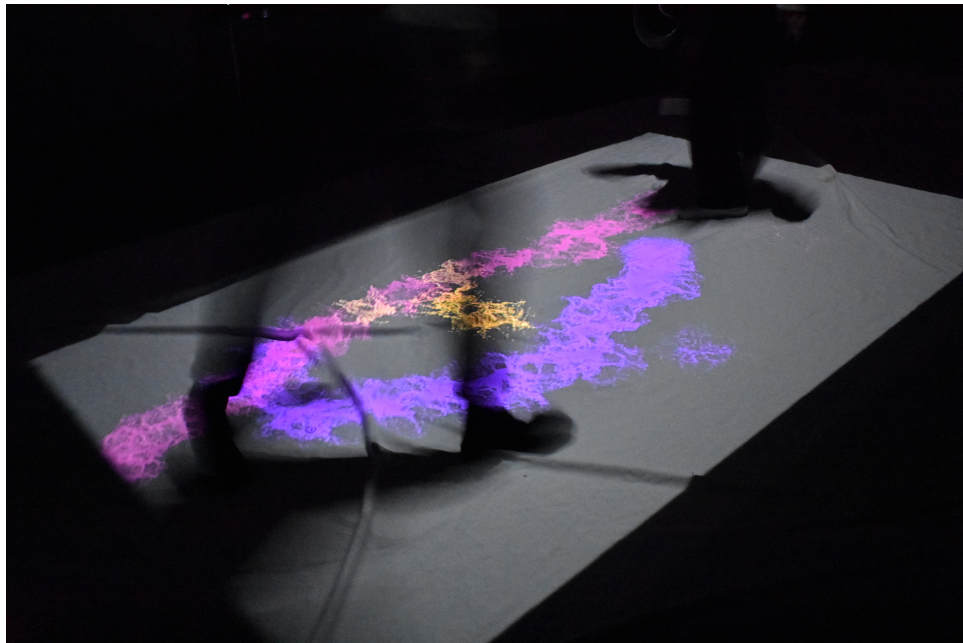


Master's Thesis

# Pulse Flow: Exploring Affective Connection Through Sound and Visuals

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# Abstract

This thesis focuses on the affective aspects of human connection, exploring how an interactive installation can create the feeling of connection between two participants. By removing verbal cues and relying on visual and auditory elements such as heartbeats, the installation tries to create a space where participants can experience a shared connection through their bodies and senses. The theoretical framework examines the nature of connection and related theories, while incorporating relevant design strategies in relation to technology, such as Interpersonal Distance, Affective-Self Disclosure, and Shared Experiences and Play. These and other strategies were integrated into the design features aiming to encourage self-awareness, awareness of the other participant, and potentially foster a feeling of connection between them. The project's implementation was achieved by integrating Kinect v2 for position tracking, real-time heartbeat detection (using the ESP32 M5Stack Atom Matrix and a pulse sensor), projections, and TouchDesigner as the primary tool for audiovisual integration. The evaluation combined both quantitative (System Usability Scale (SUS) questionnaire, movement proximity tracking and heart rate data) and qualitative (semi-structured interviews) methods. A total of 16 participants were tested, consisting of 4 familiar and 4 unfamiliar couples. The results revealed that the installation mediated a sense of connection, particularly through shared situational connection, non-verbal interaction and others. Familiar couples engaged more playfully and interactively, while unfamiliar couples described the experience as calming and meditative, appreciating the non-verbal communication. Some technical challenges, such as position tracking issues and sensor calibration errors, occurred. Future improvements will focus on enhancing interactivity and addressing the identified technical limitations.

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# Chapter 1

## Introduction

Human connection is a fundamental and deeply personal experience, important for peoples mental health, motivation and cognitive functioning [1, 2]. It is often expressed through bodily sensations, shared awareness, and non-verbal cues such as proximity and touch [1, 3]. Since technology increasingly shapes how people interact and influences the form of their experiences [1, 4], exploring ways to facilitate meaningful moments of connection through technology becomes increasingly important.

This thesis concerns the creation of an installation designed for two participants, utilizing Kinect v2, projections, and real-time heartbeat tracking to explore the feeling of connection between them. By integrating these technologies, the thesis focuses on the affective aspects of human connection and explores how visual and auditory stimuli in an interactive installation, based on participants’ movements and heartbeats, can influence their sense of connection to one another. By removing verbal cues and emphasizing evolving visuals, dynamic colour trails, and real-time heartbeats, the installation aims to create an environment where participants could experience a shared connection through their bodies and senses.

The theoretical framework explores how connection can be mediated through technology, starting with the importance of social connection and addressing the subjective nature of “connection”, which varies based on individual perceptions and context. It examines key concepts such as the affective aspects of connection, immediacy, and related theories. In addition, it incorporates relevant design strategies in relation to technology, such as Interpersonal Distance, Affective-Self Disclosure, and Shared Experiences and Play. These strategies, along with others, were integrated into the design features to encourage self-awareness, awareness of the other participant, and potentially foster a sense of connection between them.

The installation implements real-time heartbeat tracking (using the ESP32 M5Stack Atom Matrix and a pulse sensor), position detection (using Kinect v2), and audiovisual feedback (developed in TouchDesigner).

To assess the effectiveness of the installation, both quantitative data (System Usability Scale test, movement tracking, and heart rate data) and qualitative feedback (semi-structured interviews) were collected. This methodology enabled a deeper understanding of how visual and auditory elements impact the participants’ self-awareness, awareness of others, and their overall feeling of connection within the installation.

The Initial Problem Statement (IPS) of the thesis was: *“How can technology-mediated experiences facilitate human connection through sensory and emotional engagement?”*

### 1.1 Concept Overview

As mentioned, the concept of the thesis project revolves around creating a feeling of connection between two people through an immersive, interactive installation using both auditory and visual stimuli. Additionally, it explores elements of self-awareness and presence, offering an experience that is based on senses and non verbal communication.

Participants have their heartbeats monitored in real-time. The sounds of their heartbeats echo throughout the environment, allowing them to hear not only their own but also the heartbeat of the other participant. This is designed to create an intimate moment, bringing participants into the present and revealing their presence to one another.

As each participant stands in their designated position within the installation space, an abstract circular projection from the ceiling appears, first surrounding the first participant and then the second. The first participant's shape and heartbeat activate and then fade as the second participant's shape and heartbeat appear. After a while, the shape of the first participant fades in gradually, and both participants' shapes and heartbeats become active.

At this stage, the abstract shapes start evolving from abstract forms, to more geometric circular shapes, and finally into complete circles. These circles symbolise each participant's personal space.

After a brief period, the circles begin to open, visually signaling to the participants that they have to step outside. As the circles open, their heartbeats blend with the background music. This opening of the circles serves as a metaphor, encouraging participants to move beyond their individual boundaries.

When participants step out of their circles and move into the shared space, they leave behind a coloured trail unique to each participant, marking their path. When participants come closer to one another, their trails blend, creating a shared colour. In addition to this visual transformation, as participants leave their circles, ambient music begins to play, with the heartbeats of the participants blending into the music, creating a subtle tempo.

# Chapter 2

## Analysis

### 2.1 Theory-Related Analysis

In this section, the theoretical background of the project will be analysed.

#### 2.1.1 Connection and How It Is Mediated Through Technology

Social dynamics significantly influence individuals, underscoring the importance of relationships in their lives. This perspective is supported by Self-Determination Theory (SDT), which highlights the central role of social interactions in fulfilling fundamental needs [5]. Based on the SDT theory, autonomy, competence, and relatedness, meaning the feeling of being close to others, are three of the most important human needs. These needs can enhance motivation [2].

The term “social connection”, is really broad and lacks an agreed-upon definition [6]. Usually, it can be interpreted as the feeling of not being alone, having a supportive circle, experiencing a sense of belonging and closeness with others, and forming meaningful relationships that are important to the individual. [6, 7].

In this thesis, beginning with social connection, a more specific concept is explored, the feeling of connection. When considering the more specific term “connection” in interactions, defining it can be challenging. This difficulty arises not only because connection is based on a felt experience and can not be measured, but also because it varies depending on individual perceptions about it, as well as the context in which it is experienced [1].

These variations make both social connection and the more specific feeling of connection multifaceted concepts, shaped by personal interpretations and influenced by dynamic, context-dependent factors.

Stepanova et al. expand on this idea by examining how technology mediates the sense of connection. Their work, emphasizes the affective aspect of connection in this context, by stating that these experiences are mostly felt through the body, engaging sensory and emotional responses [1].

Similarly, the concept of immediacy refers to communication methods that can enhance closeness between individuals often relying on bodily nonverbal cues [3] Eye contact, body movements, and physical proximity rather than verbal communication can increase the sense of intimacy or emotional connection [3]. Its principles resonate with the sensory engagement described by Stepanova et al., particularly in mediated space that try to create emotional and physical connection [1]

Another concept relevant to this project is social presence. Social presence refers to the awareness of another’s presence in a shared space [8]. However, in the research of Stepanova et al., a mediated real sense of connection that might be aided by such social presence is not a commonly recognized concept [1]. The concept of social presence is discussed though in this section, because of its relation to the project’s design and intentions.

This thesis focuses on the affective aspects of human connection, specifically exploring how the installation can create the feeling of connection between participants. By removing verbal cues and relying on visual and auditory elements, tries to create a space where participants can experience a shared connection through their bodies and senses.

#### 2.1.1.1 Connection and design: Strategies for Mediating Connection

While there is limited literature in defining the 'feeling of connection' in technologically mediated systems, the work of Stepanova et al. provides valuable insights into its sensory, and emotional dimensions and design techniques in order to foster this feeling in mediated systems [1]. Here are their design techniques:

- **Affective Self-Disclosure:** Sharing or listening to personal, emotional or vulnerable information while trusting and being trusted by the other person.
- **Reflection on Unity:** Promotes connection by emphasizing shared humanity and the feeling that we are all alike.
- **Mirroring the Other:** Mimicking body language, expressions, or movements creates a shared embodied experience.
- **Dissolving the Self:** Ethereal experiences of awe can dissolve individual boundaries, promoting a sense of connection.
- **Embodied Metaphors:** Physical sensations or interactions that metaphorically represent emotions or concepts.
- **Interpersonal Distance:** Physical proximity can influence emotional closeness. Reducing distance, while maintaining respectful boundaries can foster a sense of connection.
- **Touch:** Physical contact can support bonding and emotional resonance.
- **Discomfort and provocations:** Navigating shared discomfort or playful provocations can push boundaries, but also can create an opportunity for connection.
- **Play:** Shared play can foster connection by creating an exploratory, and enjoyable context for interaction.

Some of the most important theories for the project, that were taken into consideration, based on the information above and other theoretical frameworks, will be further analysed in the following section.

#### 2.1.2 Theories and Frameworks Supporting Connection

##### 2.1.2.1 Interpersonal Distance and Proxemics

One of the main theories and strategies that were considered in the design of the installation, was that of Interpersonal Distance.

In an exploration of how proximity and distance can shape social interaction, Edward T. Hall's *The Hidden Dimension* introduces concepts around space and boundaries that are relevant to understanding human connection [9].

Hall's theory of proxemics explains how animals and in extend humans, maintain zones of personal and social distance. According to Hall, personal distance functions like an invisible bubble around individuals, which influences how they engage with others. When two people are outside each other's personal space ("bubble"), they are not as closely connected or involved with each other. But when their personal spaces overlap, they become more engaged. Social distance is defined as the space necessary to feel part of a group, not only physically but also psychologically [9].

Hall connects physical distance to social separation and classifies space into four zones, as can be seen in **Figure 1**. These zones are: intimate space (0-0.5 m), personal space (0.5-1 m), social space (1-4 m), and public space (more than 4 m) [10].

Reducing the physical distance between individuals by decreasing their interpersonal space, is identified as one strategy that can increase feelings of intimacy and connection [1].

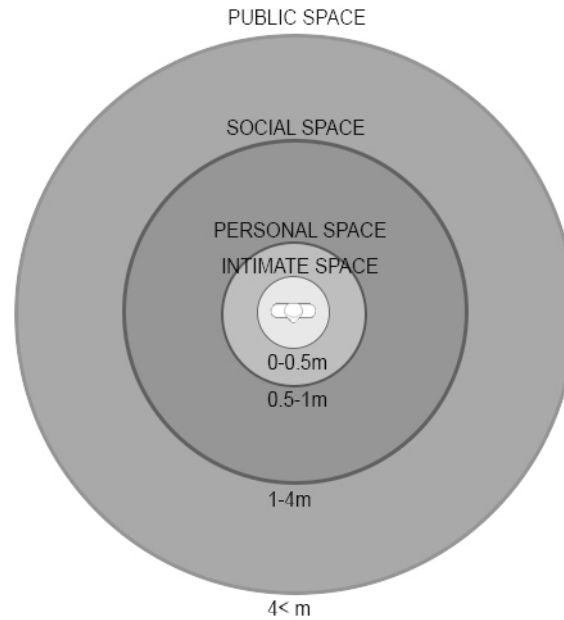


Figure 1: Hall's Classification of Spatial Zones. After <https://laofutze.wordpress.com/2014/01/03/e-t-hall-proxemics-understanding-personal-space/>

### 2.1.2.2 Affective-Self Disclosure

Self-disclosure refers to the act of sharing personal and often sensitive information with another person. This can involve details based on facts and information related to emotions or personal experiences. It can occur in various contexts and types of relationships. It is typically part of an interpersonal process, where one person reveals personal information, often in response to a mutual and shared exchange [11].

While both types of disclosures (factual and emotion oriented) share personal aspects of the self, emotional disclosures are considered to be more central to an individual's self-definition and are believed to have the capability to foster greater feelings of intimacy than factual disclosures. This is because emotional disclosure can give the listener a chance to show understanding and help confirm important parts of how the person sees themselves [12]. However, Self-disclosure is a multifaceted process that can be influenced by various factors, such as personal, relational, situational, and cultural. [11].

Systems that provide insight into an individual's emotions or affective state, such as through biodata (such as heartbeats) or other technologies, are often considered forms of self-disclosure. These systems reveal intimate aspects of a person's emotional state, making them affective self-disclosure systems [1].

### 2.1.2.3 Shared Experiences and Play

Play refers to a design strategy that encourages people to interact, and create something together, incorporating the element of playfulness [1].



Having shared experiences and engaging in shared activities, such as attending events or experiencing media together, can enhance feelings of connection and bonding. Research has shown that when individuals experience events together, their emotional and physiological responses can synchronize, fostering stronger social connections [13].

In addition, Collaborative activities reinforce a sense of belonging and connection [14], while gamification elements can facilitate collaboration [15]. Furthermore, creating with others helps prevent isolation and fosters emotional expression, leading to stronger interpersonal bonds [14].

Based on the information above, shared experiences alone can create a sense of connection, but when these experiences also involve collaboration, creativity, and playful elements, the sense of bonding is further enhanced.

## 2.2 Technical-Related Analysis

In this section, the technical research for the implementation of the project will be analysed.

### 2.2.1 Available Equipment and Proximity Detection

One important variable for the project was proximity detection. For this, the available equipment at the university was taken into consideration. To assess the proximity of participants, three depth-cameras were evaluated: Microsoft Kinect v1, Microsoft Kinect v2, and the ZED 2i Camera.

Kinect v1 uses structured light technology [16], which projects a known infrared light pattern onto the scene. The camera then, captures the deformation of this pattern by the surfaces of objects in the environment. This way it allows for the calculation of 3D information [17]. Its depth resolution (320 x 240 pixels at 30 fps) and its field of view (57° horizontal, 43° vertical) limit its ability to track users with high accuracy in scenarios where proximity and overlap between users occur. In addition, Kinect v1 can track up to 2 users in the environment and maximum 20 joints per person [16].

On the other hand, Kinect v2, works with Time-of-Flight (ToF) technology [16], which measures the time it takes for the light to return after reflecting off the object of the scene. Based on the delay, the distance of the object is calculated creating a depth map of the scene [18]. Kinect v2 has a higher depth resolution (512 × 424 pixels at 30 fps) and a wider field of view (70° horizontal, 60° vertical), allowing it to track up to 6 users compared to Kinect v1 which can track up to 2 users. Furthermore, Kinect v2 can track 25 joints per person, making it more accurate in distinguishing users [16].

For proximity and depth detection, the ZED 2i depth camera was evaluated for its features. It uses passive stereo technology, employing a dual-lens setup with a 120mm baseline to generate accurate 3D depth maps. This allows the camera to measure distances between 0.3 to 20 meters. It has a 120° field of view and AI capabilities, such as object detection and skeleton tracking [19].

Since the installation required complete darkness and the ZED 2i camera does not perform well in such conditions <sup>1</sup>, and because high-depth resolution was not a requirement for the project, the Kinect v1 and v2 were considered. Kinect v1 was selected because it supports tracking up to two participants, which aligned well with the project's specific requirements. However, it was later replaced by the Kinect v2, which will be further analyzed in **Section 4**.

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<sup>1</sup><https://support.stereolabs.com/hc/en-us/articles/206918249-Is-the-ZED-camera-IR-sensitive>

### 2.2.2 Heartbeat Detection System

For heartbeat tracking, both smartwatches and Arduino-based equipment were considered.

Smartwatches were considered for heartbeat tracking, but their cost was a significant factor, as two devices would be needed for both participants. Additionally, it was important to confirm whether heart rate data could be accessed from these devices and subsequently transferred into TouchDesigner. Many smartwatches such as Huawei Watch GT 2, provide APIs for retrieving heart rate data. However, these APIs often come with licensing restrictions or limitations on data usage. As a result, this could complicate integration into TouchDesigner.

For this reason, an Arduino-based system was initially considered as a feasible option. However, after further evaluation, the system transitioned to an ESP32-based setup. This setup was lightweight making it a more suitable choice for the project. The final system used will be further analyzed in **Section 4**.

## 2.3 Related Works

### 2.3.1 Breath of Light

A project that acted as an inspiration for the thesis is “Breath of Light”, that was presented at the 13th Shanghai Biennale in 2021. The project is an interactive, immersive installation that explores human connection and awareness through breathing [20].

The installation has a dark environment and two microphones suspended from the ceiling. Each participant has one microphone and each one’s breath triggers a corresponding orb of light on the screen in front of them. This orb expands and contracts in response to their breath.

When the participants’ breaths synchronize, a ripple of light is generated across the screen. This visual effect is accompanied by ambient sounds [20].

“Breath of Light”, acted as an inspiration for this thesis in terms of the biodata, particularly the breathing data, used as a personal, subconscious element that can evoke a sense of connection. Breathing, as an element, is a subconscious act, that people typically do not pay attention to while it occurs. It is a grounding and present experience.

In addition, the idea of having each participant’s identity represented by their own visual orb of light, which then based on a factor, in this case synchronicity, something else happens (generation of a new light) served as inspiration. It highlights how each participant is aware of their own body rhythm while also becoming aware of the rhythm of the other person.

### 2.3.2 Body Remixer

Another influential project was the “Body Remixer” [21]. It focuses on an immersive installation that utilizes Virtual Reality (VR), Kinect v2, and projections.

Kinect’s purpose was to track participants’ bodies and transform them into particles that respond to their movements. These particles can be viewed either through projections within the installation space or via a VR headset.

There are different modes in this installation, participants through touching the hand of one another, can create merge their particles and blend their body boundaries. By touching both of their hands they can exchange bodies and through shared synchronized movements they can adjust the music [21].

This project served as an inspiration because it focuses on creating a sense of connection between participants, similar to the concept of the thesis. The concept of blending boundaries through particles and representing participants as these particles, was an inspiration for the thesis project. In addition, the use of the Kinect camera to track movements was also a good example, as it provided a starting point for how participants’ movements could be tracked in the installation.

## 2.4 Final Problem Statement (FPS)

Based on the IPS from **Section 1**, and the research that followed, the IPS was narrowed down to a more precise FPS:

*“How can the visual and auditory stimuli in an installation, based on participants’ movements and heartbeats, influence their sense of connection to one another?”*

## Chapter 3

# Design

### 3.1 First Iteration of the Project: Collaborative Multisensory Interaction Using Hand Gestures

The concept of the thesis project was based also on a previous project developed for the Embodied Interaction course during MED08. This earlier project served as a foundation, and it explored multisensory integration through visual and auditory stimuli through hand movements. In addition, it focused on social interaction and the challenges it may pose for some people. It was a collaborative and artistic approach that aimed to cultivate empathy around connection.

Real-time hand gesture tracking was achieved through the use of a webcam. Each participant's hand was represented by the same abstract shape (a smoke effect) but in different colours. As the participants' hands moved closer, the colours blended, creating a new one. The visual outcome of the project can be seen in **Figure 1**. Sound also played a significant role, with the audio intensity increasing as the hands approached each other.

The project was implemented using Python along with the Arcade library, OpenCV, and MediaPipe.

However, during the implementation of the project, some challenges emerged. There was latency and desynchronization between the visual and auditory elements, which may have been caused by the computational load of shader calculations, due to the experimental integration of Python within the Arcade library. Consequently, using other platforms such as Unity or TouchDesigner might have been better for higher performance.

By taking these challenges into account for the implementation of the thesis project, TouchDesigner was selected to handle the visualization and sound.

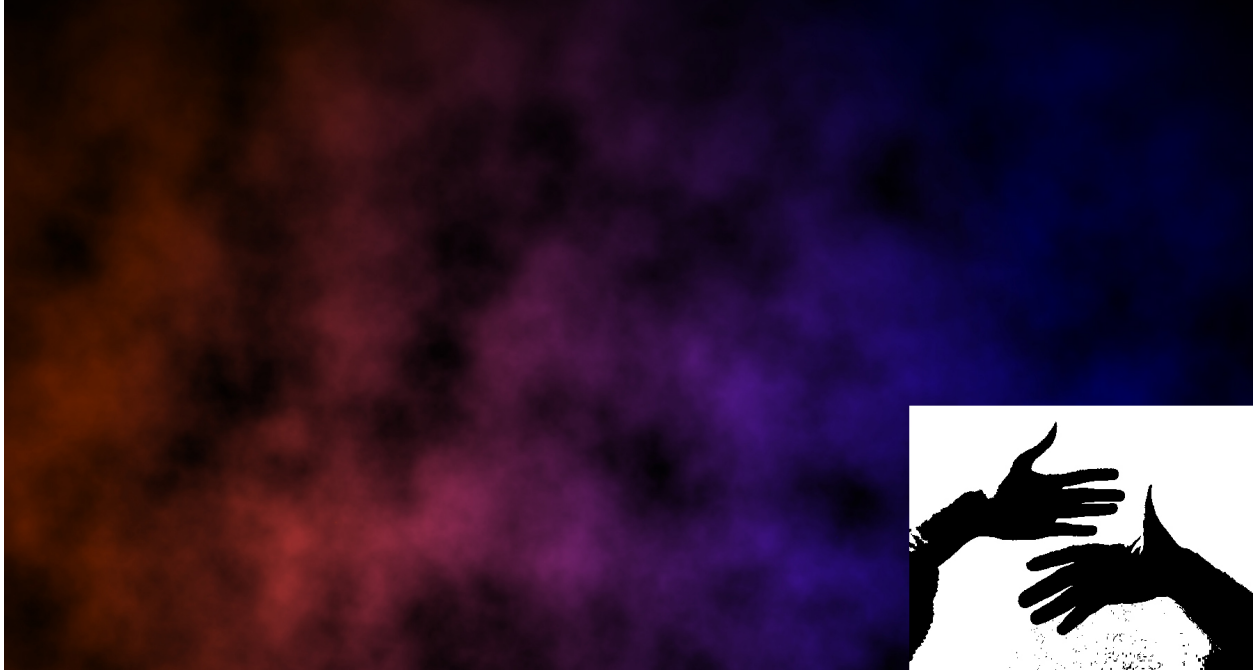


Figure 1: Embodied Interaction Project

### 3.2 Initial Goals of the Design

The initial goals of the design for the thesis installation were to:

- Promote self-awareness for each participant, enabling them to be aware of themselves.
- Foster a sense of presence, allowing participants to be aware of each other.
- Experiment and potentially create a sense of connection between participants.

