real heart is affected by visualizing a heart in VR. Therefore, the goal of the study is to explore how the aforementioned metrics are affected by representing the virtual heart in three conditions: synchronized to the subject's real heart, manipulated, or completely random. Thus, the current project will represent a thorough documentation of the entire study.

CHAPTER 2

Analysis

The current chapter will introduce the reader to the technology of VR, as well as its state of the art applications. At the same time, the basics of the human cardiac activity will be presented, with an extensive focus on Heart Rate (HR), and Heart Rate Variability (HRV). The large allocation of time dedicated to the topic is due to the heart activity representing an important component of the project, while HR and HRV are the most common, as well as accessible metrics used to represent the cardiac activity. The section will continue with an analysis of some relevant projects aimed at leveraging the knowledge gained about how the brain perceives the body, and will follow with a presentation of the concept of embodiment in VR, with emphasis on: (1) Body Ownership, (2) Embodiment, and (3) Agency, including the most common measurement tools for each. Next, an introduction to the Interoceptive Sensitivity will be provided, and the section will end with the brain's representation of the body, including some of the well-known concepts within the field (e.g., The Rubber Hand Illusion, The Uncanny Valley), with the aim to better understand how the previously introduced parts can be combined.

2.1 Virtual Reality

Virtual Reality (VR) is a trendy immersive technology, used to represent experiences which closely resemble the real world, or other highly realistic environments with congruent elements. Compared to the traditionally known User Interfaces, the technology offers a superior User Experience, as well as more opportunities for interaction by using various gestures [8]. As also shown by earlier research, VR allows for inducing the feeling of being immersed in environments which are physically impossible, without being able to detect it [71, 20].

Despite its long life - since the 60s [72] - it is not since recently that the technology started to be researched in more details, as well as applied in multiple real-life scenarios. To this date, VR is known to be successfully applied in medicine [7], rehabilitation [63], education [65], and many other fields.

2.2 Cardiac Activity

The human heart activity includes all the critical processes necessary to ensure a good functioning of the body parts which have a dependency on blood supply. The scope of the current project will limit the analysis to HR, and HRV, allowing the reader to focus on three important measures for the cardiac activity. The choice of the two metrics is motivated by HR being used in previous research to visually represent the activity of the heart [73], while HRV representing a rich source of insights on the activity of the body through the heart's perspective (e.g., mortality, stress management) [14].

2.2.1 Heart Rate

Heart Rate has been widely used as a measure for sports activity, with the potential to detect and prevent over-training [2]. Its high importance can be further confirmed by the quick evolution of Heart Rate Monitors (HRM) from laboratory instruments to compact wearable devices integrated in, for instance, compact sports watches [23]. The popularity of the measure can be explained by the findings Achten and Jeukendrup's findings [2], that it is relatively cost efficient to track HR, and its usefulness in a multitude of scenarios. At the same time, the connection between HR and other measures used to analyse training status has been shown to be affected by a range of body, or environmental aspects (e.g., hydration levels, body temperature).

The measure has also been studied in relation to other parameters, i.e., oxygen uptake. Despite the deviation window of up to 20%, and low accuracy on individual level, the HR has been shown to provide satisfactory approximations of how energy is spent by groups of individuals [2].

HR has also been shown to have a high correlation with blood pressure, emphasizing its potential to predict conditions such as hypertension, coronary heart disease, or the risk of cardiovascular and noncardiovascular death [53]. More than this, the concept of resting heart rate – the heart rate while the person is not performing any physical activity – has been studied, being linked to the progression of conditions such as coronary artherosclerorís, myocardial ischemia, ventricular arrhythmias, or left ventricular function. Even though it is not generally accepted as a therapeutic target, the outlined findings suggest its potential, and the importance of it being included in cardiovascular guidance documents [32]. At the same time, the importance of the metrics can be leveraged in multiple other realms, to benefit the end user, ultimately.

2.2.2 Measuring Real-Time Heart Rate

Measuring the activity of the heart has always been an interest for physicians, due to the multitude of insights it provides regarding the activity of the body, as mentioned in the previous section. There are multiple ways in which HR can be measured. Starting from the most simple ways, Harward Medical School suggests [38] that HR can be measured by checking either a side of the neck, or the wrist, by counting the heart beats for 15 seconds, followed by multiplying it by four. More accurately, HR can be measured in hospitals, using the so-called electronic vital sign monitors [46], which have sensors that can be attached to the patient's skin, sending to the metrics to be displayed on the screen. Additionally, it can be measured using a pulse oxiometer [5], which is a small non-invasive device attached to either a finger, toe, or earlobe. It records the levels of oxygen saturation in the lungs, as well as the heart rate. At the same time, the recent trends in medicine are making it possible to monitor patients even without them being hospitalized. One of the metrics that can be extracted without the patient needing to be present physically in a hospital is heart rate, which can be extracted using wearable monitors. This allows physicians to predict the occurrence of certain life-threatening events that can be predicted by abnormal cardiac activities [51]. Measuring the activity of the heart has become a popular metric among sport practitioners, as it represents a non-invasive, as well as time-efficient means to understand the status of the autonomic nervous system in different sports contexts. This has led to the expansion of commercially available sports watches which contain a heart rate monitor [23]. The metric is also popular in the research field, with some devices being purposefully designed and built for this reason. One of them, the Empatica E4 wristband [29], is able to capture and send real-time physiological data from the body, allowing researchers [44] to extract, and use it with an integrated API. The device was regarded as suitable for measuring physiological signals during studies on top of self-reports, which were found to differ between each other [29]. However, according to Voorhees et al. [85], the device was found to be little reliable compared to other monitors, when it comes to measuring Heart Rate Variability, which will be introduced in the following section.

2.2.3 Heart Rate Variability

Another metric for assessing the activity of the heart - Heart Rate Variability (HRV) - allows for a more thorough analysis of the relationship between the sympathetic and parasympathetic nervous systems. The measure represents the time interval between heartbeats. By analysing the

HRV, meaningful insights can be generated about the overall health of both the heart, and the Autonomous Nervous System (ANS), which coordinates the cardiac activity [1].

Compared to the previously introduced HR, HRV is more complex when it comes to measuring it. The most common way of doing it, according to Acharya et al. [1], is to examine the time series of beat-to-beat interval on a electrocardiogram. Nevertheless, the literature has proposed multiple metrics, and those can be further categorised into frequency, time, and nonlinear domain measures. As it follows, the three categories of metrics used to measure HRV will be introduced. However,

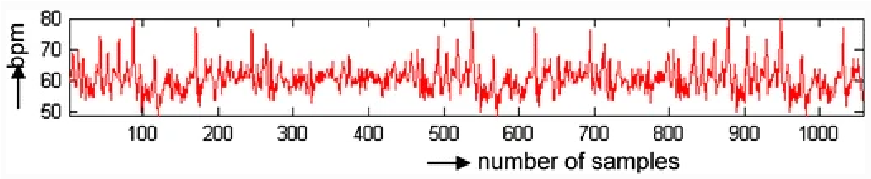

Figure 2.1: An example of heart rate variation of a subject [1].

due to the scope of the current work, the introduction will briefly touch upon the main aspects:

- **Time Domain**
  Within the Time Domain, two main indices are found: (1) Beat-To-Beat, and (2) Low Tidal Volume, which are calculated using the Respiratory Rates (RR) recorded within a predefined time window. Using the RR intervals, more metrics can be calculated: Standard Deviation of the NN interval (normalised time between two heart beats), standard error (SENN), SDSD, RMSSD, NN50, or pNN50%. These measure are specifically used for detecting, for instance, the sick sinus syndrome, complete heart block, preventricular contraction [1].

- **Frequency Domain**
  Despite being less computationally demanding, compared to the other methods, the Frequency Domain does not allow for a discrimination between the sympathetic, and parasympathetic implications of HRV. Some of the usual techniques to study the metric within the current domain are examining periodgrams, or employing the Fast Fourier Transform algorithm. To analyse the Frequency Domain, the autoregressive method is used [1].

- **Nonlinear Domain**
  Lastly, the most recent category of metrics allows for measuring and processing signals from nonlinear living bodies. More than that, it is currently being considered as more effective, when compared to the other categories, when it comes to describing the processes taking place within those bodies. One application of the findings gathered using the Nonlinear Domain methods allows practitioners to particularly study cardiac arrhythmias [1]. Despite its novelty and effectiveness, there are certain challenges which need to be considered when using Nonlinear Domain methods: (1) a high degree of noise coming from the biological data, (2) insufficiently large data sets, caused by low frequencies coming from biological data, (3) high spatial activity of the biological systems, (4) more space required for the system, in comparison to the other methods.

At the same time, HRV was found to be linked to a range of diseases (e.g., Renal Failure, Cardiac Arrhythmia, Diabetes), body characteristics (e.g., age, gender), or activities (e.g., consumption of alcohol, drugs, or nicotine) [1].

2.3 Embodiment in VR

One aspect bringing the technology of VR in front of others is the ability to create, through its multidimensional nature, the Sense of Embodiment (SoE), the feeling experiencing virtual events as if they were processed by the user's real body. This can be accomplished by, for instance, substituting real sensory input to make the experience feel more real [33]. Botvinick and Cohen. [15] first introduced the phenomenon outside of the VR realm, through inducing the sense of embodiment to a rubber hand by synchronizing the visuotactile input of the visible rubber hand and the invisible real hand. This resulted in the participants developing a strong sense of self-attribution. The ability to highly engage users in the experiences it represents, according to Tham et al. [76], is the main reason for the technology's gain in popularity in the recent years. But what is embodiment, and why is it so important to consider its implications when designing a virtual experience? The current section will provide an overview of the SoE in VR, starting from its definition, components, and ending with the known methods used to measure it.

2.3.1 Definition

When it comes to defining what the Sense of Embodiment in VR is, there have been many attempts to formalize a general definition [40]. The initial attempts to define the term started from its cognitive, and philosophical aspects, where Blanke and Metzinger [13] tried to look into what are the minimal requirements of how one is represented to the conscious experience of being the one, or what are the requirements that would allow the experience to be based on self-consciousness. By looking at the term in relation to VR, Kilteni et al. [40] suggested that the SoE is constituted by three major components: (1) self-location, (2) agency, and (3) ownership. Vignemont [24], with slight differences, but the same components, considered that "*E is embodied if some properties of E are processed in the same way as the properties of one's body*". The last definition assumes that the user might embody elements which are normally not part of the human body (e.g., a screwdriver, a pencil). Vignemont, therefore, decomposited the sense of embodiment in three dimensions: (1) spatial, (2) motor, and (3) affective. Due to the scope of the current work, the SoE will be reflected through the perspective of the research performed by Kilteni et al. [40]. Therefore, as the current section continues, the SoE's components, as determined by the chosen definition, will be described.

2.3.2 Self-Location

The first component represents the space in which the user is located. Next, the body space sets the physical limits, as well as the boundaries within which sensations are experienced [24]. If the virtual body is located in the same position as the real body, a more intense sense of embodiment will be registered, compared to when the two elements are not collocated [69]. Therefore, the first person view is considered to be more effective in terms of inducing the illusion of full body ownership [56]. Starting from the renown Rubber Hand illusion experiment [15], it was shown that the sense of self-location is modified once synchronous visuo-proprioceptive input is provided for both the real, and the fake parts of the body. Blanke and Metzinger [13] suggest that vision is more dominant than the tactile sense when it comes to inducing the sense of presence, thus the location of the stroke, as seen by the participant, is more powerful than the tactile stroke.

2.3.3 Agency

According to Argelaguet et al. [6], the sense of agency represents the perception that the user is the agent of his/her own actions. It is linked to the ability of planning an action, as well as being aware of its outcomes [24]. One can experience the sense of agency while using different tools, where it is important to know the effect of an action of the tool to achieve the expected outcome. This has been shown to be part of experiencing the sense of agency [18]. However, the sense of agency is not influenced by the degree of realism of the virtual avatars, when the size of the body parts deviate from the real size [41], nor when the virtual body parts are in unrealistic positions [78].

2.3.4 Ownership

As its name suggests, ownership represents the sense that the sensations felt by the user are generated by his/her own body [78]. Starting from the previously mentioned Rubber Hand Illusion [15], it was shown that a fake part of the body, aided by synchronized tactile stimulation, can lead to one experiencing a sense of ownership over it. At the same time, according to Ehrsson et al. [28], the sense of ownership is generated when one perceives a threat towards a fake body part. A more in-depth analysis of the phenomenon confirmed that the brain activity, while a foreign body part is threatened, is similar to when a real body part is threatened, activating the same brain areas [28]. Therefore, the process triggered by threatening the rubber hand is not merely a body reflex, but a cortical anxiety response generated by the body when a dangerous situation is detected [12].

2.3.5 Measuring Embodiment

Even though embodiment has been extensively researched, there is still a fair amount of work to be done to identify commonly agreed tools for measuring it in VR [4]. Among the approaches for measuring embodiment, researchers prefer questionnaires [59, 26, 34, 54], psychophysiological signals (e.g., Electroencephalography [3, 86]), or both combined [67]. Roth and Latoschik [59] proposed the Virtual Embodiment Questionnaire (VEQ), focusing on three main aspects: (1) ownership - the feeling of owning the body parts which the user posses in the VE, (2) agency - the feeling of control over the body's actions, and (3) change - the feeling of change perceived in the schema of the body [59]. Consisting of 12 Likert items (4 for each of the previously mentioned aspect), the researchers consider the questionnaire to be more sensitive to manipulations, allowing for a better assessment of Rubber Hand Illusion-like experiments. Gonzalez-Franco and Peck [34], on the other hand, proposed a 25-questions embodiment questionnaire, after analysing the questionnaires used in 30 past experiments. Compared to Roth and Latoschik [59], the last two researchers focus on four embodiment aspects: (1) location of the body, (2) body ownership, (3) agency and motor control, and (4) external appearance. Despite the fact that the current questionnaire includes the findings from a large body of previous research, it has not been rigurously tested, nor validated [34]. Moving forward to a more novel approach for measuring embodiment, Alchalabi et al. [3] proposed using EEG as a tool that would not involve self-reports. Despite the study was performed on a relatively low sample (20 participants), strong correlations were found with subjective levels of embodiment for the trials involving manipulations, and those not involving any manipulations. Finally, as previously mentioned, self-reports and measuring brains signals can be leveraged together, according to Skola and Liarokapis [67].

