MASTER THESIS

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DESIGNING AND EVALUATING AVATAR BIOSIGNAL VISUALIZATION TECHNIQUES FOR SOCIAL VIRTUAL REALITY

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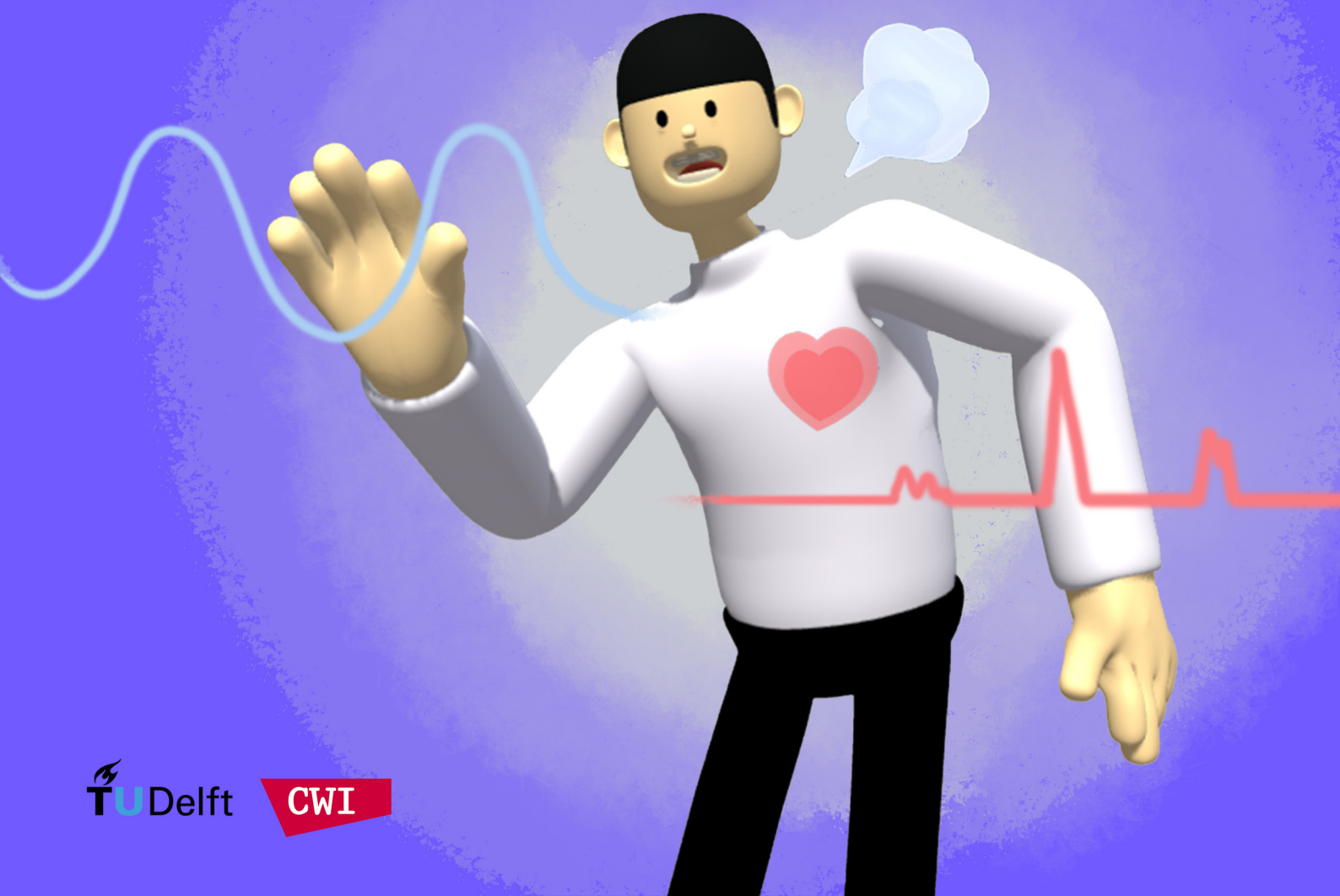

TU Delft CWI

DESIGNING AND EVALUATING AVATAR BIOSIGNAL VISUALIZATION TECHNIQUES IN SOCIAL VIRTUAL REALITY

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PREFACE

This graduation thesis marks the end of my two-years Design for Interaction master's journey at Delft University of Technology. The report is the outcome of six-month design research; it initiated from the topic of 'Sharing Live User Avatar Biofeedback in Social VR space', brought up by Centrum Wiskunde & Informatica (CWI), Amsterdam, the Netherlands.

I encountered this project when I was at my lowest self-esteem in my life; I had lost my confidence and was in doubt about my capacities. However, it was a turning point to work on the project in a field of interest with superb mentors. While the graduation journey was one of the toughest experiences, I could feel that I was alive from those highly responsible, juicy problem-solving processes. The challenges that I took let me gained confidence back both as a designer and problem solver.

Yes, it was a very meaningful project to me and I am happy to share the process with you.

Please enjoy reading, and I hope that it could bring you excitement and inspiration as well!

ACKNOWLEDGEMENT

I would like to list out names of people who supported me throughout the past half-year of this graduation journey, as this couldn't have happened without them.

First of all, my amazing supervisory team, Maarten, Pablo, and Abdo! Thank you, Maarten, for mentally supporting me, praising my works, and balancing out the project for the past months as a chair. Thank you, Pablo, for having me at CWI and being a nice big boss, always cheering me up, drawing an outlook, and supporting resources for the project to be successful. Thank you, Abdo, for the considerate amount of time, effort, and care spent on me. I was very lucky to have you as my daily supervisor. Your meticulous guidance was inspiring and motivated me to perform my true potential as a designer and researcher.

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Many thanks to IDE Korean girls, four 언니들 - Yeun, Yeonju, Ahni, and Jiyoun, who brighten up my lonely and gloomy life at Delft. All those chicken parties and short trips were a lifesaver when I was exhausted from the thesis work. Thanks to my soulmate Jiho and Tian, and all my friends who supported me all over the world, from Korea, China, and the Netherlands.

Special thanks to my YouTube teachers who helped me building VR Unity prototypes and modeling with Blender from the scratches. Thanks to all of my user study participants - interviewees, co-design session designers, final user study participants -, who gave me valuable insights and wished me luck! Thanks to countless teachers from books and YouTube, who helped me train my mind and body so that I can survive alone at a small room in Delft, during the Covid period.

Last but not least, thank you to my family, who always trust me, the true sanctuary of my life.

ABSTRACT

Social VR is the application of virtual reality that supports remote social interaction in virtual spaces. Users communicate and interact with others in the social VR environment through avatars, which are virtual anthropomorphic characters that aim to represent humans in virtual worlds. In addition, the development of the HMD and commercially available motion capture systems enable the avatars in the virtual environment to detect and reflect the real-time motions, even facial expressions of people. However, the avatars still lack an indication of biofeedback - e.g., body temperature, breathing, heart rate, muscle contraction -, which serves as social cues for communication in reality. While some features, for example, emojis, supports users to express their feeling or emotions for richer communication, the missing information often results in miscommunication in the virtual space. It remains a barrier to a fully immersed experience in the social VR space.

This project proposes a concept of visualizing biosignals of the avatars in the social virtual reality space for a richer-level interaction in virtual reality. With the technologies available to capture and reflect accurate biofeedback in real-time, we would like to explore ways and possibilities to map the bio states of the users in reality to avatars in the virtual world.

The project starts with conducting user researches to understand the current user behaviors in the social VR spaces and their perspectives on sharing biosignals. Based on the requirements gathered from the user study, the scope of the project is narrowed down to a 'watching entertainment' scenario, and the ways to visualize biosignals on avatars were explored through a co-design session with designers. After that, four biosignal visualization techniques in two biosignals - heart rate and breathing rate - are prototyped under the VR jazz bar setting. Finally, the user study is conducted with 16 pairs (32 participants in total) to test and compare the effects of each biosignal visualization technique in watching entertainment scenarios with a companion. As a result, the embodied visualizations are the most understandable and least distracting visualization methods among the four methods. Furthermore, the limitations of the research, recommendations on biosignal visualizations, and recommendations on conducting design research are provided.

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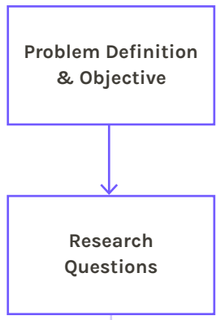


1. INTRODUCTION

This chapter presents the overview of the project, starting from introducing the context to setting the research questions.

1.1 Introduction

The paper is a Design for Interaction Master's graduation thesis: "Designing and evaluating avatar biosignal visualization techniques in the social virtual reality spaces." The general theme of the project was brought up by Centrum Wiskunde & Informatica (CWI): Sharing avatar biosignals in the social virtual reality spaces.

Social virtual reality (Social VR) is a virtual reality application that supports remote interaction in virtual space. Users interact with others through avatars, anthropomorphic character representations, in VR. However, there often presents miscommunication between users due to a lack of physiological states. Therefore, this project explores ways to visualize biosignals on the avatars in the social virtual reality space.

The project objective is to design and evaluate the avatar biosignal visualization system that solves the current user problems observed in the social virtual reality spaces. The project starts from asking a research question: "How can sharing biofeedback on avatars enhance user's social VR experience?"

Achieving the goal follows a step-by-step procedure: research, design, and evaluation phases. Appropriate design methodologies (e.g., context-mapping, interviews) are selected and adjusted to acquire desired results in both qualitative and quantitative data. The proposed designs are prototyped with a 3D modeling tool (Blender) and game development software (Unity). The final user study with 32 participants in pairs evaluates the developed prototypes. The analyzed results provide suggestions and guidelines for future biosignal visualization applications.

As a result, the project successfully comes to end by applying knowledge and skills acquired from TU Delft IDE masters program, with the topic relevant to the mission of the IDE Faculty: Design for Our Future.

Due to the outbreak of COVID-19, some of the user-involved design researches are limited to online activity. Many design directions or decisions are influenced to a certain extent. However, extra efforts are put to adjust the design methods and still achieve the initially set goal of the project.

1.2 Project Context

1.1.1 Avatars and Social Virtual Reality

Social Virtual Reality (VR)
Social Virtual Reality (VR) is the application of virtual reality that supports the remote, multidimensional interaction in virtual spaces. It is becoming increasingly adopted in the fields like social media, professional social meetings, virtual conferences, and gaming, etc. VRChat[1], Mozilla Hubs[2], AltspaceVR[3], Facebook Horizon[4] are a few of the popular platforms that capacitate social VR interaction (Figure 1).

Figure 1. Virtual avatars in Facebook Horizon

1 VRChat: https://vrchat.com/home
2 Mozilla Hubs: https://hubs.mozilla.com/
3 AltspaceVR: https://altvr.com/
4 Facebook Horizon: https://www.oculus.com/facebook-horizon

Avatar Representation in Social VR
Avatars are virtual anthropomorphic characterst that aim to represent humans in virtual worlds. Users communicate and interact with others in the social VR environment through the avatars. The avatars play vital roles in the social VR; the realism of avatars is one of the main factor affecting the sense of presence, interaction, and co-presence (Jung et al., 2017).

The development of the HMD (Head Mounted Display) and commercially available motion capture systems enable the avatars in the virtual environment to detect and reflect the real-time motions. Furthermore, the VR face-tracking features allows the depiction of facial expressions on the avatars in the VR spaces. **However, the avatars still lack an indication of biofeedback** - e.g., body temperature, breathing rate, heart rate, muscle contraction -, **which serves as social cues for communication in reality**.

Several different research showed the importance of the non-verbal communication, such as eye gaze (Garau et al., 2003) and facial expressions (Bailenson et al., 2006) through the avatars in social virtual environments. While some features, for example, emojis, supports users to express their feelings or emotions for richer communication, the missing information often results in miscommunication in the virtual space. For example, an avatar may appear peaceful in a virtual world whereas its user is very stressed or anxious in reality. It remains a barrier to a fully immersed experience in the social VR spaces.

1.1.2 Sharing Biosignals in VR

Sharing Biological Signals

Biological signals, or biosignals, are records of a biological event, which include electrocardiogram (ECG), galvanic skin response (GSR), respiration. The increasing availability of biosensors (e.g., PPG sensor, eye trackers) allows a user's biometric data to be collected and shared in real-time.

Sharing biosignals can bring about new opportunities in a wide range of scenarios as it has a social-emotional nature and thus can act as a new communication medium (Feijt et al., 2021). For example, an increase in a heart rate indicates that the person is aroused, and the perceiver may use that information to guess the emotional state of the person in accordance with the context. Studies have shown that the social biofeedback enhance the interpersonal relationship (Feijt et al., 2021) by increasing the feeling of connectedness (Buschek et al., 2018), empathy (Frey and Cauchard, 2018), intimacy (Howell et al., 2019), and more.

Visualizing Biosignals in Social VR

With the benefits of sharing biosignals, multiple approaches have been taken to adopt biosignals for communication purposes. The researchers have developed systems that visualized biosignals as graphs, numbers, icons, ambient lighting, and clothing, with different types of information and level of abstraction (Liu et al., 2017).

There were several approaches to visualize biosignals in VR environments. Previous work has shown how manipulating the shared heart rate feedback can influence interaction in collaborative virtual reality environments (Dey et al., 2019). Another work has presented a meditation platform with visualized breathing rate and brain electrical activity for inducing physiological synchronization between users (Salminen et al., 2018). **However, it remains unanswered how to visualize biosignals and map them on the avatars during social VR interactions.**

1.3 Project Direction

Problem Definition

The current avatar representation in social VR platforms doesn't reflect the user's real psychological or physiological state. The gap between the real user and the virtual avatar often results in miscommunication between the users and degrades the immersion in the virtual spaces (Figure 2).

Figure 2. A gap between the virtual and real world

Project Objective

The goal of this project is to explore the possibilities to bring biosignals into the social VR spaces and adopt them on the avatars in the visualized format; so that ultimately, it can help the current avatars in the social VR spaces to better reflect the real state of the users and help enhance the overall user experience.

The outcome of the project will be a set of biosignal visualization techniques (Figure 3). In addition, the final user evaluation on the developed prototype will verify the effect of each technique and provide guidelines for future avatar biosignal visualization scenarios.

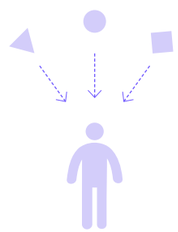


Figure 3. Set of biosignal designs on avatar

Research Question

Instead of start prototyping the biosignal visualizations, the project takes a user-centric approach to achieve an objective by asking the research question:

RQ 1

How can sharing biofeedback on avatars enhance user's social VR experiences?

This research question can be answered from two directions, thus split into two in depth questions.

RQ 1-1

How is the current user interaction in the social VR spaces and what experiences can be improved?

RQ 1-2

How is current user attitudes on sharing biofeedback and how can it improve user experience in the social VR?

Project Approach

The project consists of four main phases: user research, conceptualization, prototyping, and evaluation (Figure 4).

The research starts with understanding the current user's behavior in the social VR spaces via user research processes. Through survey and interview with context mapping technique, it broadens the knowledge on the user's avatar communication experience and the views on sharing biosignals in the social VR spaces. The design scope is narrowed down based on the study results.

The second phase explores the ways to visualize biosignals on the avatars. The co-design session with designers generates the possible biosignal visualization methods on the avatars in the social VR spaces. The specific context and the setting are finalized based on the study results and practical issues.

After, the set of biosignal visualization techniques is prototyped with software. Blender is used for prototyping 3D models and Unity is used for prototyping the entire scene.

Finally, the user evaluation session is carried out to evaluate the effects of the biosignal visualization methods. The research condition and independent variables are set; the prototypes are adjusted to suit the test setup. After the experiments with 32 participants, both quantitative and qualitative data are analyzed. The paper eventually reports the conclusion by reflecting on the research questions and ends with recommendations for future research.

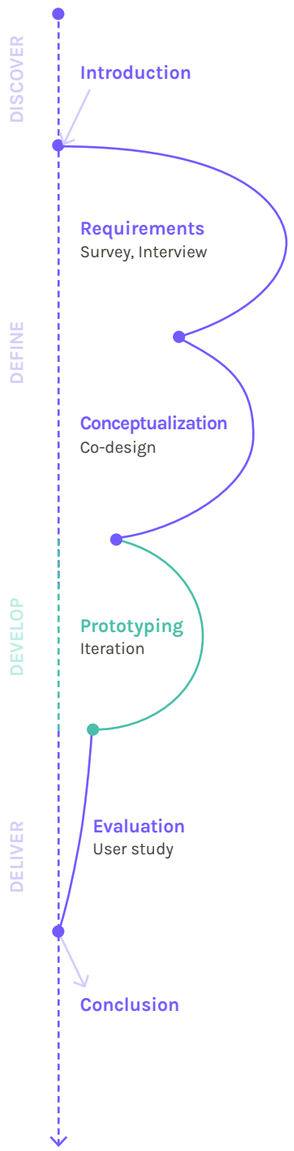


Figure 4. Project approach

1.4 Project Contribution

Each chapter of this paper has made its unique contribution to the project. The followings are the summary of what and how each chapter contributes to the project.

Chapter 2 Requirements

- The survey on interaction in social VR space was conducted; 50+ valid responses were analyzed.
- Six interviews applied with context mapping technique (sensitizing booklet) were conducted and analyzed.
- Eleven design requirements for designs in the social virtual reality were defined.
- Four objectives of sharing biosignals in the social spaces were classified.