### 3.3 Design Techniques and Elements

The overall design followed various techniques that are mentioned in the paper by Stepanova et al. [1]. The three main techniques that were used, were discussed in more detail in **Section 2.1**. As a concept, it was very intriguing because, as described in the research, everyone knows what it feels like to be connected in a way that feels authentic and this experience is something that can be primarily felt [1].

Five key elements were essential for the design to mediate a feeling of connection between participants: the Initial Circles, Heartbeats, Sound, Colour Trail, and Colour Blending. Their relationship to the theory is illustrated in the **Figure** below:

Three Main Design Strategies, that can Foster a Feeling of Connection in Technology-Mediated Systems and are Followed in this Thesis are:		Key Elements in the Design
“Interpersonal Distance and Proxemics” → Reducing distance		Colour Blending
“Affective-Self Disclosure”	→ <b>Sharing or listening to personal information</b> <i>Systems that provide insight into an individual’s emotions or affective state, such as through biodata and reveal intimate aspects of a person’s state</i>	Real - Time Heartbeats
“Shared Experiences and Play”	→ <b>Shared experiences can create a sense of connection, but when combined with experiences that involve collaboration, creativity, and playful elements, the sense emotional closeness, is further enhanced</b>	Initial Circles Colour Trail Colour Blending Sound

Figure 2: Key Elements of Design

The effort to create self-awareness for each participant was implemented in the **First Stage** of the installation. This stage involves participants standing in their designated positions, where an abstract circular projection appears around the first participant, and their heartbeat is audible for a few seconds. The same process then follows for the next participant, while the first participant’s circle is no longer visible. This process is depicted in **Figure 3**. The main purpose of this feature was to make each participant aware of their own existence separately, and then that of the other participants. Additionally, it introduced a sense of presence and created a smoother transition to the next stage of the experience. However, this feature was added later in the experience, as will be described in the **Implementation Section**.



Figure 3: First Stage of the Installation: Abstract Circular Projections and Heartbeats Activated Sequentially for Each Participant

The element of presence was also introduced in the **Second Stage**, where both abstract circles are visible and the heartbeats are audible, with the abstract circles evolving to more geometric circular shapes, and finally into complete circles, that open. The concept of this stage is depicted in the **Figure 4**. This feature was designed from the perspective of each participant. As both participants look straight ahead, they focus more on the circle of the person in front of them, which enhances their awareness of the other participant. This concept also applies to the first feature. Furthermore, as both heartbeats are audible, they form a unified composition, reinforcing the idea of their shared existence.

The abstract circle geometry primarily symbolises the existence of the person, evolving into a more formed representation of the boundaries that define an individual’s personal space, that Edward T.Hall refers to as “bubble”, as it was mentioned at **Section 2.1.2.1**.

When the circles open, it signals the participants to step outside their personal “bubble” and engage in a shared space, encouraging exploration.

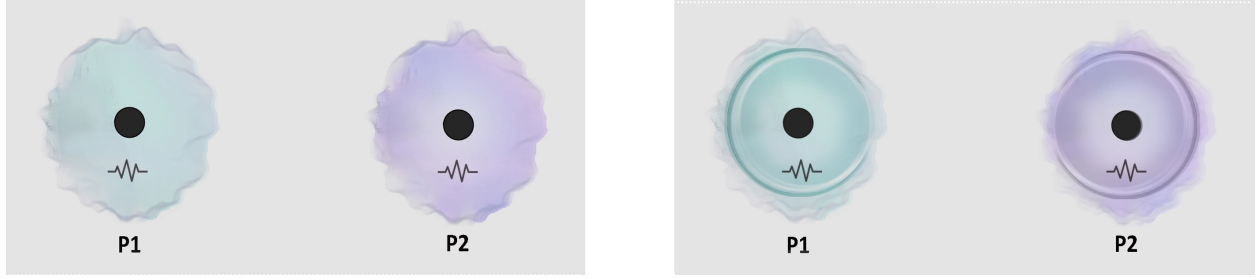


Figure 4: Second Stage of the Installation: Abstract Circular Projections Evolving into Open Circles, with Both Heartbeats Audible

In the **Third Stage**, participants still maintain their personal “space bubbles” imaginatively. As they walk, they leave a coloured trail behind them, with each person leaving a different colour. In this stage when people get closer than 1 meter, their colours blend. It is like their personal spaces overlap. The concept of this stage can be seen in **Figure 5**.

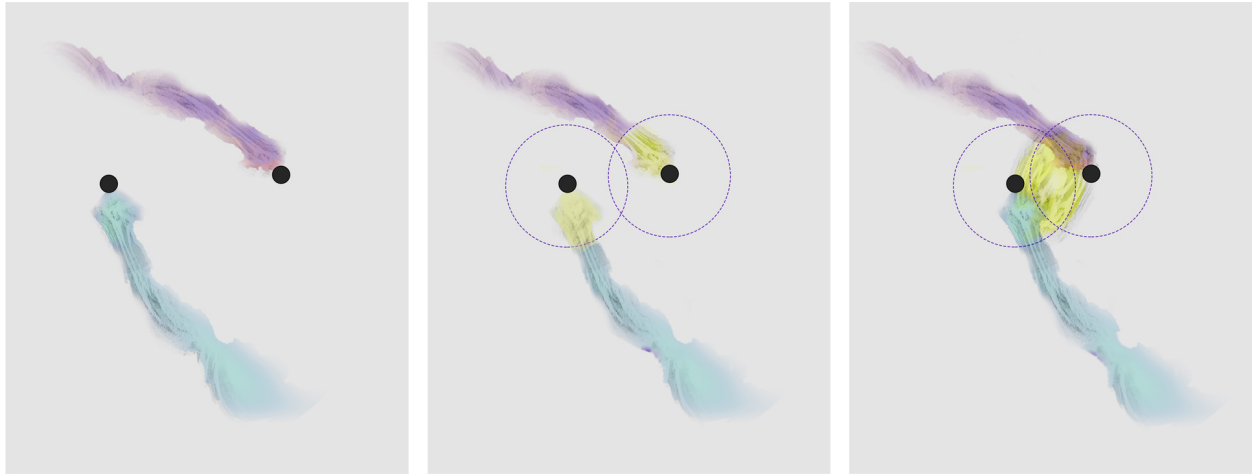


Figure 5: Third Stage of the Installation: Colour Trails that Blend when Participants Approach Each Other

### 3.3.1 Auditory and Visual Elements

As the circular geometries were analysed in the previous section, the remaining elements will be discussed more extensively in this section.

In the design of the installation, heartbeats were introduced as an element that can foster self-awareness, presence, and connection. Heartbeats reveal a subconscious as well as a very personal element and rhythm, unique to each participant.

During the first stage of the installation, when each participant hears only their own heartbeat aimed to be a moment of self-awareness and presence. Participants are invited to pause, acknowledge their own physical presence, and reflect on their existence. It is supposed to be a moment to consciously notice something usually unnoticeable.

When both abstract circles become visible and both heartbeats are audible, the installation shifts its focus to an interpersonal experience. At this stage, the heartbeats act as an element of affective self-disclosure, as it is discussed in **Section 2.1.2.2**. Heartbeats are deeply personal, representing a step toward exposing

and revealing our inner selves. By sharing physiological data with others reveals typically hidden, intimate internal states, serving as a reminder of our shared humanity and interconnectedness [20]. Additionally, they act as a unifying element, based on the reminder of their shared human existence.

The integration of both participants' heartbeats into a shared soundscape, when the circles open, marks the starting point of their shared space where they will interact and explore together. The heartbeats blend with the background music, aiming to shift the focus from the heartbeats to the shared experience, but they remain present as a reminder of their existence in this experience. The background music chosen for the installation falls into the Ambient genre. This decision was made because the background sound was intended to create a gentle, shared environment that would help people stay present. It was designed to accommodate participants' heartbeats, blending them with the background and shifting them out of the main focus for a while, without overshadowing them. This would allow participants to also shift their focus to the interaction between them.

The colour trail acts as an imprint of each participant's presence. The colours deep pink and deep purple were chosen because they both share a common red base, which creates a subtle contrast between them. While they are distinct, the contrast is not intense, instead, it is gentle, allowing the colours to complement each other.

Based on the theory referred in **Section 2.1.2.1**, reducing the physical distance between individuals was one of the main goals, as it is stated to foster the feeling of connection. As participants reduce the physical distance between them, the colours blend into a unified warm orange-yellow. This transition was purposefully chosen because orange-yellow is a warm colour that contrasts with the other colours, creating a vibrant and engaging visual effect. The blending of colours was designed not only to reinforce a sense of unity and connection, but also to serve as a playful interactive element as in **Section 2.1.2.3**, inviting participants to explore and discover how their movements and proximity influence the visual outcome.

In addition, both the colour trail and the colour blending were designed to provide an experience where people feel they are creating something together. They leave their trail, and their colours blend as a collaborative element, reinforcing the sense of "creating together".



## Chapter 4

# Implementation

### 4.1 Real-Time Heartbeat Detection System Implementation

The heartbeat detection system for this project was implemented using an ESP32 M5Stack Atom Matrix, an earlobe pulse sensor, a phone and wireless data communication over UDP. This system enables real-time heart rate monitoring by detecting pulse signals from the earlobe sensor and transmits the data over a Wi-Fi network.

Initially, the Atom Matrix was intended to get power using a power bank, allowing participants to carry it with them while experiencing the installation. However, the power bank was replaced by a phone that was connected to the Atom Matrix via a USB-C to USB-C cable. This change was made because, when connected to a power bank, the Atom Matrix stopped receiving power after some time. This issue occurred because the Atom Matrix has very low power consumption, which falls below the minimum current threshold required by some power banks in order to be active. When this threshold was not met, the power bank assumed that the device was disconnected or fully charged and shut off.

For the implementation of real-time heartbeat detection, the Arduino IDE was used. Three libraries were imported for the project:

- **WiFi.h:** Enables ESP32 to connect to a Wi-Fi network.
- **AsyncUDP.h:** Provides tools to send and receive UDP packets asynchronously
- **M5Atom.h:** Controls the M5Stack Atom's display and hardware.

Firstly, to enable data transmission, the M5Stack Atom connects to a specified Wi-Fi network, which is provided by the laptop acting as a mobile hotspot. The laptop was used as a mobile hotspot because the M5Stack couldn't connect to some Wi-Fi networks that the laptop was connected to. By using the laptop as a hotspot, the device was able to connect seamlessly without any issues.

As a result, the M5Stack Atom acted as a station within the laptop's network and communicated with the server (the laptop) on the same network.

```

const char* ssid = "mylaptop";
const char* password = "1122334455";

AsyncUDP udp;

void setup()
{
  M5.begin(true, false, true);
  M5.dis.fillpix(0x000000);
  Serial.begin(115200);
  WiFi.mode(WIFI_STA);
  WiFi.begin(ssid, password);
  if (WiFi.waitForConnectResult() != WL_CONNECTED) {
    Serial.println("WiFi Failed");
    while(1) {
      delay(1000);
    }
  }
}

```

Figure 1: Wi-Fi Connectivity

Once the device is connected to the Wi-Fi, the AsyncUDP library is used. The M5Stack Atom establishes an asynchronous UDP connection to the server with a specified IP and a specific port. Through this connection, heartbeat data can be transmitted to the server. The **Figure** below depicts the setup code for the UDP connection:

```

if(udp.connect(IPAddress(192,168,137,1), 1234)) {
  Serial.println("UDP connected");
  udp.onPacket([](AsyncUDPPacket packet) {
    Serial.print("UDP Packet Type: ");
    Serial.print(packet.isBroadcast()?"Broadcast":packet.isMulticast()?"Multicast":"Unicast");
    Serial.print(", From: ");
    Serial.print(packet.remoteIP());
    Serial.print(":");
    Serial.print(packet.remotePort());
    Serial.print(", To: ");
    Serial.print(packet.localIP());
    Serial.print(":");
    Serial.print(packet.localPort());
    Serial.print(", Length: ");
    Serial.print(packet.length());
    Serial.print(", Data: ");
    Serial.write(packet.data(), packet.length());
    Serial.println();
    //reply to the client
    packet.printf("Got %u bytes of data", packet.length());
  });
  //Send unicast
  udp.print("Hello Server!");
}
}

```

Figure 2: UDP Communication

The heartbeat monitoring is achieved by continuously reading analog values from the pulse sensor that is attached to the earlobe. The input from the sensor is connected to pin 32 on the M5Stack Atom. A threshold value is set to a specific value, which defines the pulse intensity needed to recognize a heartbeat. The threshold is specifically set to 400 to prevent the sensor from being too sensitive to minor fluctuations, such as user's movements. When the threshold is exceeded, a heartbeat is detected, and the M5Stack sends a message to the server indicating a heartbeat.

In addition, whenever a pulse is detected, the screen of the M5Stack turns red to indicate also a heartbeat. This feature was implemented both to verify the accuracy of the system during the design phase and to provide a visual cue for the participant, helping them feel that the heartbeat detection is real.

The following code shows this feature:

```
int val = 0;
int threshold = 400;
void loop()
{
    val = analogRead(32);
    if (val > threshold) {
        M5.dis.fillpix(0xff0000);
        Serial.print("Sending heartbeat");
        udp.broadcastTo("Heartbeat /n",1234);
        delay(10);
        M5.dis.fillpix(0x000000);
        delay(300);
    }
}
```

Figure 3: Heartbeat Monitoring

The same code was used for the heartbeat detection system of the second participant as well, but with a different port.

The final heartbeat detection system can be seen in **Figure 4**.



Figure 4: Final Device

## 4.2 AV Implementation in TouchDesigner

The audio-visual parts of the project were implemented in TouchDesigner, initially using the Kinect v1 camera. In the beginning, the project was designed and tested using hand movements, utilizing the Kinect v1's capability to track hand gestures. One participant was represented by the left hand, while the other participant was represented by the right hand. This setup allowed to test the project's features and understand the program, without needing constant access to the testing space, where the final tests would take place.

For the actual project, the hand gestures from Kinect v1, were replaced by the leg movements of participants. This decision was made to capture the participants' movements and proximity between them, which were essential for the project. However, after testing some of the project's features related to participant position mapping in the testing space, it became clear that a bigger range was needed to achieve the desired outcome of the project. Although Kinect v1 was sufficient for tracking two participants, it was replaced with Kinect v2 to meet this need.

The project was tested multiple times in the testing space to ensure accurate position mapping and to assess its performance in the actual environment. For the position tracking of the participants, the Kinect v2's capability to track hip movements was utilized.

To simplify the process, hand gesture tracking was retained for ease of use. By pressing the "9" key, the system switches to performance mode, where the participants' positions are stored, reducing the need for constant recalibration each time.

### 4.2.1 Kinect and Position Tracking

To track the participants' positions in real space and adjust the interactive elements of the project, both their x and z values were monitored.

Firstly, their initial positions were recorded to activate key interactive elements. The “initial positions” refer to the x and z values representing the participants' starting positions, where they are standing still and facing each other.

As can be seen in **Figure 5**, the Kinect captures data from their positions and based on defined boundaries that have been set within Bounds, the Trigger operator, connected to the Bounds, takes on a value of either 0 or 1. When participants are within the specified bounds, the Trigger switches to 1, otherwise, it remains 0.

The trigger values are then passed to a math operator labelled “Participant's Position” in the diagram in **Figure 5**, which multiplies the x and z values of each participant. When both x and z triggers are set to 1, indicating that the participant is within the defined bounds for both coordinates, the “Participant's Position” sends this value to the “main Math” operator.

When this “main Math” equals 1, it signifies that both participants are in their initial positions. At this point three actions are activated:

- Initial Circles Sequence Activation: The sequence of transforming circle geometries is triggered, in which circles transform one into another.
- The Screen Change updates the display based on the participants' positions.
- The Sound Adjustment modifies audio settings in response to the participants' positions.

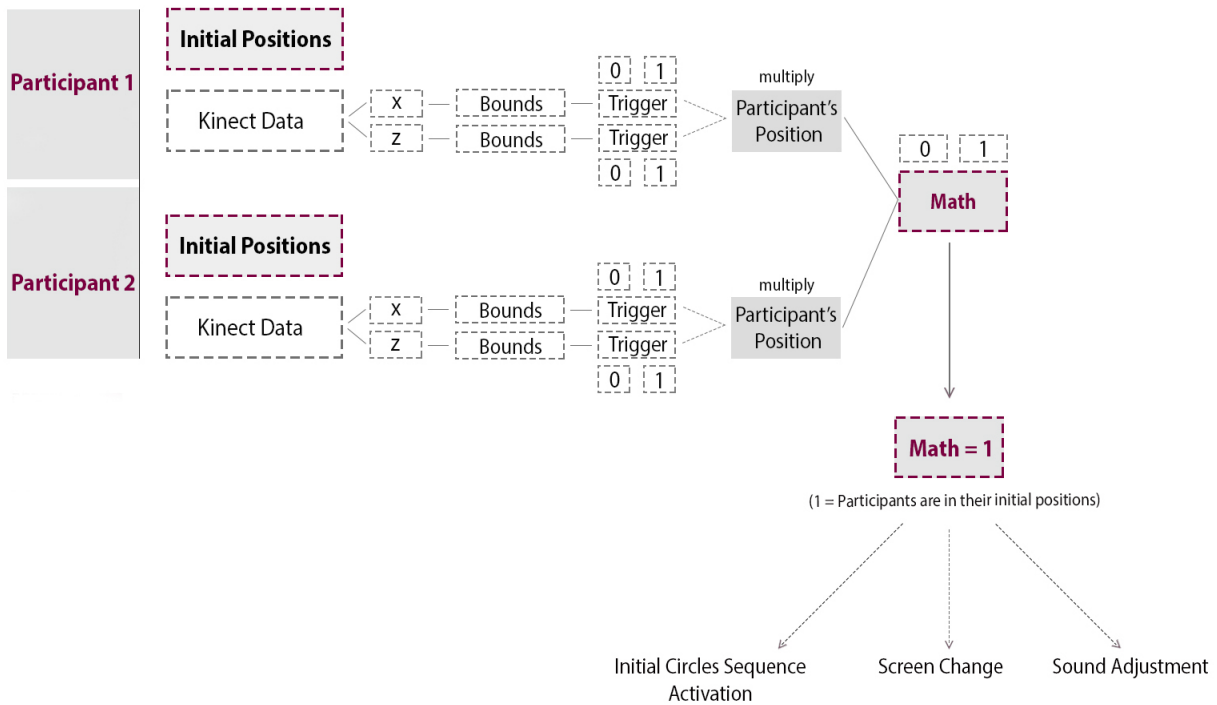


Figure 5: Initial Positions Implementation Flowchart

A similar process was followed to monitor the participants' positions and make the colour trail follow them. The process is depicted in **Figure 6**.

First, the range of x and z values was determined based on the boundaries of the participants' movement in real space along these axes, then normalized to values between 0 and 1. A math operator then adjusts these values to make the colour trail responsive to the participants' movements, controlling the speed and positioning of the colour trails relative to each participant's position. After this adjustment, the modified values are used as input for generating the colour trail and for the proximity part of the implementation, that will be analysed later.

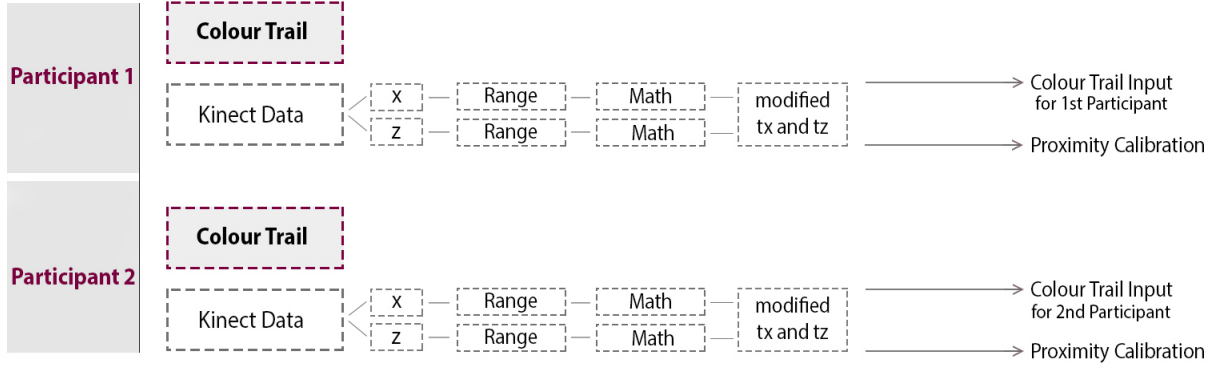


Figure 6: Colour Trail Implementation Flowchart

#### 4.2.2 Initial Circles Sequence

One of the first implementation steps concerning the interactive elements of the project, was the creation of the four different circular geometries, for the second stage of the installation (Section 3.3). As it was described, these geometries transform sequentially: the first has an abstract form, which then evolves into a more defined circular shape, then a complete circle and finally an almost half-open circle. The half-open circle was designed specifically to indicate the way out for participants. These circles can be seen in **Figure 7**.

The transition between these circles is controlled by a Switch operator, which takes the four circles as inputs. The Switch is influenced by the trigger that is tied to the “main Math” operator that was described in **Section 4.2.1**. The trigger gets activated when the “main Math” equals 1 and through another math operator, sets the total duration of the initial circles sequence to 20 seconds, adding a delay at the end for the last circle until participants step out of it.

Next, the initial circles sequence is connected to a fit parameter that adjusts to each participant's position, ensuring that the circles are positioned around them. This configuration of the participant's position was calibrated in real space during testing.

Finally, the initial circles sequence was duplicated and assigned a different colour to provide a similar experience for the second participant. Both initial circles sequences were then combined so they would appear for both participants.