2.4 Interoception

Interoception - the process of integrating and processing the input coming from body parts/organs [47] - has gained a fair amount of attention over the last period of time. One of the reasons for that is its importance in relation to mental health [57]. According to Barsalou [10], there are three main of interoceptive experiences crucial for the human body to function: (1) cognitive operations (e.g., search, rehearsal, comparison tasks), (2) representational (e.g., having a representation of an entity, even when it is not present), and (3) emotional states (e.g., moods, states). The ability to focus on certain aspects allows the human body to be able to represent an object in its absence, filter out certain events generating emotions, while storing a schematic representation of the processes in the brain areas as insula cortex [21]. This represents the basis for defining how one feels.

2.4.1 Measuring Interoception

When it comes to measuring interoception, there are multiple approaches, as well as numerous opinions on which one is the most rigorous, or most suitable for specific applications. One of the most common technique for defining how one feels is the Heartbeat Counting Task (HCT) [22, 62], which involves asking the participants to count their heartbeats over a certain time interval, followed by comparing the results to their actual heart rate over the same period, coming from a monitoring device, resulting in an accuracy index. However, the task can be negatively influenced by one's knowledge about his/her resting heart, which might influence the task's outcome. This suggests that the scores rely on beliefs about the heart rate, not the sensitivity to heart rate detection [90]. Another proposed task - The Heartbeat Detection Task (HDT) [39, 88] - consists of exposing the participants to either an auditory, or a visual stimulus which can be either synchronized or manipulated with their measured heartbeat. They are then asked to classify each trial, resulting in an accuracy score on how accurate they are able to perceive their hearbeat. This, however, is limited by how each participant perceives his/her heartbeat. To overcome these challenges, a few psychophysical alternatives were proposed (e.g., The Method of Constant Stimuli, as well as the 6-alternative-forced-choice (6AFC) task [57]). The Method of Constant Stimuli, as proposed by Brener et al. [16], includes asking the participants to assess whether or not their heartbeat sensation corresponded to tones they could hear. The tones would have certain delays, yielding precision values. At the same time, Ponzo et al. [57] consider that interoception should be measured over a larger time-span, to capture a larger range of the cardiac activity, not only when the heart is at complete rest. Therefore, the research group proposed an ecological interoceptive task, called the CARdiac Elevation Detection (CARED). The task consisted of asking the participants to wear a smartwatch over a span of 4 weeks, being asked on pre-programmed moments if their heart rate was higher than normal, mark their confidence level of the statement, as well as to include the activities that they were part of half an hour before they received the notification. Another, rather different instruments for measuring interoception is The Multidimensional Assessment of Interoceptive Awareness (MAIA) [74]. It includes 32 items, carefully chosen after a round of focus groups with field experts (e.g., yoga, Tai Chi, Somatic Experiencing), as well as their clients. The goal was to allow the measure even the smallest changes in terms of body awareness that might be caused by these therapies. The authors, however, are aware of the limitations of self-reporting, as they might be influenced by temporary emotions, as well as the presumed expectations of the research group, which would make them give please-to-read answers. The uses for the questionnaire were found in longitudinal studies (e.g., chronic pain, PTSD, birth preparation). At the same time, an improved version of the questionnaire, after the first testing phase, is available - MAIA 2, developed due to low consistency scores of the first version.

2.5 The Brain's Representation of the Body

In analysing the activity of the body, it is important to pay attention to the connection between the brain and the available stimuli, as well as where and how the input from those is stored and processed. As suggested by Graziano et al. [35], the brain's representation of the human body is not formed only based on a static structure, but on a continuously updated model, which gets multi-modal inputs from one's vision, motor feedback, etc.. The current section will introduce the reader to some of the most related aspect of the way the body is represented within the brain through the prism of 3 elements: (1) The Rubber Hand Illusion, (2) The Proteus Effect, (3) The Uncanny Valley. Finally, the phenomenon will be represented in relation to VR.

2.5.1 The Rubber Hand Illusion

Mentioned earlier, The Rubber Hand Illusion was originally reported in 1998 by Botvinick and Cohen [15], and it clearly represented the cooperation between proprioception, vision, and touch.

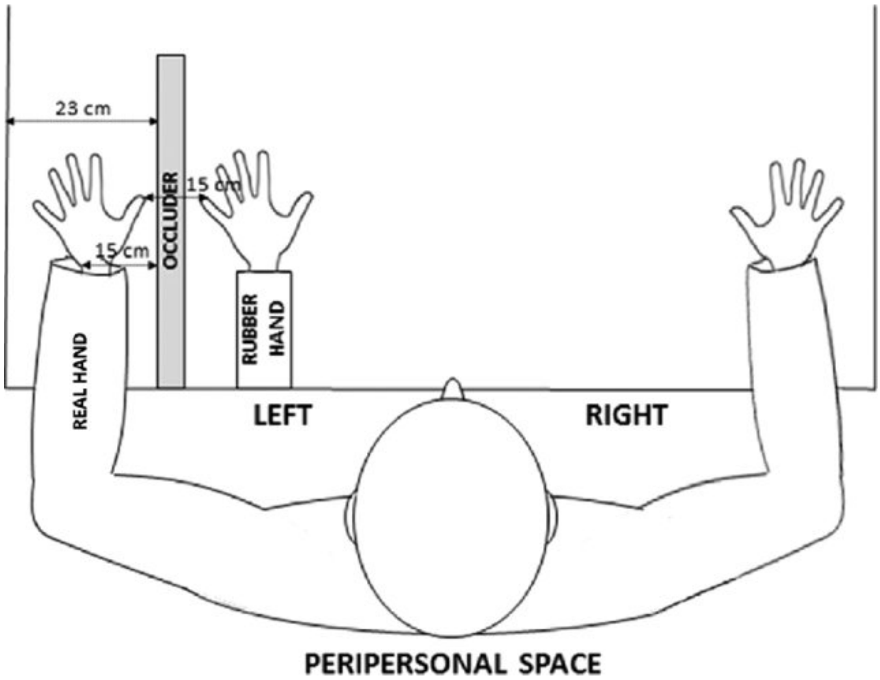

Figure 2.2: The setting required for The Rubber Hand Illusion. [45]

In the first part of the experiment, 10 participants were asked to sit in front of a table, with their left arm on the table, beside the occluder, as illustrated in Figure 2. Next, they were instructed to focus on the rubber hand, while the experimenters were brushing simultaneously both the real and the rubber hands. After being exposed to the experience for 10 minutes, each participant was asked to fill out a questionnaire, focusing on identifying whether or not they noticed certain perceptual effects, as well as answering an open-ended question to describe their overall experience. The second part of the experiment included distortions of the proprioceptive information, then the participants were asked to close their eyes, and point with the right index finger to the position of their left index finger. The findings suggested that going through the experience made the participants point closer to the index finger of the rubber hand. To move the experiment one step further, the research group included a control group, for which a slight asynchrony in brushing was included. The results suggested that the asynchrony lead to the participants not reaching as close to the rubber hand (23 mm from it), compared to the other one (13 mm from it). The study, therefore, suggests that the body, through a certain degree of inter-modal perceptual correlation, can generate a sense of ownership over foreign objects [15].

At the same time, experiments following the same concept have been performed in VR [61, 68]. The findings from the work of Slater et al. [68] suggest that a part of the body represented in VR, combined with tactile stimulation on the same part of the real body can lead to it being experienced as part of the real body. More than that, evidence was found that the extent to which the participants experienced the illusion correlated with the activity of the muscles responsible for the body part. As mentioned by the authors [68], the findings highlight the potential of the illusion to generate the experience in a full-body setting. Sanchez-Vives et al. [61], on the other hand, went a step further and tried to investigate the extent of the illusions when the tactile stimulation is absent. The results suggested that the sense of ownership was significantly lower when there was no tactile stimulation, while the proprioceptive displacement showed a significant difference (3.5 cm), with the sense of ownership and the size of the displacement being highly correlated.

2.5.2 The Cardiac Rubber Hand Illusion

An extension to the previously described Rubber Hand Illusion is represented by an experiment performed by Suzuki et al. [73]. In their work, the researchers attempted to investigate what would the effect of synchronized and asycnrhonyzed cardio-visual feedback be on the sense of ownership over the virtual hand. At the same time, they looked into the participants' interoceptive sensitivity, and whether or not it is correlated with the sense of ownership identified in the previous step.

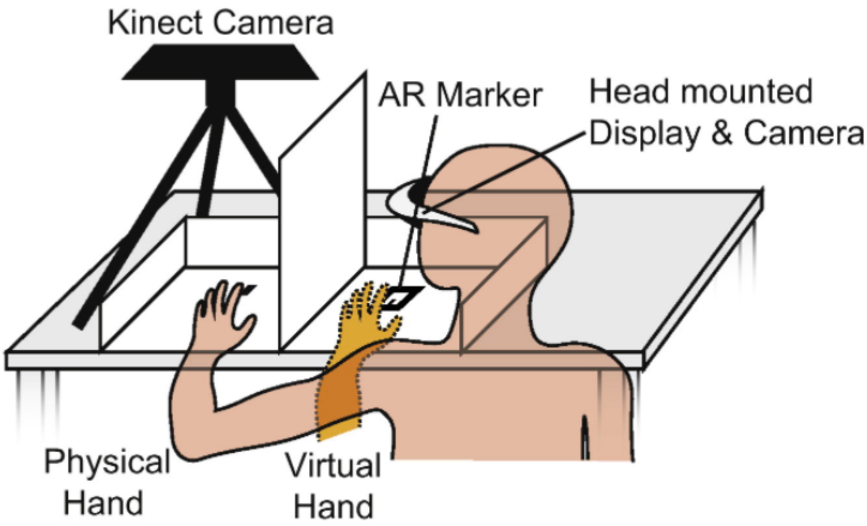

Figure 2.3: The set up used for performing the Cardiac RHI experiment [73].

The experiment, performed on 21 volunteers, included a similar set up to the one from the original RBI experiment, but slightly modernized, i.e., as seen from Figure 3, instead of using a physical rubber hand, the technology of Augmented Reality (AR) was used, along with a real-time pulse oxiometer installed on the right index finger, which produced the input for the AR animation. The movements of the virtual hand were synchronized with those of the physical hand, due to it being tracked in real-time using a Kinect Camera.

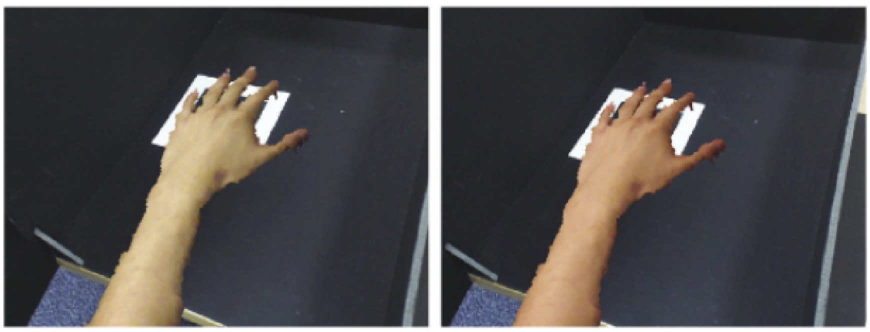

Figure 2.4: A representation of the hand in The Cardiac Rubber Hand Illusion experiment. Each heart beat was represented by a gradual animation of the skin color turning from the participant's color (left) to one suggesting that the blood flows through, represented by an overlaid red hue (right) [73].

As visible from Figure 4, the heart activity was represented through adding a red hue over the participant's skin color, which is assumed to signify the flow of blood through it. To simulate the brush stroke, a real brush was used to give the participants the sensation, while a virtual one was designed to create the visual representation. Due to the high similarity between the current project and the work performed by the authors of CRBI project, the description of the procedure will be presented in much more detail:

1. **Interoceptive Sensitivity Test (based on The Method of Constant Stimuli, described in Section 2.3)**
   The test participants were exposed to 16 trials (8 synchronous, and 8 manipulated - 50% faster, and 50% slower feedback). The sensitivity was then measured as the proportion of correct answers.

2. **Being exposed to the three conditions:**

- Cardiac Still - keeping the hand still
- Cardiac Move - freely moving the fingers
- Tactile - experiencing the paintbrush stroke
  In all three conditions, the participants were asked to focus on the virtual hand. At the same time, the experiment was divided into three blocks, with the first block including only the tactile condition, while the second and third included a mix of cardiac move and cardiac still exposures. After being exposed to each trial, the participants were introduced to an induction period (lasting 120 seconds), during which they were asked to focus on their virtual hand.

3. **Proprioceptive Drift Task**
   The current task included asking the participants to point to the perceived location of their left hand, without any visual cues, apart from a darkened environment with a ruler in it. The proprioceptive drift was then calculated as the distance from the perceived location to the actual location.