Chapter 3 Conceptualization

- An online Co-design session with six designers was designed, conducted, and analyzed.
- Three types of entertainment were categorized based on the level of user interaction.
- Six ways to express biosignal visualization on avatars in social VR spaces were defined.

Chapter 4 Prototyping

- The VR jazz bar environment with a jazz band was prototyped.
- For biosignal visualization techniques on heart rate and breathing rate were prototyped.

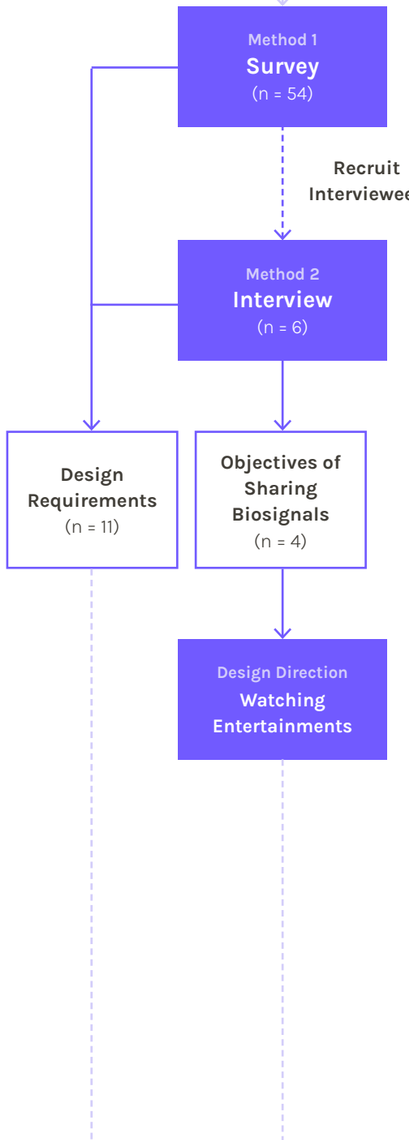
Chapter 5 Evaluation

- The questions on perceived arousal level, degree of distraction, perceived biosignal type, favorite visualization for each prototype were measured and analyzed in quantitative data for 16 pairs, 32 participants.
- The Focus group was conducted and analyzed to gather a deeper level of understanding of each answer.
- Embodied visualization method was found to be the most understandable and least distracting among the four visualization methods.

Chapter 6 Conclusion

- The limitations of the research, recommendations for the biosignal visualization, recommendations on conducting design research were discussed.

Chapter 2 Overview



2. REQUIREMENTS

The chapter 2 answers the research questions raised in the previous section and looks for the design opportunities in the social VR spaces. Insights from two design methodologies - survey and interview - will lead to setting the design direction of this project.

2.1 Method 1: Survey

The survey was conducted to understand the current social VR experiences and uses of different platforms. The main goal was to narrow down the scope of this research in terms of the target user, platform, and purposes for using social VR platforms. The secondary goal was to find the potential candidates for the subsequent qualitative design process.

Participant

The survey (Figure 5) link was posted on multiple social platforms to recruit participants, including Reddit, Twitter, Facebook groups, Whatsapp, etc. The survey was created in Google Form, with 10-15 minutes estimated completion time. 30 euros voucher for the lottery as compensation was mentioned in the description. Anyone who had experienced social VR platforms was targeted as a participant.

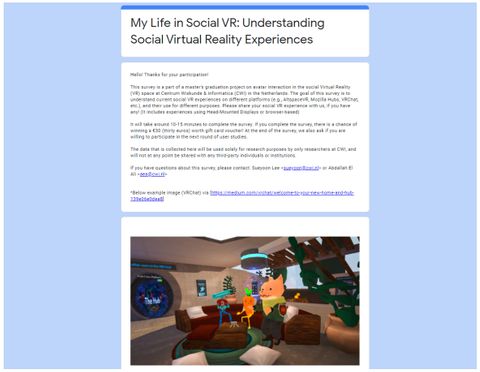


Figure 5. Google Form survey

54 valid participants submitted responses; with the age range of 13-51 (Median 24); 33 Men, 15 Women, 3 Non-binary, 1 MTF, 2 Prefer not to disclose; 48 participants reported they own a VR device; 20 participants reported they play VR every day, 5 participants reported that they play VR less than once a month, the rest were in between; 45 participants reported they have tried the specific VR platform over ten times.

Questions

The survey started with asking demographics and general VR experiences (e.g. if they own VR headsets, how often do they play, etc) (Figure 6). Afterward, participants had to select one social VR platform that they want to base their next responses on as they can get completely different VR experiences for each platform. They had to answer if they had customized their avatars or not and why did they perform in that way. Additionally, we asked about their thoughts on current avatar appearance and representation of themselves.

The next core topic of interest was the avatar interaction. We asked if they had experiences on interaction with 1) an actual real-life friend, 2) a virtual friend, or 3) a stranger, in social VR space. For each case, they had to answer how was their avatar interaction.

The survey ended by asking about their experience in other platforms with an open-ended question. In addition, we asked if they are willing to participant in the next user study session (interview and co-design session).

Most of the questions took either multiple choice or 5-point Likert scale format; only two of them were open-ended questions. The survey covered shallow but broad topics since there was no concrete direction yet. The full question list is in Appendix B.

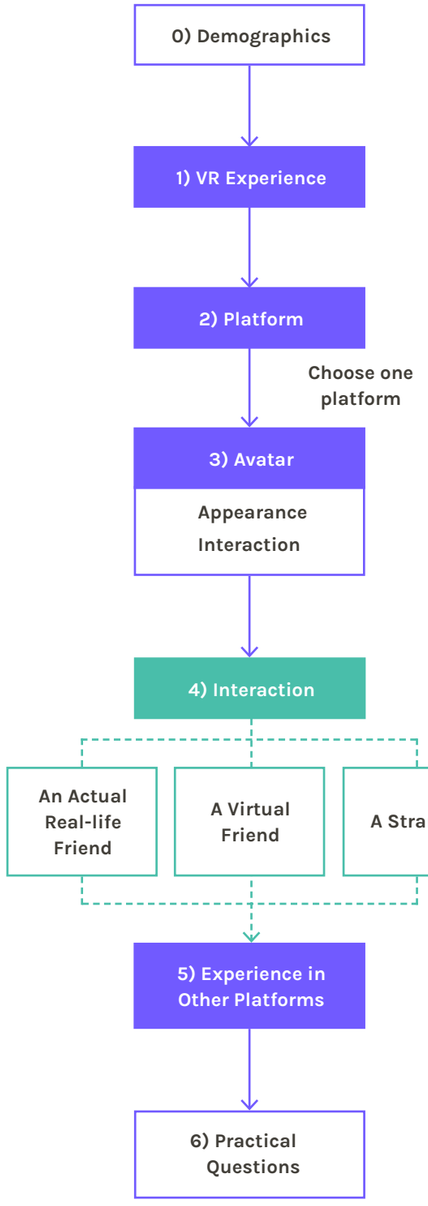


Figure 6. Survey question flow

Data Processing

The survey responses within four days after posting were analyzed. The total submission was 489; they took the data cleansing process before the analysis.

The data cleansing started with removing duplicate emails and observing open-ended questions. While observing the emails and short answers, it was found that a large number of submissions followed the same pattern, which was suspicious. For example, some of them answered 'no' with the same spacing for multiple open-ended questions in a row. The answer 'no' itself did not match with the question. Traced back to their emails, the emails followed the same format, which was 'FirstnameSurname + random few alphabets@yahoo.com' or '*** + two random numbers@gmail.com'. Of course, there were also real accounts with similar email formats. It was a manual guessing process by checking if their email account had a proper profile image or not. Hence, a large number of data were dumped to avoid misinterpretation of results. In the end, only 54 valid responses were taken into account for the analysis.

After the short analysis, interview direction and question lists were derived from the trend observed. Six survey respondents with diverse social VR experiences were recruited for in depth interview session.

2.2 Method 2: Interview

The interview was conducted to explore the current experience of using avatars in different scenarios, roles, and environments in the social VR context; to narrow down the research into a more focused target group. The interview adopted the Context Mapping technique, a generative design methodology, to help interviewees recollect their experiences in VR spaces. It was split into two parts: (pre-filled) sensitizing booklet and the main interview session (Figure 7).

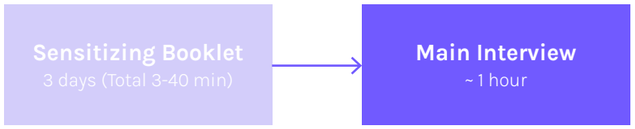


Figure 7. Interview process

Participants

The participants of the interview session were recruited via sending emails to the candidates from the survey who showed a willingness to participate in user study sessions. The participants were carefully selected based on their submitted profiles to cover a variety of ranges. Six interviewees were recruited as a result (Table 1); the interview time was scheduled individually using Doodle. They were paid 15 euro voucher at the end as a compensation.

Interviewee Conditions

- Age: from late 10s to 40s
- Gender: both man and woman
- Frequency: who plays Social VR at least once a week
- Social VR experience: less. or more than 1 year
- A different role in social VR: both participant and host of events
- Interaction with others: both who have interacted only with strangers, and who have interacted with strangers and friends

No.	Gender	Age	Ethnicity	Country	Frequency	Experience	Interaction	Occupation
1	Man	38	Caucasian	Greece	Several times a week	~ 1 year	only with stranger	Designer
2	Man	20	Caucasian	Korea	Once a week	3-4 years	all	Student
3	Woman	34	Caucasian	Canada	Several times a week	5 years	all	Designer
4	Man	21	Asian	USA	Once a week	3 years	all	Designer
5	Woman	19	Asian	USA	Several times a week	1 year	only with stranger	Designer
6	Man	32	Asian	USA	Several times a week	~ 1 year	all	Designer

Table 1. Interview participants information

2.2.1 Sensitizing Booklet

Purpose

The sensitizing booklet was designed to help the participants reflect on their 1) body reactions when meeting or interacting with someone in real life, 2) current interaction methods when meeting people in the social VR spaces (Figure 8). Two goals were formulated in the intro so that the participants can understand the expectations from this activity.

Data Collection

All the written data were transcribed in the google sheet for analysis.

Setup

The booklet was designed as three days activity with a Miro[1] board, each day activity taking around ten minutes to complete. The activity board link was sent four days before the scheduled interview date. The participants were asked to complete the sensitizing booklet a day before their interview date. The interview questions were adjusted for individuals before each interview according to their booklet results. The detailed view of the booklet can be found in Appendix D.

1 Miro: An Online Whiteboard & Visual Collaboration Platform (https://miro.com/)

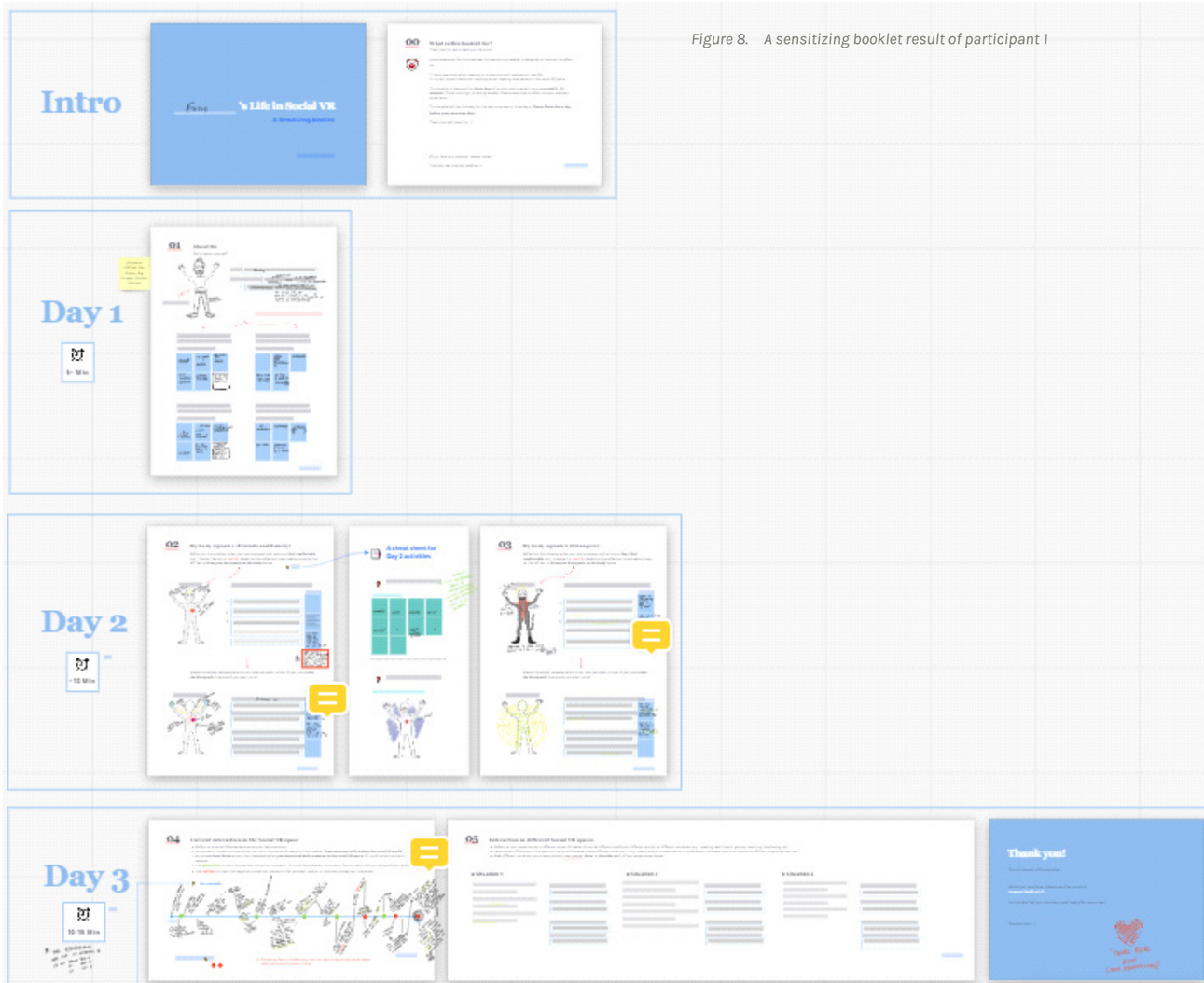


Figure 8. A sensitizing booklet result of participant 1

Booklet Design

Day 1.

Day 1 was a warm-up activity for the participants. It helped participants to be familiarized with the tool (Miro board), assuming that most of them had no experience with the sensitizing booklet and the generative session in the online environment. They were asked to first draw a self-portrait and then to write down objects or situations that make them feel comfortable, nervous, caring, etc, to reflect on their sense of emotions (Figure 9).

Day 2.

Day 2 activities asked participants to reflect on situations when meeting someone in real life: with whom they feel comfortable and with whom they feel uncomfortable. For each case, they were asked to illustrate and draw 1) their real body signals, and 2) the ideal body signals as representation. This question was based on the assumption that their real and ideal representation of biosignals would be different; to see how people want to be presented to others (Figure 10).

Day 3.

Day 3 activities were designed to collect participant's social VR experiences (e.g., meeting new friends, gaming, watching, meditating, etc) in various situations. The first section asked to 1) select one social VR experience and describe all the interaction/touchpoints of the entire journey, and 2) mark positive and negative interaction moments. The second section asked to pick three different situations they interacted with new people in social VR spaces, draw and describe their interactions in the space (Figure 11).

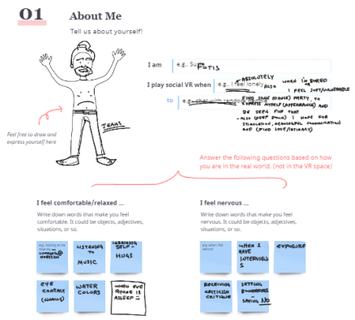


Figure 9. Day 1 result of participant 1

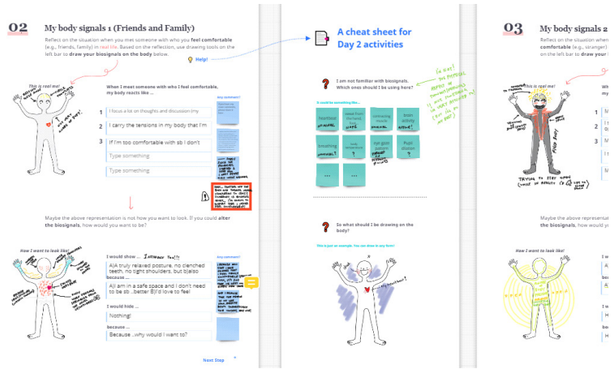


Figure 10. Day 2 result of participant 1

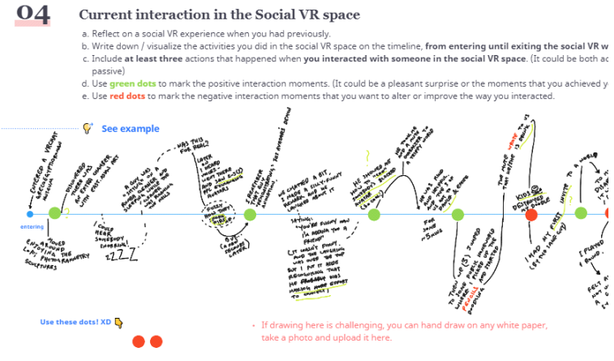


Figure 11. Day 3 result of participant 1

2.2.1 Main Interview

Purpose

While the sensitizing booklet was to help the participants reflect on their experiences, the follow-up interview was for the researcher to gain insights and deeper understanding from the sensitizing booklet. The main purposes were 1) to understand the latent desire and need of people using social VR platforms, 2) to compare the real and the ideal representations of physiological reactions when meeting people, and 3) to discover current (visual) interactions when meeting people in the social VR space under multiple scenarios.

