Master Thesis Proposal: Passive haptic stimuli & cardiac cycle modulation in a virtual reality setup.

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1. Problem & Significance

To achieve a comprehensive understanding of how our bodies shape our cognitive processes, it is imperative to delve deeper into the sense of touch[7].

Touch plays a vital role in embodied perception as it gathers information from the entire body [4]. Furthermore, touch perception interacts with coupled respiratory-cardiac cycles, optimizing tactile performance [5, 1, 10]. Additionally, touch significantly contributes to the development of multisensory experiences [2, 11] and notably, touch is instrumental in our brain's ability to sustain neural representations of the body through tactile feedback [3].

In our pursuit of fully comprehending perceptual phenomena, we have turned to Immersive Virtual Reality (IVR). IVR has proven to be a powerful tool for investigating cognitive processes as it enables researchers to assess behaviors and mental states in complex yet highly controlled scenarios. Traditionally, IVR has relied primarily on visual displays and head-hands movement tracking to create mediated experiences. However, the utilization of VR head-mounted displays in combination with ECG and haptic devices presents new challenges, in practical, technical and in terms of how it agrees with existing literature [9].

Can mediated experiences of touch yield similar results to those observed in embodied cognition? By understanding which aspects of touch can be effectively mediated and how they interact with other senses in a mediated environment, we can enhance experimental setups to explore the body-mind relationship with greater ecological validity. Additionally, this understanding will provide valuable guidelines to the industry for the development of hardware devices in this domain.

2. Thesis Topic & Goal

The primary objective of this study is to investigate the feasibility of incorporating touch-cardiac-cycle modulation studies into Interactive Virtual Reality (IVR) setups. IVR, being a system that often involves visual, tactile, and proprioceptive senses, inherently engages multiple senses or is intentionally designed as a multisensory experience. To facilitate a comparative analysis of results, a relevant recent study by Martina Saltafossi on vision, touch, and hearing as multisensory pairs [11] serves as a suitable reference. While there is limited research on two multisensory modalities and none to my knowledge using IVR, this study aims to bridge that gap. However, before delving into specific goals, it is necessary to define the concept of touch, as it encompasses various modes.

The extended classification of tactile sensation [6] provides a useful framework for understanding touch, categorizing it into five different modes based on the presence or absence of voluntary movement: (1) tactile (cutaneous) perception, (2) passive kinesthetic perception, (3) passive haptic perception, (4) active kinesthetic perception, and (5) active haptic perception. For this thesis, touch is defined as passive haptic perception generated by a vibrating Data-Glove. Based on this definition, three main goals are derived:

(i) Assess the impact of passive haptic stimuli on the reported sense of immersion in individuals. This investigation aims to quantify the extent to which passive haptic stimuli influence overall reported scores in questionnaires, shedding light on the role of touch in creating a sense of presence. Saltafossi's study refers to this as "body illusions induced by multisensory conflicts between exteroceptive sensory modalities, such as vision and touch."

(ii) Evaluate the effect of passive haptic stimuli on performance in the motor-memory task. By examining how passive haptic stimuli influence the response time and accuracy in the motor-memory task, this study seeks to reveal the influence of touch on overall behavioral outcomes in the task.

(iii) If the preceding steps yield positive results, we will test if the unlocked-stimuli triggered at diastole or systole has any effect on the response times. This goal involves reproducing existing research that identified modulations in haptic perception synchronized with the cardiac cycle, contributing to the understanding and testing of VR head-mounted displays in combination with ECG and haptic devices.

Through an investigation of passive haptic touch's influence on immersion, behavioral outcomes, and interactions with the cardiac cycle, this research aims to enhance our understanding of IVR as a research tool and further validate findings on multisensory integration and perception.

3. Methods

The experimental design, methods, and materials used in this study were developed based on the NRO-228 Study-DB: 02188.07 - TSVR Akbal/Villringer. While I did not contribute to the experimental design phase, my involvement encompassed the study implementation, data collection, and analysis. However, not all the material gathered in the original study will be utilized for this master's thesis. The heartbeat count task will be excluded to maintain focus on the specific goals of this thesis. Furthermore, the hypothesis and analysis presented in this thesis are distinct and tailored to this research project.

3.1 Participants

A total of 23 participants performed both of the full tasks. However, 2 of them did not fill all questionnaires, so we had to exclude them from the analysis, leaving us with 21 participants. The call for participants was answered considerably more by women (17) than men (5). The age across the sample was consistently around 25 years old, with the exception of one participant ($\mu = 25.1, \sigma = 6.3$).

3.2 Materials

3.2.1 Electrocardiogram (ECG):

Heart rate data is collected using an Arduino Uno and a SparkFun Single Lead Heart Rate Monitor - AD8232. The collected data is transferred through a USB 2.0 connection and integrated into the Unity log file at a frequency of 133 Hz.