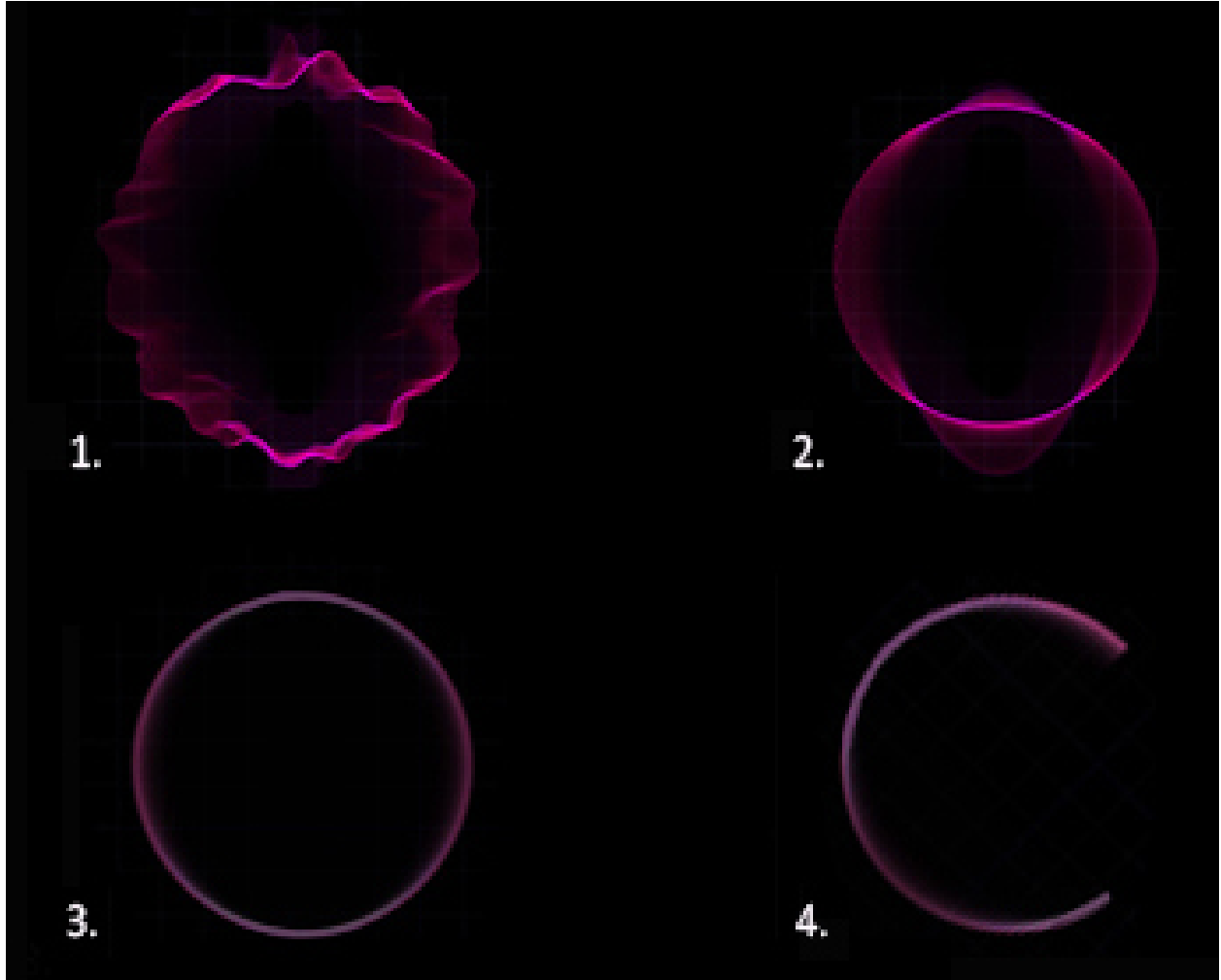


Figure 7: Initial Circles Sequence

### 4.2.3 Colour Trail

Later on, the colour trail was implemented. It would appear for both participants when they would both step out of their half-open circle. A ParticleGpu tool was used to create the colour trail. For the second participant a clone was made out of the ParticleGpu, a clone was made using a replicator. This allowed for two particle sources with only one particle system, which helped to prevent the system from becoming too computationally heavy.

The Particle Source of the ParticleGpu component is set in a way that it can emit particles based on the participants' positions which are continuously updated through the Kinect data input. More specifically, the modified tx and tz values, as mentioned in **Section 4.2.1**, have been set as the particle source.

In addition, further adjustments were made to achieve the desired effect for the particle system. The system includes a feedback loop to create a continuous trailing effect, allowing particles to stay and fade over time, while being influenced by brightness and colour adjustments.

In addition, the final colours of the particle system were made dynamic, allowing them to align with the proximity parameter of the project, based on participants' movements. This interaction will be explained in more detail later.

#### 4.2.4 Screen Change Integration

After modifying the initial circles sequence and the colour trail, both were added to the same Switch operator, which is responsible for managing the screen transition between the two. When the value of the “main Math” changes from 1 to 0, the release button is activated, initiating a 5-second delay before the screen changes.

#### 4.2.5 Proximity Implementation

To create an interactive response based on participants’ proximity and the colour trail, the modified tx (X position) and tz (Z position) values of both participants, were used. A Math operator, subtracts the values of tx (X-axis) and tz (Z-axis) for each participant as follows:

- $tx1 - tx2$  for the X-axis distance
- $tz1 - tz2$  for the Z-axis distance

This subtraction gives the distance between the two participants along each axis. By calculating the difference, the system can focus on how close the participants are to each other, regardless of their exact location within the overall space.

These values are passed through Logic operators, where bounds are applied. The bounds define a threshold range for proximity. When the difference in the participants’ positions falls within this range a Math multiplies the values. This creates a 0.5-1 meter mixing zone between participants in real space.

The final value of the Math operator is then transferred to two different Constants, one for each participant. Each Constant is linked to three different Math operators representing the RGB colours of the trail. These operators adjust the colour of the colour trail based on the distance value calculated by the main Math operator and when the distance is less than 1.5m, the colour trail of both participants changes colour.

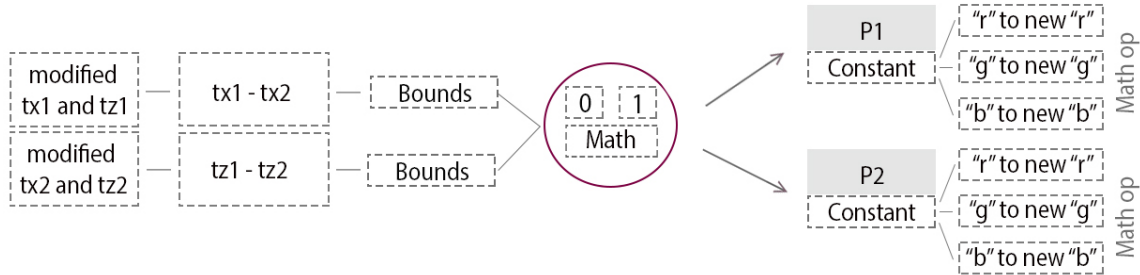


Figure 8: Proximity Flowchart

#### 4.2.6 Sound Implementation

The sound design of the project began by separating its two main auditory elements. The first element is the heartbeat sounds of both participants, which become audible when the participants are in their initial positions. The second element is the background music, which plays when the participants leave their initial positions.

To achieve this, the “main Math” operator was used once again for the Sound Adjustment, that can be seen in **Figure 5**. A Trigger operator is used once again, to switch the sound of the background to an empty Constant operator, when the participants are in their initial positions, so the background music would be deactivated.



As far as the heartbeat detection system is concerned, to pass the data from the ESP32 M5Stack Atom Matrix to TouchDesigner, a UDP In operator was used. In the UDP In operator within TouchDesigner, the “Local Address” parameter was adjusted to match the IP address of the laptop, enabling the M5Stack Atom to send data each time a pulse was detected.

Once the UDP data was received, a heartbeat sound was imported into TouchDesigner, and a script in the UDP In operator was set to trigger the heartbeat sound each time the M5Stack Atom sent a pulse signal. This allowed the sound to play with each detected pulse.

The same process was followed for detecting and incorporating the heartbeat sound for the second participant.

In addition to the background music, elements such as wind chimes and forest sounds were activated when participants stepped out of their initial positions. These sound effects were triggered in response to each detected pulse from the participants. For example, when Participant 1 stepped out of their initial position, their heartbeat signal triggered the wind chimes, which played with each pulse. Similarly, when Participant 2 moved out of their starting position, their heartbeat activated forest sounds in the same way.

### 4.3 Addition of Extra Feature and Optimisation

Later in the project, an extra feature, the first stage of the experience, as it is described in the **Section 3.3**, was added to help participants recognize each other’s presence before the initial circles sequence began. This addition created a smoother transition into the initial circles sequence and the accompanying heartbeat sounds, preventing participants from being abruptly exposed to both elements without preparation. As it was described in **Section 3** The feature included the following steps:

- **Heartbeat and Circle Appearance of the First Participant:** The first participant’s circle appeared, accompanied by the sound of their heartbeat, which was audible to the other participant. After a few seconds, both the circle and the heartbeat faded out.
- **Heartbeat and Circle Appearance of the Second Participant:** The second participant’s circle and heartbeat then became visible and audible to the first participant in the same manner, while the first participant’s circle gradually faded in, preparing for the initial circle sequence when both heartbeats and circle geometries would be activated.

Since this feature was added later, it was activated by pressing the “2” key using a keyboard input in TouchDesigner. The keyboard input triggered two separate Triggers that controlled the appearance of each participant’s circle and heartbeat sound in the intended sequence. Each circle was connected to an empty Constant to manage visibility, and by triggering a Switch, it alternated between the empty Constant and the circle based on the desired order. Similarly, for each heartbeat sound, a Switch was used to toggle between a Pattern operator and the heartbeat audio, controlling when the sound was heard.

However, during testing in the actual environment, the feature presented challenges. The heartbeats would often blend and since the two circles relied on the participants’ initial positions but were handled as separate elements, they occasionally causing calibration delays and sometimes the colour trail was triggered disrupting the intended sequence.

To resolve these issues, the implementation approach was modified, integrating the feature in a way that would avoid the disruption of the experience.

The two additional circles were integrated into the initial sequence of circles, which was controlled by the Switch operator that previously only handled the four circle geometries. Each of the new circles was connected to a separate switch, positioned before the main switch that controlled all the circles. An empty Constant operator was connected to this switch, so the circles would appear sequentially: first, the circle for participant one, and then the circle for participant two, while the circle of the participant one was gradually fading in. This switch was activated by a separate Math and Trigger system, which was triggered once again by the “main Math”. This allowed the new circles to have their own timer within the sequence.

In addition, the duration of the initial circle sequence was extended. Originally set to last 20 seconds, it was set to last 60 seconds to ensure the participants had enough time to fully engage with the experience.

In the **Figure** below the arrangement of the Initial Circles Sequence in TouchDesigner can be seen:

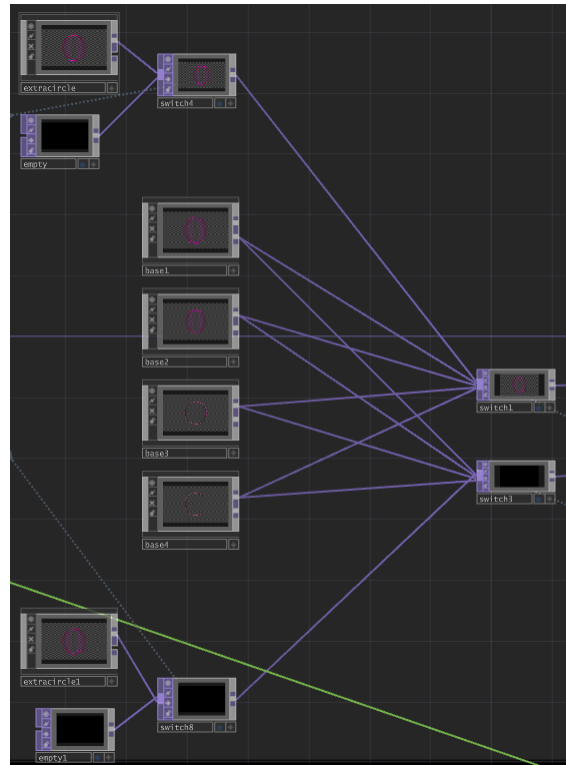


Figure 9: Final Configuration of the Initial Circles Sequence

As far as the sound is concerned, the heartbeats of each participant were mixed into the same audio output used for the initial circle sequence. A switch was used to toggle between these three inputs. This switch was triggered by the “main Math”, which activated another trigger with each math operation, ensuring the desired outcome was achieved. Because the heartbeat of the first participant was triggered after the initial circle sequence ended, the second participant’s heartbeat sound was added to the background music that played once the participants stepped out of their final circle geometry so they can both be audible.

The wind chimes and the forest sounds that were triggered by the pulse signal when participants were stepping out of their circle geometries, were removed and the heartbeat sounds replaced them. This decision was made to avoid shifting the focus of the experience or distracting the participants out of the state they were in before. Introducing different sounds could probably disrupt the flow, drawing attention away from the heartbeat sounds.

The final configuration of the sound in TouchDesigner can be seen below:

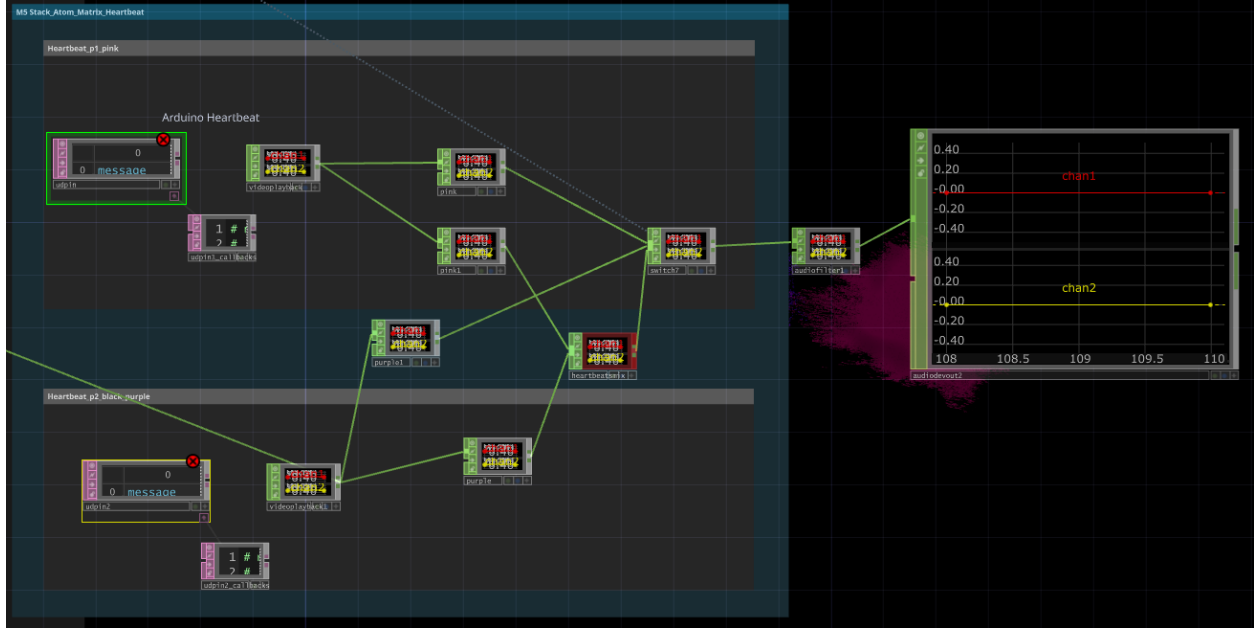


Figure 10: Final Sound Configuration of the Initial Circles Sequence

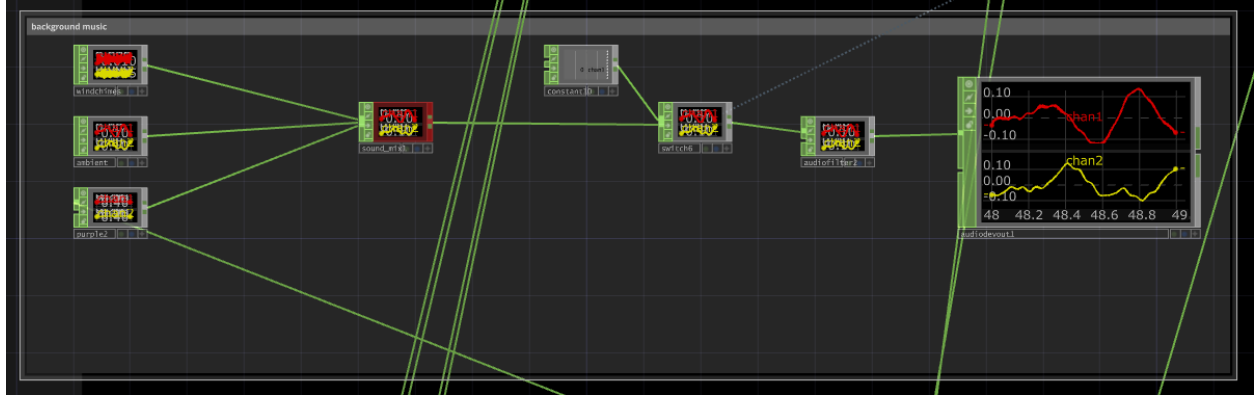


Figure 11: Final Configuration of Background Music

#### 4.4 Installation's Implemented Stages in Real Space

In this section, the final implemented stages of the installation in its real-space setup are presented:

#### 4.4.1 Initial Circles and Heartbeats



Figure 12: First Stage: Abstract Circular Projections and Heartbeats Activated Sequentially for Each Participant



Figure 13: Second Stage: Abstract Circular Projections Evolving into Open Circles, with Both Heartbeats Audible

#### 4.4.2 Colour Trail and Colour Blending Based on Proximity

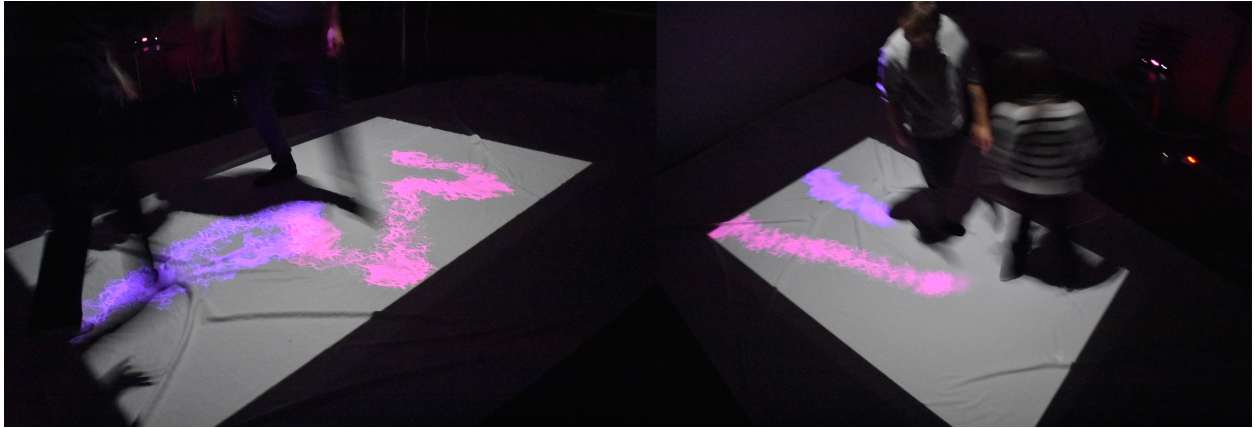


Figure 14: Third Stage: Colour Trail



Figure 15: Third Stage: Colour Blending

## Chapter 5

# Evaluation

### 5.1 Evaluation Methods

The evaluation process was designed to answer the FPS *“How can the visual and auditory stimuli in an installation, based on participants’ movements and heartbeats, influence their sense of connection to one another?”*. It is an exploratory question, and to answer it, both quantitative and qualitative data were collected for the evaluation.

To answer the research question, the analysis was based on three subcategories:

- **Movement Analysis:** This subcategory, focused on the movements of the participants influenced by the experience. It examined how participants moved closer to or farther from each other during the experience, using quantitative data derived from their x and z positions in TouchDesigner.
- **Heart Rate Analysis:** This subcategory was related to the participants’ heartbeats to see if their pulses were synchronised as they moved closer to each other and if there were patterns in the changes of their heartbeats in response to the audiovisual experience. The analysis also explored how their heartbeats reacted during the experience. Heartbeat data, concerning the timing of each participant’s pulse, was recorded in TouchDesigner.
- **Participant Experience:** This subcategory focused on how participants described their feelings during the overall experience. Qualitative data were gathered through semi-structured interviews, which were also recorded.

The analysis also incorporated observations of these elements, which are referenced in the text where relevant.



## 5.2 Procedure



Figure 1: Procedure Setup

The test was conducted at the Augmented Performance Lab in Aalborg University in Copenhagen. The setup included a Kinect v2, a laptop, a ceiling-mounted projector, a white fabric for the floor so the visuals are visible and speakers.

To select participants, a purposive sampling approach [22] was used. The participants were divided into familiar and not familiar groups. This division was implemented to assess the effectiveness of the installation and to explore how participants experienced it both with prior familiarity and without prior familiarity. Additionally, participants were selected based on their availability and willingness to participate.

The Pre-Test questionnaire included a consent form for allowing the recording of participants' interactions within the installation and the interviews as well questions related to whether they had alcohol or caffeine consumption before the test.

The test didn't involve a lot of instructions, as the main focus of the project was to observe how participants felt and responded naturally to the experience. The instructions given were limited to where participants should stand in the installation space and the request to not talk to each other during the experience.

The initial test did not aim to involve many instructions, as the main focus of the project was to observe how participants felt and responded naturally. However, it became clear after the first two pilot tests that some form of guidance was necessary due to technical limitations. The combination of the project's design in TouchDesigner and the Kinect system caused it to lose track of participants when they moved even slightly. As a result, the stage where the abstract circles were appearing could suddenly stop, and the colour trails would appear instead. Therefore, participants needed clearer instructions. The final instructions given were: "You are not allowed to talk. In the beginning, you have to stay still and observe, until you are invited to explore the space." The goal was to provide as little information as possible to encourage participants to remain still and observe both their own presence and the other person, without making unnecessary movements. Additionally, the phrase "until you are invited" was intended to imply the opening of the circles, signalling when they could step out.

The request to avoid talking was made to maintain the sensory-focused nature of the installation, which relies on auditory and visual stimuli. In addition, verbal communication could have possibly distracted participants from engaging with these elements. This decision also encouraged them to focus on their own experience and the presence of the other person, by listening to each other's heartbeats and observing the evolving visuals, rather than engaging in dialogue.