Setup

The interview was a 1-hour activity and was conducted in English online using Zoom and Miro board. The consent form was shared to request recording before the start. The interviewer screen-shared the participant's prefilled sensitizing booklet; hence, participants were able to refer back to the booklets when answering the questions and the interviewer had control over the time and direction of the interview. In the end, the interviewees completed the Big Five Inventory questionnaire (John et al., 1991) and wrote feedback on the entire interview process via Google Form.

Questions

The interview started with asking follow-up questions to the sensitizing activity. Interviewees explained their answers written on the booklets; additional questions were asked spontaneously during the ongoing interview. The list of questions was adjusted and expanded as the interview progressed, influenced by the results of previous interviewees. The initial interview script and the list of questions can be found in Appendix C.

Data Collection

1. The interviewer took a note in Google sheet during the interview.
2. Each interview was screen-recorded via Zoom. The audio files were firstly auto-transcripted with a tool (https://trint.com/); the drafts were corrected manually afterward. Significant quotations from the script were highlighted and then were collected to the google sheet for analysis. The collected sentences were compared, grouped, and regrouped multiple times until generating meaningful trends and insights.
3. Big Five Inventory results were also calculated; the scores were referenced back when analyzing the interview.

2.3 Results and Findings

Results from the sensitizing booklet and the main interview were collected and analyzed. It provides answers to the research questions raised in Chapter 1: “How can sharing biofeedback on avatars enhance user’s social VR experience?” The first part covers the current user’s behavior and interaction in the Social VR space and then possible scenarios in sharing biofeedback.

2.3.1 Current user’s behavior & interaction in Social VR

This section answers to the research question 1-1: “How is the current user interaction in the social VR space and what experiences can be improved?”

A. Avatar Representation in Social VR

Avatar is a self-representation of a user in social VR spaces. How people decorated or customized their avatars were influenced by several factors.

1 Based on the type of relationship

In VR space, people had less pressure and were more confident when interacting with strangers, as they could customize their avatars to how they wanted to be seen. The anonymity in VR supported people who found difficulties in presenting themselves in real life. On the other hand, they didn’t care much about their representation when meeting with real friends, as it was not important to reflect the reality.

P2: “I think in VR, for me, it’s much easier to initiate a conversation with strangers because I don’t feel like I’m facing them face to face.”

P1: “To my real-life friends, I could even wear an avatar of a spaceship, because I know they know me, so my appearance doesn’t have to reflect truthfulness.”

2 Based on the type of social VR platform

‘Type of platform’ was a more critical factor when deciding avatar representation and behaviors, compared to the type of relationship. People tended to adjust their avatar representation and behavior based on the type of social VR platforms they visit. Users decorated their avatars based on their goals of interaction; their within-VR identity and behavior followed the avatar’s look in each social VR platform.

P3: “So in AltspaceVR, I designed my avatar to look like myself. But then also other platforms like VRChat, the avatar that I embody is Joker. So i’m an Asian male, but it doesn’t represent who I am as much as my avatar in AltspaceVR.”

B. User Behavior in Social VR

People showed patterns in their behavior when exploring VR spaces. Some of the patterns resembled that of real life, some of them were unique in the social VR setting, and some were unique due to missing aspects in VR (Figure 12).

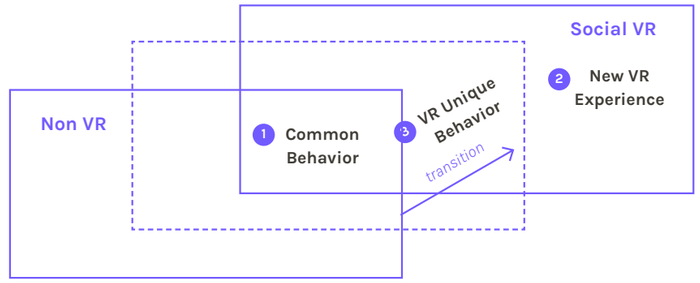


Figure 12. User behavior patterns in Social VR

1 Common Behavior

1-A: Try to find a meaningful connection

Before entering the social VR spaces, people put effort into finding a world or event where they can spend meaningful time. Sometimes they register for events in advance or use other social platforms, such as Discord or Reddit, to get relevant information. Once in the social VR spaces, people tried to find a group of people with whom they can resonate and share commonalities.

1-B: Try to show respectful manner

People showed respectful behaviors when interacting with others via their avatars. Even when they were no longer interested in a topic of conversation, people tried to show respect by not interrupting the conversation and waited until finding the right time to leave the group; however, it sometimes resulted in annoyance.

P1: “I don’t find a break to say, “Hey guys, I’m sorry to interrupt your chatting, going.” So it’s very difficult for me. It may even stay up for 30 or 60 minutes more than I want to, until I find a proper break.”

1-C: Try to find comfort in space or people

People spent the first few minutes adapting to the new environment; they either explored to find a comfortable space and look for a person who they already know or who shares common interests or backgrounds.

1-D: Try to guide and provide a comfortable experience (as a host)

Guiding and providing a comfortable experience to guests was an inevitable goal for the host of the events. Hosts cared about guests’ personal space and comfort level; thus, they used indirect communication methods - such as text chat - to interact with guests.

I used text chat to communicate with others in the room, and let them know I was also available by voice if needed because some find it jarring when a voice appears and they are not sure who you are. I didn’t want to invade the space or comfort levels of incoming guests.

2 New VR Experiences

2-A: Explore new technologies and experience

Some people visited social VR platforms solely for exploring technology purposes instead of socializing or networking. They tested out possibilities of action and limits in environments by physically touching and grabbing objects. The exploration was not limited to the spaces but also applied to customizing avatars representations.

P3: "So I kind of started playing with that and see, you know, what I could and could not do in the space."

2-B: Look for an immersive experience

VR enabled people to get immersive experiences under imaginary settings and scenarios. The first-person perspective feature played an important role in providing an immersive experience.

P5: "And that's why I love playing Among Us VRChat, it's more immersive and you get to first-person and walk around it."

2-C: Use objects or tools to initiate interaction

Virtual objects from the virtual environment, unintentionally, worked as a medium that elicits interaction between people.

P5: "When I started interacting with others, we started as mute and she was mute too. Eventually, we were feeding ducks. We started to open up.."

3 VR Unique Behavior

3-A: Try to express emotion

People tried to express their emotions using emojis, hand gestures, voice chat (and body movements if full-body tracking was possible). Sometimes, they had to memorize the list of button combinations to perform certain gestures; it often resulted in miscommunication by pressing wrong buttons or due to low variety in the available expressions.

3-B: Try to prove the presence

People tried to prove their presence in VR via some means, such as emojis, as the presence was not apparent in VR spaces.

P3: " Also making sure that I'm making people aware that I'm there and able to talk by I think I was someone was saying something."

3-C: Try to check the presence of others

In reverse, people complained about not being able to check the presence of others. However, there is no other way but to approach actively and see if the person responds.

P5: "let's just say someone's like daydreaming or like looking in the distance, It's kind of hard to see that in avatars."

3-D: Try to check the interests of the audience (as a host)

As a host, lecturer, or manager of events, they tried to check the avatar's reactions to make sure the audiences are satisfied with the events. They assumed audiences' interest from the avatar's body directions, avatar movements, emoji reactions, or directly sending private messages to ask about their satisfaction rate.

2.3.2 Sharing Biofeedback in Social VR

This section answers to the research question 1-2: "How is current user attitudes on sharing biofeedback and how can it improve user experience in the social VR?"

Objectives of Sharing Biofeedback

People shared the potential cases that sharing biofeedback might be useful in social VR. From the example cases, their internal desire of sharing biofeedback was categorized into two major objectives.

1 Biofeedback makes an immersive VR experience

1-1 : Share live feelings and emotions with others to add excitement

This objective focuses on sharing feelings and emotions so that it can improve the quality of the current experiences. Sharing feelings and emotions can help build a more intimate relationship in long-distance or reflect on activities together, etc.

P4: "I can also see perhaps like a heartbeat type of thing could be something used in like an intimate relationship."

1-2: Share live biofeedback with others to add reality

This objective focuses on adding a reality that is missing in the VR spaces. The concept can be applied to playing social deduction games, horror games, understanding others' status better, etc.

P2: "Mafia, it will be amazing because you can see other people's cardiograms and try to guess if they're lying or not."

2 Biofeedback alters human behavior

2-1 : Share live biofeedback with others to guide or improve current behavior

This objective focuses on guiding or improving the current behavior through VR where the data can be visualized. The concept can be applied to medical application, exercise, training, simulation purposes, etc.

P4: "The ability to tell people to slow down their breathing and people able to observe their heartbeat could be useful for measure how they're doing and like trying to relax. (meditation)"

2-2: Measure biofeedback to track and be self-aware of current behavior

This objective focuses on tracking and self-awareness of the current behavior. The application of this goal mostly overlaps with the previous goal (2-1), but only the visualization focus should be on self-awareness.

P5: "I would like to see that a bit more information on how I've acted."

2.4 Design Direction

While understanding user interaction in social VR and perspectives on sharing biofeedback, potential design spaces were discovered. Both practical issues and personal interests were considered and compared based on the results and findings of the user research phase to narrow down the design scope.

Comparing Social VR Scenarios: Based on the Objective of Sharing Biofeedback

The objectives of sharing biosignals in social VR spaces were used as a stepping stone to compare different scenarios and choose a design direction. Hypothetical design scenarios and biosignal visualization visionaries were drawn for each case used for making decisions to move on to the next step (Figure 13).

Figure 13. Hypothetical biofeedback sharing scenario comparison

Direction Decision

My interest and practical limitation were also considered when narrowing down the scope of this research. As a result, 'watching entertainment in the social VR space' was set to the design space (Figure 14).

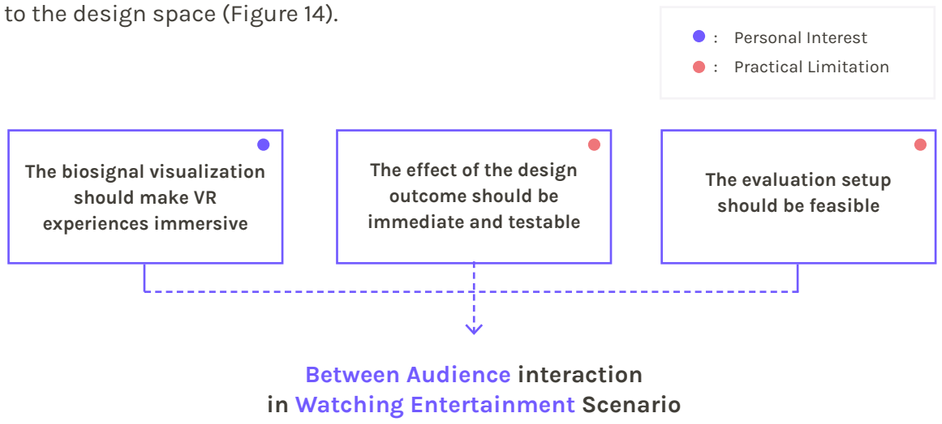


Figure 14. Narrowing down the scope of design research

Research Question and Design Goal

After answering the first research question, the second research question was raised: "How to visualize avatar biosignals for immersive VR experience in watching entertainment scenarios?" (Figure 15).

Entertainment activities included watching a movie at a cinema, participating in a live concert, watching a ballet performance at a concert hall, etc. The more specific condition, including the type of user relationship and the type of entertainment, was still undecided at this stage. Three types of biosignals - Heart rate, EDA, and breathing - were chosen for the next step.

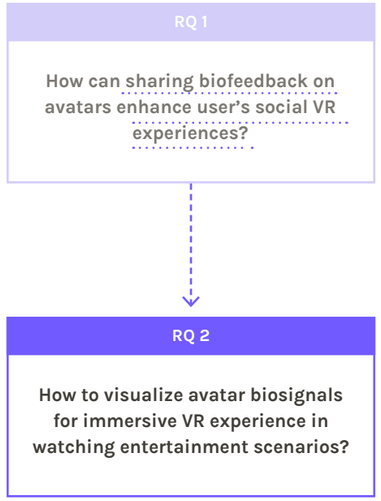
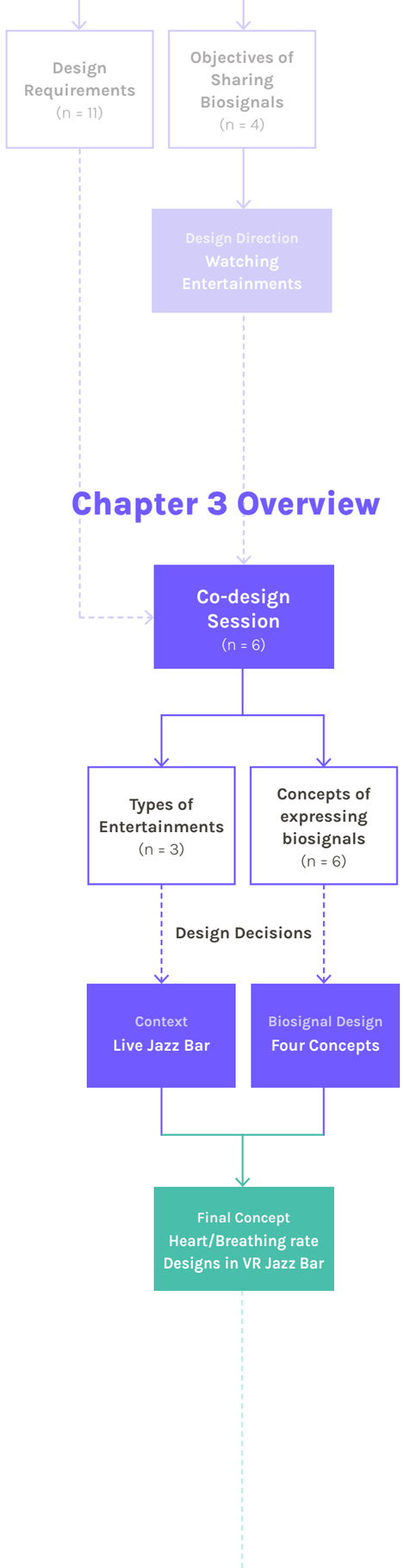


Figure 15. Research quesetion flow



3. CONCEPTUALIZATION

The chapter 3 sets the final design concept of this project to answer "how to visualize avatar biosignals for immersive VR experience in watching entertainment scenarios?". Co-design activity process will be dealt with in depth from the session preparation to insight generation.

3.1 Co-design Activity

Co-design, one of the participatory design methodologies, was conducted 1) to look for a suitable case of sharing biosignals within the watching entertainment scenarios and 2) to collect visualizing ideas from the participants. The Co-design activity was split into two parts: (pre-filled) sensitizing booklet and the main co-design session (Figure 16).

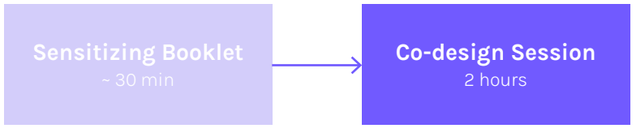


Figure 16. Co-design activity process

Participants

The participants of the Co-design activity were recruited via social media postings (Whatsapp group, Facebook community)
The requirement of the participants was a designer, who:

- possesses a drawing tablet
- is confident at expressing ideas with quick sketches/drawings
- has experiences of watching entertainments (e.g., movie, play, concert, etc) with others in a public setting

Experiences or knowledge in Social VR were not required from the participants. As a result, six designers with different backgrounds were recruited (Table 2).

Overall, the recruited designers had limited experience in social VR platforms, except for one person who had 30-50 visit experience in Social VR. One person tried the Social VR platform once; three people had limited VR experience; one person had no experience at all in VR.

No.	Gender	Occupation	VR / Social VR Experience
A	Woman	Master's student (DFI)	Social VR (Novice)
B	Man	UX Designer	VR only
C	Woman	Master's student (DFI)	None
D	Man	Freelance artist (Previously: UX Design Lead)	Social VR (30-50 times)
E	Woman	Master's Student (DFI)	Social VR (Once)
F	Woman	UI Designer	VR only

Table 2. Co-design session participants information

3.1.1 Sensitizing Booklet

Purpose
The sensitizing booklet was designed to help the participants reflect on watching entertainment experiences with others in real life and learn the social VR concept.

Setup
The booklet was designed as a 30-minute activity using a Miro board, and the boards were sent two days before the main session (Figure 17). The participants were asked to complete the sensitizing booklet before the co-design session.

Data Collection
All the written data were transcribed in the google sheet for analysis.