4. **Questionnaire**
   Adapted from the original questionnaire used by Botvinick and Cohen [15], the current version attempted to investigate the sense of ownership over the virtual hand. In addition to this, a 5th question was added, asking the participants to judge whether or not the tactile-visual, and the cardio-visual feedbacks were synchronized or not. The questionnaire consisted of the following 5 items [73]:

   (a) "*It felt as if the virtual hand was my hand*"
   (b) "*It seemed as if I had more than one left hand*"
   (c) "*It seemed as if I were feeling a table in the location where the virtual hand was*"
   (d) "*It felt as if I no longer had a left hand, as if my left hand had disappeared*"
   (e) "*Was visual feedback synchronized to the tactile stimuli? [Tactile]/was cardio feedback in time with your own heartbeats? [Cardio]*"

   Each participant was asked to answer on a 7-point scale (-3 - strongly disagree; 3 - strongly agree).

The experiment's procedure, therefore, looked similar to:

1. Interoceptie Sensitivity Task
2. First Block: Tactile
   (a) 4 trials (3.5 minutes each) - synchronous, and manipulated
   (b) Proprioceptive Drift Test
   (c) Induction Period for 120 seconds
   (d) Proprioceptive Drift Test
   (e) Questionnaire
3. Second Block: Cardiac Still and Cardiac Move
   (a) 4 trials (3.5 minutes each) - synchronous, and manipulated
   (b) Proprioceptive Drift Test
   (c) Induction Period for 120 seconds
   (d) Proprioceptive Drift Test
   (e) Questionnaire
4. Third Block: Cardiac Still and Cardiac Move

(a) 4 trials (3.5 minutes each) - synchronous, and manipulated

(b) Proprioceptive Drift Test

(c) Induction Period for 120 seconds

(d) Proprioceptive Drift Test

(e) Questionnaire

The results indicated that the sense of body ownership can be modulated by an integration of exteroceptive and interoceptive inputs, i.e., the syncrhonous cardio-visual feedback provided a much higher sense of ownership of the hand represented in the virtual environment. At the same time, a positive correlation was observed between the Interoceptive Sensitivity and the Proprioceptive Drift Difference in the tactile condition, which contradicts the findings from previous similar research [77], which Suzuki et al. [73] explained as being due to the differences in the Interoceptive Sensitivity Task, which in their relied on both interoceptive and exteroceptive (audio) inputs.

2.5.3 The Proteus Effect

The current capabilities of the technology of VR allow one to experience highly immersive VEs, where the representation of the user's avatar is manipulated (e.g., different skin color, height). Proposed by Yee and Bailenson [91], the Proteus Effect examines the change in behaviour caused by an altered self-representation in VR. As Kocur et al. [42] suggested, this change in behavior is caused by the strong connection between the avatar viewed in VR and the user.

Figure 2.5: A scenario involving the Proteus effect: a user represented by an African/American female avatar, while being in a confrontation with a white avatar within the VE [52].

According to Groom et al. [36], the way users are portrayed in VEs has an effect on the way they perceive race-related issues even beyond the virtual experiences. In their work, they discovered that those users which were embodied by white avatars within the VE showed a lower racial bias outside the virtual experience, as opposed to those embodied by black avatars. While seemingly unusual, the Proteus Effect can be leveraged to benefit users. For instance, in an experiment performed by Yee and Bailenson [91], the effect of assigning users to more attractive avatars within the VE was examined on the extent to which they would act more intimate in "*a self-disclosure and interpersonal distance task*" [91], compared to assigning them to avatars which are less attractive. The second part of the study, the research group examined if representing the avatars as taller compared to the users' real heights would make them act more confidently during negotiations, in comparison to users represented by shorted avatars. The authors argue that the effect has its origins in the deindividuation phenomenon that can occur in darkened rooms, where the anonymity is much higher, and there are less social cues [91]. Therefore, in a VE, the avatar that users see is the main identity cue, which has a significant effect on the users' behaviour. Similarly to the way people wearing black uniforms are perceived to show more aggression, seeing a virtual avatar can induce users to change their behaviour as to satisfy the stereotypes and expectations related to the avatar's appearance. The effects of the Proteus Effect have not been extensively explored, due to the emerging character of the concept. However, the research already performed is highlighting its potential, along with the proposals for future studies, i.e., examining the effect of a more powerful-looking appearance over the amount of force applied by a user in real-life [43].

2.5.4 The Uncanny Valley

Coined 52 years ago by Mori [50], the Uncanny Valley consists of the discomfort generated by looking at fairly realistic virtual representations of humans [17]. Considering the continuously growing graphics capabilities within the realm of VR, it is becoming an important aspect to consider, while developing immersive VEs.

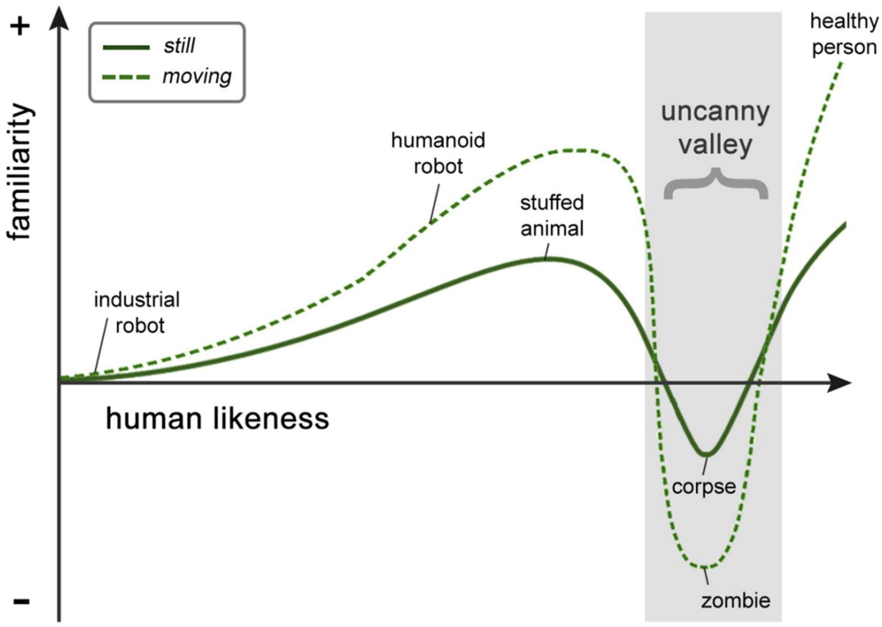

Figure 2.6: A graphical representation of the Uncanny Valley [70].

As it can be seen from Figure 4, once a virtual character is becoming more and more human-like, the emotional connection between it and the viewer is becoming stronger and stronger. However, there is a level of human likeness that is so close to the user that the familiarity drops, resulting in an unpleasant, uncomfortable experience. This stage, however, comes right before a degree of human likeness where the familiarity jumps even higher than before. As mentioned earlier, the current capabilities allow for designing highly realistic representations of human characters. However, as the degree of realism goes up, so do the viewers' expectations on the set of aesthetics used to guide the characters [17], and the more realistic the character appears to be, the higher are the expectations on how realistic his/her movements must be. There is a risk that the quality of the animations do not match the realism of the character, which would eventually lead to the impression that the character being viewed is not real. As demonstrated, different parts of the body have varying degrees of influence over the formation of the Uncanny Valley effect, i.e., eyes represent a powerful cue for humans to identify falsehood, which starts from the innate ability to detect the perceptual state of an organism by looking into its eyes [87]. At the same time, eyes play a significant role in predicting other people's actions [9]. Therefore, when eyes do not fully communicate one's intentions, the viewer starts experiencing fear [17].

The concept of Uncanny Valley in relation to embodiment was studied by Alonzo et al. [27] in the context of the previously mentioned Rubber Hand Illusion. However, instead of measuring the different levels of realism within VR, the study compared three virtualization levels: (1) real, (2) robotic, and (3) virtual. These were examined in relation to two different types of touch: (1) real, and (2) virtual. The results indicated that virtualizing the hand had a negative effect on embodiment. At the same time, the lowest degree of embodiment was recorded when either of the senses was virtualized, i.e., when the participants of the study either just saw their hand virtualized, or when the tactile stimulation was virtualized.

2.5.5 Corporeal Awareness

A recent sub-field within the realm of VR consists of analysing the effect of physiological input (e.g., breathing, cardiac activity) on the feeling of having a body in real life, which acts in concordance with one's intentions, and that takes a physical space. According to Monti et al. [49], the powerful capabilities of VR allow one to manipulate the corporeal awareness by combining the exposure with physiological input. In their study, the focus was on breathing, and the findings suggested that its influence is as important as the visual input, and even more important than any of the previous cues studied for body agency. At the same time, they investigated whether the perspective of viewing the virtual avatar influenced the sense of embodiment, too. The experiment procedure, therefore, included a condition where the participants viewed themselves from the first-person perspective, as well as one where they could see themselves from a third-person perspective. More than that, the experiment considered the effect of appearance on the sense of ownership over the body.

The results indicated that the appearance, breathing, as well as perspective influence one's sense of ownership over the virtual body. More than that, the sense of agency was influenced the most by the viewing perspective, and breathing. The current study, therefore, indicates that the corporeal awareness is influenced by a large number of factors, which opens the possibilities for investigating whether manipulating these inputs might change the functioning of the real body.

2.5.6 Conclusion

The current chapter presented an overview of the technology of VR, together with the basics of the human cardiac activity. At the same time, a higher emphasis was put on the HR, and HRV metrics, due to their high value, and wide applicability among heart-related studies. The hardware, and techniques used to measure/calculate the two metrics were described, as well. Next, an overview of the SoE was provided, including some of the available definitions, as well as sub-components, and instruments which can be used to measure it. At the same time, the concept of interoception was introduced, together with the known techniques of extracting it. Lastly, the way the body is represented in the human brain was described, focusing on well known concepts (e.g., The Rubber Hand Illusion, The Uncanny Valley). The section, therefore, represents the theoretical foundation for upcoming parts of the project.

CHAPTER 3

Final problem statement

The previous studies, as well as the theory covered, allow the research group to formulate the problem statement that the current project is investigating, as well as a set of requirements, which would allow for a systematic execution of the experiment.

3.1 Research Questions

Starting from the work performed by Botvinick and Cohen. [15], extended Suzuki et al. [73], as well as the findings from Monti et al. [49], the current work will focus on investigating whether or not the sense of embodiment over the virtual body will be influenced by the temporal harmony of the heart in three conditions: (1) when the activity of the virtual heart is syncrhonized with the activity of the real heart, (2) when the activity of the hearts is manipulated, and (3) when the activity of the virtual heart is following a random pattern. More than that, the heart's real activity will be investigated in the previously mentioned conditions. Lastly, the interoceptive sensitivity will be measured for each condition.

Therefore, the current project will focus on the following research questions:

1. **To what extent can the synchronous visuo-cardiac feedback influence the Sense of Embodiment over the virtual heart, in comparison to manipulated, and random visuo-cardiac feedback?**

2. **How does the manipulated visuio-cardiac feedback influence the participants' real cardiac activity?**

3. **How does synchronous, and manipulated visuio-cardiac feedback influence the participants' Interoceptive Sensitivity?**

The study is motivated by the findings obtained from the original Rubber Hand Illusion experiment [15], as well as the more recent extensions using the technology of Virtual Reality [49], or Augmented Reality [73]. The main interest, therefore, lies in investigating the capabilities of the continuously evolving technology of VR in combination to the already known illusions that the human brain can experience. It is expected that the knowledge gathered within the context of the current work will serve as a meaningful addition to the already existing research body within the field.

3.2 Requirements

To be able to answer the previously enunciated questions, the research group assumes that the following requirements must be fulfilled:

- The technology of choice for representing the experience must be Virtual Reality. (resulting from section 2.4)
- The cardiac activity data must be collected using a real-time tracking device. (resulting from section 2.1)
- The experiment must include three conditions: (1) synchronized heart activity, (2) manipulated heart activity, and (3) random heart activity. The input for (2) must represent an upscaling and a downscaling of the data coming for (1). (resulting from 2.4)
- The designed VE must allow the user to view his/her avatar, including the heart. (resulting from 2.4)
- The VE must include the instruments used to measure the Sense of Embodiment, as well as Interoceptive Sensitivity. (resulting from sections 2.2, and 2.3)
- The developed prototype should log the participants' answers to the questionnaires, as well as both the real, and the manipulated heart activity metrics. (resulting from section 2.4)

CHAPTER 4

Methods

To be able to answer the previously formulated research questions, an experiment must be designed, which would include the three mentioned conditions, and which must take into account the requirements outlined in the previous chapter. The current section, at the same time, will represent a comprehensive description of the entire evaluation procedure, starting with the theoretical reasoning behind the research questions, the instruments used to collect the needed metrics, and ending with a detailed description of the software, hardware, and physical setting used to perform the experiment, as well as how the gathered raw data will be converted into meaningful insights.

4.1 Study Design

The previously established research questions represent the starting point for the design of the current study, together with the metrics and procedures used in the similar work, described in the Analysis section, which provide inspiration, and allow the research group to use elements of experimental set up which were tested by other practitioners. Another critical factor is the available time-frame, and resources that are at hand, which might lead to reducing the complexity of the study. Nonetheless, all skipped elements will be documented in the Limitations, and Future Work sections, allowing the reader to get an idea of what the study might have looked like in a perfect scenario.

Due to the existing time constraints, the low likelihood that the findings could be negatively influenced by random noise, as well as the assumption that the activity of the heart would not be affected by the sequence of the conditions, it was decided to proceed with a **within-subject experiment**. Therefore, the study consists of one independent variable - the activity of the heart represented by Heart Rate, and it is split in three conditions:

- Synchronized Heart Rate
- Upscaled and/or Downscaled Heart Rate
- Random Heart Rate

Since the current study is attempting to investigate whether or not visual cardio feedback affects the Sense of Embodiment, as well as the real activity of the heart, it was decided to employ the three conditions mentioned earlier with the following specifications:

- **Synchronized Heart Rate**
  The input for the animation of the virtual heart would be unmodified real-time value provided by the Empatica E4 wristband.