After the experience of the installation, a System Usability Scale (SUS) test [23] was conducted, to test the efficiency of the system and how intuitively participants could interact with the installation as well as if, and to what extent, technical issues interfered with the participants' experience.

After the SUS test, a semi-structured interview [22] was conducted in pairs. The semi-structured interview format was chosen for this study to allow flexibility in exploring participants' experiences and to gather more in-depth data. In addition, since the project focuses on the interaction and connection between participants, conducting interviews together allowed for an exploration of their shared experience. The paired interviews are more time-efficient, which was also a practical consideration given the study's constraints. While individual interviews might have allowed participants to talk more freely without any influence from the other participant, their shared experiences could provide valuable insights and encourage meaningful dialogue.

The questions were designed to address participants' overall experience, their self-awareness and the presence of the other participant, their connection, their feelings about different parts of the experience and how those parts made them feel, as well as the role of visual and auditory elements.

These questions were later used to explore the connection between the proximity and heartbeat elements of the project, as well as to stand alone as additional information of the experience.



# Chapter 6

## Results

The total number of participants was 16, consisting of 8 pairs, 4 familiar and 4 unfamiliar. While this is not a large sample size to provide representative, reliable, or generalizable results for answering the research question, it serves as a starting point. Additionally, regarding the quantitative data, it is important to note that most participants reported consuming caffeine within the three hours prior to the experiment, as indicated in the pre-screening test. Caffeine consumption might have influenced their physiological responses.

### 6.1 Quantitative Data Analysis

#### 6.1.1 SUS Results

The SUS Score of the project was calculated according to the instruction of [23]. The mean score of the installation was 76.40 out of 100. This indicates that the usability for the installation falls into the good category [24].

However, it is important to note that three questions from the SUS test may not be entirely relevant to this installation. Specifically:

- *“I think that I would need the support of a technical person to be able to use this system”*
- *“I would imagine that most people would learn to use this system very quickly”*
- *“I needed to learn a lot of things before I could get going with this system”*

The first statement, regarding the need for technical support, is less relevant as the system’s interaction is intentionally simple and self-explanatory. Similarly, the second and third statements focus on “learning” to use the system, which does not align with the project’s nature of natural and seamless interaction. As a result, these questions may not fully reflect the usability of the installation and could have affected the SUS results.

However, as discussed in **Section 5.2**, the SUS test was conducted to evaluate the system’s efficiency and determine if, and to what extent, technical issues interfered with the participants’ experience. Even though these questions don’t fully align with the installation’s nature, the standard SUS scoring process was maintained to preserve the integrity of the assessment and provide a baseline for analyzing the overall user experience.

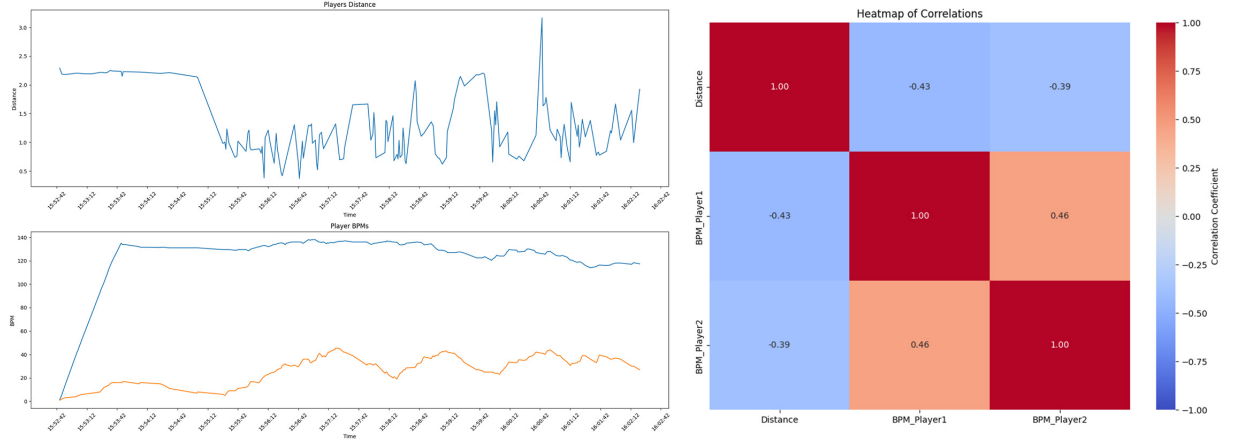
In this context, the SUS score of 76.40 can be seen as a positive indicator of the installation’s usability and a promising starting point for further refinement of the installation, though not entirely reliable. Additionally, the score will be analyzed alongside user feedback on technical issues to help us better understand how any technical problems affected the experience.

## 6.1.2 Movement and Heart Rate Data Analysis

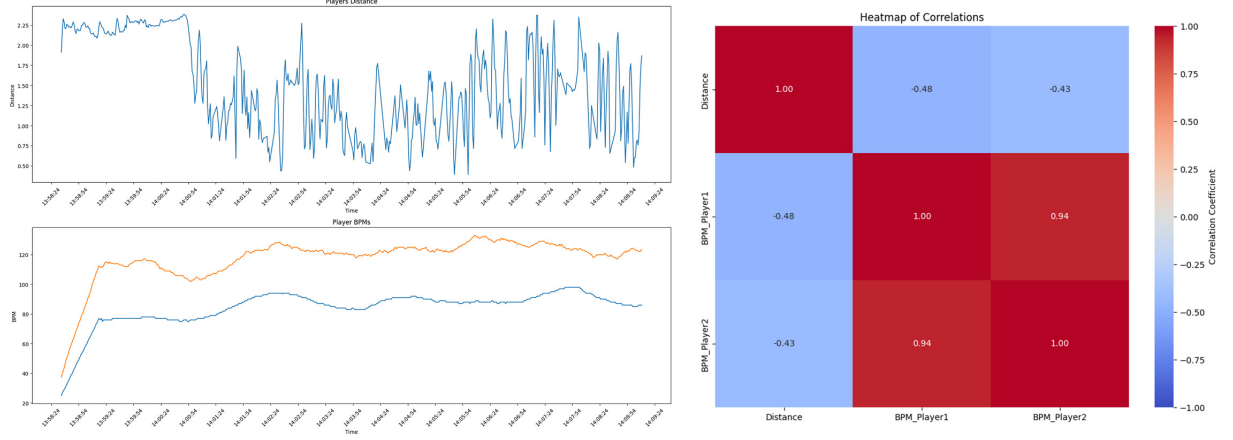
### 6.1.2.1 Familiar Couples

The graphs of the quantitative data for the familiar group are presented below. In the time-series graphs, Participant 1 is represented in blue and Participant 2 in orange.

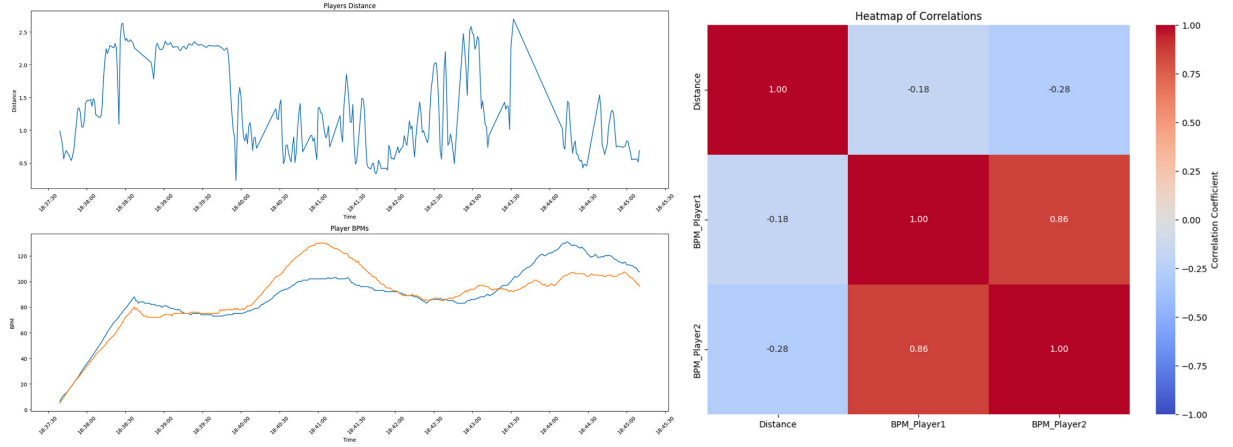
#### Couple 1



#### Couple 4



### Couple 5



### Couple 6

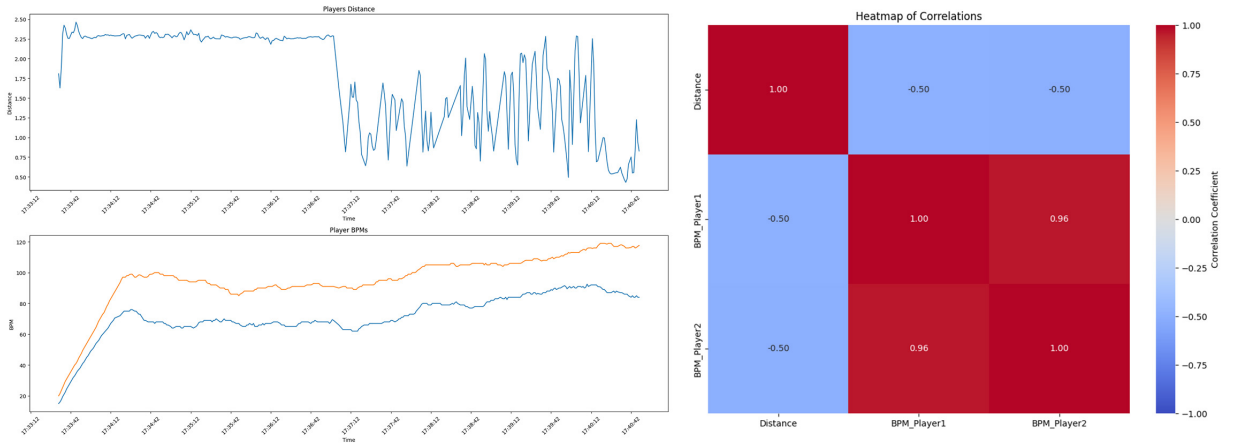


Figure 1: Time-Series Graphs and Correlation Heatmaps for Familiar Couples, Showing the Relationship Between BPM and Distance

For **Couple one**, the correlation between heart rates is moderate (0.46). The negative relationship between distance and BPM (-0.43 and -0.39) suggests that proximity has a mild influence on their physiological states.

From the time-series graphs, it can be seen that participants started moving around 15:55:00. One minute before they started experiencing the “Initial Circles and Heartbeats”. It is important to note here that Participant’s 1 heart rate, has not been fully regulated yet. This might cause some inconsistencies in the way Participant 1’s heart rate sounds during the experience, as their heartbeat is audible first.

**Couple four**, demonstrates strong heart rate synchronization, with a correlation of 0.94 between Participant 1 and Participant 2, meaning that their heartbeats follow similar patterns over time. The moderate negative correlations between distance and BPM (-0.48 and -0.43) indicate that as they move closer, their heart rates increase.

This can also be seen in the time-series graphs. From these graphs, it can be seen that participants started

moving around 14:00:59. One minute before, they started experiencing the “Initial Circles and Heartbeats”. From this experience it can be seen that the heart rates of one of the participants, are decreasing slightly.

**Couple five**, shows a strong positive correlation between their heart rates (0.86), indicating a high degree of synchronization. The correlation between distance-BPM is relatively weak, with -0.18 for Participant 1 and -0.28 for Participant 2. This suggests that while their heart rates are synchronized, proximity does not strongly influence their physiological responses.

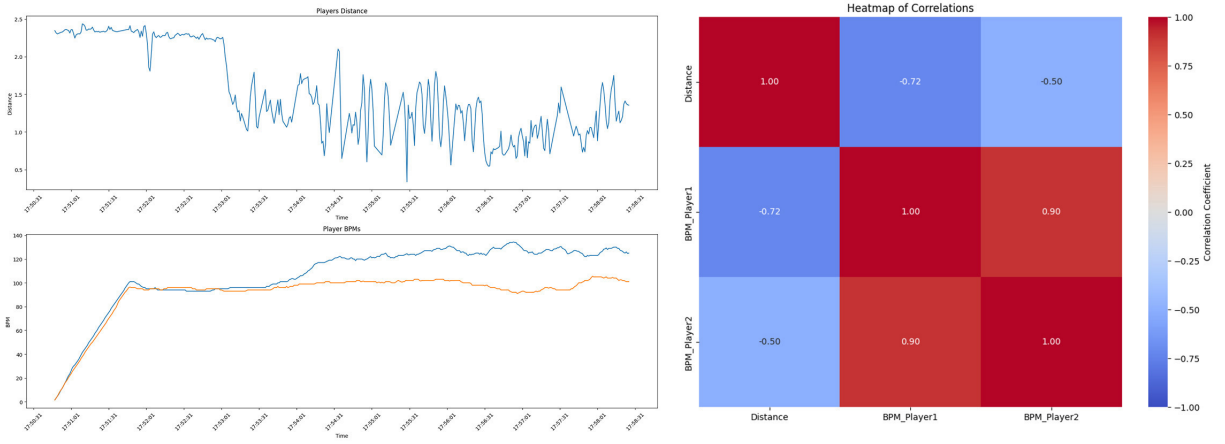
From the time-series graph, it can be seen that the participants start moving around 18:39:50. The “Initial Circles and Heartbeats”, started one minute before. While this feature was active, their BPMs seem to align slightly. Their BPMs also seem to align slightly around 18:42:05 and they continue to remain somewhat aligned until around 18:42:35.

**Couple six**, shows a strong synchronization (0.96) between the two participants’ BPMs. The moderate negative correlations (-0.50) suggest that as the participants move closer, their heart rates tend to increase.

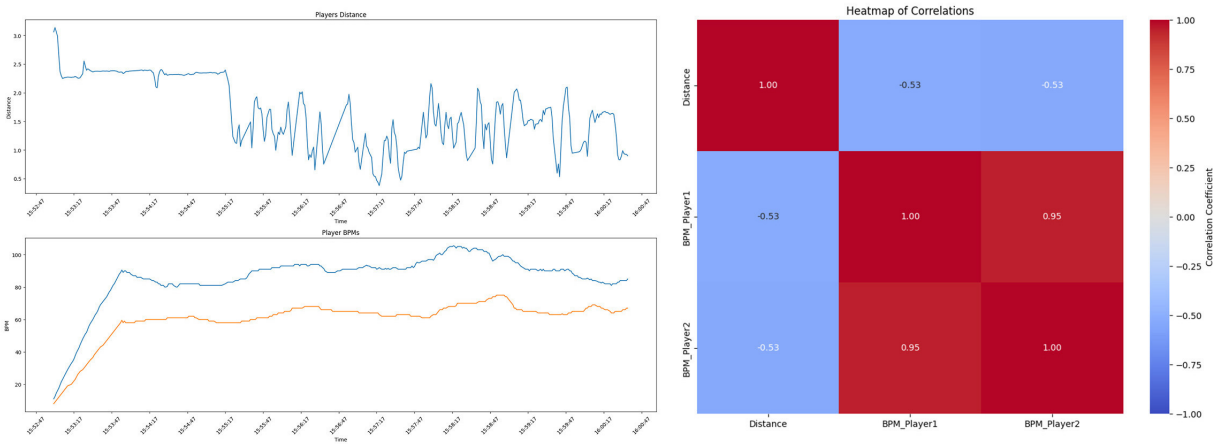
From the time-series graphs, it does not seem that the “Initial Circles and Heartbeats” affected their physiological data.

### 6.1.2.2 Unfamiliar Couples

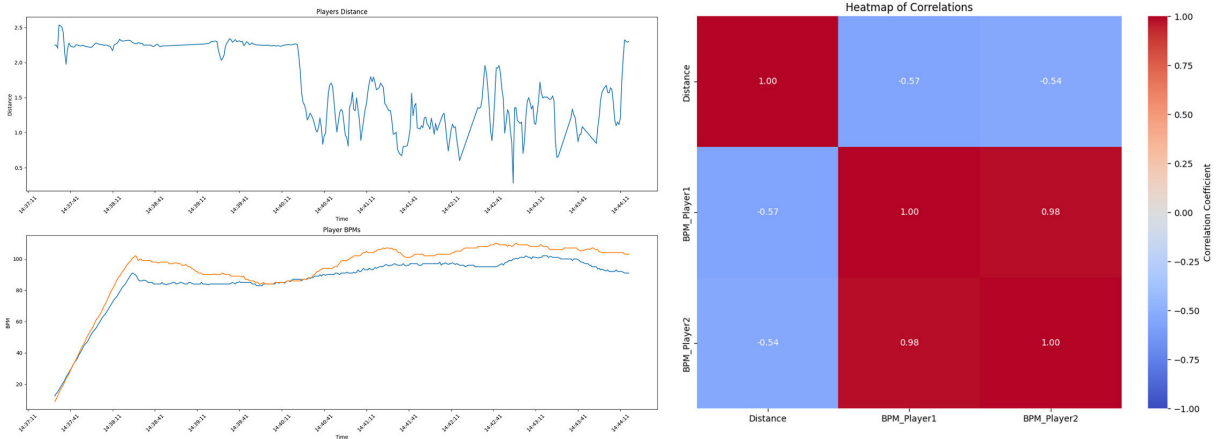
**Couple 2**



**Couple 3**



### Couple 7



### Couple 8

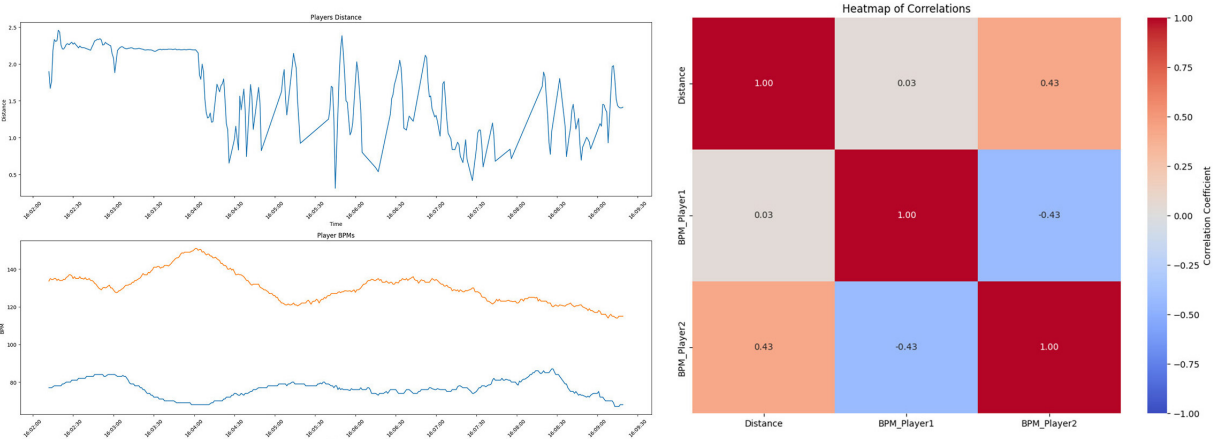


Figure 2: Time-Series Graphs and Correlation Heatmaps for Unfamiliar Couples, Showing the Relationship Between BPM and Distance

**Couple two**, shows a moderate negative relationship between distance and BPM (-0.72 for Participant 1 and -0.50 for Participant 2), indicating when distance decreases, their heart rates tend to increase. Their heart rate synchronization is strong (0.90), reflecting a significant degree of physiological synchronization.

From the time-series graphs, it can be seen that participants, started moving around 17:53:05. One minute before, the “Initial Circles and Heartbeats” feature became active. At this time, their BPMs, seem to align slightly before they start moving.

**Couple three**, shows strong synchronization between their heart rates (0.95), meaning that their heart rates increase and decrease together. However, the relationship between distance and BPM is moderately negative (-0.53 for both players), meaning that as the distance between them increases, their heart rates tend to moderately decrease.

**Couple seven**, demonstrates very strong heart rate synchronization (0.98). The distance-BPM correlations

are moderately negative (-0.57 and -0.54), suggesting that when distance increases, their heart rates decrease, but not significantly.

From the time-series graphs, it can be seen that before they started moving, their heart rates seem to align slightly.

**Couple eight**, displays weaker heart rate synchronization, with a correlation of -0.43 between Participant 1 and Participant 2, indicating that their heart rates are moderately negatively correlated, meaning that as one participant's heart rate increases, the other's tends to decrease. The distance-BPM relationship is slightly positive for Participant 2 (0.43), suggesting that as the physical distance increases, their heart rates, tend to increase as well. For Participant 1, the distance-BPM correlation is nearly neutral (0.03), meaning that there is no significant relationship between distance and heart rate for this participant.

From the time-series graph, it can be observed, that when the heart rates of the one participant increase, the other's tend to decrease. Participant 2's heart rates, seem to increase during the "Initial Circles and Heartbeats" feature. The heart rates of the Participant 1, seem to decrease at this stage.

### 6.1.2.3 Conclusions: Familiar and Unfamiliar Couples

Familiar couples stayed 8.88 minutes in the installation, a bit longer than the unfamiliar couples, that stayed 7.43 minutes.

From the graphs, it appears that familiar couples tended to maintain smaller distances between each other more frequently compared to unfamiliar couples.

Familiar couples had more consistent BPM correlation with a mean of 0.805. compared to unfamiliar couples, who had a mean of 0.60. The results suggest that familiar couples show higher heart rate synchronization, which could imply that familiarity or emotional closeness plays a role in physiological synchronization.

While the results reveal high correlations between heart rates, especially in some pairs (e.g., 0.96, 0.98), these values may be artificially inflated due to potential limitations or errors in the heart rate sensors. Extremely high correlations can sometimes indicate sensor calibration issues, or oversensitivity to subtle changes, rather than reflecting perfect physiological synchronization.

In general both familiar and unfamiliar have negative correlations between distance and BPM. This suggests that, for many couples, as the distance between them increases, their heart rates tend to decrease.

The unfamiliar couples tend to show stronger negative correlations (e.g. Couple 2 with -0.72), than the familiar couples. Familiar couples tend to have weaker negative correlations (e.g. Couple 5 with -0.18). The positive correlation in Couple 8 (P2: 0.43) indicates that for one individual, a slight increase in distance leads to an increase in heart rate.

The fact that unfamiliar couples tend to show stronger negative correlations indicates that physical proximity may have a stronger influence on their heart rates. When the distance between them increases, their heart rates decrease. This could suggest that, for these couples, moving further apart might lead to lower physiological arousal. This could potentially be due to reduced discomfort, but this explanation is not certain.

Familiar couples, in contrast, show a weaker negative correlation, this could suggest that familiarity and comfort might make the effect of distance on heart rate less intense, as they may feel more intimate regardless of proximity.