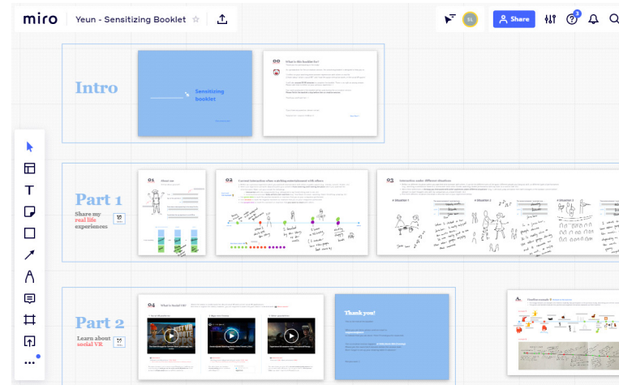


Figure 17. A sensitizing booklet result of participant C

Booklet Design

Part 1. Share my real-life experiences
Part 1 guides participants to reflect and share their real-life experiences in entertainment activities (Figure 18). Participants referred to the booklet answers when they were sharing experiences in the main Co-design session; the answers were transcribed and used again in the analysis process. A detailed view can be found in Appendix E.

Part 2: Learn about Social VR
Part 2 introduces the participants to the social VR concept (Figure 19). Three videos [123]were sourced from YouTube and embedded in the Miro board; they covered general information about the social VR platforms and the current social VR usage in the entertainment sector. The required section to watch was 10 minutes long, but participants were suggested to freely explore and acquire relevant knowledge. In this way, participants were able to gather sufficient knowledge in social VR before the main Co-design session even if they had not experienced social VR platforms before.

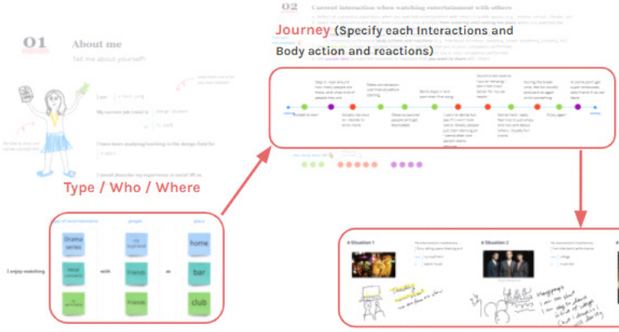


Figure 18. Sensitizing booklet Part 1 example

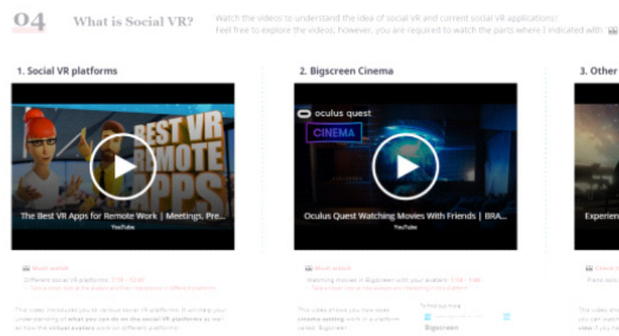


Figure 19. Sensitizing booklet Part 2 example

1 Social VR Platforms: https://youtu.be/jFJw312AHYE
2 Bigscreen Cinema: https://youtu.be/fA2cW2qgGgs
3 Other possibilities: https://youtu.be/SjPd9MCBh7Q

3.1.2 Main Co-design Session

Purpose

A co-design session was conducted to generate ideas for visualizing bio-signals (heart rate, electrodermal activity (EDA), and breathing) between audiences during entertainment activities (e.g., movie, play, concert, musical performance, etc) in the social VR setting.

Setup

The co-design session was planned as 2 hours online activity; it was conducted in English using Zoom and Miro board. Participants had to prepare their own drawing tablets in advance. Completing the sensitizing booklet on the Miro board, participants had already gained enough familiarity with the drawing tools before the main co-design session. Less familiar terms or concepts (e.g., EDA) were explained during the introduction phase with images and simple terms (e.g., sweat responses).

On-line Teamwork

Participants were divided into three teams; each included one design Master's student and one designer working in the industry. Each team was sent into different breakout rooms for an ice-breaking session, three rounds of ideation sessions, and a constructive feedback session. The purpose of dividing into teams was to foster interaction between participants and to provide equal opportunity for individuals to contribute in the co-design session.

Data Collection

The Co-design session was audio recorded for future references. All the design ideas generated from the Co-design session were compared to each other and grouped to set a meaningful pattern; the process was repeated multiple times until it resulted in a clear standard classification.

Timeline

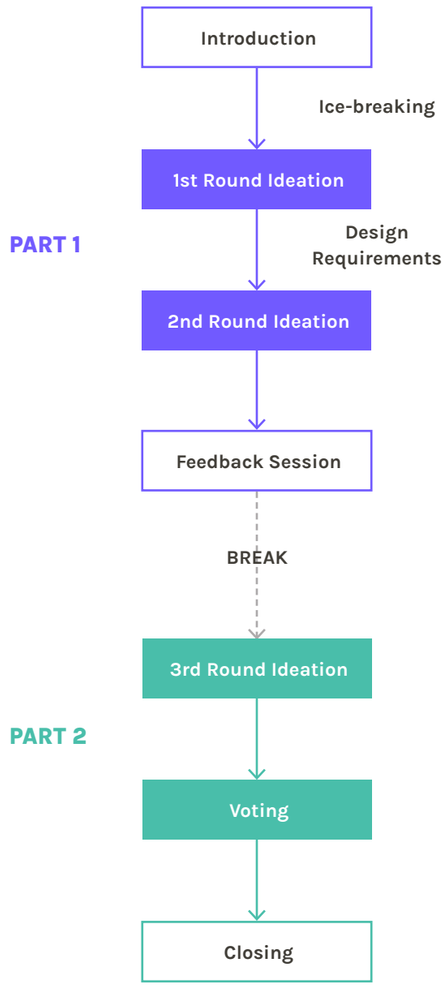


Figure 20. Co-design session timeline

Material Design

Main board

Materials required for the session were put all together into one Miro board. The board was divided into multiple sections; arrows indicate the timeline flow (Figure 21). A detailed view of the mainboard can be found in Appendix F.

- **H:** It includes images from relevant literature, including body map, examples of animating colors, previous non-VR biosignal visualization studies.

A : Schedule & Team info
B : Reflection (Sensitizing Booklet)
C : Types of biosignal (Literature / Research Phase)
D : Ideation template
E : Scenario example (Sensitizing Booklet)
F : 1st Round (Ideation template)
G : Design requirements (Research Phase)
H : Biosignal visualization example (Literature)
I : 2nd Round (Ideation template)
J : Constructive feedback method
K : 3rd Round (Ideation template)
L : Voting criteria

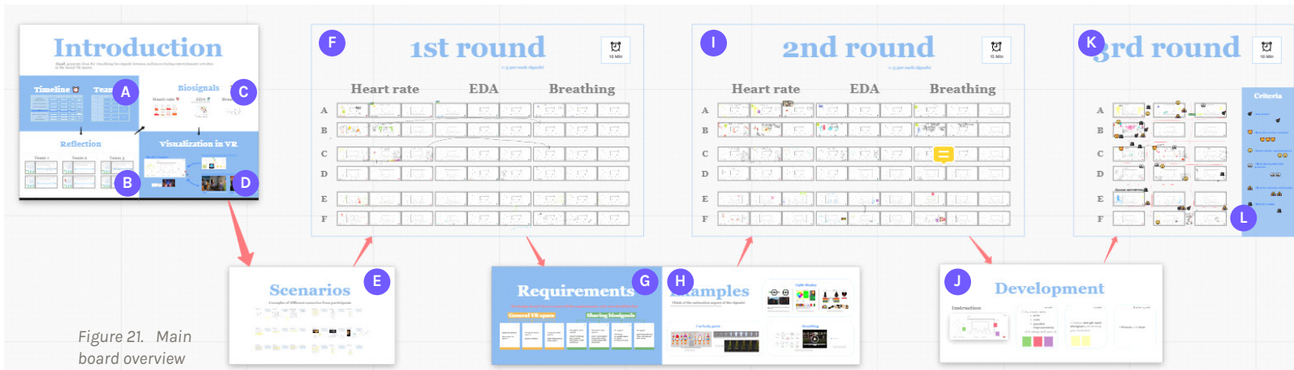
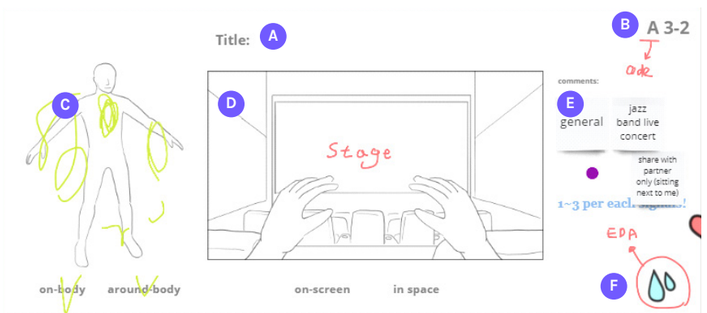


Figure 21. Main board overview

Ideation board

The ideation template was designed to express one visualization idea per template (Figure 22). Each template provided two types of wireframes: a 3D avatar body model and a first-person perspective VR camera view screen. Participants were free to either use both of the wireframes or select one of the wireframes.

- **B:** Alphabet indicates the code of each participant (from A to F). <First number> indicates the ideation round (from 1 to 3). <Second number> indicates the ideation number (from 1 to 9).
- **F:** The icons represent which biosignal to visualize in each template. (Heart - heart rate, Blowing wind - breathing, Sweatdrop - EDA)



A : Title
B : Template number
C : 3D Avatar body
D : VR first-person perspective camera view
E : Comment section
F : Biosignal type icons

Figure 22. Ideation template example

Design Requirements

Participants were introduced to the following design requirements for visualizing biosignals in the Social VR space, between the first and the second ideation rounds. They were asked to consider and meet at least one of the seven requirements when coming up with ideas; three were about general VR space and four were about sharing biosignals (Figure 23). These were derived from the insights collected from the interviews in the research phase (Chapter 2).

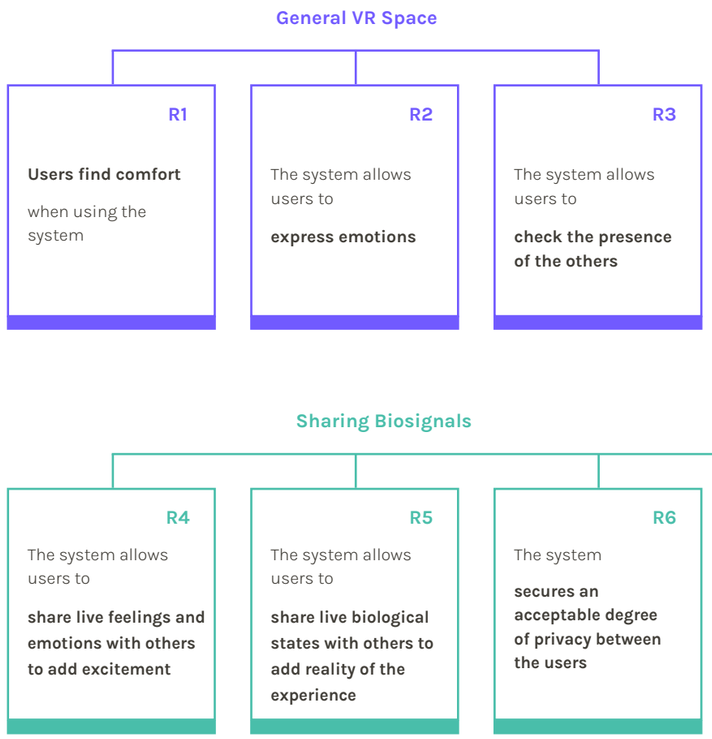


Figure 23. Seven design requirements presented in the co-design session

3.2 Results and Findings

Results from the sensitizing booklet and the main co-design session were collected separately and analyzed. Two major classifications were obtained from the analysis: 1) Types of entertainment, 2) Avatar biosignal visualization methods. The results from the sensitizing booklet helped to observe people's distinct interaction patterns in various watching entertainment settings; the results from the main co-design session helped to categorize and define places to visualize biosignals in Social VR spaces (Figure 24).

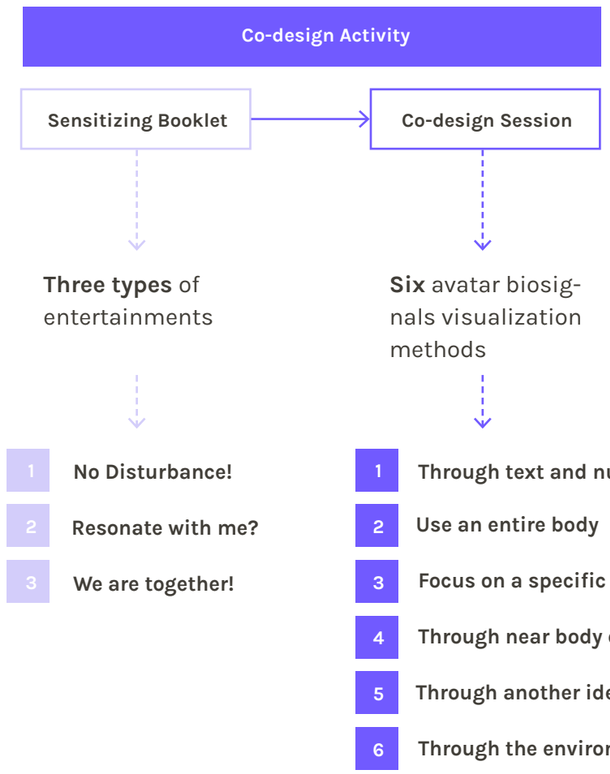
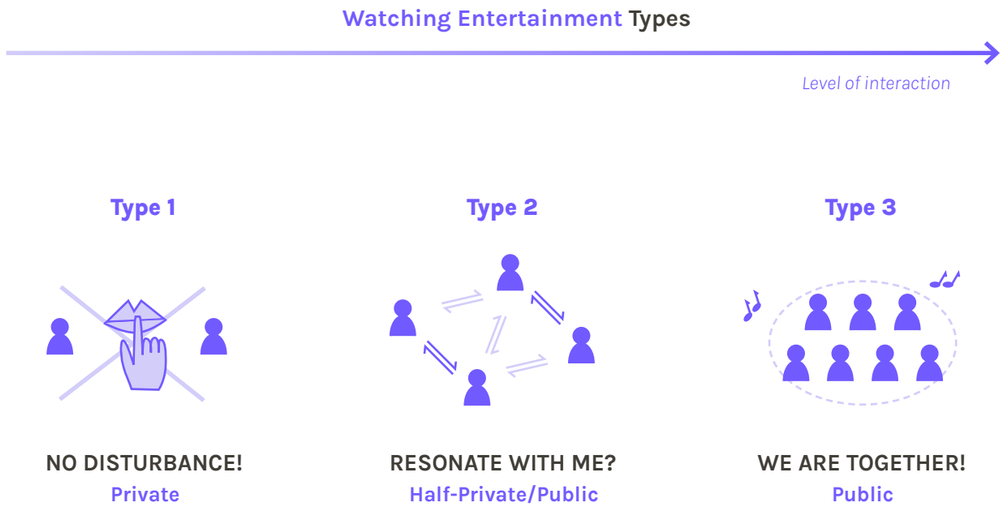


Figure 24. Co-design analysis overview

3.2.1 Degree of Interaction and the Types of Entertainments

According to the data collected from sensitizing booklets, people behave correspondingly in different entertainment scenarios. Based on the interaction characteristics, the entertainment activities were categorized into three types:



The first type refers to entertainment activities in a private and quiet setting; the example cases are **watching opera at the opera house, watching drama genre movies at the cinema,** etc (Table 3). Paying attention to the contents of the entertainment is relatively important under the Type 1 setting. Therefore, people are willing to concentrate on the contents during the show rather than interacting with others. They usually share thoughts after the main event.

The second type positions in between the first and third types - the entertainment activities in a half-private and half-public, chilled setting; it includes **listening to music at a live jazz bar, watching stand-up comedy at a comedy club,** etc (Table 4). In this type, people enjoy the content as well as the mood of the surrounding; they are curious about how other people are reacting to the entertainment during the events.

The third type refers to entertainment activities in a public and open setting; it embraces **participating in electronic music festivals at an open-air stadium, joining DJ events at a bar,** etc (Table 5). People relish all the aspects of the surroundings - people, environment, main events. They constantly interact with other audiences, even if they do not know them personally.

Type 1 No Disturbance!

Participant.	Type	People	Place	Interaction
A	opera	my family	opera house (classicla music hall)	*During the show, I tried to focus on the show, while if there was something I wanted to say, whisper to my family.*
A	stand up comedy	a friend	comedy club	*During the show, we never really made conversation because we were listening to the comedian.*
B	thriller movie	girlfriend	cinema	*Because I was so into the movie, my attention was just transfixed into the movie and I did not care about my surroundings or how nice and luxurious the cinema was.*
D	a movie about a dog	some German guys	cinema	*I assume I was keeping chatting during the film to a minimum since I don't like disturbing plus I want to be immersed. Most probably whispering to the person on my left if at all.*
E	story telling opera	boyfriend	opera house	*We were focused on the show.*

Table 3. Type 1 interaction examples

Type 2 Resonate with me?

Participant.	Type	People	Place	Interaction
A	stand up comedy	a friend	comedy club	*We constantly laughed, and I sometimes turned around to see if my friend was also laughing at it or not.*
C	listening music	friends	live jazz bar	*It was really good to see how other people enjoyed that moment.*
C	dancing	friends	jazz bar	*It is nice to see other people dancing and it resonates with me as well, to enjoy that moment.*
C	orchestra	friends	theater	*I want to know how other people feel about the music, especially depending on the mood of the music (sad, pleased, gloomy, magnificent,...etc)*

Table 4. Type 2 interaction examples

Type 3 We are together!