- **Manipulated Heart Rate**
  The input for the animation of the virtual heart would consist of real-time input from the Empatica E4 wristband down-scaled by 20 beats per minute for one half of the condition, and by it being up-scaled by 20 beats per minute for the other. The sequence of the modifications would be reversed for half of the participants, i.e., the first half of the participants would start with the visual feedback being up-scaled in the first half, then down-scaled in the second half, while the second half would start with it being down-scaled, then up-scaled.

- **Random Heart Rate**
  The input for the current animation is provided by a function that returns a random value between the range of 60 and 120.

After each condition, the research group is attempting to measure the Sense of Embodiment of the virtual heart, the interoceptive sensitivity, as well as the changes in the activity of the real heart during the condition in which the heart rate is manipulated. To measure the Sense of Embodiment, an adapted version of the Virtual Embodiment Questionnaire, initially proposed by Roth and Latoschik [59] is used. As illustrated in Appendix 1, the questionnaire was adapted to measure the embodiment of the virtual heart, i.e., the term "body" was replaced by "heart", while the Change section of the questionnaire was eliminated, due to it not being realistic for human beings to notice the heart changes the section is trying to assess (e.g., weight, appearance). At the same time, to measure the interoceptive sensitivty experienced by each participant, a question from the questionnaire leveraged by Suzuki et al. [73] is used. Lastly, in the manipulated Heart Rate condition, apart from logging the manipulated heart rate used for the manipulation, the research group decided to log the unmodified values, which would allow for an assessment of the extent to which the real activity of the heart can be affected.

4.2 Sampling

To gather the data required for answering the previously mentioned research questions by employing the study design described in the previous section, it was decided to use non-probability convenience sampling [11]. This represents an effective way of recruiting participants, with little impact on the quality of the data. The main area from which participants will be recruited is Aalborg University, Copenhagen, with a focus on the Multisensory Experience Lab. Before starting the experiment, each participant will be introduced to the project, followed by them being presented with a consent form. The goal for the current study is to evaluate it on approximately 20 people, which is how many people the study performed by Suzuki et al. [73] employed.

4.3 Experimental Setup

The current section will introduce the reader to the set up used to perform the current experiment, including the hardware, and software products used, the space in which the study will be tested, as well as the illumination requirements, and the role of each group member during the procedure.

To facilitate the experiment, it was decided to use the Oculus Quest 2 Headset [48], due to its hand tracking capabilities, which would allow for a more natural interaction with the Virtual Environment, as well as the non-problematic availability of the device. Next, to track the participants heart activity, it was decided to use the Empatica E4 wristband [29], due to it being preferred among practitioners, as well as the integration with the Unity game engine, which, through an API, allowed the research group to extract the real-time heart rate, and sent it to Unity to serve as basis for the animation. To run the project, an i7, MSI stationary computer, with a Nvidia RTX2080 Super graphics card will be provided by the lab to be used throughout the duration of the study.

The software used to develop and run the study, as it was alluded in the previous paragraph, was the most recent version of Unity3D, according to the start of the development process - version 2021.2.10 [84]. Correspondingly, the latest software version of the Empatica E4 Manager - v2.0.3.5119 [31] - will be used, to facilitate the functioning of the device, as well as integration to Unity.

Due to the high required simplicity of the set up, the testing space will not have any special requirements. Therefore, an area in the lab or the adjacent rooms will be used. The requirements, however, for the space is to have a decent illumination level, as it is required for an accurate tracking for the Oculus Quest 2 headset, as well as a desk and a chair, used to place the hardware, and allow the participant to sit down throughout the experience. At the same time, due to an external opportunity, the test will also be performed within Novo Nordisk, where a room for testing, as well as a screen will be facilitated by the company.

To ensure a smooth recruiting and testing process, the two members of the group will have two specific roles, which will be rotated: one member will be recruiting participants, trying to find students/lab researchers interested in the project, while the other member will ensure a smooth on-boarding to the testing procedure, as well as support throughout the entire experience. To reduce the amount of distractions, the noise level will be minimized, allowing the participants of the study to focus on the animation of the pulsing heart within he Virtual Environment.

4.4 Procedures and Measures

This section consists of a detailed presentation of the evaluation process, including the metrics to be gathered, as well as the reasoning behind choosing each element.

The first step in recruiting participants is introducing them to the goal of the project, to make sure they are fully aware of what the procedure will consist of. The presentation will have a standardized form, as specified in the test plan attached as Appendix 2. Despite slight deviations from the script are allowed, it is recommended to follow it to the maximum extent possible, to ensure consistency among the information the participants receive. In case any questions arise about the goal of the project, or testing procedure, the research group should be prepared to provide an accurate answer.

Next, each participant will be introduced to a consent form, used to specify in detail the most essential aspects of the study (e.g., how the results will be treated, that the participation in the study is voluntary). At the same time, it acts as a check point to ensure that the research group does not miss any important steps (e.g., fully informing the participant about the goal of the study, as well as the procedure). Both the consent form, as well as the pre-questionnaire will be presented to the participants in the style of a Google Form.

To get a better understanding of the sample, a pre-questionnaire will be used. This will ensure that the research group has a brief understanding of each participant's age, gender, and occupation. More than that, to have a starting point for the conversation on interoceptive sensitivity, a Likert item regarding their familiarity with their own resting heart rate will be presented.

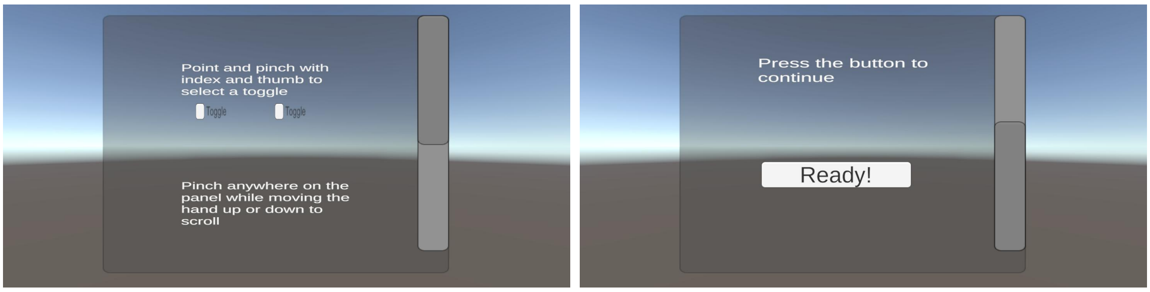

Figure 4.1: The task that the participants will be faced with when entering the VE. On the left, one can see the two instructions, while the right screenshot shows the view of the panel when the participant scrolls down.

The next step will consist of introducing the participants to the set up, asking them to put on the Empatica E4 wristband on their left hand, followed by setting up the Oculus Quest 2 headset. Each participant will be assisted in putting on the devices, to ensure maximum comfort, as well as a smooth execution of the experimental procedure. Once present in the VE, the participants will be faced with a task, which has as a goal to introduce them to how they can rank the Likert items in the questionnaires presented afterwards, along with how to navigate through them. Once ready, the participants will be guided to press on the corresponding button.

The next step is randomizing the order of the three conditions which the participants will be exposed to. It was decided to set the exposure to each condition to 120 seconds, as compared to 210 seconds in the study performed by Suzuki et al. [73], due to the lower number of elements involved in the exposure. During this time, the participants were instructed to focus on the activity of the virtual heart they could see reflected in the mirror in front of them.

After each condition, the participants were asked to fill out the adapted form of the VEQ, along with the item examining the intoreceptive sensitivity. To reduce the complexity of the procedure, and reduce the confusion among the participants, it was decided to combine the two elements, instead of presenting them as two different questionnaires. The data gathered would be used to calculate the total score for the participant's Sense of Embodiment, as well as give the research group an estimate of their interoceptive sensitivity. Once the participants were exposed to all three conditions, and completed the corresponding questionnaires, the Virtual Experience would end, and the participants would be asked to take off the hardware.

Once they have taken the headset and wristband off, the participants would be asked to fill out a post-questionnaire, allowing the research group to understand what are the general impressions after the experience. At the same time, an important point is to understand what strategies they used to detect whether or not the virtual heart was beating in sync with their own heart. Once completed, the research group will express their gratitude for taking part in the experiment. The entire procedure is expected to last between 12 and 15 minutes.

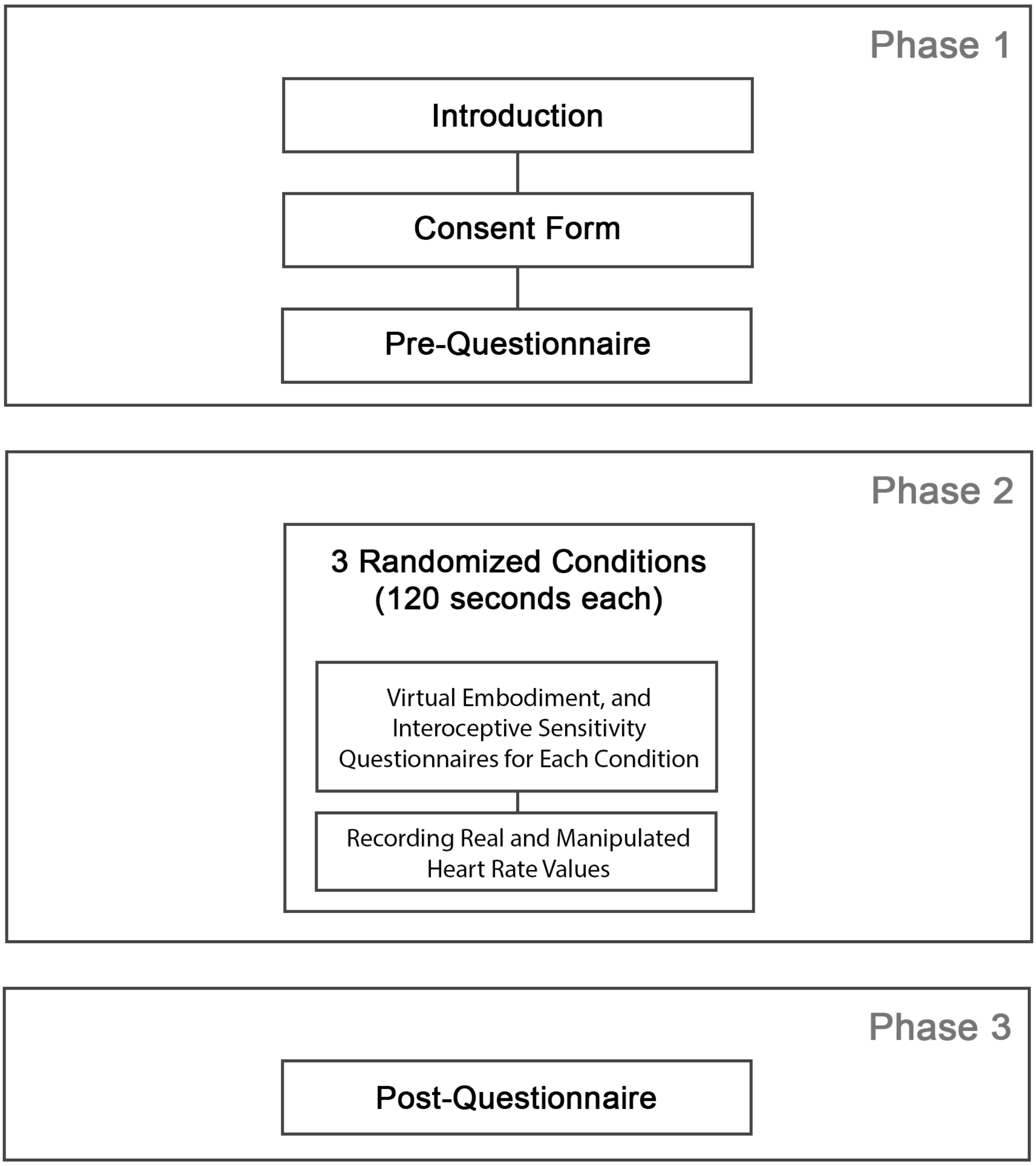

Figure 4.2: A visual overview of the evaluation procedure.

4.5 Data Analysis

Once the raw data has been gathered, it needs to be analyzed, and converted into meaningful insights, allowing the research group to answer the previously established research questions. The current section will introduce the reader to the procedure used to analyze the data. It will be structured according to the data gathered:

- **Pre-Questionnaire**
  Tools used: Excel, and MATLAB
  The data gathered using the pre-questionnaire will include: age, gender, occupation, whether or not they tried VR before, and familiarity with their resting heart rates.
  For age, and familiarity with their resting heart rate, the means of the values will be found, along with the standard deviations. When it comes to gender, and occupation, and whether or not they tried VR, the numerical summary of the results will be provided.

- **Sense of Embodiment**

Tools used: MATLAB
Since the original VEQ questionnaire was adapted to fit the purposes of the current study, some Likert items were removed, resulting in it being impossible to calculate all the sub-scores defined by the authors of the study. However, the scores for one numerically intact category (Control/Agency) will be calculated according to the original instructions, i.e., generating the mean. At the same time the total embodiment score will be calculated as the average of all the scores obtained in the SoE section of the questionnaire.

- **Interoceptive Sensitivity**
  Tools used: MATLAB
  The current part includes one binary question, followed by three Likert items. Therefore, a numerical summary for the binary question will be provided, while the total score will be calculated, similarly to SoE, as the average of the obtained values.