3.2.2 Head Mounted Display & Lighthouses:

The VR setup includes an HTC Vive head-mounted display (HMD) with two lighthouses. The headset specifications include a Dual AMOLED 3.6" diagonal display, with 1080 x 1200 pixels per eye (2160 x 1200 pixels combined), a 90 Hz refresh rate, and a 110-degree field of view. The lighthouses are equipped with SteamVR Tracking, G-sensors, gyroscopes, and proximity sensors. Both the HMD and lighthouses are connected using USB 2.0. For this study, the VR controllers were not used, and instead, hand tracking was performed using the Leap Motion sensor.

3.2.3 Leap Motion Controller:

The Leap Motion Controller has a field of view of 150x120 degrees, with a variable range of roughly 80 cm (arm's length). It weighs 32 grams and is mounted on the HMD. The device features two 640x240 infrared cameras with a frame rate of 120 fps.

3.2.4 Data Gloves:

The data gloves used in the study are equipped with magnetic sensors and connected to Unity using a microUSB connection. These gloves provide haptic feedback through 10 vibrotactile actuators, offering a wide range of tactile sensations with 1,024 levels of intensity. The gloves also incorporate complete finger tracking using six 9-axis Inertial Measurement Units (IMUs). These IMUs enable precise tracking of finger movements, allowing for accurate gesture recognition and enhanced interaction in virtual environments.

3.3 Experimental Procedure:

After being debriefed and receiving information about the experiment, participants completed the following tasks:

(i) Edinburgh Handedness Questionnaire

(ii) PRE-Cybersickness Questionnaire

Following the completion of the first set of questionnaires, the participants were taken to another room where the IVR (Immersive Virtual Reality) equipment was set up. This equipment included a head-mounted display (HMD), data gloves, and an ECG (Electrocardiogram) device. Participants underwent a short training session before proceeding with the heartbeat count task and the IVR memory-motor task.

(iii) PRE-Heart Beat Count Task (HCT) for one minute. (This task is not considered in this thesis.)

(iv) IVR Memory-Motor Task: In this environment, participants were positioned in front of a virtual table and given sufficient time to acclimate to the virtual surroundings. A sketch of a puzzle was displayed in front of the virtual room, which they needed to memorize. During the memorization phase, participants kept their virtual hands open with palms facing up. Subsequently, the sketch disappeared from their visual field, and a red ball was introduced from the top, appearing in either one of the hands. Participants observed a template on the table, which was an identical representation of the initial sketch they had memorized. Their task was to place the ball in the correct location on the template as quickly as possible. Throughout 108 trials, three different conditions (relevant haptic stimuli, irrelevant haptic stimuli, and no haptic stimuli) were randomly presented an equal number of times (36 times each). The trials appeared rapidly, one after the other. The start of each trial was marked by placing the ball in a hand, and the end of the trial was marked by the moment the ball reached the designated location on the template.

(v) POST-Heart Beat Count Task (HCT) for one minute. (This task is not considered in this thesis.)

The final step of the experiment involved two questionnaires aimed at extracting information on several relevant fields for the goal of this thesis:

(vi) Virtual Reality Subjective Evaluation Questionnaire

(vii) POST-Cybersickness Questionnaire

3.4 Measurements

3.4.1 Immersive Virtual Reality (VR):

The VR experience was presented and tracked using an HTC Vive head-mounted display (HMD), two lighthouses, a Leap Motion sensor, and Haptic Data Gloves. Movement data from the data gloves, Leap Motion device, and the HMD was collected. For movement analysis, only the wrist movements tracked by the Leap Motion device were considered, excluding the fingertips' magnetic tracking sensor data. All movements were recorded in a Euclidean coordinate system (X, Y, Z) with the original calibrating point set at (0, 0, 0). This provided a total of nine streaming sources of data (e.g., Headset X, Headset Y, Headset Z, and so on). Notably, rotational data was not included in the analysis.

Additionally, in the game output data, there are flags that signal if a button was pressed, if the ball is placed in the holder, and when the trial started.

3.4.2 Electrocardiogram (ECG):

Heart rate data was collected using a USB cable and integrated into Unity Engine. This information was coupled with all other Unity data at a frequency of 133 Hz.

3.4.3 Questionnaires:

(i) Virtual Reality Subjective Evaluation Questionnaire: This self-made questionnaire consists of 26 items oriented towards capturing whether the VR experience felt real for the participant or not. It explores the level of engagement, hand movement, task difficulty, and other controlling factors. The questionnaire uses a Likert scale ranging from one to seven.

(ii) PRE/POST-Cybersickness Questionnaire: The version applied in this study is a shorter adaptation of the simulator sickness questionnaire (SSQ) [8]. It employs a Likert scale ranging from one to four, with labels going from "not present," "somewhat," "clearly," and "very strongly." The questionnaire includes 16 items based on symptoms, such as "fatigue" and "general discomfort," among others.

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