Participant.	Type	People	Place	Interaction
A	electronic music festival	friends	olympic stadium	*We never kept being quiet. We kept on shouting, or even screaming during the DJ set.*
A	electronic music festival	friends	olympic stadium	*We talk to other groups of people sometimes, any time of the show. Before, during, after the set. We jumped around, tried to dance...*
B	romantic movie	girlfriend	clubroom	*Some of my friends just chatted with other friends and didn't pay attention to the movie.*
D	DJing event at a bar (electronic)	various friends and acquaintances	a bar	*I went there with another friend and we sat with other people half turned towards the music half-chatting among us.*
D	DJing event at a bar (electronic)	various friends and acquaintances	a bar	*The music was loud and we were drinking too so we were chatting a lot loudly.*

Table 5. Type 3 interaction examples

3.2.2 Ways to Express Biosignals in Social VR

Avatar Biosignal visualization ideas from the co-design session were collected and grouped with similar characteristics in terms of the way to express the biosignals; there were categorized into six concepts (Figure 25). This guideline can be adapted to any other future biosignal visualization beyond the current scenario of watching entertainment.

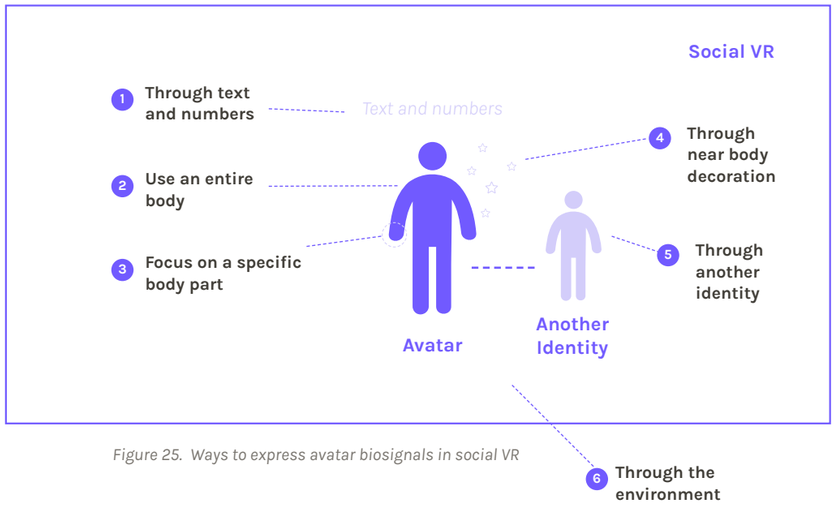
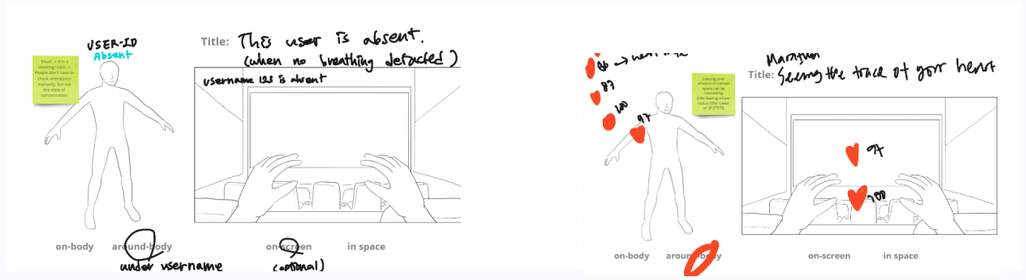


Figure 25. Ways to express avatar biosignals in social VR

Concept 1 Through text and numbers

Raw biosignal data can be visualized directly with text or numbers. It may be accompanied by simple icons or illustrations which can clarify the meaning of the text and numbers. The representation is straightforward with no need for interpretation; however, it may not be a harmonious way of representation in the entertainment setting.



Example 1-1. This user is absent

"User name or ID and his presence hover over the avatar in a text form. You can see whether the person is absent in the VR space. The message can be also shown on the UI screen." - Participant A

Example 1-2. Marathon: Seeing the trace of your heart rate

"The heart rate - bpm - is displayed in numbers with heart emojis. They trace after your avatar; you can even leave your heart rate at the space of your desire. " - Participant B

Concept 2 Use an entire body

The avatar body as a whole can be deformed through color changes or body distortions. The change of biosignals leads to exaggerated movement or actions of the avatar bodies. Interpretation is straightforward; it may suit better in an open, public space.

Example 2-1. I'm glowing up!

"Your avatar glows up! You can change the glowing color as you wish - or the color can be changed according to your biosignals. It could be effective at dance festivals, music concerts, and especially Idol concerts." - Participant A

Example 2-2. Geometric distortions

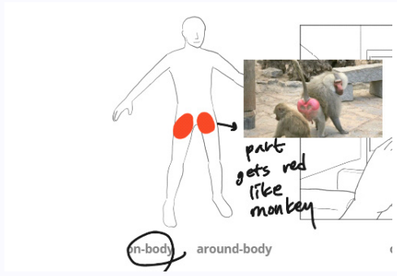
"Avatar bodies can have geometric distortions; this concept can be applied to any biosignals. Humidity could melt limbs, tension makes the body like Picasso distorted ...," - Participant D

Example 2-3. Sweaty suits

"The sweats cover the body when your biosignals indicate that you are scared. The body as a whole could be shrunk, showing exaggerated behavior. It could be interesting to apply when watching horror movies with friends, to have fun. " - Participant E

Concept 3 Focus on a specific body part

The deformation of the avatar could occur at a specific body part instead of the body as a whole. The representation is symbolic and exaggerated. It is requisite that the visualized result is of common knowledge to avoid misinterpretation. As it focuses on a specific body part, the effect may not be conspicuous especially when the avatars are not facing each other.



Example 3-1. Monkey excited

"A companion that carries your biosignals. Heartbeat changes the color of the companion. It can be detached and can move around. You can see the animals roaming the room but you can't see which belongs to whom." - Participant D

Example 3-2/3/4. Flush/Shocked/Panic

"Avatars can express their emotions with exaggerated facial expressions, like the ones from a game called 'animal crossing'" - Participant A

Concept 4 Through near body decoration

Biosignals visualization on avatar can be expanded to near body decoration. The representation is symbolic and requires an interpretation to uncover the meaning of each symbol. It could be used in both crowded and private settings, and the variation is endless.

Example 4-1. Weather mood

"It shows your mood today. According to your heartbeat, your 'weather' changes, like from raining to snowing. You can choose to see the other people's mood as well when you wish." - Participant C

Example 4-2. Energy Ribbons

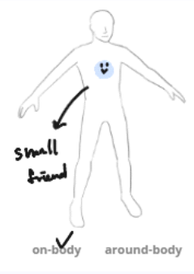
"Energy ribbons float upwards around the chest and overhead. Speed and tribulations indicate breathing and airflow. It can be used during performances, sports events, or even chatting.." - Participant D

Concept 5 Through another identity

Biosignals can be visualized via a new medium or system: through another identity. As it is detached from the avatar body, the identity that carries your biosignal could be used anonymously in a crowd setting. This concept can be used in both crowded and private settings, and again the variation is endless.

Example 5-1. Companion

"A companion that carries your biosignals. Heartbeat changes the color of the companion. It can be detached and can move around. You can see the animals roaming the room but you can't see which belongs to whom." - Participant D



Example 5-2. Bubble friend

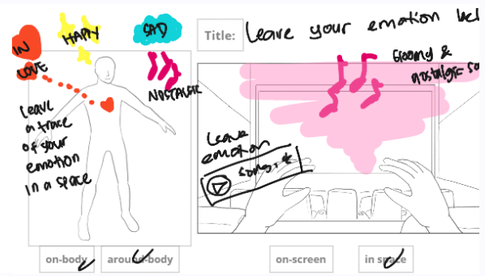
"You have a small bubble friend. It grows bigger when you breathe in and smaller when you breathe out." - Participant C

Concept 6 Through the environment

Biosignals can influence the environment or the surroundings of the avatar' in VR space. The size, shape, or color of objects nearby can be transformed according to the biosignals. On the contrary, the avatar can leave biosignals in the virtual spaces in a certain form.

Example 6-1. Mindfulness generates vivid life

"The grasses surrounding the avatar grow as you breathe. It grows bigger when you breathe in and smaller when you breathe out. It may be useful for meditation cases, to synchronize the breathing patterns with others." - Participant A



Example 6-2. Leave your emotion behind

"You can leave a trace of your emotion in a virtual space while walking around. Each emotion or biosignal can be presented in a certain form, like heart, star, cloud, and you can save and pin your emotion wherever you want." - Participant B

3.3 Concept Direction

3.3.1 Environment Setting

From Co-design, types of entertainment activities had been segmented, and the guideline for visualizing biosignals had been established. Three entertainment types were compared to decide the final prototype environment (Figure 26).

	Type 1 NO DISTURBANCE!	Type 2 RESONATE WITH ME?	Type 3 WE ARE TOGETHER!
Space	Private	Half-private, Half-public	Public
Current Interaction	• People are willing to focus on the show when the content is relatively important (e.g., opera, movie) • They usually share their thoughts after the main event.	• People enjoy the content as well as the mood. • They are curious about how other people are enjoying the moment during the event.	• People enjoy all the surroundings (e.g., people, environment) • They constantly interact with others, even with people they don't know personally.
Possible Direction	• New opportunity to share biofeedback privately	• Add excitement	• Add excitement
Concerns	• Biosignal may disturb people?	• How to build/set up a good quality environment?	• How to build/set up a good quality environment?
Suitability	✕	●	▲

Figure 26. Environment Setting Comparison

Type 2 <Resonate with me?> was the most reasonable environment to adopt the biosiganl visualization concept among the watching entertainment types. '**Live jazz bar**' was selected to be the final environment considering the prototyping and user test feasibilities.

3.3.2 Biosignal Visualization Type

After the environment had been selected, some of the avatar biosignal visualization methods were adjusted to fit the live jazz bar environment. Four design concepts were concretized for the final prototype as a result (Figure 27). (1) was omitted for its directness and less space for design; (2) was omitted for its exaggeratedness for the half-public, half- private jazz bar environment.

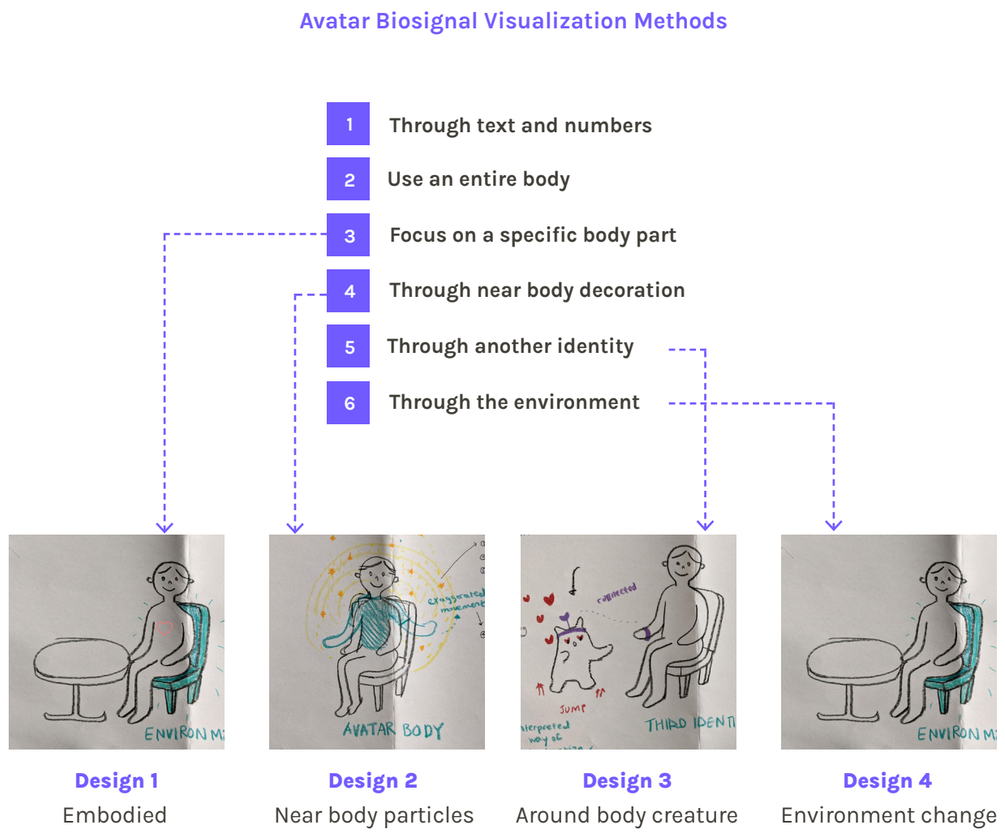


Figure 27. Biosignal Visualization Types

4. PROTOTYPING

The chapter 4 introduces the technical setup and the final design prototypes of both the VR environment and the biosignal visualization. In addition, it explains how each of design decisions were made.

4.1 Technical Setup

Platform

Unity version 2020.3.3f1 (Figure 28) was used to create the VR jazz bar and biosignal visualization prototypes. Universal Render Pipeline, a prebuilt Scriptable Render Pipeline, had to be adopted instead of Unity's built-in renderer to use the Shader graph function for building desired visualization effects.

Figure 28. Unity

Device

HTC Vive Pro Eye model (Figure 29) was used for the prototype development stage.

Figure 29. HTC Vive Pro Eye setup

Modeling

All the 3D avatars and models for the biosignal visualization were built with a 3D modeling tool called Blender (Figure 30). **Blender** is a free, open-source 3D creation program that has plenty of free online tutorials.

Some of the 3D models for building the jazz bar environment were sourced from **Sketchfab**, which is an online platform where the 3D creators can upload, share and sell their 3D artworks.

Rigged avatar animations were downloaded from **Adobe Mixamo**, an online database of 3D characters and animations.

Figure 30. Programs used for modeling

4.2. Environment Design

Building an aesthetically appealing environment was a must in addition to visualizing the biosignals. For users to feel the real jazz band vibe when testing the prototype, the jazz bar environment and the biosignal visualizations had to look harmonious. Thus, all the jazz bar elements were carefully designed to create a purposed effect and to prevent the mismatch among them.

4.2.1 Atmosphere

Bar Setting

The jazz bar consists of a stage, six tables, twelve chairs, and extra ornaments. The stage is for the jazz band performance, five tables are for the crowd, and one table is for the user who will be sitting within the VR (Figure 31). With the current setup, the user can see his companion, the crowd, and the jazz band in one view.

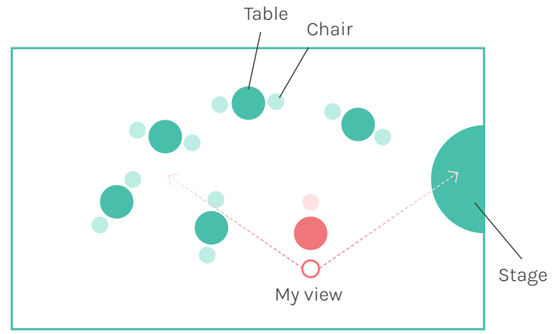


Figure 31. Jazz bar top view

Western Saloon model from Sketchfab worked as a rudimentary frame for building the overall jazz bar setup.

Lighting

Two light brown point lights were attached to the chandeliers on the ceiling to create a dark and dim atmosphere. The use of lighting played a major role in creating a jazz bar atmosphere (Figure 32, 33).

Figure 32. Jazz bar environment (without light setup)

Figure 33. Jazz bar environment (with light setup)

4.2.2 Audience and the Jazz Band

Audience

Avatar models were built in Blender (Figure 34); hairstyle and the color of the clothes were varied for each avatar so that it prevents a copy-and-paste feeling. All the avatar models were rigged with the auto-rigging function in Mixamo. 'Sitting Idle' animation (from Mixamo, Figure 35) was applied to the rigged avatars so that they can bring them lives in the jazz bar (Figure 36).

Band performers

For the jazz band on the stage, four avatar models were built with Blender, and instrument models (Bass, Guitar, Piano, Drum) were sourced from Sketchfab. 'Playing Drums', 'Guitar Playing' and 'Piano Playing' animations were downloaded and applied to the matching rigged avatar. Body parts of the avatar were repositioned so that they are appropriately linked to each instrument with the help of the Animation Rigging Package from the Unity Asset Store (Figure 37, 38).

Modeling Process

Figure 34. Avatar modeling in Blender

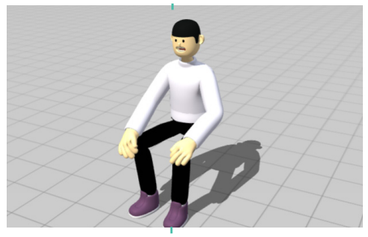


Figure 35. Sitting Idle animation

Figure 36. Jazz bar crowds

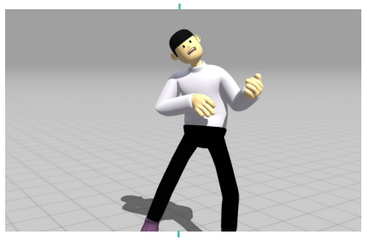


Figure 37. Guitar Playing animation

Figure 38. Jazz band

Music

'A Brand New Start' - Genre: Jazz & Blues; Mood: Happy - was selected as the music that the live band is performing to add a reality to the jazz bar; the soundtrack was downloaded from the free music list of the Youtube Audio library. The soundtrack file was attached to an empty game object and placed in the middle of the stage so that it can create a spatial sound effect that the sound is coming from the jazz band.