- **The Influence of Being Exposed to Visually Manipulated Heart Activity**

  Since the data will consist of the reports generated from Unity, containing the information extracted from the Empatica E4 wristband, it will be, first of all, pre-processed. Part of the pre-processing will be converting the date-time fields to be able to numerically process them. Next, the data will be filtered, to leave only the heart rate values, and the time stamp. Once done, the data will be split based on the order of the manipulations:

  1. Upscaled first, then downscaled
  2. Downscaled first, then upscaled

  Next, the data will be split according to the order of the manipulations, resulting in 4 categories:

  – Order 1: Upscaled
  – Order 1: Downscaled
  – Order 2: Downscaled
  – Order 3: Upscaled

  For each category, the first, and last 20 seconds intervals will be extracted, followed by calculating the mean, and standard deviation for each. To check if the data is normally distributed, the Jarque-Bera test [75] will be used. If the data will be normally distributed, a t-test [58] will be employed, to identify whether or not the obtained differences are statistically significant.

- **Post-Questionnaire**
  The post-questionnaire will provide the research group with: a score for the overall impression of the experience, as well as elaboration on it, and a binary question on whether or not the participants used any strategies to detect if the virtual heart was in sync with their own heart, followed by an optional elaboration.
  For overall impression, the mean, and standard deviation will be calculated, while the elaboration will be analyzed and presented using axial coding [64]. The answers for the binary question will be represented as a numerical summary, and axial coding will be applied again to represent the qualitative data.

4.6 Conclusion

To sum up, the current section introduced the reader to the methods leveraged to run the study, starting from its general design, followed a description of who will take part in it, what hardware and software will be used, as well as the exact experimental set up, and the measures mentioned, together with how they will be analyzed.

CHAPTER 5

Design and Implementation

This section introduces a summary of most important parts of application design which is closely tied to the experimental design, the requirements, along with implementation: how the data was extracted from the Empatica E4 wristband [29], the questionnaire incorporated within the VE, and the overall system flow.

5.1 Design

To support the experimental design's purpose, the attention should be focused on the virtual heart. To accomplish this, it was decided that the bare minimum is going to be displayed in terms of visuals inside the VE. The following elements will be discussed that make up the VE of the experiment: the avatar from head to torso, since a seated position will be taken, the mirror, the ground platform, the questionnaire, and basic lighting, to ensure a clear representation of all the other elements.

The avatar represents a generic humanoid, with visual features that do not stand out. It was built using "MakeHuman" [37] - a free open source software that allows for customizing a number of features. In Unity, the avatar was made transparent, to display the heart inside the chest, as well as to make it look even more generic. This is due to the high number of people who would take part in the study, and customizing the avatar for each participant would represent an impossible task in itself. To give a sense of ownership, and to reduce co-location conflicts, the avatar's head mimics the movement of the headset, while the virtual hands follow the real hands. With the help of Unity's IK (Inverse Kinematics), the whole arm is manipulated according to the hand. Since the participants are meant to be sat down, while there is no easy way to track the position of the legs, it was opted to skip displaying any virtual legs. The heart model with pre-made animation was purchased from Sketchfab [66]. It was decided to use a close representation of what heart organ looks like, even if normally a person cannot see their heart. However, it is assumed that all the participants will feel associated to it.

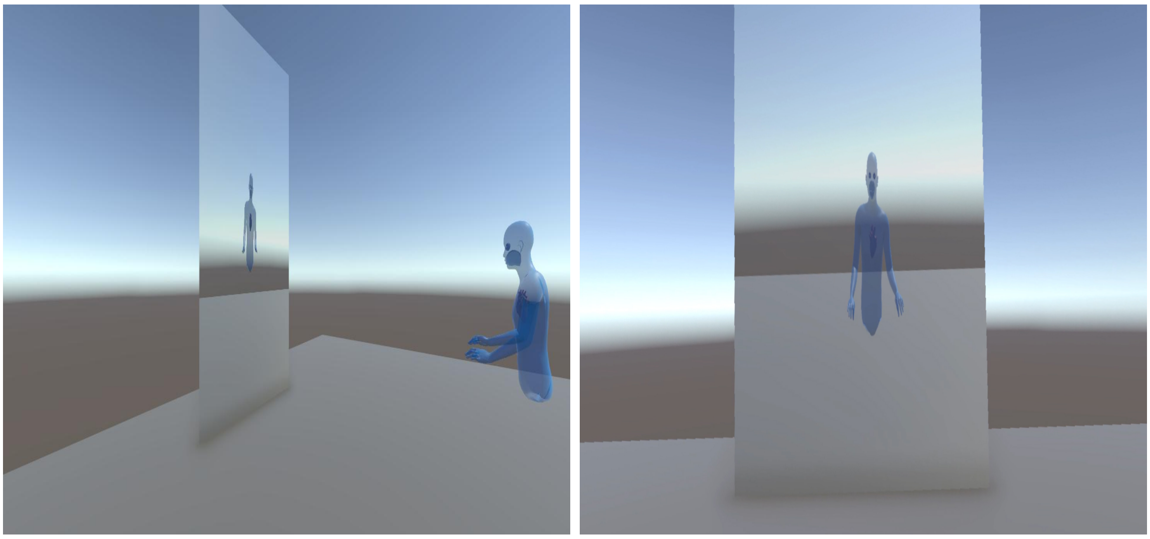

Figure 5.1: Avatar in front of the mirror caption

The environment itself included a simple mirror, to ensure that the heart is clearly visible, as well as the ground collider, to ensure that the environment is not floating in the air. Lastly, it included enough light to avoid hindrance in seeing all of those elements, along with the questionnaire after each condition. The questionnaire's interface was directly taken on how hand tracking interfaces are done with Oculus menus, and apps. The visuals themselves were the default Unity's User Interface, with color customization. It was decided to use the hand tracking interface, since it is robust enough, while also allowing for the participants to simply use their hand to answer the questionnaire, instead of having to pick up the controllers every time. After running a couple of tests, it was decided to use simple toggles for each question, as it only needs to be pressed while being visually obvious which toggle means what, and which of the toggles are already selected. The other item is a button to be pressed when the participants feel like they have finished answering all the questions. A safe system was also in place, which would not allow the participant to progress, unless all questions were answered. In total, there were 13 questions after each condition. To fit them all in one form, it was decided to utilize scrolling. As mentioned earlier, it was copied from the Oculus interfaces, i.e., clicking anywhere on the window, while moving the hand itself up or down, will engage easy scrolling.

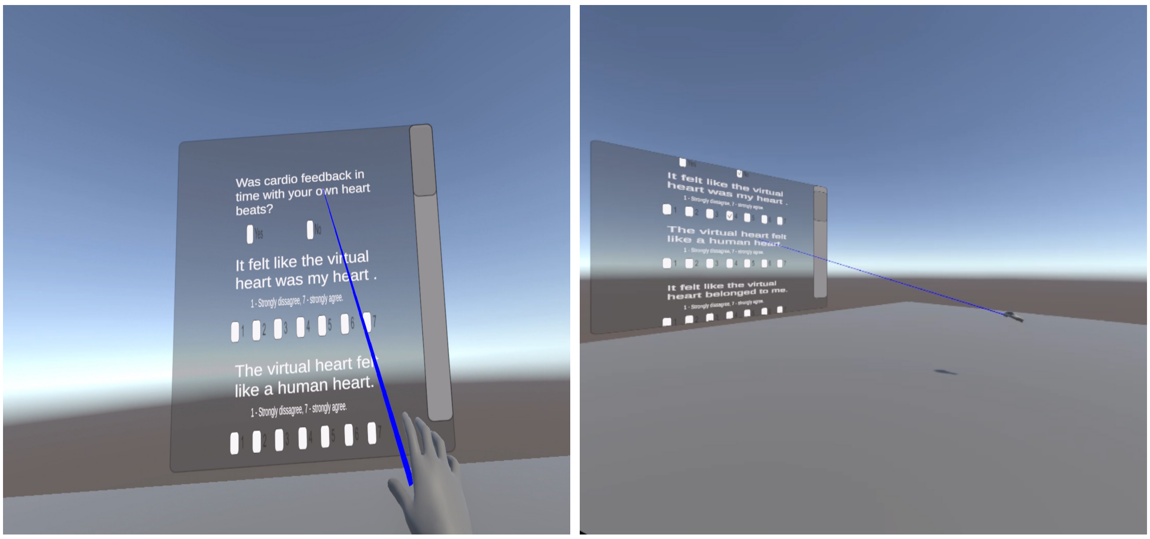

Figure 5.2: Questionnaire caption

5.2 Implementation

The following second will introduce the reader to the documentation of the most important parts of the implementation. It will start with explaining the overall systems in terms of states, and how best Unity practices were used to build the foundation. At the same time, the other features will be described more thoroughly: how the Empatica E4 wristband was integrated with Unity, matching the real movements with the avatar, and the questionnaire's interface.

The system was designed in a way to be fully independent, i.e., it would require little to none input from the research group when running the study. The following states and what the system should do when entering a particular one is illustrated in figure 5.3. Shortly, the system has four states, when it is started, everything is prepared and the system is on hold for the participants input prompting to begin, which is when it enters condition state, enabling all the necessary elements until the predetermined amount of time runs out, then moving to questionnaire state. When the form is filled, and submitted, it will enter another condition. Once the last questionnaire has been submitted, the application is shut down.

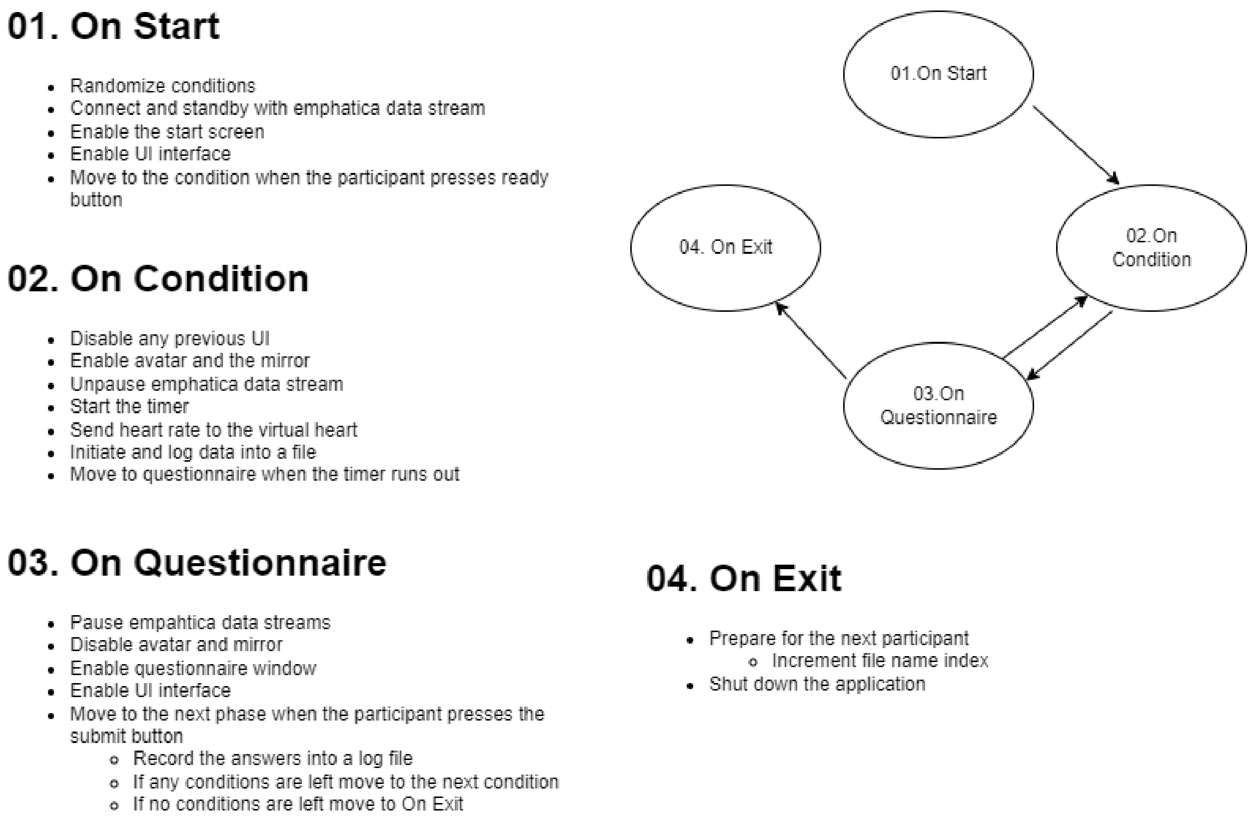

Figure 5.3: Life cycle diagram of the system.

The backbone of the system consists of the so-called scriptable objects, which act like data containers inside project files, easily referenced by objects living in the scene, but not directly affected by them. Unity's open project [83] use them as data relays, to signal and transmit data when needed, removing in scene dependencies, which are the usual suspects for bugs, and other issues. The event system was inspired directly from the open project [83], and the principal idea is that data signals are broadcasted from one game object, and all the listeners that attached to this specific event will respond in their own unique way, as illustrated in 5.4.