For the participant who has a positive correlation and belonged to an unfamiliar couple, it might suggest that for this individual, being farther apart increases physiological arousal, which could be interpreted as some alertness or excitement, possibly in anticipation of getting closer again.

## 6.2 Qualitative Data Analysis

The method used for the analysis of the qualitative data was content analysis [22]. The interview data were analyzed and organized into categories. Groups of data were then formed, primarily based on the interview questions, with some refinements. The categorized and simplified data can be seen in the **Appendix 10.1**.

### 6.2.1 Overall Experience of the Installation

The main adjective used to describe the overall experience of the installation was fun. Participants' familiarity with one another influenced their initial perception and engagement with the installation.

- **Familiar pairs** approached the installation with a sense of engagement and mostly playfulness, exploring movements and interactions early on. The experience was often described as fun, relaxing, and playful, with a clear focus on collaboration and colour blending.
- **Unfamiliar pairs** initially exhibited more hesitation, with self-awareness dominating at the start. Over time, their experience transitioned towards shared exploration, described as interesting, immersive, and collaborative. Participants appreciated how the installation facilitated non-verbal interaction and connection, emphasizing its calming and meditative aspects.

### 6.2.2 Perception of the Installation's Concept

The second question of the interview was, *"What do you think the installation was about?"*. This question was asked in order to determine whether participants engaged with the intended themes of the installation, even indirectly, and to assess how intuitive the experience was in conveying its intended meaning. Additionally, this question was asked because listening to different interpretations of the main themes is valuable, as it can shed light on aspects that were not previously considered.

The participants' perceptions of the installation focused on themes of movement and interaction, which were mentioned most frequently. They also emphasized the dynamics between the two participants' movements, colours, sounds, and how these elements interacted.

Another participant described the concept of the installation as symbolizing the changes that can occur when crossing paths with another person. This was also mentioned by another participant, but in a slightly different, metaphorical way, as 'how crossing paths with other human beings can interact and how the connection might change things.' This suggests that human encounters can have an impact on people's lives, with each person being represented by a unique colour, and "yellow" symbolizing change. Another participant referred to the idea of "bonding between strangers". These observations are interesting and closely related to human interaction. These responses, however, came from participants who were in an unfamiliar pair, indicating that they might have been more attuned to this aspect of the project.

The concept of collaboration, particularly in the context of participants' movements, was also mentioned. Additionally, some participants noted the calming effect of the installation, with one stating that the main concept was stress reduction and another comparing it to dance.

These responses suggest that participants engaged with some of the intended themes, including movement, interaction, collaboration, and to some extent, connection.

### 6.2.3 Initial Circles and Heartbeats Feature in Relation to Awareness

The "Initial Circles and Heartbeats" feature corresponds to the first and second stages of the installation.

This feature was tested separately to assess whether it achieved its intended purpose of encouraging participants to focus on self-awareness, the presence of the other person, and both simultaneously. Additionally, it was important to evaluate this aspect because the heartbeats were presented without any background music, and wanted to test how this would feel for the participants.



For the first couple (familiar), the circles were not particularly noticed, and the heartbeats did not appear to escalate in a way that felt natural. The heartbeats seemed unsynchronized.

In the second couple (unfamiliar), the first participant noted that the circles were initially perceived but quickly faded, while the heartbeats had a calming effect, especially at the beginning and continuing throughout the experience. This suggests that the heartbeats played a significant role for this participant, and as they mentioned “they felt very nice”, with the circles seeming to pass by quickly, as the heartbeats were the main feature of focus. This could indicate that the first participant was more aware of themselves than of the other person. The second participant initially found the heartbeats stressful when tracked but gradually became more aware of the other participant while standing in their circle, showing a shift from self-awareness to awareness of the other’s presence.

In the third couple (unfamiliar), both participants were aware of themselves, during this feature. The second participant also used the phrase “Felt that they were building up for something (the heartbeats)”. This statement “Building up for something” can suggest that the participant experienced a growing tension or anticipation during the installation, as they were listening the heartbeats. The idea that the heartbeats were “building up for something” implies a sense of climax or readiness for a shift in the experience. As the second participant paid attention to their heartbeat, they eventually became aware of the second participant’s heartbeat.

In the fourth couple (familiar), both participants felt also anticipation and that the heartbeats were preparing them for something to happen, with a growing awareness of each other’s presence.

In the fifth couple (familiar), one participant commented on the feature, saying, “I think it was a nice intro, kind of like two hearts getting there”, suggesting they were likely aware of both their own and the other person’s presence. The other participant stated that was self-aware, before noticing the visual of the other person. This participant was the first to mention the “wavy circle” of the other person (abstract circle geometry) and refer to the visual aspect of the feature at this point.

For the sixth couple (familiar), the first participant was “weirdly aware” of their heartbeat, indicating they were self-aware. The second participant noted a sense of anticipation, which could be interpreted as a subtle tension building during the experience.

The seventh couple (unfamiliar) shared similar introspective experiences, with both participants focusing on both heartbeats. The first participant even questioned if they could control their heartbeat, indicating a heightened sense of self-consciousness. The second participant found the overlapping rhythms of the heartbeats interesting, possibly indicating a sense of unity or connection through the shared experience.

In the eighth couple (unfamiliar), the first participant stated that they were self-aware and described feeling relaxed and spaced out. The second participant, however, focused on their own heartbeat as well as the other’s, trying to calm themselves down to influence the heartbeat. This suggests that the heartbeats became a central feature of awareness for both participants.

From the observations, it is evident that the heartbeats were the main feature that participants focused on during this phase. One participant felt stressed from having their heartbeats tracked. Two participants felt relaxed listening to the heartbeats and four participants experienced feelings of anticipation. Most of the participants were aware of themselves and the other person. Some were mostly aware of themselves.

As a result, the feature provoked awareness of both participants’ presence as well as self-awareness in most participants. However, the feeling of anticipation, which was not part of the original design intent, emerged during the experience. While this sense of anticipation could serve as a trigger at the beginning of the installation to engage participants, it may be better to reduce it slightly. The heartbeats could be implemented in a gentler way, such as lowering their volume, so the experience remains self-reflective without triggering stressful feelings. Especially, if people might feel stressed when they are tracked, as one of the participants. The comment, “I think it was a nice intro, kind of like two hearts getting there”, was very positive, but this feature might be more appreciated if delivered in a gentler manner. Additionally, there were some technical difficulties, such as issues with the pulse-related data for the first couple of participants, which may have impacted their experience. These issues should be addressed to ensure smoother execution.

#### 6.2.4 Colour Trail, Sound and Heartbeats in Relation to Awareness

In the analysis of participant experiences, a clear progression from self-awareness to an increased awareness of their partner and then the shared experience can be observed.

During the experience, after exiting the circles, most participants were initially more self-aware, focusing on their own colour trail. Gradually, they became aware of the other person, and as the colours began to mix, their awareness shifted to the shared experience. This shift in focus toward colour blending and the shared experience was reflected in participants' statements, such as, 'Okay, we are in this together' and 'In the beginning, you are kind of observing the other person to see what's going on, and then as time passes, it becomes more of a shared experience than, you know, focusing on yourself' and "When realizing that the interaction matters, it became more about the other person... and how can we cross paths intentionally".

**Familiar couples**, gradually moved from self-awareness to the other person's awareness and the shared experience, often reaching a state of collaboration earlier in the process. In addition, they also focused on the playful aspect of the project, running, dancing, and trying to create the yellow colour with their movements. This is an observation that was made, as an external viewer.

The **unfamiliar couples** also experienced a shift in awareness, moving from self-awareness to awareness of the other person and the shared experience. In contrast to the familiar couples, some participants noted that, at the beginning, they were conscious of not wanting to be an obstacle in the other person's path. This reflects a more heightened awareness of themselves and the other person for a more careful approach to the interaction. Phrases such as, "I think at the beginning was just like we both wanted to experience our own spaces and just not stand in the other person's way", and "I was trying to be mindful, not to be an obstacle to the other player".

One participant also from the unfamiliar group, mentioned what was mentioned earlier in the familiar couples "But I'm sure that, if we'd known each other, we would have done it differently because we would have probably started moving against each other much earlier".

As a result, there was a gradual shift in awareness for all couples when the colours started blending. Familiar couples seemed to engage more and sooner to the collaborative aspect of the project, and experimenting. The unfamiliar couples also interacted, but in the beginning, they were more aware of themselves in space and the other person, so they wouldn't be an obstacle. They approached the interaction in a more careful manner.

#### 6.2.5 Connection Baseline without Verbal Communication and the Feeling of Connection in the Installation

The question for this part was: *"How do you experience or perceive the feeling of connection in a setting where speech is not involved with strangers or people you know?"*. This was an important question in the interview, as it established the baseline for what people consider as a feeling of connection when no verbal communication is involved. It focused on the affective aspect of the connection and it was also interesting in terms of research.

Most participants in this question took their time to think about it and most of them started to describing when they are feeling connected with others.

For example, the first couple (familiar) described experiences like concerts or festivals, where people come together for a **shared purpose**, all singing the same song and they are all syncing into something together. They also mentioned funny moments on the metro, when something happens and you look at someone, and both of you end up laughing. The third couple (unfamiliar) also shared similar examples of this feeling and emphasized the importance of context, noting that the sense of connection varies depending on the situation. In their conversation, they agreed that, "For me, the connection with strangers in day-to-day life is mainly driven by **sharing some space or an event**, or something like that. Like, if something

happens around you and you're experiencing it with someone, you might **share that feeling**. For instance, you go to an art exhibition or a performance, or even if an accident happens, you might share the **same emotional response** to it". In addition, the sixth couple (familiar) also agreed on something similar, with one participant saying, "when you share something or you have an **external stimuli** as a concert you overcome this kind of awkwardness and kind of everybody is random and an individual, and then you have a singing and then you sing together, chant together, I don't know, like also being sad together. So yes, I think it's like this **coming from single to unity**", "It needs to be **some kind of common reference for some connection to happen**. So like watching a beautiful sunset or we don't have to talk with whoever we're watching with". The seventh couple (unfamiliar) also shared the same idea about connection and the shared experience, "I guess sometimes you're going to feel like you're part of a like a bigger picture or group, group feeling especially like specific situation like concert. Yeah, then you kind of become **one entity to some extent**". Finally, one of the participants from the 8th couple also shared the same idea about connection.

These examples suggest that an external stimulus, such as sharing the same space, event, situation, or feeling, or experiencing the same emotional response, can foster a sense of togetherness, as discussed in **Section 2.1**. This shared experience, whether it's an event or a common emotional response, leads to a feeling of connection between individuals. All of these elements can be categorized as "Shared Situational Connection."

Participants who fit into this category all reported feeling connected in this way during their experience of the installation. The first couple (familiar), mostly through the collaborative aspect and the shared experience, mentioned that "It was like I was a kid playing with another kid". The third couple (unfamiliar), said that they definitely felt connected due to sharing the same experience. The sixth couple also said that they felt connected during the interaction, most specifically they said "So yes, I think it's like this coming from single to unity. But it was quite representing, like when the colour would change and the yellow, yeah, that's it", "I felt very connected, and I broke the silence and talked and I told him I'm glad, I'm glad I met him, yeah". The seventh group also agreed and one participant said: "It is like hanging around with a friend, sometimes you can appreciate the silence and just chill. And this was not exactly like that, but it was an experience that made me feel that way. I didn't get the stranger vibes. It was a safe place. It made me appreciate the moment with another person". The participant from the eighth couple, as well as the fourth couple, said that they felt connected while sharing the experience and collaborating.

Also another interesting comment that was added at some point from one participant of the sixth couple was: "I think it's a thing of interpreting intentions... you map the movement of the other person, and you understand the intentions, then you start feeling more connected."

Two participants pointed out the role of body language in feeling connected. One participant of the sixth couple also added that "I think also for me it's a more body thing. So, you know, like looking at each other, touching each other, moving together. So because I think this makes like an kind of underlying sense of connection and then you can kind of sink in together" and the participant from the eighth couple pointed out "I feel like there's been a lot of times where, you know, gestures in general and especially face mimicry and just the way that you act around each other and react just purely physical to what is happening and what the other person does". The same person also added: "I mean, even though we didn't really say anything at first, I feel like we quickly aligned and understood what we were going for in terms of our goal. It was only at the end that we communicated very briefly with words; it was more of a confirmation of what we already knew".

The participant of the eighth couple, felt connected, and added that "It offers a sort of like unspoken legitimization of being 2 strangers who have absolutely no experience with each other before... leaning into it"

Some participants mentioned that the way they perceive connection without verbal communication is through touch. One specifically said "I think for me it's touch, like when I touch someone, like a hug or something like that, that triggers for me like a sense of connectivity". The participants also from the fifth group agreed on touch, as the main way of feeling connected without speech, and one of them mentioned proximity.

When these participants were asked if they felt connected during the experience, they responded positively. Although the experience did not include any elements that triggered haptic feedback, the participants from the fifth group, who were familiar with each other, touched hands during the experience. Their sense of connection was created when they were collaborating and were trying to create the “yellow” colour.

One of the participants of the second couple (unfamiliar), pointed out that they would not easily feel connected to somebody. It is mostly related to their inner feeling, “I’m deciding if I will give and if I will be open to a person and that it’s like my inner feeling”, and their speech though they mentioned that, “we have to share the same idea of how the world is”, suggesting that their concept of connection is closely tied to deeper personal beliefs and values. This response highlights that the feeling of connection is highly subjective for this individual and cannot be easily applied to the context of the project. It also raises an interesting point: for this person, connection is a selective experience.

When asked if they felt connected, this participant replied “somewhat,” explaining that they felt connected because they knew me and I knew the other participant (their partner in the installation). This suggests that for this individual, knowing the people involved in the experience was an important factor in feeling connected, emphasizing the importance of context in their sense of connection.

The interviews revealed that the feeling of connection without verbal communication varied based on individual experiences and the context. Most participants can feel connected through shared experiences (shared situational connection), body language, gestures, touch and proximity. However, one participant stated that connection is more about personal openness and shared values, suggesting that connection is a more selective experience for some.

In conclusion, the installation facilitated a sense of connection for most participants and provided an opportunity to explore the affective side of connection through shared experiences and different emotions, non-verbal cues, and collaboration.

#### **6.2.5.1 The Role of Visual and Auditory Elements in Creating the Feeling of Connection**

In this section, the role of the auditory and visual elements of the installation will be examined to determine how they contributed to the feeling of connection.

As far as the visuals are concerned, the visuals played the central role in creating the feeling of connection, especially through their collaborative aspect of colour blending. Phrases like “visuals were important and engaging”, “I thought that it stopped playing the heartbeat. I wouldn’t notice it at all. I would notice the music kind of. But I think the whole experience in the end, for me, is that you notice more your movements and the movements of the other person than the music”, highlight their primary role in the overall experience.

As far as the auditory elements are concerned, some comments were gathered: “heartbeats were very cute. I think to me personally, it played quite a nice role to know this kind of this syncing out and syncing in of the face of heartbeats, background music did not play any role for him it could have been the same with just the heartbeats”, “audio and visuals were adding a relaxing narrative to the experience, music was very fitting to the experience”, “The audio was meditative and helped with focus. I was forgetting the beats but then I was noticing them again during the experience. The beats, contributed to the connection and I was aware of rhythm, identifying which beat was faster or slower”, “The music is very well suited”, “It conveys a calmness and I think it takes out from the awkwardness of the situation”, “The music created a relaxed environment”, “The overlapping heartbeats were interesting, like rhythm and flow”, “Heartbeats soon lost their role. I hadn’t really noticed them. And I started paying more attention to the lights themselves. And for me that the background music was part of that experience, a part of that space, whereas the heartbeats, I was aware they were happening, but it just became part of the music for me” and “The music with the heartbeats was a rhythm to work on... guiding our movements, setting a pace”.

As a result, even though the auditory elements did not play the main role in creating the feeling of connection and the main role of the experience, played a subtle yet significant role in shaping the participants' experience. While some participants found the heartbeats particularly engaging, describing them as “cute” and “interesting” for their rhythmic and synchronizing qualities, others felt that the heartbeats lost their prominence over time, blending into the background music. This was a nice comment to hear because the heartbeats blending with the music, fading from the main focus but still present, was part of the design's intention. As participants highlighted, the heartbeats, along with the music, were setting the pace for their movements. The background music was widely perceived as relaxing, calming, and fitting to the overall experience, helping to decrease any awkwardness and create a meditative atmosphere. Overall, the auditory elements supported the installation by enhancing relaxation, guiding movement, and subtly fostering connection between participants.

### 6.2.6 Comments about the Technical Aspect of the Project

One comment about the technical aspect of the project was that the heartbeats felt unrealistic. Some participants noted that they swapped colours with the other partner during the experience, but as they said in the interviews, they enjoyed it, as it added an element of surprise and fun. Three participants commented that the system was very responsive and accurately followed their movements, meaning the colour trail was highly responsive.

### 6.2.7 Summary of Qualitative Results

- The overall experience of the installation was described mostly as fun. It was also described as relaxing, meditative, and calming.
- Familiar couples, engaged more quickly with the collaborative aspects of the installation, experimenting with movement and interaction.
- Unfamiliar couples, began with some hesitation, self-awareness and cautious interaction to avoid obstructing one another, but gradually transitioned to shared exploration and collaboration.

The participants perceived some of the intended themes of the installation, such as movement, interaction, collaboration, and, to some degree, connection.

The “Initial Circles and Heartbeats” as a feature:

- Provoked awareness of both participants' presence as well as self-awareness in most of the participants
- Two participants felt relaxed listening to the heartbeats
- It generated feelings of anticipation, with some participants describing it as a buildup. While this can engage participants, reducing its intensity may help, especially for those who feel uneasy with being tracked
- Positive feedback included comments such as “I think it was a nice intro, kind of like two hearts getting there”, indicating the symbolic qualities were appreciated

The Colour Trail, Background music and Heartbeats as a feature:

- A gradual shift in awareness occurred for all couples when the colours started blending
- Familiar couples engaged more quickly and actively with the collaborative aspect and experimentation
- Unfamiliar couples also interacted, but approached the interaction more cautiously to avoid being an obstacle to the other person

Categories for Connection Without Verbal Communication:

- Shared situational connection: through shared experiences, emotions, and external stimuli. Examples: concerts, festivals, and exhibitions

- Body language, gestures, and proximity
- Touch
- Personal openness and shared values

Findings of the Feeling of Connection through the Installation:

- The installation facilitated a sense of connection for most participants
- Most participants felt connected through the shared experience, body language, gestures and the collaborative aspect of the installation, mostly through shared situational connection
- One participant emphasized personal openness and shared values for connection, and felt somewhat connected to the other person

Role of Visual and Auditory Elements in Connection

- Visual Elements: The visuals, particularly the colour blending, played a central role in creating connection and fostering collaboration.
- Auditory Elements: The heartbeats and background music provided subtle but significant support to the experience:
  - Heartbeats: Participants found the heartbeats interesting and rhythmic, with some describing them as “cute” and “engaging”. The heartbeats got out of the main focus when they blended with the music, which was part of the design’s intention. This was nice, as participants mentioned that the heartbeats, combined with the background music, set a pace for their movements.
  - Background music: The music was widely perceived as calming and meditative, reducing awkwardness and creating a relaxed atmosphere
  - The auditory elements supported the installation by promoting relaxation, guiding movement, and subtly contributing to the feeling of connection between participants. .

As far as the Technical Part of the Project is concerned:

- For two participants, the first couple, the heartbeats felt unrealistic
- Some participants noted that they swapped colours with the other participant during the experience, but as they said in the interviews, they enjoyed this feature, as it added an element of surprise and fun.
- Three of the participants commented that the system, meaning the colour trail, was very responsive to their movements

## 6.3 Triangulation of Quantitative and Qualitative Results

By comparing patterns in heart rate synchronization, distance-BPM correlations, and participants’ self-reported experiences, this section aims to assess the alignment of these results, with a focus on the FPS.

However, several limitations must be considered when interpreting these findings:

- Small Sample Size: The study included only 16 participants
- Sensor Accuracy: Potential inaccuracies in heart rate sensors may have influenced the BPM correlations
- External Factors: Caffeine consumption may have impacted the results

### 6.3.1 Heart Rates and Perceived Connection

Quantitative Data:

- Familiar couples had a mean of BPM correlation: 0.805 and unfamiliar couples: 0.60. This suggests that there was a degree of **physiological synchrony** between the heart rates of the participants.
- In some time-series graphs, participants' BPMs visibly align to similar levels, indicating moments of **physiological alignment**. More specifically:
  - For Couple 5 (familiar), this alignment is particularly noticeable during the colour trail phase of the project.
  - This alignment is also observed in Couple 2 (unfamiliar), during the “Initial Circles and Heartbeats” phase.
  - For Couple 7 (unfamiliar), alignment occurs before they start moving, during the “Initial Circles and Heartbeats” phase.

The physiological synchrony, especially among familiar couples, who showed stronger synchronization than unfamiliar couples, is consistent with previous research suggesting that shared experiences can lead to synchronized physiological responses, which may reinforce social connections [13]. The physiological alignment observed in the time-series graphs can indicate similar levels of arousal or focus in response to the shared stimuli. This momentary alignment can indicate that the participants are attuned to the same environmental cues, such as the visuals or heartbeat sounds.

Qualitative Data:

The physiological synchrony results align with the self-reported experiences of participants in the interviews and their feelings of connection. Most participants felt connected in an affective way, primarily through sharing the same experience, a phenomenon that in this thesis is described as “Shared Situational Connection.” Others reported feeling connected through non-verbal cues such as body language and the collaborative aspects of the project.

The shared experience, along with non-verbal and collaborative elements, likely evoked emotional responses such as joy, calmness, or a sense of togetherness, all of which are part of the affective dimension of connection and align with the physiological data.

Looking at the moments mentioned earlier for these couples that showed physiological alignment and attempting to triangulate them with the interviews, Couple 5 described their experience during the colour trail phase, stating: “The heartbeat was the same, and then I would notice it, and then it would become different”. This could correspond to a moment in the time-series graph where the BPMs appear to align; however, this cannot be stated with certainty.

Regarding Couple 2, they did not mention any experiences similar to this, nor was anything like that observed. In their interview, one of them stated that the heartbeat felt very nice and was the main focus during the “Initial Circles and Heartbeats” phase of the project, while the other mentioned feeling stressed from being tracked. Overall, their BPM correlation was 0.90, indicating high synchronization. However, while one participant stated that they felt connected, the other reported feeling somewhat connected.

Regarding Couple 7, they exhibited physiological alignment during the “Initial Circles and Heartbeats” phase. However, no mention of feeling this alignment was made during the interview. Despite this, the couple showed a very strong BPM correlation and reported feeling connected.

In conclusion, the analysis of heart rates and perceived connection shows a relationship between physiological synchrony and participants' experiences of connection. While some participants' graphs showed physiological alignment, only one out of the three couples noticed a potential alignment.