Stage

Stage curtain and stage light models were downloaded from Sketchfab; the size and materials of the models were modified to create the desired stage atmosphere (Figure 37, 38).

One white and one yellow spotlight were placed in the front part of the stage; four blue and two red spotlights were placed in the back part of the stage.

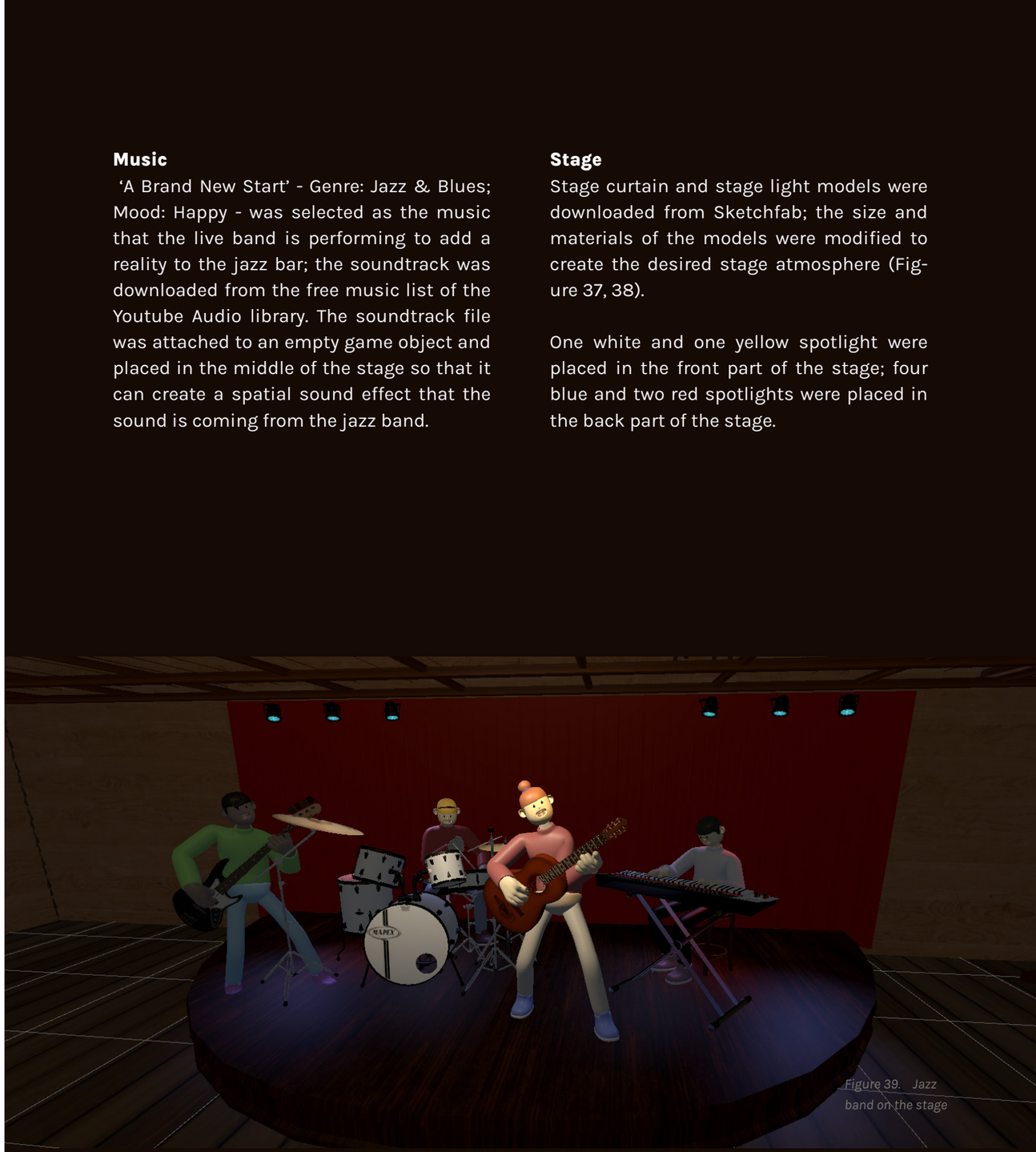


Figure 39. Jazz band on the stage

Figure 40. Jazz band on the stage (back)

4.3 Biosignal Visualization Design

4.3.1 Biosignal implementation

Toolkit for biosignal generation

The biosignal data with the desired duration, noise, and rate was artificially generated with **NeuroKit2,** a Python Toolbox for Neurophysiolocial Signal Processing.

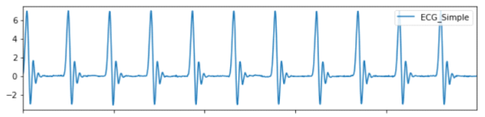


Figure 41. Cardiac Activity (EGC) (duration = 10, simple)

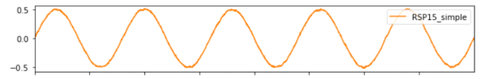


Figure 42. Respiration (RSP) (duration = 20, rate = 15, simple)

Choice of Biosignals

Heart rate and breathing rate were selected for the final user study. Electrodermal Activity (EDA) was neglected after the co-design session as it was claimed to be an ambiguous signal under the jazz bar setup.

Heart rate (ECG) and breathing rate (RSP) show different characteristics in the graph. Figure 41 and 42 are examples of heart rate (cardiac activity, EGC) and breathing rate (respiration, RSP), both of which were generated with Neurokit. Heart rate has a clear peak in one cycle whereas the breathing rate rather shows a gradual wave graph. These characteristics had resulted in a need for taking a different approach while visualizing signals in Unity, even under the same design concept. The details will be explained further under the design concept description.

Use of Biosignal data in Unity

The artificially generated biosignals were saved as CSV and put under the Resources folder in Unity. A total of six biosignals (High, Rest, and Low arousal for heart rate and breathing rate) was saved into one CSV file. Each column was then saved into a separate array and called when needed for biosignal animation.

Generated Biosignals Info

- Duration: 24 seconds
- Sampling rate: 1000 (default)
- Heart rate (bpm): High - 150, Rest - 100, Low - 50
- Breathing rate (bpm): High - 21, Rest - 14, Low - 7

```
rsp7 = nk.rsp_simulate(duration = 24, respiratory_rate=7, method = "sinusoidal")
rsp14 = nk.rsp_simulate(duration = 24, respiratory_rate=14, method = "sinusoidal")
rsp21 = nk.rsp_simulate(duration = 24, respiratory_rate=21, method = "sinusoidal")

ecg50 = nk.ecg_simulate(duration=24, method="simple", heart_rate=50)
ecg100 = nk.ecg_simulate(duration=24, method="simple", heart_rate=100)
ecg150 = nk.ecg_simulate(duration=24, method="simple", heart_rate=150)
```

Figure 43. Codes to generate the six biosignal dataset

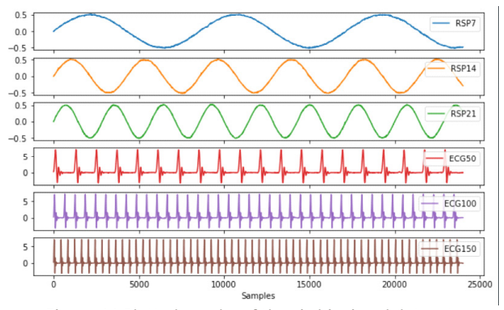


Figure 44. Plotted graphs of the six biosignal dataset

4.3.2 Design implementation

Biosignal Visualization Design

Design 1: Embodied

The first concept adopts a familiar biosignal representation method with a symbolic and straightforward design (Figure 45, 46). The embodied icon was set as a standard point among the four different biosignal visualization methods. A 3D heart icon and breath bubble icon were built with Blender.

- Both for the heart rate and breathing rate, the biosignal data were mapped to the size of the embodied icon.

Figure 45. Embodied heart rate visualization

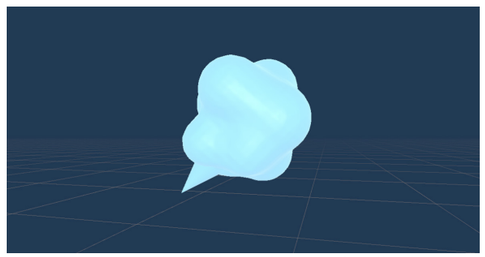


Figure 46. Embodied breathing rate visualization

Design 2: Near body particles

The second concept is to represent biosignals through particles near the avatar body (Figure 47, 48). The amount, color, spiral shape, and frequency of particle emissions were controlled to transmit the intended biosignal data into particles. The Particle System from Unity was used to implement near-body particle effects.

- For heart rate, particles gave a burst when the heart rate reached its peak from one EGC cycle. The number of particles for one burst was adjusted for different arousal levels.
- For breathing rate, a bundle of the particles was visualized into a sine graph of respiration. The start speed and amount of particles were controlled so that the sum of the particles on the scene is maintained.

Figure 47. Near body particle heart rate visualization

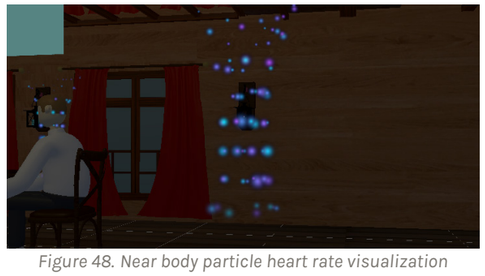


Figure 48. Near body particle heart rate visualization

Design 3: Moving creature

The third concept is a third-party identity that carries the biosignals of the main avatar (Figure 49, 50). One of the ideation sketches from the co-design session was chosen for the prototype. A cat-like, moving creature was built in Blender. 'Idle' and 'Walk in Circle' animations were applied to bring the creature to life.

- Both for the heart rate and breathing rate, the biosignal data were mapped to the emission intensity of the material applied to the moving creature.

Figure 49. Moving creature heart rate visualization

Figure 50. Moving creature breathing rate visualization

Design 4: Environment change

The fourth concept is using the surroundings when expressing the biosignals of the avatar (Figure 51, 52). As the environment is case-dependent, appropriate elements had to be selected to apply this concept; tables and chairs where the avatars sit were chosen under the jazz bar scenario. A new material shader with an emission effect was applied to the rim of the table and the head of the chair, which originally was assigned a dull wooden texture; it was the same material shaders that applied to the 'Moving creature'.

- Both for the heart rate and breathing rate, the biosignal data were mapped to the emission intensity of the material applied to the table and chair.

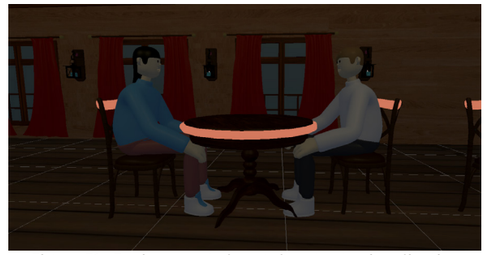


Figure 51. Environment change heart rate visualization

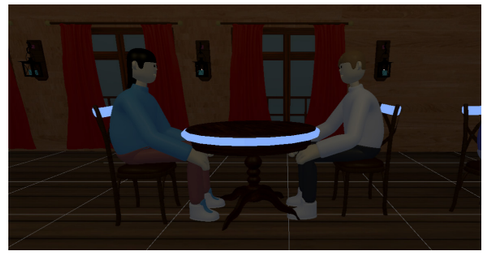


Figure 52. Environment change breathing rate visualization

Color of the biosignal visualization

Choice of color: Red and Blue

Color is one of the critical factors that can alter the cognitive experiences of the viewers. Colors have three main components - hue, brightness, and saturation - that determine the characteristics. Bright colors tend to be associated with high valence and low arousal, while saturated colors tend to be more arousing than unsaturated colors. In terms of the hue, the different wavelength of the color contributes to how pleasant it is; wavelengths between 475 and 525 (purple to green) are the most pleasant, followed by wavelengths above 585 (yellow to red), whereas the wavelength between 565 and 575 (green to yellow) is the least pleasant (Valdez & Mehrabian, 1994).

There is yet no research on the direct mapping between the biosignals and the hue of colors. Furthermore, there are already multiple independent variables - biosignal type, arousal level, design - to control. Thus, the most representative hue was assigned for each biosignal; red for heart rate and blue for breathing rate. Brightness and saturation were controlled as similarly as possible for four different biosignal visualization so that can minimize the undesired variant in perceived arousal level. In addition, these fall into the colorblind-friendly combination.

Shader graph

Shader graph function in Unity was used to define the material of prototypes (around body creature and environment change) (Figure 53, 54). It allowed changing the emission level of the prototype materials fluently according to the biosignal data within the color ranges for red and blue respectively.

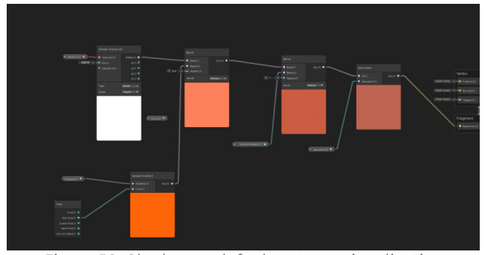
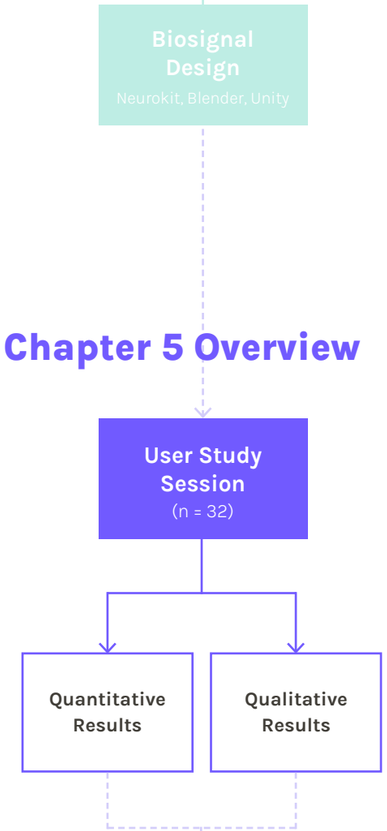


Figure 53. Shader graph for heart rate visualization

Figure 54. Shader graph for breathing rate visualization

Figure 55. Final biosignal visualizations overview



5. EVALUATION

The chapter 5 presents the detailed process of the user study session, evaluating the effects of the final prototypes built in chapter 4. The results will be analyzed into quantitiative and qualitative data.

5.1 User Study Session

The user study was conducted to test and compare the effect of different biosignal visualization methods in the VR jazz bar environment.

Method

Each session was designed as a 1-hour experiment that consists of questionnaires and a Focus group. Two participants were invited to one session in a spacious room with two VR setups (Figure 56). No prior task was asked of the participants before the session. The experiment was conducted for five consecutive days in the common room of the International Student House in Delft.

Participants

The participants were recruited through multiple advertisement methods. A Notion page with experiment information was posted on social media (Whatsapp groups; Facebook community). Additionally, a one-page flyer was posted in the student house building with a QR code that directs to the Notion page. There was no specific requirement for the participants except for the safety rules regarding the Covid-19 situation. Participants were asked to sign up for the experiment only if they do not have any symptoms (e.g., cough, fever, etc). They were compensated with 10 euro gift vouchers (VVV) right after the session. One-third of the participants signed up for the test either on-site being interested or through word of mouth of the previous participants, as the experiment was set up in the common room right next to the student house building.

Overall, 32 participants were recruited; with the age range of 19-37 (Mean 26.66); 18 women, 13 men, and 1 non-binary; 23 students (either Bachelor or Master's), 4 researchers, 3 designers, 1 architect, and 1 research assistant; 29 participants reported they have tried VR at least once; 7 participants reported they have tried social VR platforms at least once.

Setup

Two participants were seated facing each other with their own VR headset for the within-VR tests (Figure 57), even if some of the test was an individual task.

Figure 56. Room setup

Figure 57. Two sat participants during the test

Basic VR jazz bar prototypes developed in the previous chapter were adjusted into two different experiment-specific settings. These two identical files were each installed in two VR-capable devices before running the test.

Unity File 1: Jazz bar with questionnaire setup

The participant avatar sat in front of a companion at the same table (Figure 59). The Likert-scale questionnaires were presented in front of the participant (Figure 58). The within-VR questionnaire template was sourced from VR Questionnaire Toolkit (https://github.com/MartinFk/VRQuestionnaireToolkit); C# scripts and JSON files were adjusted so that Unity scenes present different biosignal visualizations settings based on the scene number on the questionnaire panel.

Participants were able to rate the Likert scale of the questionnaires within the VR environment with one button of the VR handle.

Unity File 2: Jazz bar Focus group setup

Two participant avatars and one researcher avatar were sitting at the same table in the VR jazz bar (Figure 60, 62). The jazz band was still present but the music was off. On the opposite side of the jazz band, four avatars with four different biosignal visualization methods were presented (Figure 61). These were to help the participants referencing the biosignal visualization designs during the Focus group interview. **Photon Unity Networking 2** (PUN 2), a Unity package for multiplayer games, was used for networking between two Unity files.