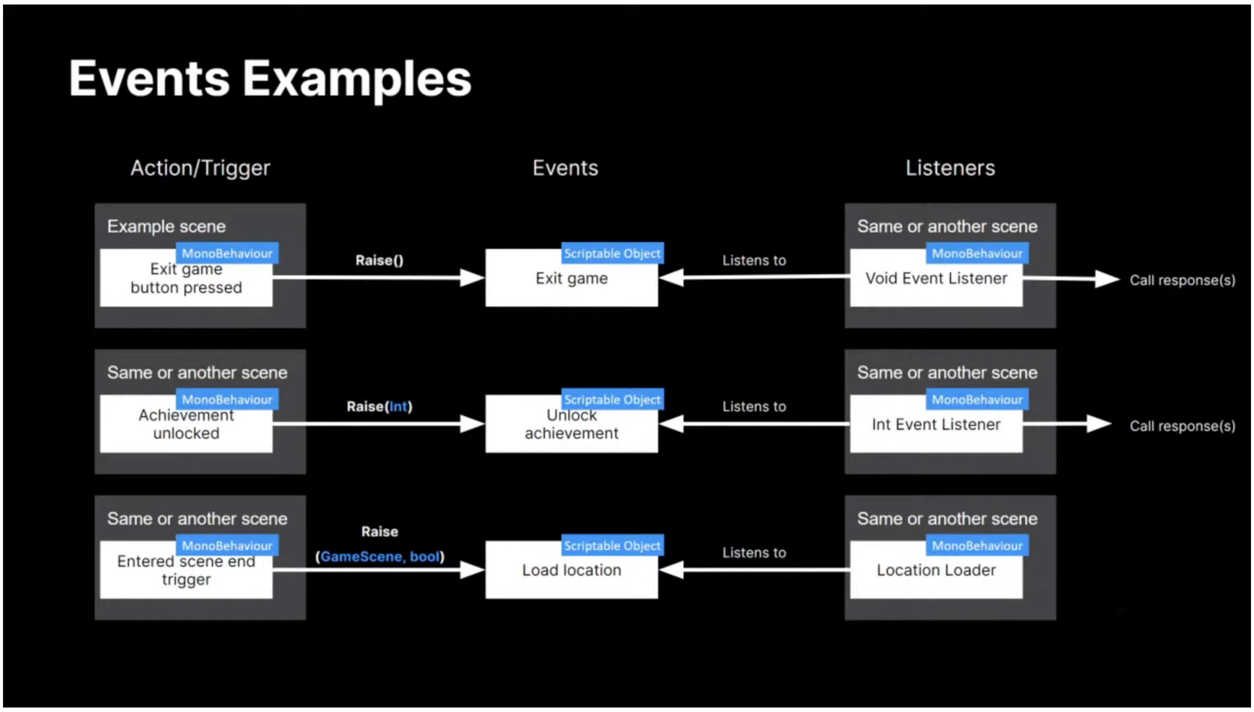

Figure 5.4: Event system diagram [83]

The conditions in the system are defined and recognized as numbers:

- 0 - Synchronized
- 1 - manipulated (Random)
- 2 - Manipulated

This list of numbers is then randomized with Fisher-Yates shuffle algorithm [89], along with the index, which is incremented after each condition. All of these are stored in a custom scriptable object. The implementation for the integration with Empatica is heavily inspired from an online resource [25], made available from Saha et al. [60] work. The wristband provides a way to connect wirelessly to a PC, and stream the data trough a local server. In Unity, it is is simply required to have to access it as a client that sends, and receives messages to that server. For that purpose alone, it is started with a class that handles the TCP connection (appendix 4). Another class, Empatica Manager(appendix 5), which is a mono-behaviour class, is meant to be executed as an instance of a running scene, i.e., it has to be bound to a game object, create an instance of the TCP connection, then automatically establish the connection to the Empatica wristband. The following figure 5.5 is a graphical representation of how the connection looks like.

Protocol Example

Please find below an example of messages exchange between client and server during a brief acquisition session.

```
[OPEN TCP CONNECTION]
==> server_status
<== R server_status OK

==> device_list
<== R device_list 2 | 9ff167 Empatica E4 available | 7a3166 Empatica E4 available

==> device_connect ffffff
<== R device_connect ERR the requested device is not available

==> device_connect 9ff167
<== R device_connect OK

==> device_subscribe bvp ON
<== R device_subscribe bvp OK

<== B 123345627891.123 3.212
<== B 123345627891.327 10.423
<== B 123345627891.472 12.665

==> device_disconnect
<== R device_disconnect OK
[EOF]
```

Figure 5.5: Typical Empatica connection procedure [30]

The Empatica Manager class has other two significant functions, controlling the heart model animation, and logging required data into log csv files. Depending on the condition, it will send either the heart rate as it is, or, in case of it being manipulated, the altered version. To manipulate the heart rate, the Unity animation curve was employed [81], where the horizontal axis represents time, and the vertical determines if the value will be reduced or increased, as represented in figure 6.3. Next, it is amplified with a specific scalar, and summed up with the raw heart rate signal, which is received from the Empatica wristband. In the case of the asynchronized condition, the actual heart rate is completely bypassed. Instead, a random number from a predetermined range is sent every time the heart signal is received from the Empatica data stream.

Figure 5.6: The Manipulation curve, the horizontal axis - time (0 to duration of the condition, mapped 0 to 1), and the vertical axis, representing what the value should be, in accordance to time.

Logging is handled by another helper class named csv tool (appendix 6), which takes care of initiation of the file in a specified location with the desired naming, and simple functions to write the pending data. Participant index used to name the files is stored in a scriptable object, and is automatically incremented for each participant. Simultaneously, a timer (appendix 7) mono behaviour class counts down the set time amount. When it runs out it prompts the system to make changes and assume the following state.

For the avatar movement, a tutorial was used as a base [19]. It utilizes the Unity's animation rigging package [79] to set up specific constraints that are used to map the headset, and the hand movement to the avatar with the help of a mono behaviour class avatar manager (appendix 8). On the side of Oculus hardware, everything is taken care by the native integration package [82]. The package also includes pre-made solution for interfacing with Unity's User Interface system. The only difficulty encountered was getting the right direction on the selection line drawn, as it required to apply a small workaround [80].

The virtual questionnaire was built from standard Unity UI elements. The participants would select their answer to the question with toggles, and each toggle belongs to a group, i.e., only one toggle per group is allowed to be selected. To manage the questionnaire state, a mono behaviour class named Q manager (appendix 9) was created. Every time a toggle is selected, it checks if every question was answered, and, in case it is, a button is unlocked, pressing which will submit the answers, and trigger through the event system to continue to the next corresponding state. Logging the answers is done in the same way as the Empatica data is logged. The game objects were purposefully named according to their meaning in the questionnaire so that only their names have to be collected and appended to the file.

5.3 Conclusion

That concludes design and implementation chapter. The limitations encountered during this stage of the project will be mentioned in the limitations section, and all the remaining scripts that were not mentioned here are available in the appendix. Before the study was initiated on real participants, several pilot tests were taken. Only slight adjustments needed be made, due to the naming conventions used in a different machine from the one this system was developed, which helped the research group to keep the format of the logged data intact.

CHAPTER 6

Evaluation

After the experiment data has been successfully gathered, the next step towards answering the previously established research questions consists of processing it, to convert the raw data into meaningful insights. Within the context of the current work, the most essential elements are the data required to determine the total score for the Sense of Embodiment experienced by each participant, as well as both the raw and the manipulated heart rate values, used to find out whether or not the manipulated visual feedback can influence the real cardiac activity of the participants.

Not less important, the aforementioned pre, and post-questionnaires will serve as a basis for determining who took part in the experiment, what is their background, as well as how the experience was perceived. One important element that the research group is expecting to discover from analyzing the data is whether or not the participants used any strategies to identify if the heart rate they witnessed in the animation was in sync with their own heart rates. The findings from this last part would open the window for better understanding the techniques that can be used to detect the manipulations, which can serve as basis for further research.

6.1 Results

The experiment took place between the 9th and the 13th of May. During the first day, the research group evaluated the prototype on 4 employees from Novo Nordisk, at the company's facilities in Bagsværd. During the rest of the period, the main place used for testing was the Multisensory Experience Lab from Aalborg University, Denmark. A slight deviation, which caused a delay in evaluating the prototype on more participants was an unforeseen error with the Empatica E4 wristband, which restricted the research group from being able to collect the cardiac activity metrics for two days. During the entire procedure, the research group took the necessary precautions to prevent the spread of the almost-forgotten Covid-19 virus (e.g., keeping distance from the test participants, disinfecting the hardware between uses).

6.1.1 Participants

The total number of participants in the experiment was 20 (18 males; 2 females). However, the report generated for Participant 17 did not include the complete logs from the Empatica E4 wristband, because of unknown causes. Therefore, all of the results from this point will not include the corresponding participant, leaving the total number of participants to 19. The average age of the participants is 26.6 (SD = 3.68), while the most common occupation reported is students (14 participants). Out of 19 respondents, only 3 had never tried Virtual Reality. When asked about their familiarity with their own resting heart rate, the average score was 4.15 (SD = 1.92), on a scale from 1 to 7 (1 - Very Unfamiliar; 7 - Very Familiar).

6.1.2 Sense of Embodiment

As the original questionnaire for measuring the Sense of Embodiment in VR, developed by Roth and Latoschik [59], was modified, it was not possible to directly apply all the formulas for calculating the total score, as well as some two of the sub-scores. Nevertheless, the sub-score for Control/Agency can be calculated, and the formula used to find it will be the same as suggested by the original work, i.e., finding the average of the scores.

After processing the data, the following results were calculated for each condition:

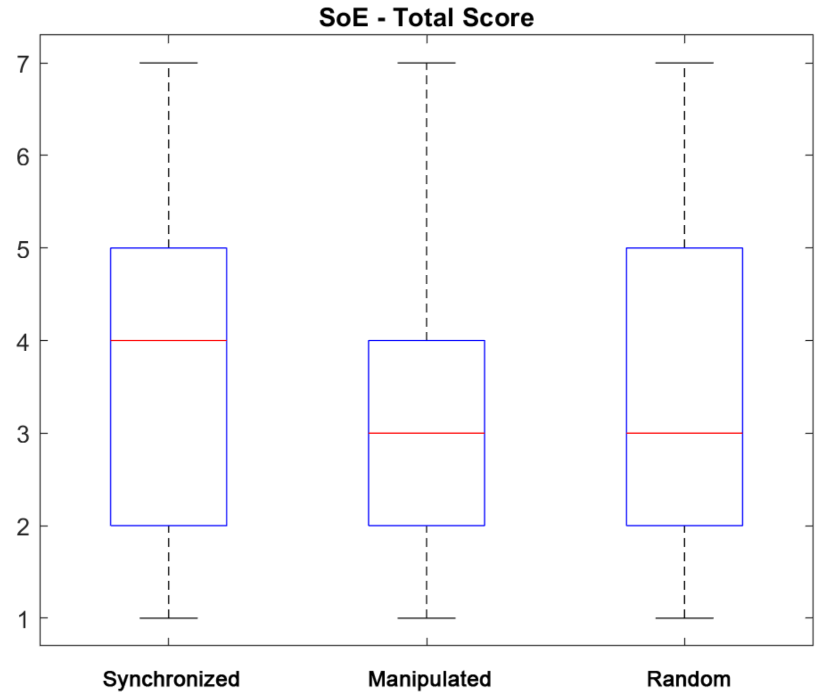

Figure 6.1: The total score for the Sense of Embodiment for each condition. Synchronized: 3.70 out of 7 (SD = 0.91); manipulated: 3.0 out of 7 (SD = 0.56); Random: 3.45 out of 7 (SD = 0.64).

Despite the data was not found to be normally distributed, using the Friedman's ANOVA test [55], a statistical significance was identified at p = 0.015.

Next, the scores for the Control/Agency sub-scale were calculated:

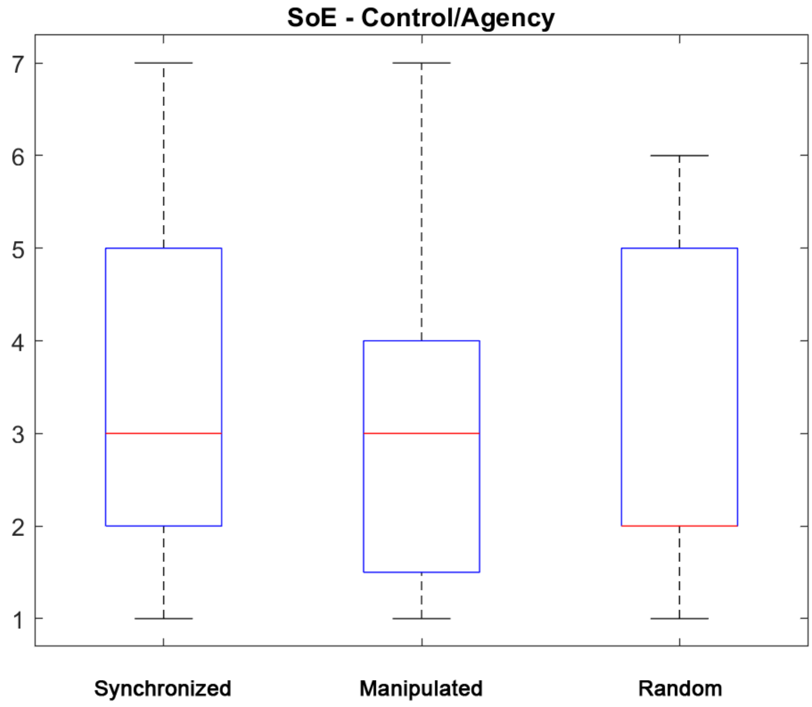

Figure 6.2: The score for Agency/Control sub-scale of the Sense of Embodiment for each condition. Synchronized: 3.81 out of 7 (SD = 0.91); Manipulated: 2.77 out of 7 (SD = 0.07); Random: 3.11 out of 7 (SD = 0.18).

Similarly to the total score, the data was not found to be normally distributed. Therefore, the same Friedman's ANOVA test [55] was used, which yielded a statistical significance at p = 0.029.

As it can be seen from the previous findings, the condition where the heart rate used to animate the virtual heart was in sync with the participant's real heart rate produced the highest scores for both Control/Agency (1.04 higher than manipulated Heart Rate, and 0.7 higher than Manipulated Heart Rate), as well as total embodiment (0.7 higher than manipulated Heart Rate, and 0.25 higher than Manipulated Heart Rate).