### 6.3.2 Movements and Perceived Connection

Based on the theory from Stepanova et al., as mentioned earlier, physical closeness and decreasing proximity can reinforce the feeling of connection. The design of the installation focuses on this aspect, reducing physical proximity between participants. This goal was pursued through the use of colour blending, creating the “shared yellow colour”.

From the graphs, it can be observed that participants often decrease their distance, moving closer together during the experience.

This trend is further supported by the qualitative results, which suggest that participants were focused on the collaborative aspect of the installation, particularly when they tried to recreate the yellow colour effect together. An observation from Couple Six illustrates this: at one point, the participants were very close to one another, and one participant seemed to adjust their position to better engage with the other. They stayed close, looking at each other as they created the yellow colour. As mentioned in the qualitative analysis, one participant later said, “I broke the silence and talked. I told him I’m glad, I’m glad I met him.” This was the moment being referred to.

### 6.3.3 Triangulation of Quantitative Data and Participants’ Feedback

From the time-series graph of Couple 8, it can be observed that Participant 1’s heart rate decreases during the initial circles phase. In the interviews, Participant 1 mentioned feeling relaxed and spaced out, which aligns with the graph. In contrast, Participant 2’s heart rate increases during this phase, and they reported feeling conscious, trying to assess if they were stressed and understanding their emotional state. This also aligns with the graph’s depiction.

During the interviews, participants from the first couple noted that the heartbeats felt unrealistic. The time-series graph shows that Participant 1’s heart rate had not fully regulated at the start of the “Initial Circles and Heartbeats” phase, which may explain the inconsistencies in the audible heartbeat.

In addition some participants mentioned that they swapped colours with their partner, during the experience, but that was a fun aspect of the project and they enjoyed it as they mentioned in the interviews. Finally three participants commented that the system, meaning the colour trail, was very responsive, to their movements and the calibration was good.

The SUS test result of 76.40 suggests that the system scored a “good” level of usability. This positive usability rating aligns with participant comments, which highlighted strengths and some areas for improvement.



# Chapter 7

## Discussion

### 7.1 Overall Experience

As it was mentioned earlier, the overall experience of the installation was mainly described as fun. The **Familiar couples**, engaged with the installation playfully and quickly, describing their experience as fun, engaging, collaborative, relaxing, with one participant mentioning that the main concept was stress reduction. The **Unfamiliar couples** were more cautious while interacting and they described the experience, calming, meditative, and they appreciated the non-verbal interaction and focused more on other aspects of the experience within the installation.

The **Familiar couples** engaged a bit longer with the installation, but with no significant difference.

Some positive comments that described the experience were:

- *“I think it was a nice intro, kind of like two hearts getting there”* (participant from a familiar couple)
- *“you can lose yourself and start playing around with the concept”* (participant from a familiar couple)
- *“It was like I was a kid and I was playing with another kid”* (participant from a familiar couple)
- *“It is like hanging around with a friend, sometimes you can appreciate the silence and just chill. And this was not exactly like that, but it was an experience that made me feel that way. I didn’t get the stranger vibes. It was a safe place”, “It made me appreciate the moment with another person”* (participant from an unfamiliar couple)
- *“It offers a sort of like unspoken legitimization of being 2 strangers who have absolutely no experience with each other before...leaning into it”* (participant from an unfamiliar couple)
- *”Kind of immerse you somehow digitally, kind of takes you away a bit from the real world for a second”, “Kind of reinforces people’s movements and dynamics”, “But I feel maybe calmer”* (participant from an unfamiliar couple)

### 7.2 Answering the FPS

This section aims to answer the final problem statement based on all the results. The research question addressed in this thesis was: ***“How can the visual and auditory stimuli in an installation, based on participants’ movements and heartbeats, influence their sense of connection to one another?”***. This exploratory question focuses on the affective dimension of connection, specifically examining how the sensory stimuli within the installation can influence participants’ sense of connection to one another.

From the triangulation of the quantitative and qualitative data, it appears that the sense of connection between participants, particularly its affective aspect, was mediated through the installation.

- Firstly, most participants stated that they experienced the affective aspect of connection, while engaging with the installation. The majority reported feeling a “**Shared Situational Connection**”, an important concept discussed earlier in **Section 6.2.5**, which refers to the feeling of connection between individuals that arises from experiencing the same external stimulus, event, or emotional response in a shared context.
- Secondly, participants emphasized the significance of body language in fostering a sense of connection. One participant highlighted this aspect of the installation and how it contributed to their sense of connection. As a result, the installation fostered a sense of connection by **removing verbal cues and encouraging participants to rely on body language and gestures**.
- Other participants emphasized the importance of **collaboration, playfulness, and creating together** in fostering a sense of connection.

All of these triggered emotional responses such as joy, exploration, and a sense of togetherness, all of which align with the affective dimension of connection.

The feeling of connection reported in the interviews aligns with the physiological synchrony observed between participants’ heart rates, especially for familiar couples that had a mean of BPM correlation, 0.805, but also for unfamiliar couples who had a mean of 0.60. In addition, some participants’ graphs depicted physiological alignment, one of the three couples noticed a potential alignment. As mentioned earlier, synchronized physiological responses that arise from shared experiences can reinforce social connections [13].

However, a factor that must be considered here, as mentioned in other sections, is that high heart rate correlations (e.g., 0.96, 0.98) may be inflated due to sensor limitations or calibration issues, rather than perfect synchronization.

More specifically, as far as the visual and auditory elements of the project are concerned:

- **Visuals**

- The colour blending in the colour trail played a significant role in creating a sense of connection. The creation of the “yellow colour” became the central feature of interaction, provoking feelings of playfulness, shared creation, and a sense of unity.
- The visuals were designed to encourage collaboration and shared experiences, aligning with the theory discussed in **Section 2.1.2.3**, which highlights that shared experiences and collaborative activities can reinforce connection.
- The colour blending aimed to decrease proximity between participants, a factor that can foster a sense of connection [1]. While the graphs show that participants significantly decreased their proximity, only one participant explicitly mentioned proximity as a key factor in their sense of connection. Though proximity likely contributed, it was not directly perceived or addressed as a central element in fostering connection.

- **Auditory Elements**

- The heartbeat sounds were not the primary factor in fostering connection but still influenced participants’ experience. Some found the heartbeats engaging, with one participant describing them as “a nice intro, kind of like two hearts getting there”, suggesting a subtle sense of unity.
- For others, the heartbeats blended into the background music, which was part of the design,
- The background music primarily helped foster a sense of calmness and relaxation, reducing awkwardness.

As a result, while the combination of auditory elements did not directly foster a sense of connection between participants, it created a relaxing, meditative atmosphere by promoting relaxation and calmness, and setting a pace for participants’ movements.

In conclusion, the installation mediated a sense of connection primarily through shared experiences, by removing verbal cues, and through collaboration, playfulness, and creating together. The visual and auditory elements also played significant roles. While proximity was likely a contributing factor, it was not perceived or mentioned as a key element in fostering connection. The visual elements, particularly the colour blending, were central to this experience, while the auditory elements subtly shaped the atmosphere and created a relaxed, open environment for connection.

## 7.3 Assessing Self-Awareness and Awareness of Others

This section briefly summarizes the participants' self-awareness and awareness of others during their interaction with the installation, as these were key goals of the design.

- **Initial Circles and Heartbeats in Relation to Awareness:**

For most participants, the feature provoked both self-awareness and awareness of their partner.

- **Visual and Auditory Elements in Relation to Awareness:**

During the experience of the installation, there was a gradual shift in the awareness of participants, from self-awareness, to the other person's awareness and then to the shared experience, especially when the colours were blending. The familiar couples engaged with the collaborative and playful aspects of the installation more quickly, while the unfamiliar couples were more cautious at the beginning, focusing on themselves and the other person, aiming not to be an obstacle, which highlights a higher level of awareness.

- **Physical Proximity and Heart Rates**

An additional factor indicating awareness was physical proximity, as reflected in the correlation between distance and BPM. Both familiar and unfamiliar couples showed negative correlations between distance and BPM, meaning their heart rates decreased as physical distance increased. Unfamiliar couples exhibited stronger negative correlations, suggesting that proximity had a more significant influence on their physiological responses. This can indicate that unfamiliar couples were more aware of their movements and each other, as they were exposed to different dynamics compared to familiar couples. Conversely, familiar couples showed weaker negative correlations, likely due to comfort and familiarity.

## 7.4 Limitations and Areas for Improvement

### 7.4.1 Technical Areas for Improvement

In terms of the technical aspect of the project, the design approach in TouchDesigner presented limitations, particularly regarding position tracking and the activation of the "Initial Circles and Heartbeats".

During the first two pilot tests as it was mentioned in the Test Procedure description in **Section 5.2**, it was challenging to ensure both participants stayed within a specific range, for the experience to begin, without instructions.

However, due to this difficulty, instructions were added to ensure participants remained still at the start. While these instructions were phrased in a way to avoid disrupting the experience, the need for them might have affected immersion. With fewer instructions, other aspects of the installation, like the intuitiveness of the visual cues (e.g., the circles opening), could have also been assessed. The phrase "In the beginning, you have to stay still and observe, until you are invited to explore the space" was sometimes interpreted by participants as needing to wait for instructions on when to move out of their circles. Specifically, the phrase "until you are invited" was understood in this way.

The problem stemmed from the way the TouchDesigner project was structured, requiring both participants to be in their initial positions for the experience to start. The tracking range couldn't be too large, or the circles would trigger unexpectedly during the colour trail. Conversely, the range couldn't be too small, or even slight movements would stop the sequence too early, causing the colour trail to appear.

In addition, the Kinect camera sometimes confused who was Participant 1 and Participant 2, resulting in a mix-up of their colours, one participant who was supposed to have the pink colour ended up with purple instead, during the experience, but it was not always like this. However, this seemed to be a fun aspect for the participants, and they enjoyed it.

The main issue, though, was that even if everything was calibrated and set for the test, the Kinect sometimes confused the initial positions of Participants 1 and 2, mistakenly thinking Participant 1 was Participant 2, and vice versa. As a result, the values for their ranges had to be manually adjusted, before the test.

These technical challenges did not significantly interfere with the participants' experience. The issue that had the most impact was the need for participants to be careful about remaining still in their initial positions.

Another comment was that the heartbeats felt unrealistic. The participants who noticed this though, it might have been because the first participant's heart rate was not yet regulated when the experience started. Additionally, some correlations were also unusually high, suggesting potential issues with the pulse sensors. Despite this, the sensors seemed to work well for the other couples, and no further issues were noticed.

## 7.4.2 Testing Areas for Improvement

In terms of testing, there were some limitations due to the projection from the ceiling. The projection area was not very large, and increasing the projection size would have required hanging the projector higher, which wasn't possible due to space constraints. A larger projection area would have provided more space for the participants to explore, potentially making the experience more engaging.

Additionally, a larger sample of participants should have been tested to gather more and diverse results.

Finally, caffeine consumption should have been avoided, but controlling whether participants had consumed caffeine was challenging.

As far as the concept is concerned, The "Initial Circles and Heartbeats" feature created an unintended sense of anticipation, which could trigger engagement but may also cause stress, especially for people who might feel stressed from being tracked.

## 7.5 Future Works

To address the issues mentioned above, particularly regarding the technical aspects, the design approach could have been altered by:

- To not disrupt the immersion of the participants with instructions, an intuitive visual feedback system could be implemented to show them where their correct positions are and if they are within the activation range. In addition to this, a non-interactive feature could be added, between the "Initial Circles and Heartbeats" and the "Colour Trail". For example, if participants move, the "Initial Circles and Heartbeats" could freeze, instead of triggering the "Colour Trail". The system could also be activated only when one of the participants is standing still in their initial position.
- Experimenting with an alternative approach in TouchDesigner, could involve using a timer. When Kinect detects the participants, a timer could be triggered to activate the "Initial Circles and Heartbeats", ensuring the experience starts at the right moment.

- Another approach that could be more reliable is using the ESP32 M5Stack Atom Matrix, which is used with the pulse sensor, to also start the experience. Once participants are in their designated positions, one of them could press the onboard button on the M5Stack to manually trigger the start of the experience. By pressing the button, participants would signal their readiness, sending a specific UDP message to TouchDesigner to start the experience.

To address the issue of Kinect not recognizing the identities of participants, especially at the beginning, an approach could be to explore machine learning algorithms or other methods for improving tracking accuracy based on data, offering more reliable participant identification and position tracking.

Since the mix-up in participant colours appeared to be a fun element for the participants, future studies could explore ways to intentionally incorporate such elements into the design, if the goal is to intensify the playful aspect.

To address the issues with the heartbeat sensors, a baseline period at the start of the experience to stabilize both the sensors and heart rate readings could have been beneficial. Additionally, smoothing the incoming data using filters like low-pass filters would help reduce noise and fluctuations.

To address the testing limitations, future work could explore several improvements, such as using an additional projector or alternative projection techniques like multi-projector setups, which could expand the projection area without requiring additional space. Furthermore, increasing the sample size could better reflect the range of experiences. Additionally, implementing pre-test guidelines to control factors such as caffeine consumption would help ensure more consistent results.

As far as the concept is concerned, the features of the project could be improved to enhance the overall experience:

- The visuals could be triggered not only when participants are in close proximity but also when, for example, whenever they have a pulse at the same time. However, to ensure interactivity, the proximity-based shared colour would be kept, and a new colour would be added when their pulses match, adding an extra colour to their shared creation.
- Instead of only blending colours to create a shared hue, such as the yellow in this iteration, new evolving visuals, like dynamic patterns or particle systems, could be generated to provide a more immersive and interactive experience.
- The “Initial Circles and Heartbeats” feature could be implemented more gently, perhaps by lowering the volume or by using a less intense sound for the heartbeats, or by blending the heartbeat sounds more smoothly.
- A further enhancement could involve personalized auditory feedback: each participant’s heartbeat could be paired with unique sounds (e.g., ambient tones, drums, or specific instruments). These individual sounds could blend together as participants synchronize, creating a dynamic musical composition that reflects their proximity and synchronized movements.
- Once, touch is important for some participants, maybe the addition of haptic feedback could be considered.

## Chapter 8

# Conclusion

The project began with the IPS: *“How can technology-mediated experiences facilitate human connection through sensory and emotional engagement?”*. In the **Analysis Section 2**, both the theoretical and technical frameworks were presented.

The theoretical part explores how connection can be mediated through technology, starting with the importance of social connection and later addressing the subjective nature of “connection”, which varies based on individual perceptions and context. Key concepts, such as the affective aspects of connection, immediacy, and others, are discussed.

In addition, design strategies that can foster the feeling of connection are presented. The three main strategies that played an important role in the thesis are: Interpersonal Distance and Proxemics, Affective Self-Disclosure, and Shared Experiences and Play.

The technical part focuses on the equipment and systems available for implementation. The Kinect v2 was used for position tracking, while heart rate detection was implemented using an ESP32 M5Stack Atom Matrix and an earlobe pulse sensor.

Prior research, such as Body Remixer and Breath of Light, which inspired the thesis, is also reviewed.

In the **Design Section 3**, the initial goals were outlined, which included promoting self-awareness, fostering mutual awareness between participants, and experimenting with ways to potentially create a sense of connection. The design techniques, combined with the theories from the previous chapter, are then discussed in relation to these goals, showing how each stage of the project and element contributed to achieving them.

In the **Implementation Section 4**, the real-time heartbeat detection system is described, utilizing the ESP32 M5Stack Atom Matrix, an earlobe pulse sensor, a phone, and wireless data communication over UDP. The integration of this feature into TouchDesigner is then explained, along with other elements such as position tracking and audiovisual responses. In TouchDesigner were implemented:

- Position Tracking:
  - Participants’ positions (X and Z values) were tracked using Kinect v2.
  - Proximity was calculated, triggering visual responses like colour blending and screen transitions.
- Heartbeat Detection:
  - Real-time heartbeat data was transmitted using the ESP32 and UDP communication.
  - Heartbeat sounds were triggered based on pulse signals and integrated into the background music.
- Interactive Visuals:
  - The Initial Circles Sequence was activated when participants stood still in their designated positions.

- The Colour Trail adjusted dynamically based on movement and proximity.
- Sound:
  - Heartbeat sounds and ambient music were incorporated.

In the **Evaluation Section 5** the test procedure is described, which aimed to answer the FPS: *“How can the visual and auditory stimuli in an installation, based on participants’ movements and heartbeats, influence their sense of connection to one another?”*.

For this purpose Quantitative and Qualitative data were collected, tracking participants’ movement proximity, heart rates and participants’ experiences through semi-structured interviews. In addition a SUS test was conducted to determine whether technical issues interfered with the user experience and to evaluate the system.

The test, conducted at Aalborg University, involved a purposive sampling approach, with participants categorized as familiar or unfamiliar with each other, to assess the installation’s effectiveness and compare participants’ experiences with and without prior familiarity. The procedure aimed to have minimal instructions but that was adjusted due to technical challenges.

The total number of participants was 16, consisting of 8 pairs, 4 familiar and 4 unfamiliar.

In the **Results Section 6**, the results were analysed and then triangulated. The SUS test scored 76.40, indicating good usability. Even though some questions were less relevant due to the system’s nature, the SUS scoring process was kept, to serve as a baseline, for the overall user experience. This result aligns with participants’ feedback, which highlighted both positive aspects of the project and areas for improvement.

The overall experience of the installation was described as fun and relaxing. Familiar couples engaged playfully and quickly, enjoying the collaborative and calming aspects. Unfamiliar couples were more cautious but found the experience calming and meditative, appreciating the non-verbal interaction. While familiar couples interacted a bit longer, both groups valued the experience. Positive feedback included comments, such as being in a safe place, playing with another person, and appreciating the moment with someone else. Unfamiliar couples also noted how the installation allowed them to connect despite being strangers, offering a sense of immersion and calmness.

The findings indicate that the installation mediated the affective aspect of connection, primarily through creating shared situational connection, by removing verbal cues and encouraging communication through the body, by encouraging collaboration, playfulness and creation. Visual elements, especially the colour blending, played a significant role in creating a sense of unity, while auditory elements, such as heartbeat sounds and background music, helped set a calming, immersive atmosphere. The physiological synchrony observed between participants’ heart rates, aligned with the reported connection from the interviews, highlighting the role of shared stimuli in reinforcing social bonds.

In terms of the other two initial design goals, promoting self and mutual awareness, the “Initial Circles and Heartbeats”, provoked both self and awareness of the other participant, the rest of the visual and auditory elements encouraged a shift toward shared awareness.

Furthermore, physical proximity emerged as an additional factor influencing participants’ awareness of each other, with unfamiliar couples showing stronger correlations between distance and heart rate. This suggests that unfamiliar couples were more attuned to their movements and each other, highlighting the different dynamics they experienced compared to familiar couples.

The physiological results may not be fully reliable, as high correlations between heart rates could be due to sensor calibration issues or oversensitivity, rather than perfect physiological synchronization.

In terms of areas for improvement, the project faced several technical limitations, particularly with position tracking and the activation of the “Initial Circles and Heartbeats” feature.

The challenge of ensuring both participants stayed still to begin the experience led to the introduction of instructions, which, while helpful, may have impacted immersion and assessing other aspects of the project.

Additionally, the Kinect camera occasionally confused participants' identities, resulting in colour mix-ups, which were often seen as a fun aspect. However, the main issue was that the Kinect sometimes misidentified the initial positions of Participants 1 and 2, requiring manual adjustments. While this did not significantly disrupt the overall experience, it could have been avoided.

Additionally, the pulse sensors should be checked, as some correlations were unusually high.

Testing limitations included a small projection area and a small sample size, which limited the space for exploration and the diversity of results.

Future improvements could include addressing the issues above and improvements in terms of the concept and its interactivity.