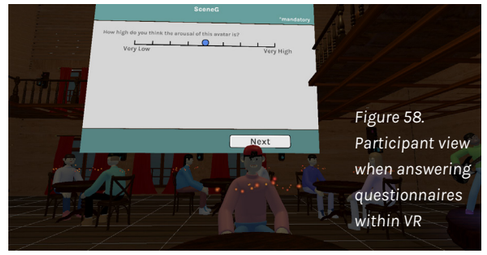


Figure 58. Participant view when answering questionnaires within VR

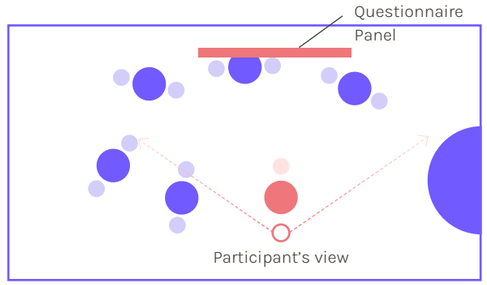


Figure 59. Questionnaire setup top view

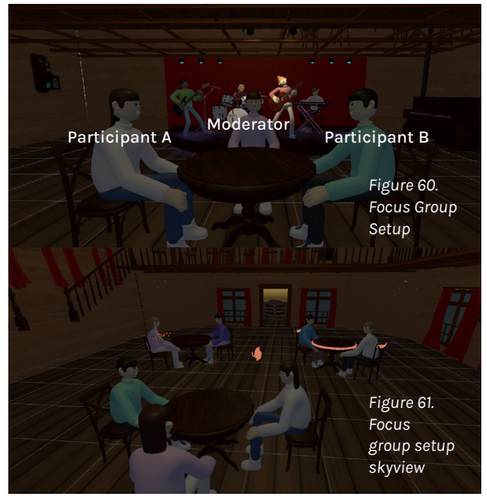


Figure 60. Focus Group Setup

Figure 61. Focus group setup skyview

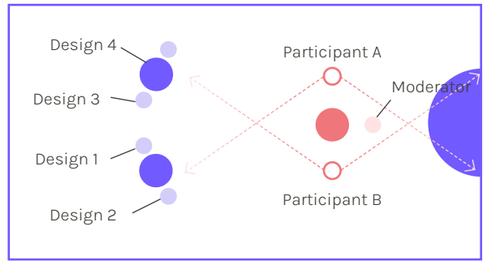


Figure 62. Focus group setup top view

Procedure

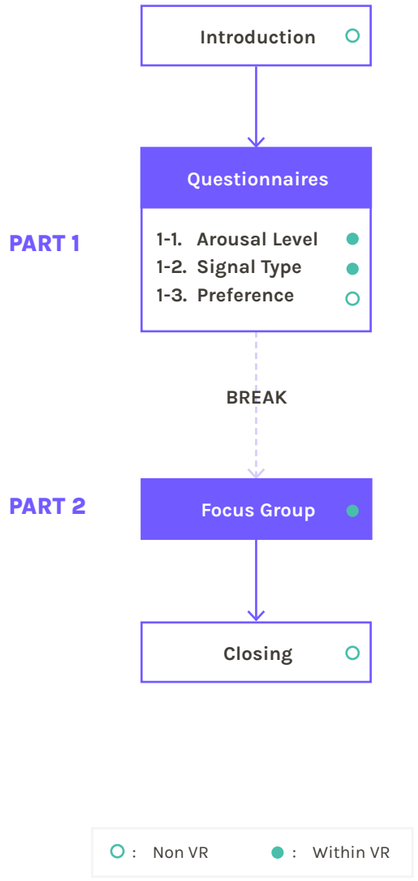


Figure 63. User study procedure

Introduction

Participants filled in a consent form and a general information form (Appendix G). After completing the forms, participants were told the background and goal of the research. A one-page participant manual helped them grasp the overview of the research and see what to expect in the VR space. The manual can be found in Appendix. The participants moved to the designated seats for VR experience and wore VR headsets.

Part 1. Questionnaires

Three independent variables (IVs) were controlled for the questionnaire setup (Table 6).

IV1: Visualization Type (n = 4)	Embodied Around-body particles Moving creature Environment change
IV2: Biosignal Type (n = 2)	Heart rate Breathing rate
IV3: Biosignal Rate (n = 3)	Low Rest High

Table 6. Independent variables (IVs)

The questionnaire consisted of three parts: 1-1) Arousal Level Questions, 1-2) Signal Type Questions, 1-3) Preference Questions.

Part 1-1 and 1-2 took place within-VR jazz bar space. All the questions were in 9 points Likert-scale format. The gender of the companion avatar in VR was also evenly distributed; the woman and man avatar characters were presented in consecutive order to prevent gender bias.

Part 1-3 took place outside of VR, via Google form, as it was not necessary. Instead, gif images of each biosignal visualization were provided as a visual aid.

1-1 Arousal Level Questions

Participants guessed and rated the arousal level of the avatar for each scene (Figure 64). 24 scenes was presented in a randomized order (IV1 x IV2 x IV3 = 4 x 2 x 3 = 24 conditions).

Q1) How high do you think the arousal of this avatar is? (Very Low: 0 === Very High: 8)

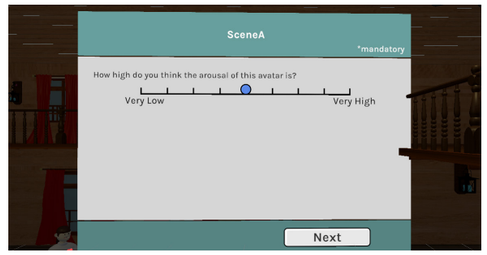


Figure 64. Part 1-1 Question form

1-2 Signal Type Questions

Participants rated each biosignal visualization design for its suitability (Figure 65). 8 scenes were presented in a randomized order (IV1 x IV2 = 4 x 2 = 8 conditions). IV3 was not considered and set to 'Rest' arousal level.

Q1) Is this visualization more suitable for showing someone's heart rate or for breathing? (Heart Rate: 0 --- Breathing Rate: 8)

Q2) I find this visualization distracting. (Strongly Disagree: 0 --- Strongly Agree: 8)

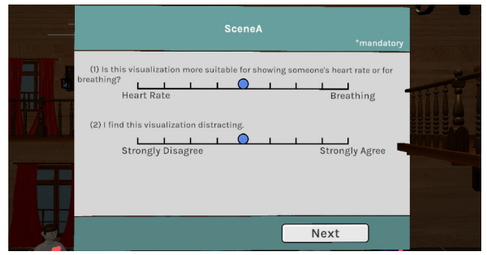


Figure 65. Part 1-2 Question form

1-3 Preference Questions

Participants voted for their favorite visualization for showing the heart rate and breathing rate of a companion (Figure 66). 8 scenes were presented. (IV1 x IV2 = 4 x 2 = 8 conditions) IV3 was not considered and set to 'Rest' arousal level.

Q1) My favorite visualization for showing heart rate on a companion is: (1. Embodied, 2: Near-body particles, 3. Moving creatures, 4. Environment change)

Q2) My favorite visualization for showing breathing rate on a companion is: (1. Embodied, 2: Near-body particles, 3. Moving creatures, 4. Environment change)

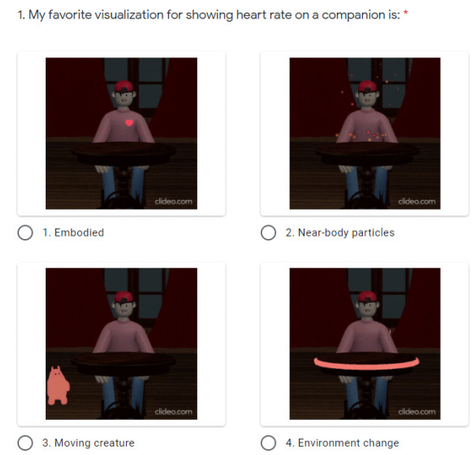


Figure 66. Part 1-3 Question form

Part 2. Focus Group

After a break, participants were invited to the VR jazz bar focus group setup (Unity file 2). The gender of the avatar representation in the VR environment matched the physical gender of each participant. The Focus group was a semi-structured interview with a prepared question list. Participants gave reasoning to Part 1 questionnaire answers and discussed topics including the added value, limitation, privacy issues, application of biosignal visualization.

Closing

Participants filled in Igroup Presence Questionnaire (IPQ) (Schubert et al., 2001) form to rate the sense of presence experienced in a virtual environment. 10 euro voucher cards were given as compensation at the end of the session.

Data Collection

- **Before**: consent forms and participant general information forms were collected manually before the test.
- **During**: answers to the Arousal Level Question (1-1) and Signal Type Question (1-2) were saved into CSV file; answers to the Preference Question (1-3) were saved into Google sheet; entire Focus Group essions were recorded and some footages were taken during the sessions.
- **After**: answers to the IPQ (Igroup Presence Questionnaire) were saved into Google sheet.

5.2 Quantitative Results

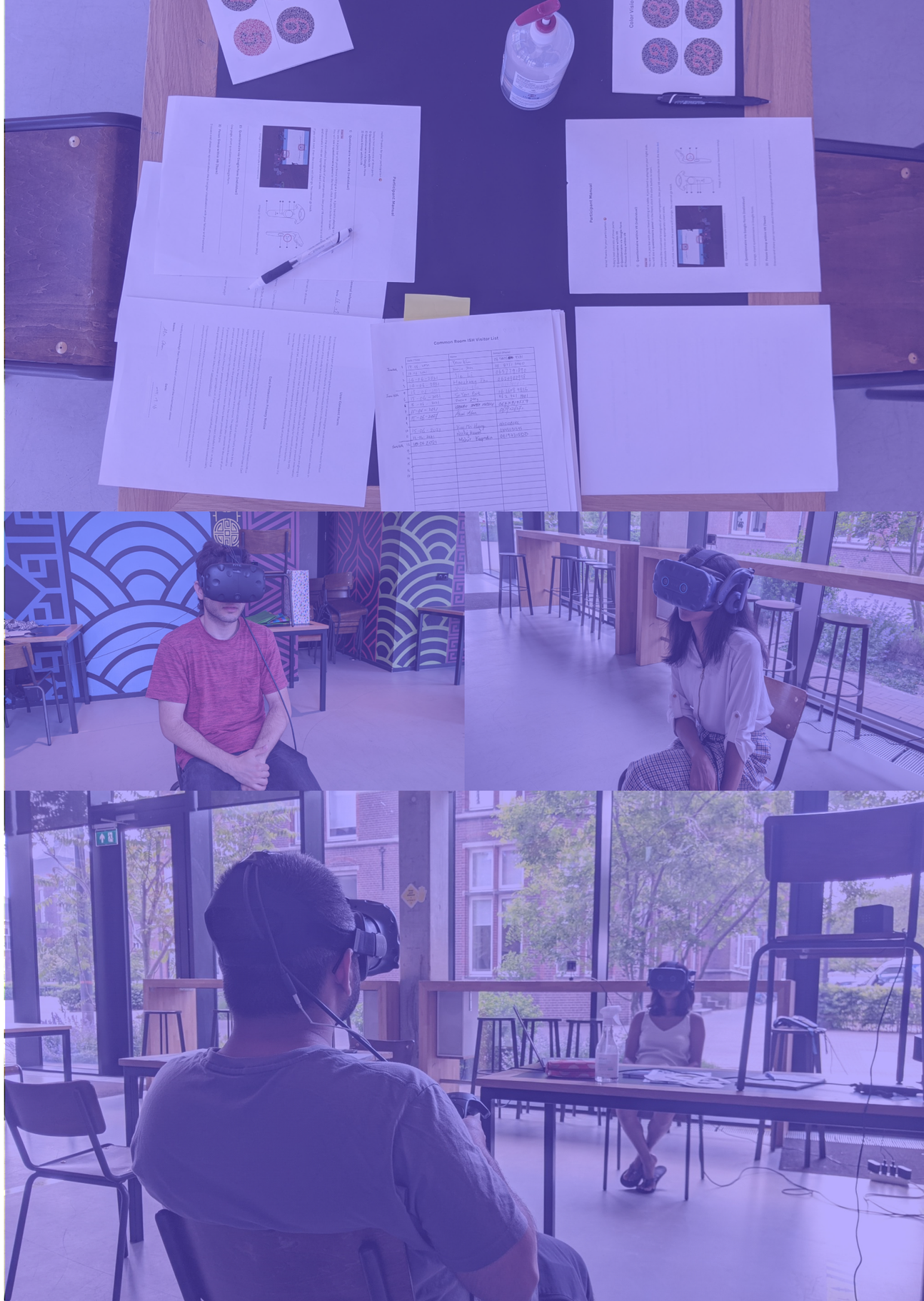
This part shows the quantitative result obtained from the user study: IPQ score and Part 1 questionnaire results.

Igroup Presence Questionnaire (IPQ)

Table X shows the result of the Igroup Presence Questionnaire. IPQ had a 7-point Likert-type scale, ranging from - 3 to 3. IPQ general presence and three subscales (spatial presence, involvement, and realism) were calculated in mean and standard deviations. The created jazz bar environment gave a degree of general presence (m = 1.313), while it provided a low level of realism experience (m = -0.508).

Subscale	Mean	SD
G = sense of being there	1.313	1.091
SP = spatial presence	0.994	1.464
INV = involvement	0.305	1.575
REAL = experienced realism	-0.508	1.602

Table 7. IPQ subscale results



Transmitting the Biosignal: Interpreted Arousal Level

The arousal level of the biosignals was measured on 9 points Likert scale (left: very low, right: very high); the values were later mapped from 1 to 9 for the analysis (1: very low, 5: rest, 9: very high).

As shown in Figure 67, participants were able to distinguish three arousal levels (low, rest, and high) for Embodied and Near-body particles visualizations; however, the difference in arousal rating is unclear for two others.

As shown in Figure 68, participants were able to distinguish three arousal levels for Embodied visualization. Participants rated all three the same degree of arousal for Near-body particles visualization. The result for the rest shows no pattern.

Comparing the heart rate (Figure 67) and the breathing rate (Figure 68), it is clear that participants interpreted the arousal level of the heart rate much higher than that of the breathing rate.

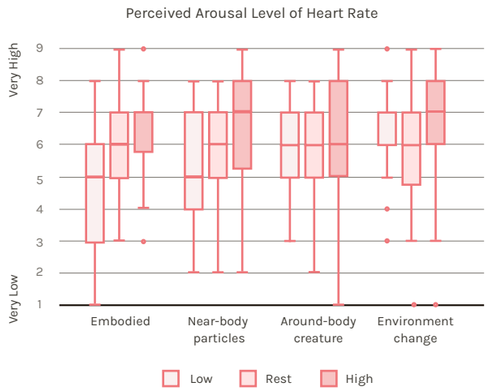


Figure 67. Arousal level of the heart rate visualizations

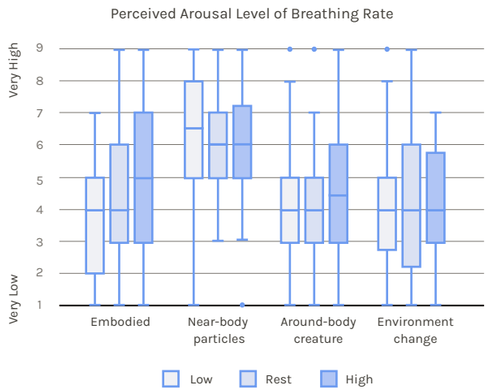


Figure 68. Arousal Level of the breathing rate visualizations

Suitability of Signal Type

The suitability of visualization for either heart rate or breathing rate was measured on 9 points Likert scale (left: heart rate, right: breathing rate); the values were later mapped from 1 to 9 for the analysis (1: heart rate, 9: breathing rate).

As shown in Figure 69, participants interpreted visualized biosignals for all designs as intended types; heart rate as heart rate and breathing rate as breathing rate.

Participants were highly confident in rating signal types for the Embodied visualization, for both heart rate (median: 1) and breathing rate (median: 9). Participants were least confident in rating signal types for the Near-body particles visualization, especially for the heart rate (median: 5).

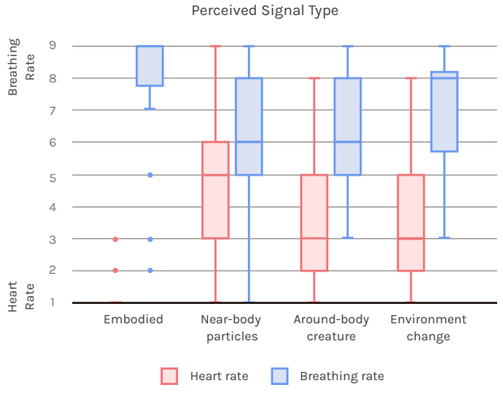


Figure 69. Suitability of signal type

Degree of Distraction

The degree of distractions of each visualization method was measured on 9 points Likert scale (left: strongly disagree, right: strongly agree); the values were later mapped from 1 to 9 for the analysis (1: strongly disagree, 9: strongly agree).

As shown in Figure 70, participants felt the Embodied visualization the least distracting (median: 2.5) and the Around-body creature the most distracting (median: 6) for the heart rate visualization. For the breathing rate visualization, Environment change (median: 4) was the least distracting followed by Embodied (median: 4); Near-body particles (median: 6) were the most distracting one.

Regardless of signal types, participants felt the least distraction from Embodied visualization and most distraction from Around-body creature visualization.