6.1.3 Interoceptive Sensitivity

At the same time, it was attempted to get an idea about the interoceptive sensitivity experienced by the participants in each condition. It was decided to apply the same logic as in the previous step, i.e., calculate the averages for each condition. On top of that, there was a binary question, and the answers will be summarized:

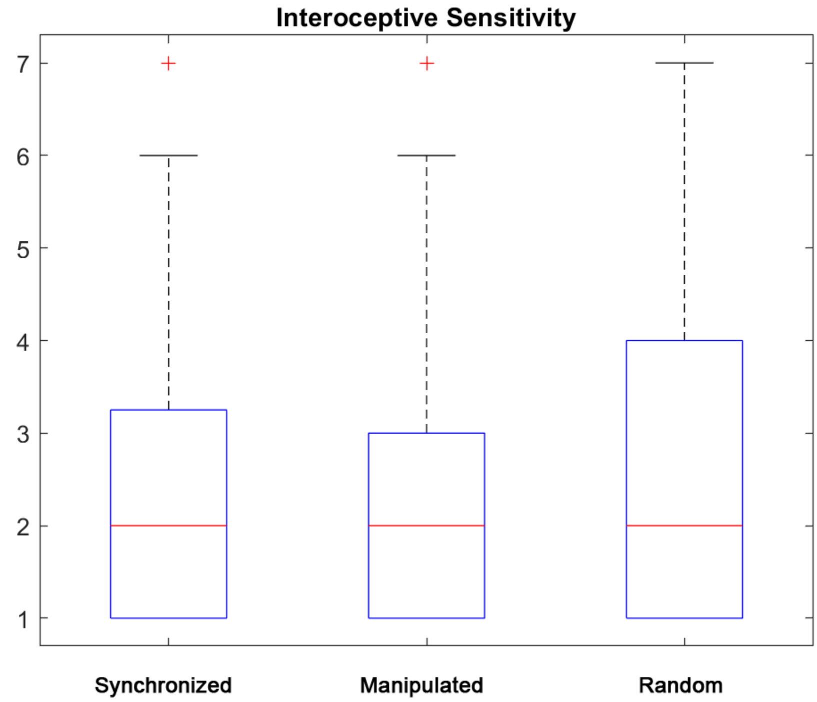

Figure 6.3: The score for Interoceptive Sensitivity for each condition. Synchronized: 2.40 out of 7 (SD = 0.70); Manipulated: 2.52 out of 7 (SD = 0.36); Random: 2.36 out of 7 (SD = 0.34).

After analyzing the data, it was not normally distributed, and no statistical significance was found, using the Friedman's ANOVA test [55], at $p = 0.69$.

When asked whether or not the heart beat of the virtual heart the participants were exposed to was in sync with their own heart beat, the following results were obtained:

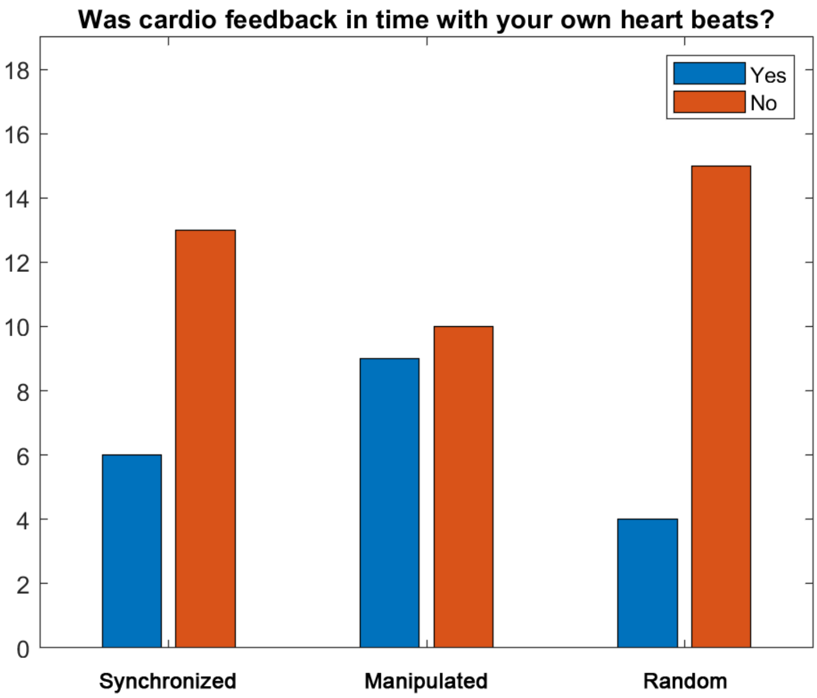

Figure 6.4: The data obtained from the question on whether the participants felt that the virtual heart they were exposed to was in sync with their own heart.

The first finding from the current section is the generally low scores for interoceptive sensitivity. The condition in which the heart rate was manipulated yielded the highest score for interoceptive sensitivty (0.16 higher than Manipulated Heart Rate, and 0.12 higher than Synchronized Heart Rate), while the binary question bring the Synchronized Heart Rate condition as the one found to be in sync with the participants heart beats (5 higher than Manipulated Heart Rate, and 3 higher than Random Heart Rate).

6.1.4 The Impact of Visual Manipulations Over the Activity of the Real Heart

The second main area of interest of the current study is examining whether or not exposing participants to a virtual heart which is beating slower and/or faster than their real heart can impact the activity of their real heart. Therefore, as mentioned earlier, each participant was exposed a condition in which the virtual heart was animated by the manipulated input from his/her heart. As seen from Figure 6.5, half of the participants had their heart rate amplified during the first minute of the exposure to the condition, and reduced during the second minute - this was reversed for the other half of the participants, which includes one participant less, due to a technical issue which did not allow for an accurate collection and logging of the data.

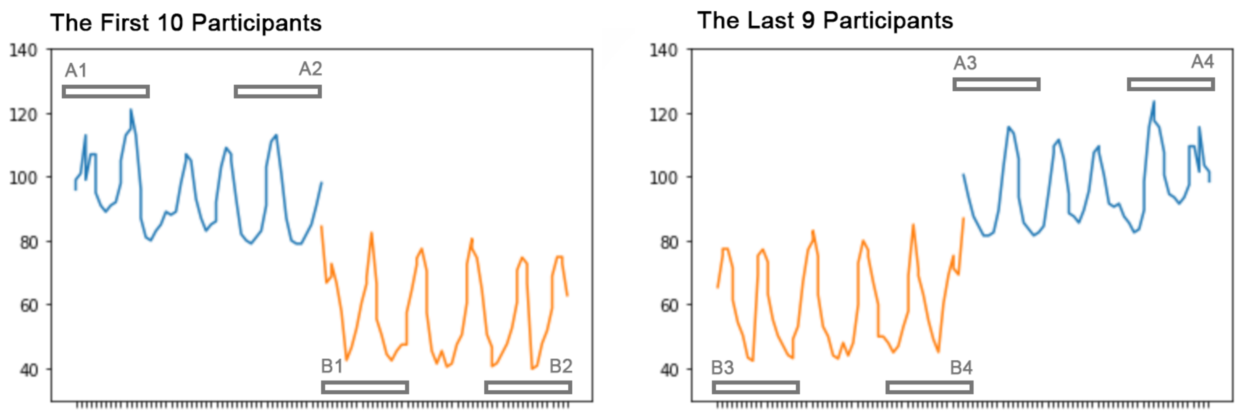

Figure 6.5: An illustration of the plotted heart rate used to animate the heart in the condition in which it was manipulated. On the left, an example of the heart rate being amplified during the first minute is shown, followed by it being reduced. This was applied for the first 10 participants, while the remaining of the test participants had the order of the manipulations reversed.

After running the data through the Jarque-Bera test [75] to detect if it comes from a population with a normal distribution, it was found that the data is normally distributed. Next, the mean for each interval was calculated, along with the standard deviation, as seen in the table bellow:

Interval	Mean	Standard Deviation
A1	78.1395	10.5036
A2	77.8117	10.4991
B3	72.8100	12.1823
B4	69.6324	12.8097
A3	75.6678	10.3065
A4	76.5305	9.6000
B1	69.8249	10.7520
B2	70.2876	11.4187

Figure 6.6: The calculated means, and standard deviations for the 20 second intervals containing heart rate values. A1 - A4 and B1 - B4 represent the 20 second intervals for each step analyzed.

Based the paired-sample t-test [58], it was found out that only the difference between B3 and B4 is statistically significant at the default 5% significance level, i.e., the participants' cardiac activity slowed down significantly, after viewing a heart that is beating with 20 beats slower than their own heart.

6.1.5 Post-Questionnaire

When asked to rate their overall impression of the experience on a scale from 1 to 7 (1 - I did not enjoy it at all; 7 - I enjoyed it very much), the participants provided a relatively high score: 5.05 (SD = 1.35). Next, the participants were asked to elaborate on why they chose the corresponding score. By applying a quick axial coding [64] exercise, it was found that the results could be categorized as it follows:

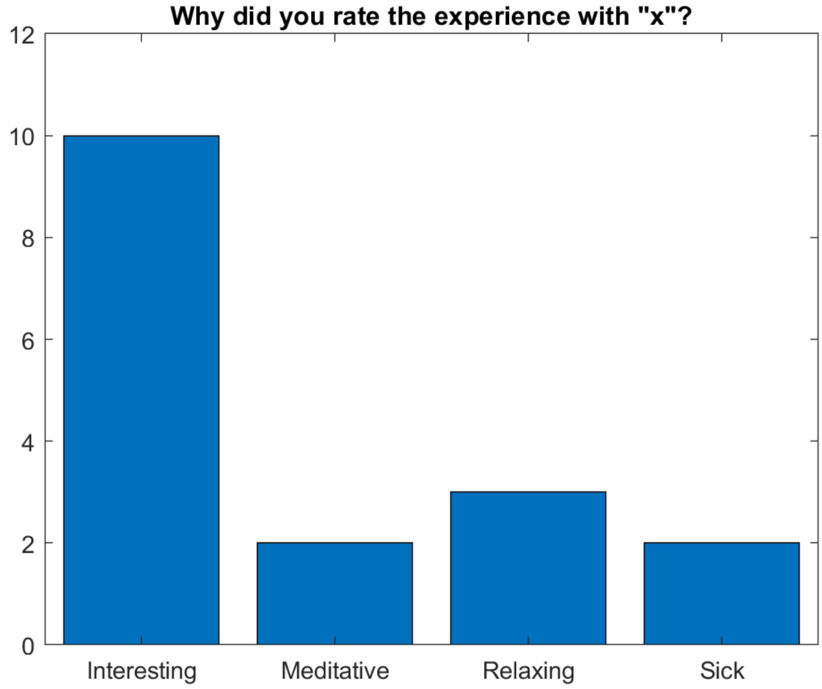

Figure 6.7: The categories describing how the subjects elaborated, when being asked why they rated the experience with the corresponding score.

As it can be seen, most participants found the experience to be either interesting, relaxing, or meditative. 2 participants felt sick: 1 due to hardware reasons, and 1 because the experience.

The next step consisted of finding out whether or not the participants used any strategies in detecting whether or not the virtual heart was in sync with their own heart beat. Out of 19 participants, 13 used some strategies, 5 did not, and 1 answered "Maybe". The participants who used strategies were further asked to elaborate and describe them. To summarize the findings, the axial coding technique [64] was applied again, yielding the following findings:

- Control the breathing, then checking how the virtual heart will act (e.g., breathing faster/slower, hold breath) - 7 Participants
- Could feel it (e.g., listening to the real heart, feeling it through ears) - 6 participants

6.1.6 Conclusion

To sum up, the current section presented an overview of the results obtained during the experiment. It started with a short overview of the time and place of conducting the study, as well as a description of the sample who took part in it. In total, the data from 19 people was valid to be used for the analysis. Next, the scores for Sense of Embodiment experienced by the participants was calculated, and represented, with the condition in which the heart rate was synchronized yielding superior results. When it comes to interoceptive sensitivity, the scores were relatively low, with the condition in which the heart rate was manipulated returning the highest score, while the binary question used to find out if the participants thought the virtual heart was in sync with their own heart beats bringing the condition in which the heart rate was synchronized to the top. The research group also investigated how displaying a different heart activity in the VE can impact the real heart rate, and the results showed a statistically significant difference for the condition in which the participants started with the heart being reduced, i.e., the participants' heart started beating slower (approximately, 3 beats per minute) shortly after being exposed to this condition. Lastly, the experience was perceived positively by the participants, being considered mostly interesting, and relaxing. Lastly, most of the participants (13) used a strategy for detecting whether or not the virtual heart was in sync with their own heart. Examples of the strategies used are: breathing faster, or slower, listening to the real heart, etc..

CHAPTER 7

Discussion

The current section will introduce the reader to the discussion based on the previously obtained results, after performing the experiment. At the same time, the findings will be described through the perspective of other projects which focused on topics that are closely related to the current work. At the same time, some limitations were encountered throughout the procedure, and they will be documented in close detail, to ensure transparency over the entire workflow. To prevent other researchers from stepping on the same mistakes, some of the limitations, as well as the authors' personal contributions will be formulated in the form of future work elements.