## Chapter 9

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# Chapter 10

## Appendix

### 10.1 Qualitative Research Simplified Data

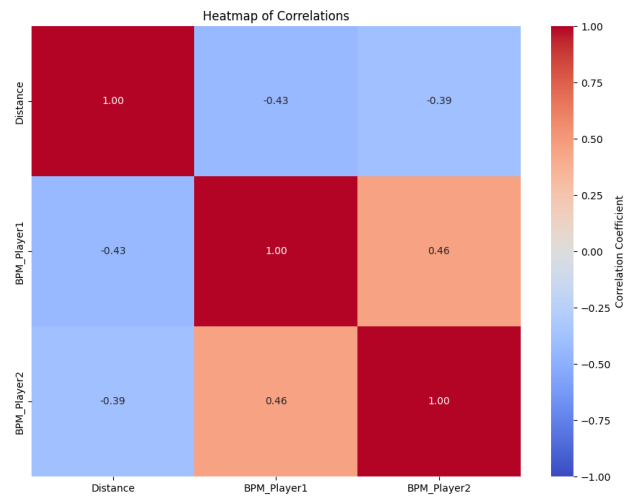
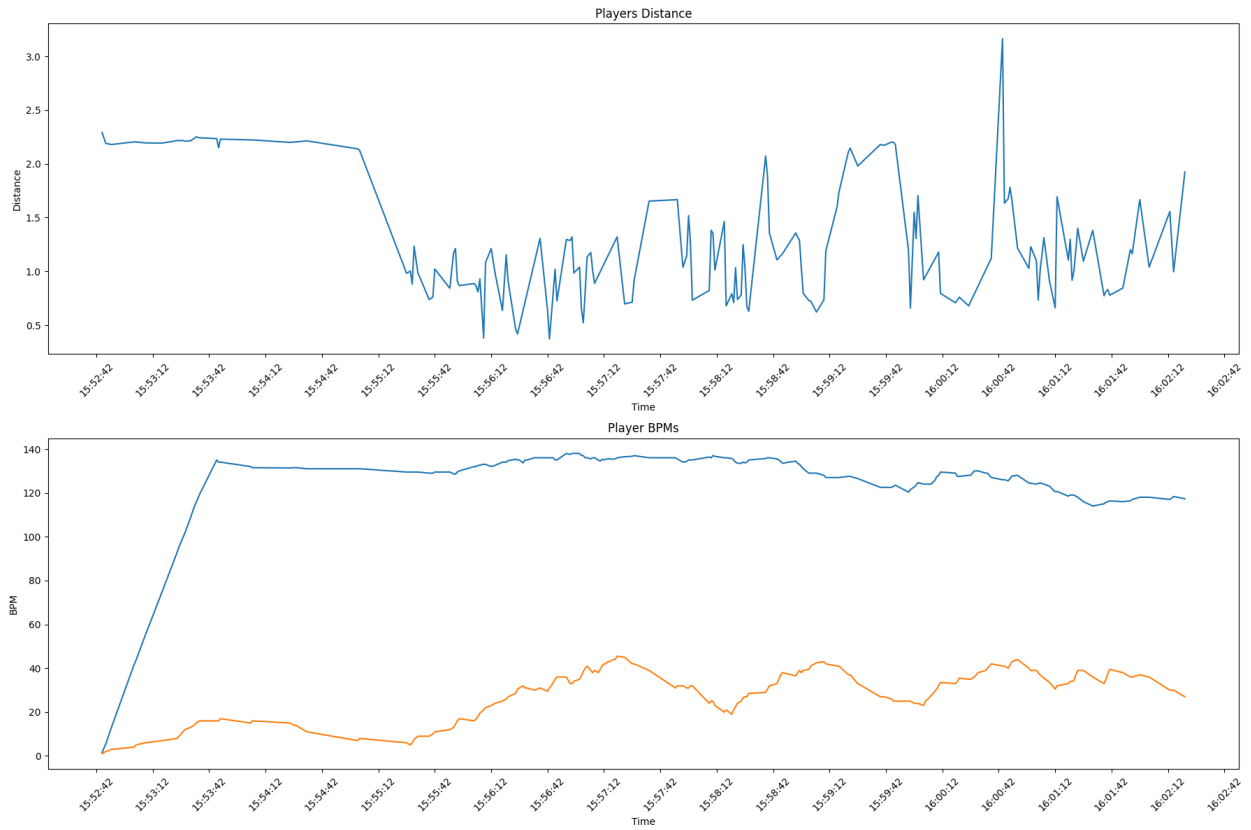
Participants	1st Couple	2nd Couple	3rd Couple	4th Couple	5th Couple_SI	6th Couple	7th Couple_VD	8th Couple
<b>Familiarity</b>	Familiar	Unfamiliar	Unfamiliar	Familiar	Familiar	Familiar	Unfamiliar	Unfamiliar
<b>Overall Experience</b>	Fun, Playful, Engaging, Enjoyed collaboration on colour mixing  "Fun trying to find ways to combine the colours, we were there for some time actually"	Calming, Meditative, Relaxing	Interesting, Enjoyed the immersive aspects of the installation, especially the merging of beats and colors	Fun, relaxing, appreciated the calming and stress-relieving aspects	Fun, playful, engaging, curious about yellow aura, interesting experiment	Fantastic, pretty fun and interesting	Fun, it was interesting to see our footprint kind of highlighted on the ground in a colourful way	Both participants found the experience enjoyable, playful, and interesting, mentioning that they haven't done anything like that before
<b>Perception of the Installation</b>	Movement and how two agents interact in space	Exploring patterns, dynamics between movements and visuals	Both focused on how movements, colors, and sounds interacted, and the cooperative dynamics between them	<b>Speaker 1:</b> Decreasing stress <b>Speaker 2:</b> dance	Movements and collaboration	Senses	<b>Speaker 1:</b> "It was about how crossing paths with other human beings can interact and how the connection might change things."  <b>Speaker 2:</b> "How you have the red aura and the purple aura, but when you cross paths, changes come"	<b>Speaker 1:</b> "Bonding maybe?.. trying to see how two strangers can connect"  <b>Speaker 2:</b> movement and interaction
<b>Colour Trail, Background Music, Heartbeats and Awareness</b>	1st couple, familiar: Initially more aware of themselves and their colour trail when they started interacting after the circles, later shared exp. colour blending	<b>Speaker 1:</b> <u>Circles</u> , self-aware and stressed with heartbeats, and then aware of the other person. <b>Colour trail:</b> aware of his trail, not become an obstacle to the other person, then colour blending, aware of the experience  <b>Speaker 1:</b> <u>Circles</u> , self aware, then when he got out, self aware. <b>Blending of colours:</b> aware of the other person  <b>Gradual shift of awareness</b>	<b>Speaker 2:</b> more aware of myself from place to place, <u>Circles</u> aware of myself, they were building up to something, when colours starting merging aware of both of them  <b>Speaker 1:</b> <u>Circles</u> , self awareness, and then both awareness and realisation of both heartbeats, colour trail: where we are both standing in space-> aware of both and then shared experience	<b>Speaker 1:</b> aware of the shared experience. "I feel like I was kind of aware of myself and like a resting sense, like just feeling my body and like walking around a bit having like fun, like trying to get the colours I splashed around and stuff"  <b>Speaker 2:</b> more aware of the shared experience	<b>Speaker 2:</b> Initially more self-aware, but as the experience progressed, became more aware of the other person's movements and connection  <b>Speaker 1:</b> gradual shift from self awareness to the shared experience	<b>Speaker 1:</b> in the beginning more aware of myself, later more aware of the other person see where the other person is stepping and then the shared experience "Ok, we are in this together"  <b>Speaker 2:</b> "yes, in the beginning you're kind of observing the other person to see what's going on and then as the time passes, I think you becomes more of a shared experience than, you know, focusing on yourself."	Both participants were more focused on their own experience (self-awareness), which shifted to awareness of the other person and interaction.  <b>Speaker 2:</b> "When realizing that the interaction matters, it became more about the other person... and how can we cross paths intentionally"	<b>Speaker 1:</b> in the beginning in the circle, self awareness, but then the shared experience  <b>Speaker 2:</b> present, and focused on the experience itself. Aware of himself and the other person the whole time
<b>Initial Circles and Heartbeats Feature in Relation to Awareness</b>	Didn't notice them as a feature, technical issue, with heartbeats	<b>Speaker 1:</b> Circles noticed at the start but faded quickly, but the heartbeats, were calming for him in the beginning and later, -> self aware  <b>Speaker 2:</b> He was more aware of himself in the beginning found heartbeats stressful when tracked, then aware of the other person	<b>Speaker 2:</b> Circles: more self aware. "Felt like they were building for something to happen"-> aware of the experience  <b>Speaker 1:</b> "Paying attention to like how the sound and, and my own heartbeat that I saw in the light like the coordination of it. And then it took me a while to notice that like your heartbeat also came in" -> self aware and shift to other's awareness	<b>Both:</b> Felt like they were preparing for something, to happen to fight, more aware of the other person	<b>Speak 2:</b> "I think it was a nice Intro, kind of like 2 hearts to get there".  <b>Speaker 1:</b> aware of themselves, and then the other person's visual wavy circle.	<b>Speaker 1:</b> "I was weirdly aware of the heartbeat. Like you're not aware of your heartbeat"-> self awareness  <b>Speaker 2:</b> Anticipation	Both participants were self-aware during the heartbeat phase, and both heartbeats...  <b>Speaker 1:</b> "It added self awareness, like what is my heartbeat like? Can I control it with my breath?"  <b>Speaker 2:</b> "The overlapping rhythm... was interesting."	<b>Speaker 1:</b> I felt relaxed, spaced out a bit, in the beginning circles: self aware  <b>Speaker 2:</b> conscious and aware of his heartbeat, and the others, tried to calm himself down to affect the heartbeat
<b>Connection baseline without Verbal Communication</b>	Shared Situational Connection: meaning in events like concerts, when people feel connected because they share something, or when something happens in the metro	<b>Speaker 1:</b> Touch <b>Speaker 2:</b> he has to know somebody first, doesn't feel like this	<b>Speaker 1:</b> Shared Situational Connection <b>Speaker 2:</b> Shared Situational Connection and when you share the same feeling about a situation	Shared Experience	<b>Speaker 1:</b> Touch and being close in proximity  <b>Speaker 2:</b> Touch	<b>Shared Situational Connection</b> "you overcome this kind of awkwardness and kind of everybody is random and an individual, and then you have a singing and then you sing together, chant together, I don't know, sad together. So yes, I think it's like this coming from single to unity. But it was quite representing, like when the colour would change and the yellow, yeah, that's it. an external stimuli then with strangers, I think it's, it has to do more with something happening, something going on for some case, because you know, you experience the same thing, like your perception is the same setting, right? So for some reason I thought of a demonstration. Right now in demonstration, you're together with strangers, but you do feel connected because you're there for the same purpose. But if you go to a protest and to demonstration, you're there because you feel something is wrong. And this shared feeling with everyone at demonstration, we are very still connected to the strangers there needs to be some kind of common reference for some connection to	<b>Shared Situational Connection</b>  <b>Speaker 1:</b> It is like hanging around with a friend, sometimes you can appreciate the silence and just chill. And this was not exactly like that, but it was an experience that made me feel that way.  <b>Speaker 2:</b> guess sometimes you're going to feel like you're part of a like a bigger picture or group, group feeling especially like specific situation like concert. Yeah, then you kind of become one entity to some extent.	<b>Speaker 2:</b> The participant described how non-verbal interaction, gestures, and mimicry can facilitated a feeling of connection, body language sometimes more important  <b>Speaker 1:</b> Situational Shared Connection

<b>Role of Visual Elements: Colour Trail</b>	Visuals important, there were more engaging	Played a central role; visuals were engaging and facilitated exploration.	And yeah, I think the of course the also the visual aspect was interesting by sensing someone else's presence more, again, more about the other person's presence than my own.	Collaborative element		I thought that it stopped playing the heartbeat. I wouldn't notice it at all. I would notice the music kind of. But I think the whole experience in the end, for me, you notice more your movements and the movements of the other person than the music.	Visuals played a central role in creating engagement and connection. Speaker 3: "Our footprints were highlighted in a colorful way... it showed the collaborative aspect." Speaker 2: "The color change and overlapping was fun to observe."	The visuals were described as guiding and rewarding movement, fostering playfulness and experimentation.
<b>Role of Auditory Elements: Music &amp; Heartbeats</b>	The visuals were more engaging didn't pay attention to audio	Speaker 1: paid attention to heartbeats but struggled to map them to the visuals/audio. Speaker 2: part of the experience	Speaker 1: heartbeats was very cute. I think to me personally, it played quite a nice role to know this kind of this sinking out and sinking in of the face of heartbeats, background music didn't play any role for him it could have been the same with just the heartbeats. Speaker 2: heartbeats soon lost their like, role. I haven't really noticed them. And I started paying more attention to the lights themselves. And for me that the background music was part of that experience, a part of that space, whereas the heartbeats, I was aware they were happening, but it just became part of the music for me.	audio and visuals were adding a relaxing narrative to the experience, music was very fitting to the experience	"The audio was quite meditative. So it's concentrate you and then the the beats they also I kept forgetting that there's there's beats when you start playing, but then you remember and then you start listening that were So the music connection part, I don't know if music actually helped, but then the the beats, yeah, of course they did. Because then if you notice them and think, OK, so which one is faster, which one is slower? Or just to see if it if it matches and then it definitely makes you a bit more connected like with with the other person"	Speaker 1: the music is very well suited Speaker 2: conveying a calmness and I think it takes out from the awkwardness of the situation,	Speaker 1: "The music created a relaxed environment." Speaker 2: "The overlapping heartbeats were interesting, like rhythm and flow."	The music and heartbeats had both calming and introspective effects  Speaker 1: Described the combination as "a rhythm to work on... guiding our movements."  Speaker 2: heartbeats and sound set a pace for moving
<b>Nice Quotes and Comments</b>	was a kid and I was playing with	"I felt relaxed and at ease to explore and play around." "Towards the end, it felt more collaborative, like we were creating something together." "When my heartbeat is tracked, I feel stressed, but after that it was a really relaxing experience". "Mindful, not be an obstacle to the other person." "How can I contribute with my patter"	"Kind of immerse somehow digitally, kind of takes you away a bit from the real world for a second". "Kind of reinforces people's movements and dynamics" "I think at the beginning was just like we both wanted to experience our own spaces and just not stand in the other person's way. But I'm sure that, like, for instance, if we'd known each other, we would have done it differently because we would have probably started moving against each other much earlier!" "But I feel maybe calmer" "Yeah, just chill. Not looking forward to sitting on my bike in the cold."	It was like maybe passing a person on the street, like the yellow kind of reminds me of that. "	"I think it was a nice Intro, kind of like 2 hearts to get there."	"you can lose yourself and start playing around with the concept."  "I think it's a thing of interpreting intentions... you map the movement of the other person, and you understand the intentions, then you start feeling more connected."  <i>This emphasizes how the installation created an environment where participants engaged in a subtle, non-verbal dialogue, fostering connection through movement, observation, and mutual understanding</i>  And sometimes I would act accordingly and circle around as he would, and some other times maybe I wouldn't act in synchronicity with him from an observer's point of view. But in my point of view, I was acting in synchronicity even though I was acting the other way.	It is like hanging around with a friend, sometimes you can appreciate the silence and just chill. And this was not exactly like that, but it was an experience that made me feel that way.  "I didn't get the stranger vibes. It was a safe place."  "It made me appreciate the moment with another person."	"It offers a sort of like unspoken legitimization of being 2 strangers who have absolutely no experience with each other before... leaning into it".  "It was like a rhythm to work on, like guiding our movements setting a pace."