7.1 Findings

The purpose of the current work, which was later formulated in three research questions, was to assess the influence of exposing subjects to an avatar containing a virtual heart the activity of which is described by the three conditions of the study: (1) in synchrony with the participant's real heart rate, (2) manipulated (amplified, and/or reduced), and (3) random over the subjects' Sense of Embodiment, activity of the real heart, as well as Interoceptive Sensitivity. To answer the questions, the current experiment, which was described in details in Section 4 was designed, implemented, and tested on 19 participants. At the same time, the research group got inspired from the similar research [73], when it comes to the duration of the exposure for each condition, as well as the value by which the heart rate is amplified and/or reduced. In the study performed by Suzuki et al. [73], a 3.5 minute exposure is used, and a 30% increase/decrease for manipulating the heart activity. However, due to the slight differences between the studies, the values were adjusted. Therefore, instead of 3.5 minutes, as suggested by Suzuki et al. [73], the exposure to each condition within the current work was limited to 2 minutes, due to the lower number of factors involved in it (e.g., no physical stroking is required in the case of the current work), which reduce the complexity of the experience, as well as keeping in mind the goal of not providing a bad experience for the test subjects. At the same time, the previously mentioned study used the relative 30% value to amplify and/or reduce the heart rate values, while the research group decided to use a 20 beats decrease/increase, as it was intended to have the same value for everyone, instead of the relative approach.

As mentioned earlier, the study was tested on a sample of 19 participants, which was caused both by the time constraints, as well as the difficulties encountered with the Empatica E4 wristband. Therefore, even though the current results allow the research group to make some assumed conclusions, a much larger sample would be needed, to identify the implications in a more ecologically valid environment.

7.1.1 Sense of Embodiment

Starting from the Sense of Embodiment, as mentioned in section 6.2, the total scores for all three conditions were relatively low (3.45 to 3.70 out of 7). It can be assumed that this is caused by the the human body being fundamentally different in real life, i.e., the heart is not visible in real life. More than that, This can be explained by the discrepancy between the visual aspect of humans, and the aspect of the avatar used for the purpose of the study. At the same time, one important finding is that the condition in which the heart rate was synchronized yielded the highest score for the SoE, indicating its potential to be used in future similar studies. Next, looking at the Control/Agency sub-scale scores, it can be noticed that the condition in which the heart rate is synchronized is, once again, superiod to the others. Therefore, based on the results obtained from the current study, with the exact settings, it can be concluded that the synchronized visual feedback produces a higher Sense of Embodiment, as well as the sense of Control/Agency, more specifically.

7.1.2 Interoceptive Sensitivity

Next, the research group attempted to investigate how the previously mentioned condition affect the Interoceptive Sensitivity. Based on the data obtained, it can be said that the amount of participants who correctly answered whether virtual heart was in sync with their own hearts was the highest for the condition in which the heart rate was synchronized (9 out of 19, compared to 4, and 6 out of 19 for the other two conditions). However, when it comes to the score calculated based on the rankings from the Likert items, the condition in which the heart rate was amplified and/or reduced yielded the highest score for Interoceptive Sensitivity (0.12 higher than for the condition in which the heart rate was synchronized, and 0.16 for the condition in which it was reduced). The overall values are, however, generally low (2.36 - 2.52 out of 7). This, however, represents an area for further work, as there might a large number of causes that might lead to subjects not being able to have a high Interoceptive Sensitivity (e.g., the surroundings, the technology selected - VR).

7.1.3 The Impact of Visual Manipulations Over the Activity of the Real Heart

At the same time, the results indicated that exposing the subjects first to a heart that is beating by 20 beats per minute slower than the real heart of the participants can reduce their real heart rate by approximately 3 beats per minute. This was the only significant difference that was identified by the research group, which can have interesting implications for future work, as the technique could be used in scenarios where it is intended to reduce the real heart rate of subjects. The finding is interesting, due to the same downscaling now yielding the same results in the condition when it was applied in the second part of the exposure. The other two cases, when the heart rate was amplified, showed an increase only when it was performed in the second half of the exposure, even though the difference was not statistically significant. Even though the results present some value, a better case scenario would involve splitting the amplification, and reduction into two separate condition, to avoid the implications of their order of execution on the results.

Lastly, it was important to understand how the participants perceived the experience, which yielded a high score (5.05 out of 7), with many of them reporting that it was an interesting experience, and that the exposure was relaxing, or meditative. However, two participants felt sick, one of them due to technical issues, while the other due to the exposure to the environment. Even though the number is relatively low, it is important to research more, and understand the causes for them feeling sick in more detail. Also, it was found that most of the subjects used strategies to detect whether or not the virtual hearts were in sync with their own heart. These were: (1) trying to control the breathing rhythm to see if the virtual heart will change its activity, or (2) trying to feel their own pulse, by listening to their real heart, or feeling it through the ears. The research group considers these findings to be of high value for understanding how subjects try to track the activity of their heart within VR.

7.2 Limitations

As mentioned in the last section, even though the study was performed, yielding raw data which was then converted into meaningful insights, the research group encountered some limitations. Describing these limitations represents an important step, as it puts the findings in a context, as well as allows other researchers to avoid the same mistakes as the research group. Due to the the issues to be addressed in the current sections coming from different categories, it was decided to group them. Therefore, the limitations of the current study will be split into: (1) Procedural, and (2) Hardware Limitations. At the same time, the limitations will be converted into future work elements, which will be described in the next section.

7.2.1 Procedural Limitations

Due to the existing time constraints, the research group had to take some decisions, which would allow a good execution of the procedure in good time. However, some of them have impacted the project, and, therefore, they will be described as it follows.

As it can be seen from the previously presented results, the order of the introduced manipulation impacts the effect over the real cardiac activity, i.e., the effect of reducing the heart rate of the virtual heart on the real cardiac activity was different based on the sequence in which the manipulation was introduced. Therefore, even though there was a statistically significant decrease in heart rate when reducing it before its amplification, and an increase, even though insignificant, in the heart activity was recorded in the opposite case. The results might have been affected by the carry-over effect of each condition.

Another limitation was the absence of the condition where no virtual cardiac activity was represented. This did not allow the research group to have a baseline value for both the SoE, nor for the Interoceptive Sensitivity. Therefore, even though the findings suggest that the synchronized virtual heart activity can impact the SoE, as well as Interoceptive Sensitivity, it is still unclear how these values differ from seeing no virtual heart, at all.

7.2.2 Hardware Limtiations

At the same time, the research group identified some technical limitations, which prevented the study from being fully executed based on the previously defined plan.

The first limitation consisted in the Empatica E4 wrist band's reliability, and flexibility. Despite the device is non-intrusive, easy to install, with good integration capabilities to other interface, it does not allow for a precise identification of the time when an event occurred (e.g., a heart beat). Therefore, it was assumed that there was a slight discrepancy between when the actual heart beat took place and when it was displayed through the means of the virtual heart. Therefore, the hardware did not allow the research group to display the activity of the virtual heart in complete synchrony with the subjects' heart rates.

Another limitation was the high sensitivity of the wristband, i.e., even a slight movement of the hand on which it is installed would result in a gap where the heart rate values would not be updated, displaying one continuous value. This limitation has clearly influenced the results, as some of the data might be distorted, due to some subjects moving their arms slightly, even though they were instructed not to.

At the same time, the headset used within the scope of the study is highly sensitive to light, i.e., its tracking system performs better in a well-illuminated room, compared to one in which the illumination level is lower. Therefore, due to the unavailability of the same room for performing the experiment for the entire duration of the study, the research group moved to a different room, which had a different lightning set up. This resulted in the tracking system working differently, making some participants unable to rate the Likert items due to the "pinch" movement not being correctly detected.

7.3 Future Work

As stated earlier, the aforementioned limitations can become elements of future work, which would increase the validity of the current study, and would provide even more ecologically valid results. Therefore, the current section will represent a glimpse into what the research group considers to be an improved experiment.

Based on the first limitation mentioned in the previous section, it is recommended that the procedure of the current study is adjusted, so that amplifying and reducing the heart rate of the virtual heart is split into two separate conditions. This would allow for a more valid comparison, reducing the probability of the data being affected by the sequence of their immediate execution. At the same time, another condition should be added, in which no virtual heart is displayed, allowing the research group to have a baseline for comparing the metrics. This would allow for an investigation into how displaying the heart can affect the SoE, and Interoceptive Sensitivity, instead of just the three ways in which the virtual heart is pulsing.

At the same time, the practitioners working on the same category of projects are recommended to use another tracking device for measuring the activity of the heart. One example could be an oxiometer, as shown in the study performed by Suzuki et al. [73]. This would allow for a more synchronized representation of the cardiac activity, as well as higher quality of the data extracted. At the same time, for a better execution of the study, with a lower chance of technical glitches caused by the poor tracking accuracy of the Oculus Quest 2 headset, it is recommended that a well-illuminated room, with consistent light is used, while a quick fix would be using the controllers. This would allow for a better user experience of the answering the questions integrated in the virtual questionnaire.

The research group is well aware of the limitations posed by using self reports to extract data from subjects. Therefore, a suggestion for future studies, as seen in the study performed by Skola et al. [67], is to use a larger set of instruments, i.e., self reports, as well as psychophysiological data, so that the findings are triangulated, resulting in more accurate findings.

Moreover, another element which might improve the experience is using a different visual representation of the heart, to examine whether or not it has an effect over the SoE, or Interoceptive Sensitivity. Moreover, the study could be extended by introducing other environmental effects (e.g., sound, tactics), and examining their effect, as well. Lastly, as also seen from the previously examined studies, the sense of ownership was a metric regarded with a high amount of interest by the other researchers [73]. Therefore, it can be assumed that introducing it will increase the usefullness of the current study.

CHAPTER 8

Conclusion

In conclusion, the current project is examining the representation of the human heart in Virtual Reality, and more exactly on the effect of visually manipulating it over the experienced Sense of Embodiment, Interoceptive Sensitivity, as well as the activity of the real heart, compared to when the heart activity is fully synchronized with one's activity, or when it is completely randomized.

The study is partly inspired from the work performed by Suzuki et al. [73], as well as Monti et al. [49], who suggest that the technology of Virtual Reality can be used to change one's corporeal awareness, if combined with physiological input. After the relevant theory was analyzed, and some of the most relevant studies were examined in details, the research group decided to design a within subject experiment consisting of three conditions of representing the virtual heart: (1) in complete synchrony with the real heart, (2) amplified/reduced activity, (3) completely random, within a defined range. These three conditions were examined through the prism of: (1) the experienced Sense of Embodiment, (2) the Interoceptive Sensitivity, and (3) the effect over the activity of the real heart. Therefore, the following research question were defined:

1. **To what extent can the synchronous visuo-cardiac feedback influence the Sense of Embodiment over the virtual heart, in comparison to manipulated, and random visuo-cardiac feedback?**

2. **How does the manipulated visuo-cardiac feedback influence the participants' real cardiac activity?**

3. **How does synchronous, and manipulated visuio-cardiac feedback influence the participants' Interoceptive Sensitivity?**

To be able to answer the research questions mentioned above, an experiment was designed, consisting of a 120 second exposure to each condition, along with a set of questionnaires used to gather the raw data, which later would be translated into meaningful insights on the SoE, Interoceptive Sensitivity. Apart from the questionnaires, the real and/or manipulated heart rate was collected from each participant, allowing for an analysis on the influence of each condition on the activity of the real heart.

Once the experience was designed, and implemented, the project was tested within the facilities of the Multisensory Experience Lab from Aalborg University, as well Novo Nordisk, partly. In total, the data collected from 19 students was considered to be viable to be used in the analysis. It is important to note that the size of the sample might impact the validity of the findings, thus the results should perceived considering this aspect.

The data obtained highlighted the superiority of the synchronized condition over the Sense of Embodiment, yielding a higher score compared to the other two conditions, as is also the case when it comes to Interoceptive Sensitivity. At the same time, the findings suggest that exposing participants to a condition in which the heart rate is reduced by 20 beats per minute can decrease the activity of the real heart with statistical significance.

Finally, the research group suggests that representing a virtual heart which is pulsing in synchrony with one's real heart can induce a higher Sense of Embodiment, as well as Interoceptive Sensitivity, as compared to manipulating it, or using random input. At the same time, exposing one to a visual representation of a heart which is beating slower than his/her real heart can affect the activity of the real heart by reducing its beating rate.

Appendix

- **Appendix 1: VEQ Adjustments**
  https://docs.google.com/document/d/1U1AsFeVZKFKQXECNLgknk-au4dTNx9gr94lhJE$_eJ7I/edit?usp$
  sharing
- **Appendix 2: Test Plan**
  https://drive.google.com/file/d/1pdExXGu0n3jAGA4Ao1omTXFGvFOij7KQ/view?usp=sharing
- **Appendix 3: Implementation Scripts Complete**
  `https://drive.google.com/drive/folders/107ny0Rd8hXLkwDB3UNiIiZlZmMPXHlyt?usp=`
  `sharing`
- **Appendix 4: TCP Connection Script**
  `https://drive.google.com/file/d/1Xl6hDF26GKYONXWACHaH9XBa5SqQJuCj/view?usp=sharing`
- **Appendix 5: Empatica Manager Script**
  `https://drive.google.com/file/d/1eS195WKOCuQ7VZMLBzhaDVe2WyRRxWXi/view?usp=sharing`
- **Appendix 6: Csv Tool Script**
  `https://drive.google.com/file/d/1aFIsRVRt5bhL1RMfo1VXbh5SmG6fIKHC/view?usp=sharing`
- **Appendix 7: Timer Script**
  `https://drive.google.com/file/d/1WPdg7O-jQ3YQ5HgzGlQSv18orCEsrPlS/view?usp=sharing`
- **Appendix 8: Avatar Manager Script**
  `https://drive.google.com/file/d/1UvK1E3Y8h3rzOhEhVBaNCd9bklMGmHSM/view?usp=sharing`
- **Appendix 9: Q Manager Script**
  `https://drive.google.com/file/d/1FWgo-MS7s13YQhhIsMLji2C2N-kdcP6T/view?usp=sharing`
- **Appendix 10: Project Video Presentation**
  `https://drive.google.com/file/d/1nBJKD-nnSZ4X9sCFAkG1z3Tj0fFLJkV7/view?usp=sharing`

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