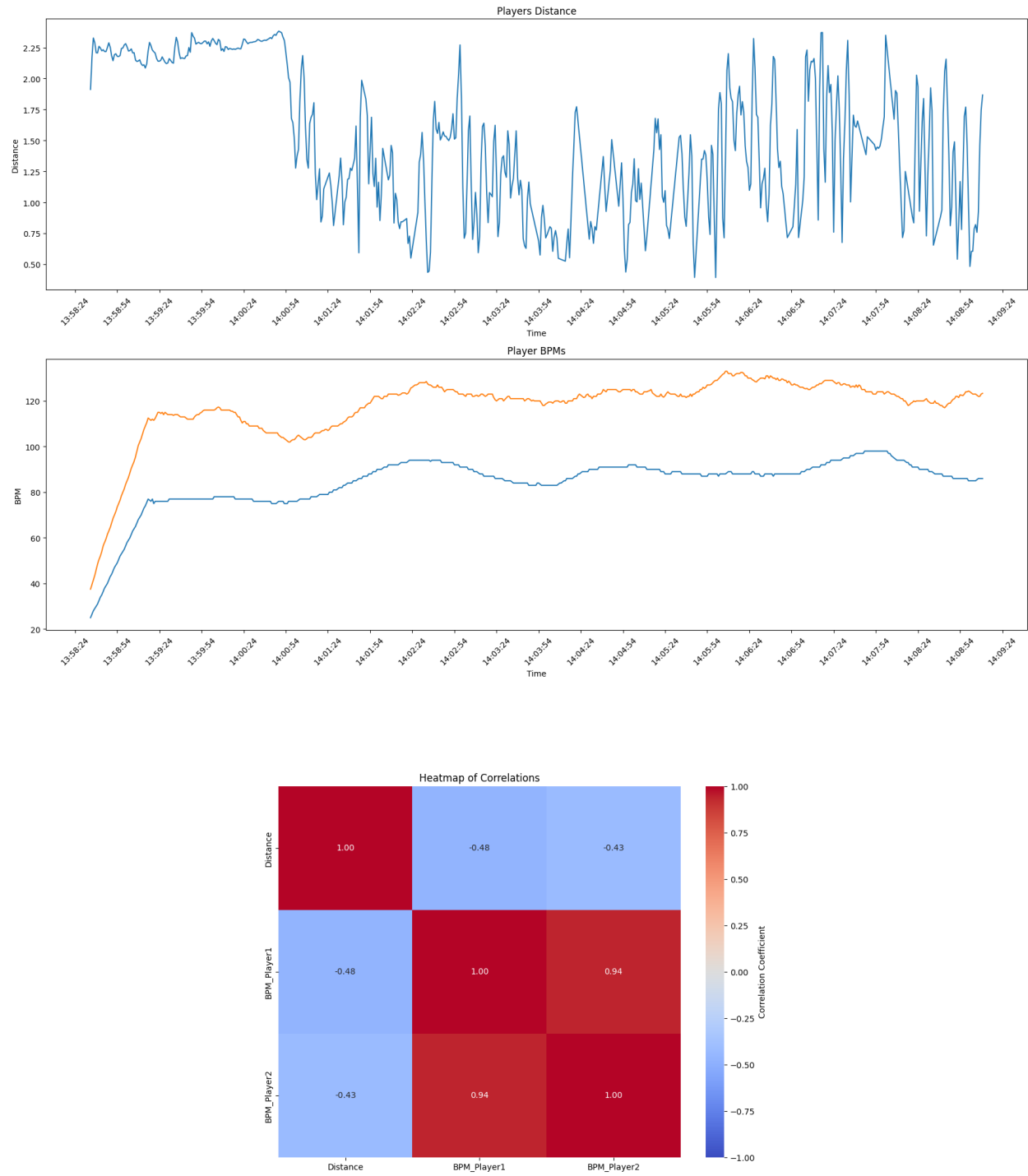
## 10.2 Quantitative Results

### 10.2.1 Familiar

- Couple 1

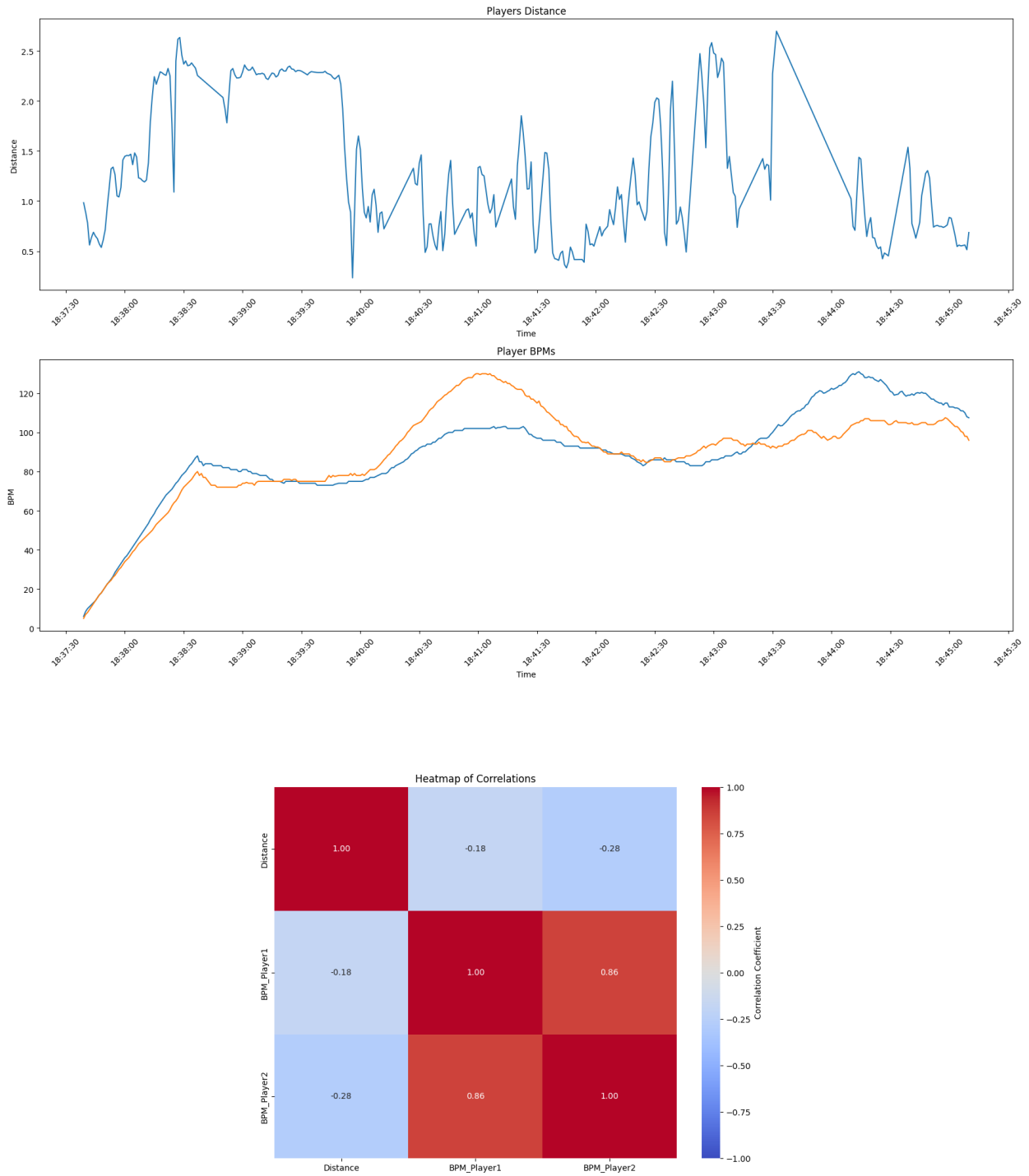


- Couple 4

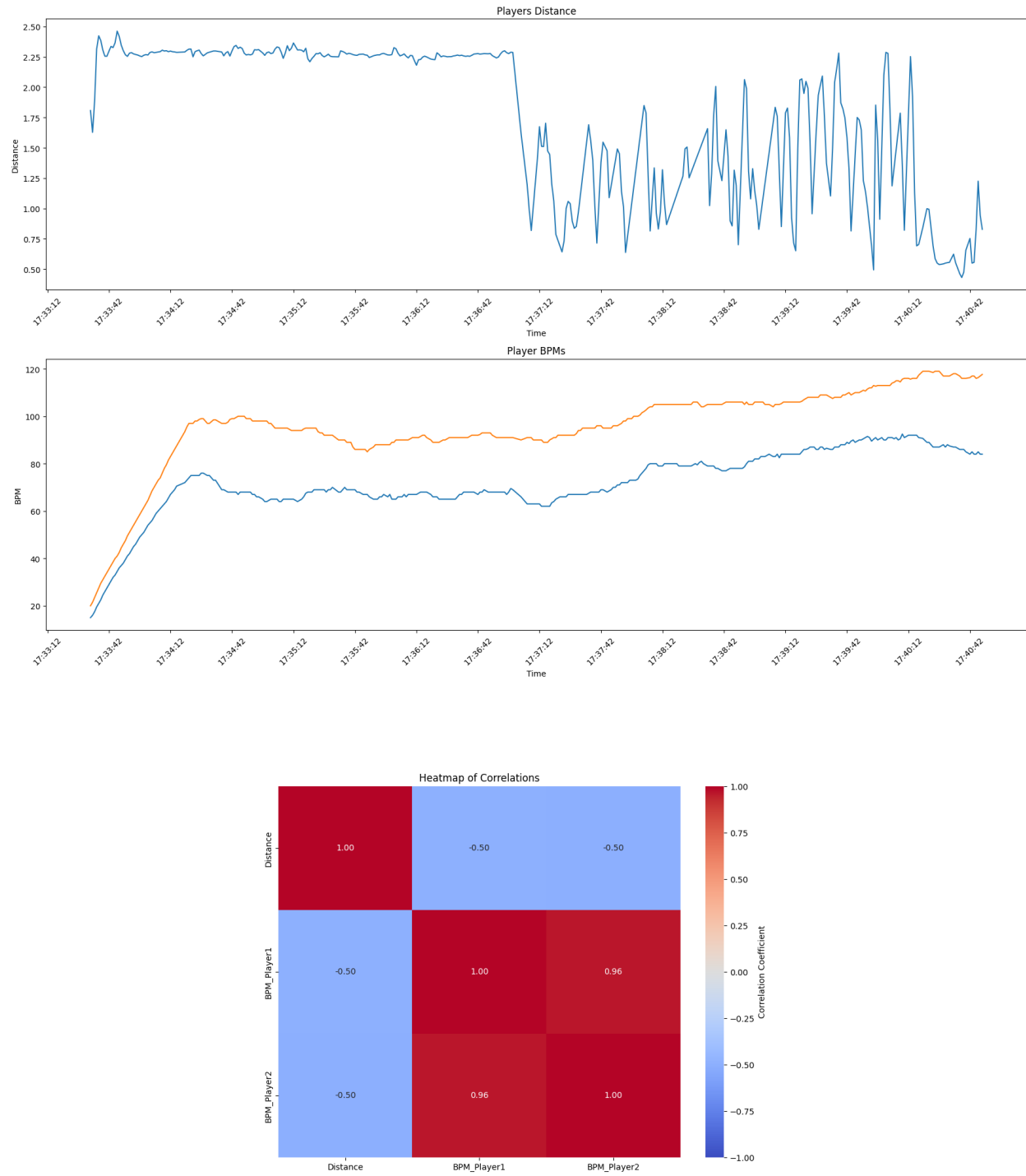


- Couple 5



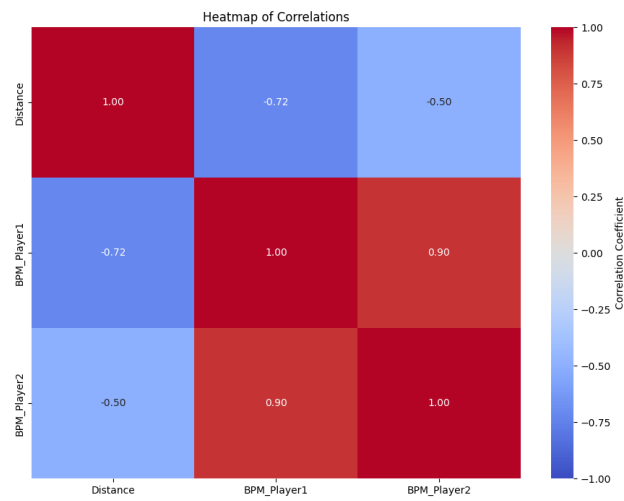
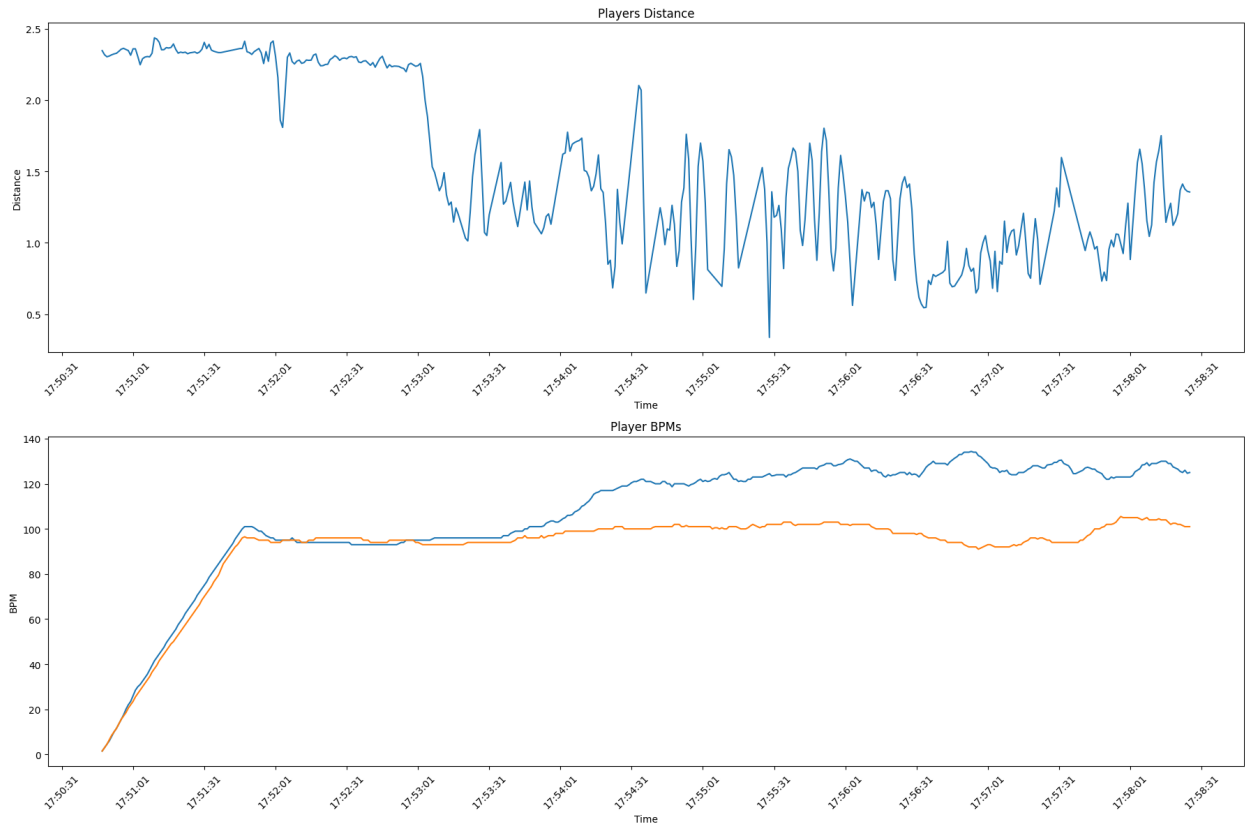


- Couple 6

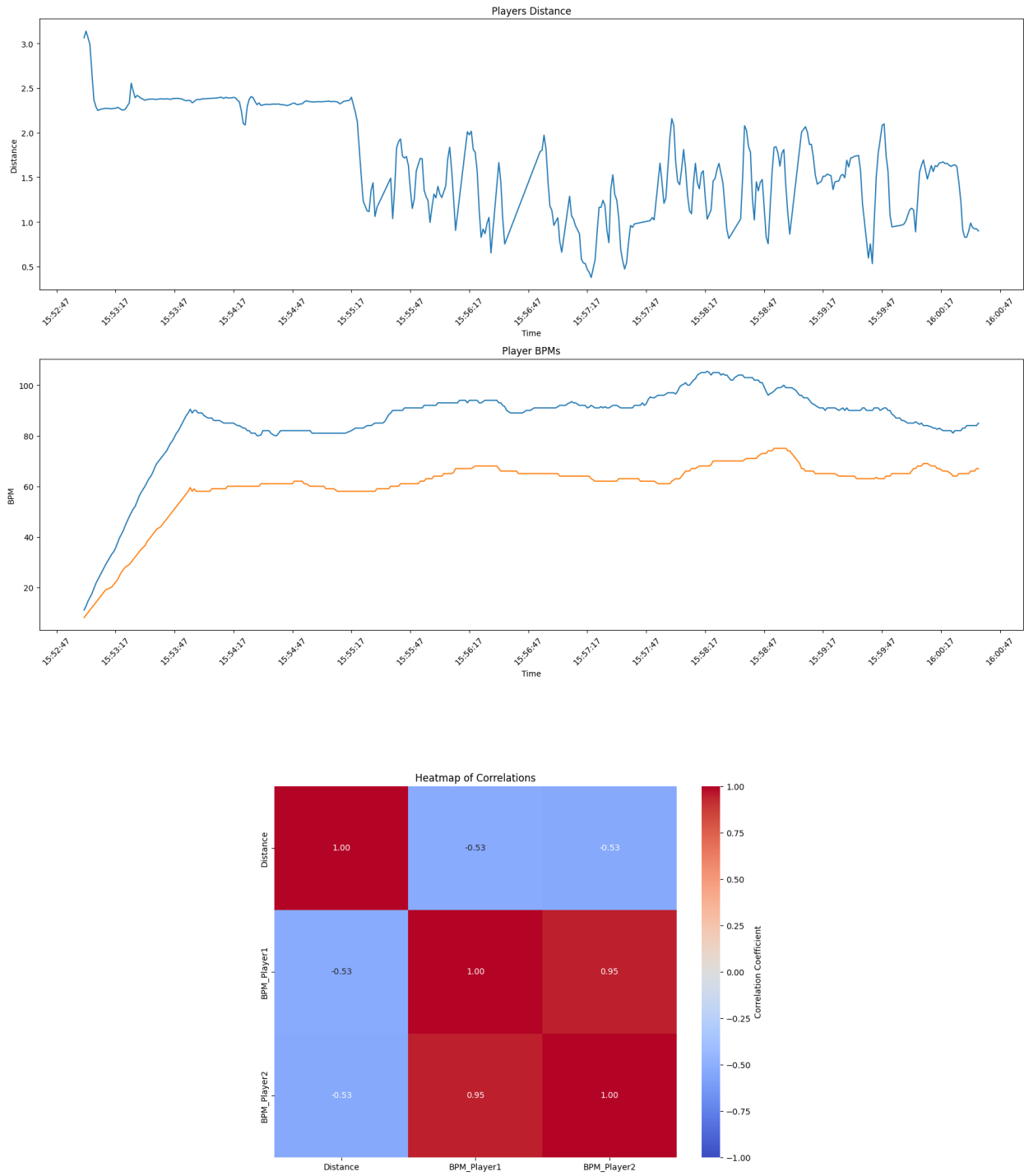


### 10.2.2 Unfamiliar

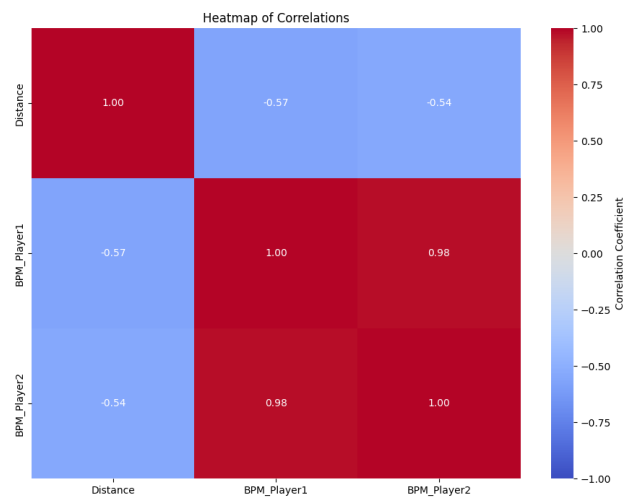
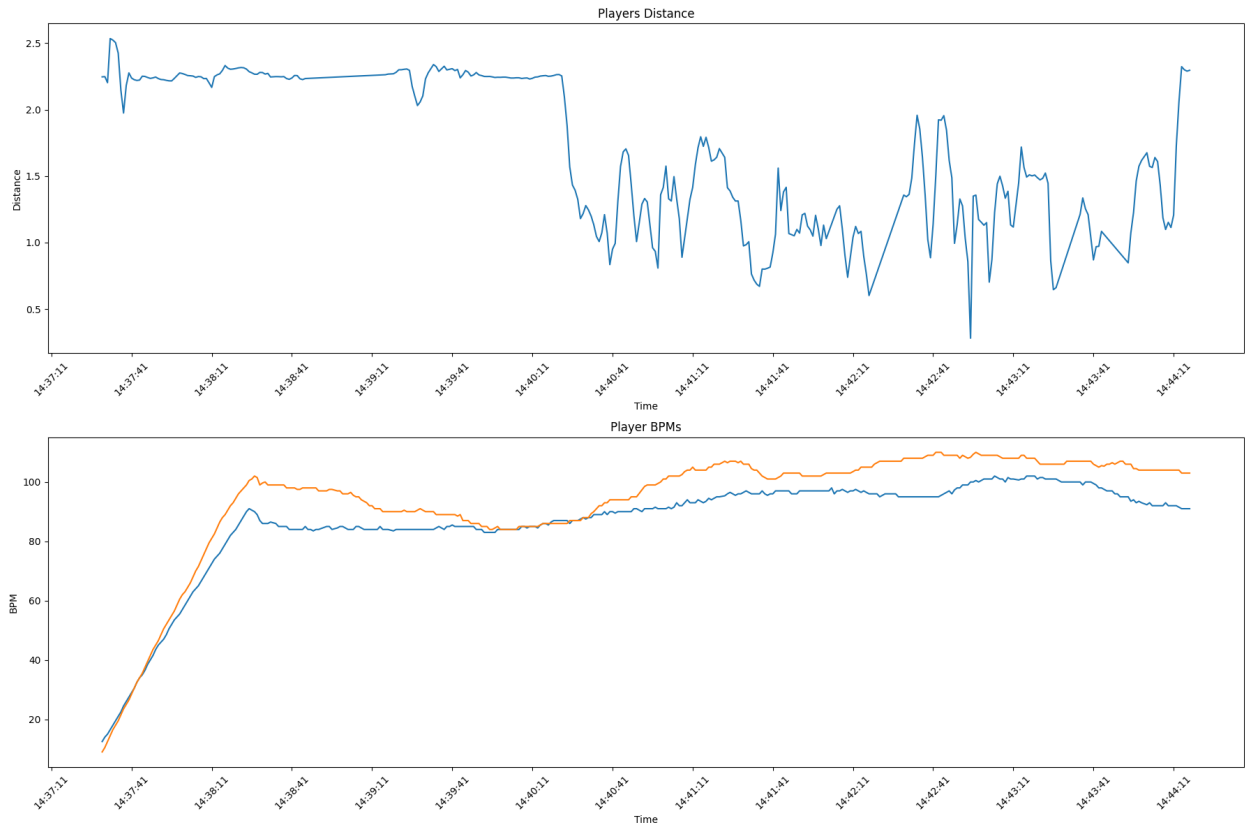
- Couple 2



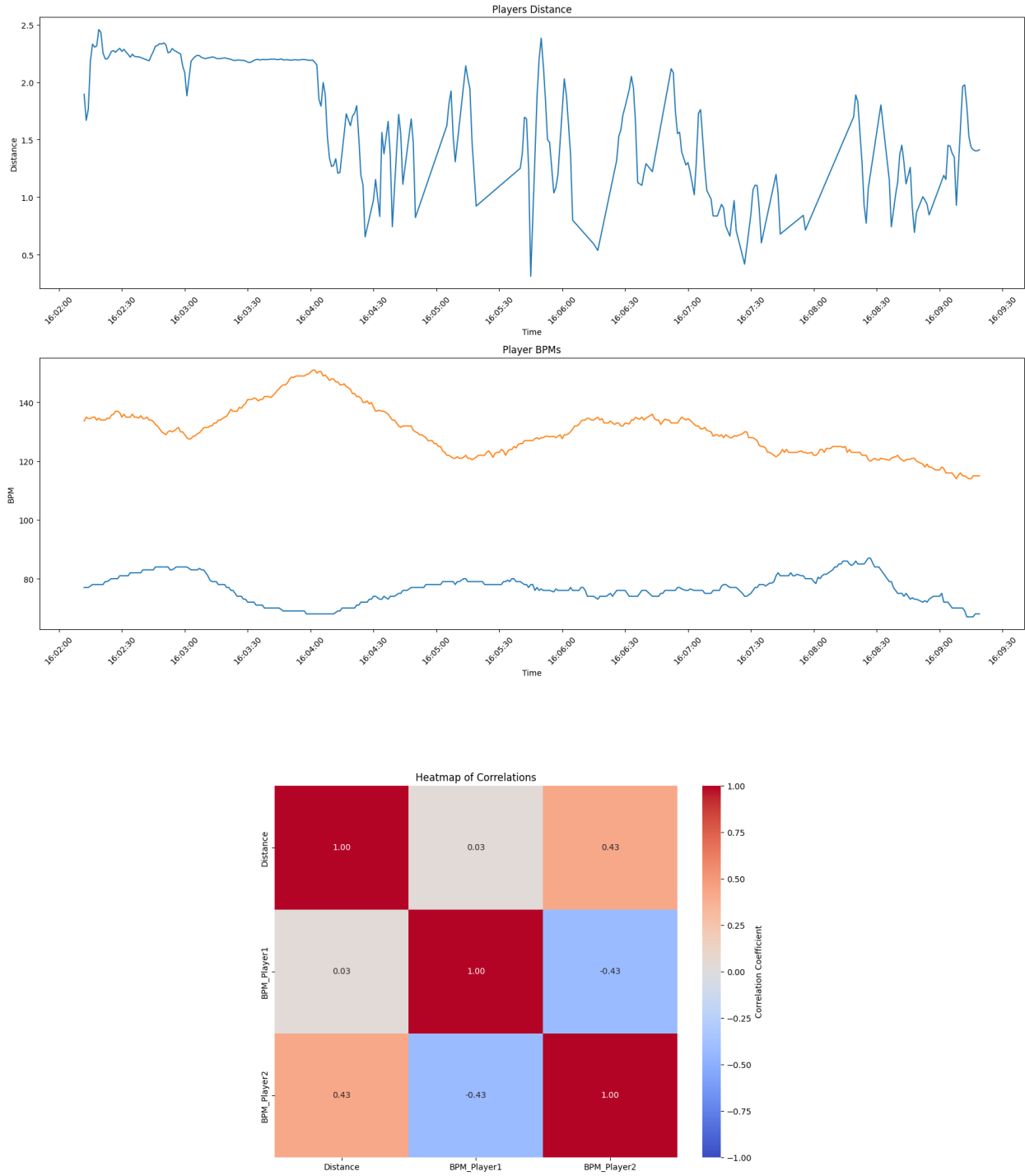
- Couple 3



- Couple 7



- Couple 8



## 10.3 Questionnaire and Additional Material Regarding Evaluation

### 10.3.1 SUS Questionnaire

**Thank you for participating in the test.**

**You will be asked questions that will contribute to my thesis project for MED10. By consenting to participate, you give permission for video recording, interview recording, and for the data gathered through the questions to be used in the research. These findings will support my work.**

**The data you provide will only be used for research purposes and academic projects within Aalborg University.**

**None of your personal information will be released for public or private use.**

**The test is voluntary and you can end the test at any time without consequences.**

**I have read and agree to the terms**

(2) ☐ Yes

**What is your age?**

\_\_\_\_\_

**Have you consumed any caffeine (coffee, tea, energy drinks, etc.) in the past 3 hours?**

(2) ☐ Yes

(3) ☐ No

**Have you consumed any alcohol within the last 3 hours?**

(2) ☐ Yes

(3) ☐ No

**Stop :)**

**I think that I would like to use this system frequently**

(1) ☐  
Strongly

(2) ☐

(3) ☐  
Neither

(4) ☐ Agree

(5) ☐  
Strongly

disagree

Disagree

agree nor  
disagree

agree

**I found the system unnecessarily complex**

(1) ☐  
Strongly  
disagree

(2) ☐  
Disagree

(3) ☐  
Neither  
agree nor  
disagree

(4) ☐ Agree

(5) ☐  
Strongly  
agree

**I thought the system was easy to use**

(1) ☐  
Strongly  
disagree

(2) ☐  
Disagree

(3) ☐  
Neither  
agree nor  
disagree

(4) ☐ Agree

(5) ☐  
Strongly  
agree

**I think that I would need the support of a technical person to be able to use this system**

(1) ☐  
Strongly  
disagree

(2) ☐  
Disagree

(3) ☐  
Neither  
agree nor  
disagree

(4) ☐ Agree

(5) ☐  
Strongly  
agree

**I found the various functions in this system were well integrated**

(1) ☐  
Strongly  
disagree

(2) ☐  
Disagree

(3) ☐  
Neither  
agree nor  
disagree

(4) ☐ Agree

(5) ☐  
Strongly  
agree

**I thought there was too much inconsistency in this system**

(1) ☐  
Strongly  
disagree

(2) ☐  
Disagree

(3) ☐  
Neither  
agree nor  
disagree

(4) ☐ Agree

(5) ☐  
Strongly  
agree



**I would imagine that most people would learn to use this system very quickly**

- |                           |                           |                           |                                 |                           |
|---------------------------|---------------------------|---------------------------|---------------------------------|---------------------------|
| (1) <input type="radio"/> | (2) <input type="radio"/> | (3) <input type="radio"/> | (4) <input type="radio"/> Agree | (5) <input type="radio"/> |
| Strongly                  | Disagree                  | Neither                   |                                 | Strongly                  |
| disagree                  |                           | agree nor                 |                                 | agree                     |
|                           |                           | disagree                  |                                 |                           |

**I found the system very cumbersome to use**

- |                           |                           |                           |                                 |                           |
|---------------------------|---------------------------|---------------------------|---------------------------------|---------------------------|
| (1) <input type="radio"/> | (2) <input type="radio"/> | (3) <input type="radio"/> | (4) <input type="radio"/> Agree | (5) <input type="radio"/> |
| Strongly                  | Disagree                  | Neither                   |                                 | Strongly                  |
| disagree                  |                           | agree nor                 |                                 | agree                     |
|                           |                           | disagree                  |                                 |                           |

**I felt very confident using the system**

- |                           |                           |                           |                                 |                           |
|---------------------------|---------------------------|---------------------------|---------------------------------|---------------------------|
| (1) <input type="radio"/> | (2) <input type="radio"/> | (3) <input type="radio"/> | (4) <input type="radio"/> Agree | (5) <input type="radio"/> |
| Strongly                  | Disagree                  | Neither                   |                                 | Strongly                  |
| disagree                  |                           | agree nor                 |                                 | agree                     |
|                           |                           | disagree                  |                                 |                           |

**I needed to learn a lot of things before I could get going with this system**

- |                           |                           |                           |                                 |                           |
|---------------------------|---------------------------|---------------------------|---------------------------------|---------------------------|
| (1) <input type="radio"/> | (2) <input type="radio"/> | (3) <input type="radio"/> | (4) <input type="radio"/> Agree | (5) <input type="radio"/> |
| Strongly                  | Disagree                  | Neither                   |                                 | Strongly                  |
| disagree                  |                           | agree nor                 |                                 | agree                     |
|                           |                           | disagree                  |                                 |                           |

### 10.3.2 Semi-structured Interviews Questions

#### **Overall Experience**

- How was your experience in the installation?
- What do you think this installation was about?

#### **Self Awareness – and Other Awareness**

- Throughout the experience, were you more aware of yourself, the other person, or the shared experience? When did you feel these shifts?

#### **Connection**

- How do you experience or perceive the feeling of connection in a setting where speech is not involved with strangers or people you know? Did you feel anything close to this feeling while experiencing the installation?
- When did you feel more connected to the other person?

#### **Role of Visual and Auditory Elements**

- What role did the visual and auditory elements of the installation (heartbeat sounds, visual projections) play in creating this connection?
- How did the installation's visual and auditory stimuli affect your emotions at different stages of the experience?
- How do you think that the other person felt while interacting with you?

#### **Feelings about different parts of the experience and connection**

- When you were in your circle listening to your heartbeat and the other person's, how did you feel?
- How did you feel when you left the circle with the visuals and audio?
- How did you feel when your colours started blending?

#### **Other**

- Is there anything else you'd like to add about your experience?