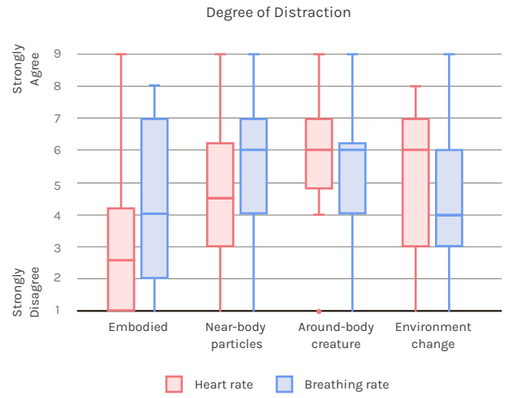


Figure 70. Degree of distraction

Favorite Visualization Method

The favorite visualization method for showing heart rate and breathing rate on companions was voted as a multiple-choice (single answer) question (Figure 71, Table 8).

Embodied (84.4%) visualization technique was the clear winner for showing heart rate; it was followed by Around-body creature (9.4%), Near-body particles (3.1%), and Environment change (3.1%).

For breathing rate, Embodied (37.5%) and Environment change (34.4%) were more preferable visualizations; Near-body particles (18.8%) and Around-body creature (9.4%) were less preferable visualizations.

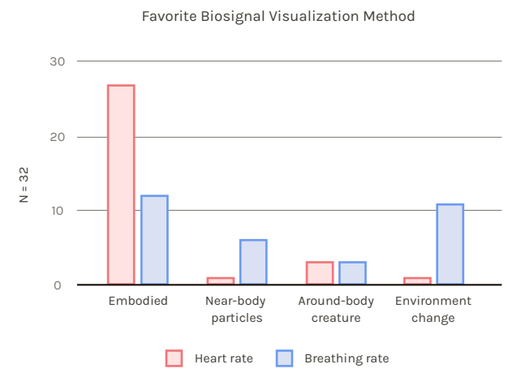


Figure 71. Favorite visualization method

	Embodied	Near-body particles	Near-body particles	Environment change
Heart rate	27	1	3	1
Breathing rate	12	6	3	11

Table 8. Favorite visualization method

5.3 Qualitative Results

This part covers the qualitative results obtained from the user study during the Focus group session. Firstly will be focusing on the current design methods presented in this research and then will extend the discussion to the biosignal visualization as a whole (Figure 72).

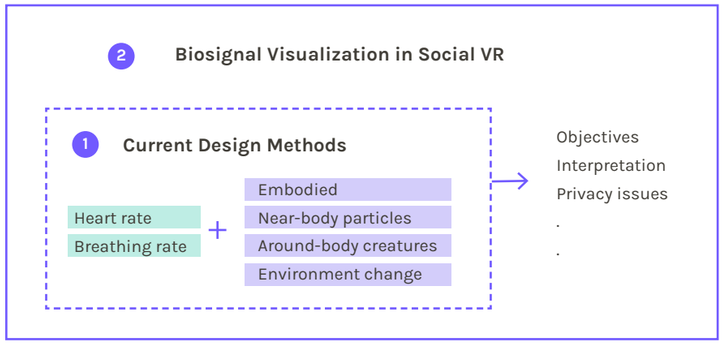


Figure 72. Qualitative results overview

5.3.1 Current Design Methods

Comparing the Four Biosignal Visualization Methods

Participants shared their impressions on four biosignal visualizations methods; the answers cover the reason for selecting their favorite visualization methods and the advantages and disadvantages of each biosignal visualization.

Method 1: Embodied

Participants complimented embodied design for its familiarity and intuitiveness among all. As the visualizations were iconic and familiar than the others, it took less time and effort for participants to perceive the meaning. They were able to interpret the visualizations right away by the speed and the size change of the visualization. Some mentioned that embodied ones are the least distracting, therefore they will be able to focus on the conversation even with the visualizations in the front.

*22: because I think if I'm in front of someone, then **I want to focus on a conversation**. So that was the most direct one and takes me less effort to understand.*

For heart rate, embodied visualization was chosen as a favorite visualization because it was the easiest to understand and least distracting one, even if it may be considered less creative and traditional.

3: but I think I still prefer the traditional heartbeat. That was maybe less creative but it's quite straightforward.

For breathing rate, embodied visualization was still intuitive and easily associated with breath; however, one mentioned that it was not very comfortable because the breathing rate is relatively slower than the heart rate, and the slow rate of bubble size change became a distraction as a result. Another mentioned that the breath bubble design was negative since it reminded her of a sigh - with a negative connotation.

21: The embodied symbol of breathing was not very comfortable; because the breathing is very slow so you get distracted.

Method 2: Near-body Particles

Near-body particle visualization gave an aura or overall feeling atmosphere to participants. However, the majority commented that it was confusing, distracting as it is surrounding the person, and it is hard to associate with breath or heart rate.

12: The particle ones are cool, but it's unclear for me. It's hard to notice its speed change. And it's surrounding the person I'm talking to, so it will be a little bit distracting.

For heart rate, one mentioned that she liked the near-body particles as they gave a 'firey' feeling and she could imagine the glowing use case in the concert scenario.

28: I could totally see, for example, in the concert, it's glowing up

For breathing rate, some mentioned that the particle-going-up animation was a nice indication for breathing; it was also mentioned that the particles were more aesthetic compared to other visualization methods.

31: Because it is more aesthetic. I think it conveys better than the other icons.

Method 3: Around-body Creature

Participants mentioned that the around-body creature was too cute, thus distracted their experiences in the VR jazz bar. Many participants regarded the around-body creatures as separate identities due to the distance between the creatures and the avatar; thus, it created a general atmosphere instead of representing one person. Some of the design elements of the Around-body creature often resulted in misinterpretation and confusion to the participants.

3: It was difficult for me to associate the animal with a specific person because they were quite distant.

For heart rate, one mentioned that the ambiguity of the Around-body creature was merit for representing the biosignal, as it is not directly related to her.

28: I liked the character showing the heartbeat because it's not really directly related to me. So I felt like it's less shameful.

Method 4: Environment Change

Environment change visualization was suitable for affecting the atmosphere of the room, instead of showing the feeling of one person. Participants liked the fact that they can choose to look at it or not since it is located on the side of the table; one mentioned that she preferred the environment change as it has a subtleness as an interior design but still can catch the eyes.

26: Because you can look at it and not look at it both. So that was really good for me because I was comparing the same experience with what happens in real life.

Participants liked the environment change to indicate breathing rate because it was organic, calming, soothing, and a nice indication of breathing.

27: I liked that it seemed more soothing and not so jarring. I kind of like the lights just switching, dimming, lighting up - that was a nice indication of breathing.

5.3.2 Biosignal Visualization in Social VR

Objectives of the Biosignal Visualization

It was found that there were three categories of intrinsic motivation that people had from sharing biosignal visualizations in Social VR spaces (Figure 73).

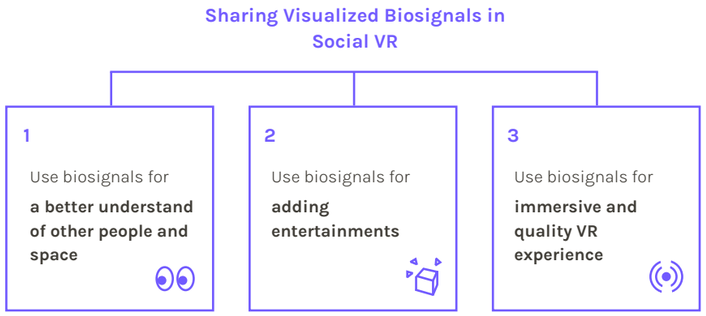


Figure 73. Objectives of sharing visualized biosignals in Social VR

1 Use Biosignals for a Better Understand of Other People and Space

Participants desired to use visualized biosignals to understand the people they meet and the space they are present.

Firstly, a number of participants (P0, 8, 12, 13, 25, 29, 31) noted that they want to know the emotions of the others through the biosignals to understand them better. Knowing the accurate biosignal data was not important for them, if the biosignals are not able to tell the emotions of the others.

P12: " So if these data cannot let me understand their emotion, then it will just be an extra information for me."

Even if it is not emotion, participants (P1, 13, 14, 18, 30) wanted to reveal something out of the biosignals to make it useful, instead of getting the raw signal data.

P11: "I just don't know how the heart rate and breathing rate are the ones to focus on, if you really want to make it actually useful."

Some participants (P4, 18, 31) claimed that they only care about their friends' or families' biosignals but not the stranger's. It is because they use biosignals as indicators of other's feelings or states so that stranger's biosignal data become noise to them.

P11: "For example, if you step into the room, you don't know anybody, but you want to know what is happening, right? You want to know and can act accordingly."

Additionally, visualized biosignals can help people see the general vibe or mood of the space (P11, P30); it acts as an indicator of the mood of the space, thus users can act accordingly.

P11: "For example, if you step into the room, you don't know anybody, but you want to know what is happening, right? You want to know and can act accordingly."

2 Use Biosignals for Adding Entertainments

Having visualized biosignals in the Social VR space could act as an entertainment factor.

Firstly, some participants (P3, 8, 9) mentioned that visualized biosignals on the avatar could work as an icebreaker. Biosignals themselves could be something to comment on to start the conversation (P8, 9). P3 even suggested that customizing the biosignal visualization method under the set of basic rules could make the space more colorful and let people start a conversation by commenting on the unique avatar.

P8: "In an actual bar, I wouldn't usually go up to a stranger and start conversation. But if I see his or her heart rate going up and down, I might go and make comments"

P3: "I see your little animal, where did you get it? How can he represent you?"

Visualized biosignals could keep participants entertained as a background effect to the monotonous VR environment (P3, 14, 16, 18, 23). In this case, participants are focused on other interactions, for example, in the conversation with others. The biosignals are not of their major interests, however, still serve as side entertainment.

P3: "Yes, I'm focused on the person I'm interacting with. So the other people, I can leave their signals on. Just keep my curiosity there, right."

P18 "VR chats, after a certain point, it can become a bit monotonous. And this can make the VR experience a bit better."

Under this objective, few participants (P0, P1) even claimed that they would rather be curious about and look at the biosignals of the strangers instead of someone they know.

P0 "it would be more interesting to look at a person who I met for the first time."

3 Use Biosignals for Immersive VR Experience

Biosignal visualizations can make the VR experience more immersive by adding reality or setting another layer of experience to the current atmosphere.

Some participants (P0, 2, 16) marked that the visualizations of the biosignals give them a more real-person feeling compared to when there is only an avatar, which has not much difference between the computer character.

P16: "I feel like I'm in the video games but not in a real conversation. But if you show a heartbeat or a breathing, even though it's avatar, i feel like more connected. "

On the other hand, some (P0, 31) suggested that the biosignal visualizations in a crowded setting, for example, at the concert, will contribute to setting the atmosphere of the environment; even if the data is not accurate, metaphorically showing data of what people feel or the excited states can add something more to the experience.

P31: " If we are at a concert, if I can see everybody's biosignal, and it could contribute to the atmosphere."

While most of the people commented on perceiving others' biosignals, few mentioned that they are willing to see their own biosignal (P4, 10); one even focused on the 'sharing' part. P4 said that sharing the visualized data simultaneously in the concert-like atmosphere would help him elicit emotions.

P4: "Visualizing the biodata and sharing it with others simultaneously would help elicit my emotion."

Elements affecting the Biosignal Interpretation

For most cases, participants interpreted the signals correctly from speed and light emission changes; however, some mentioned they were confused when interpreting the biosignals and shared the elements they took into account when rating the arousal level (Figure 74).

Figure 74. Interpretation of visualized biosignals

Color

Color influenced the interpreted arousal level of each scene. Participants often linked red to 'warm' 'high arousal' 'hot' and blue to 'calming' 'low arousal' 'cold'; on the other hand, one mentioned that she associated her personal preference of color to the rating of arousal level since she was excited when seeing her favorite color.

P28: "Sort of inherently blue is a calming color and red is a very arousing color. That was the most difficult for me to differentiate because every breath felt more calming while every red color felt more aroused."

Design Elements

Some design elements confused the participants interpreting the biosignals from the visualizations. For example, for Near-body creatures, participants tried to take all the components (e.g., walking direction, movement, etc) into account when guessing the arousal level; however, those elements were only part of the design element and were not related to any biosignal.

P23: "But also for the creature, it was confusing when the creature started to move."

Environment (Music)

Occasionally, participants had taken the music from the jazz band into account when they rated the arousal level. The jazz band music was for creating the jazz bar atmosphere only and had no association with the biosignal visualization at all; however, some participants mentioned that the music influenced the rate of biosignals or the other way around.

P7: "Coordinating with music, as well as the beat, the intensity of the light increases."

Aspects of Breathing

Only the speed (heart rate - bpm, breathing - Hz) of the biosignals were the variables for the arousal level; however, a few participants additionally tried to consider the depth of the breathing when guessing the arousal level. Moreover, one cycle of the breathing rate is gradual and much slower, thus less manifest compared to that of heart rate, which has a clear peak. As a result, it was harder to perceive when merged with other design elements.

P20: "For example, breathing could be slower than the heart rate is. It could be heavy, but at a slower rate, and both could potentially indicate higher arousal."

Privacy Issues: Sharing Visualized Biosignals

Participants shared their standpoints on sharing biosignals based on their experiences. Few participants claimed that they don't mind privacy issues; however, the majority mentioned conditions or concerns about sharing biosignals on social VR.

Conditions on Sharing Biosignals

The capability of being fully aware of and having **control** over sharing biosignal was an important issue for some participants (P3, 4, 6, 31). There was no further problem if those are satisfied.

P3: "Just give me the option to turn it on and off. "

P31: "Yeah, if they have agreed to share their data, then it shouldn't be a problem."

For some participants (P3, 6, 8, 30), it was highly **dependant on the scenario and people.** The acceptable degree of sharing biosignals varied according to the cases - e.g., conference, cinema, - or the relationship to the opponent - e.g., friend, stranger.

P11: "I am okay with sharing my data with that person who I know. But not everyone in the room."

Some participants (P16, 27) claimed that **heart rate and breathing rate are acceptable**. Unlike other biodata - for example, brain activity, retina -, they are already explicit and readable from outside; thus, it doesn't intrude on someone's privacy even if collected.

P16: "It's not really important for breathing. For example, if VR takes our retina, then that's the problem. But if you want to know my heartbeat, just take it."

One mentioned (P15) that the **current design is acceptable** due to its abstract level. The designs were filtered to certain extent even if the most direct one (embodied). It didn't matter as long as the visualization show the exact biosignal rate numbers.

P15: "You don't see the exact number, it doesn't say 96 or so."

Concerns on Sharing Biosignals

Participants (P1, 10, 14, 15, 22, 30) wanted to avoid too much transparency by sharing actual feelings, such as revealing innermost feelings or being caught in a lie. It may be critical in professional scenarios - e.g., business meetings. Some were willing to add the noise purposefully to the raw biosignal data.

P1: "I'm a bit worried, I may lie while I talk to people."

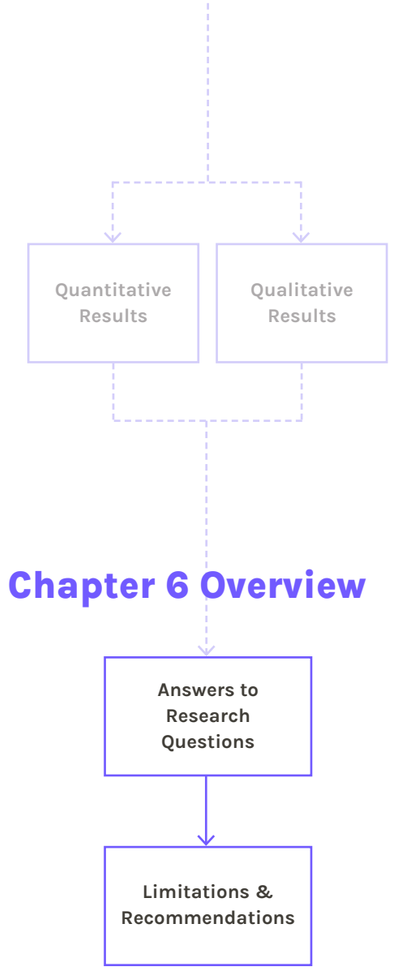
P22: "Maybe I can show 80 percent of real data and the other 20 are fake data so that I can hide something."

However, at the same time, participants (P11, 14) wanted to see other people's biosignal visualization while it may not be fair; they only want to receive other's info and hide their own.

P14: "I don't know if I want them to know what I'm actually feeling. But I would love to know what they are feeling."

One (P30) brought an issue that biosignal may provide additional factors to judge a person in addition to the currently available private details, including name, age, occupation, etc.

P30: "When you become an avatar, and you try to share your private details like name, age, occupation, which are the ones how people can judge you, but your biodata could also add another option for people to judge you."



6. CONCLUSION

It comes to the final chapter of this project. The chapter 6 reflects back to the research questions raised during the research process and concludes up with listing the limitations and recommendations to the research.

6.1 Reflecting the Research Questions

This section reflects on the research questions raised throughout the research process and answers them with the results from each design step (Figure 75).

First Research Question

This research started with the idea of sharing biosignals through avatars in VR to better reflect the users current state and enhance the immersion in the VR environments. The first research question raised was:

RQ 1 *How can sharing biofeedback on avatars enhance user's social VR experiences?*

The question was answered from two directions, each focusing on understanding the 'current user behavior and interaction in social VR' and 'sharing biofeedback in social VR'.

RQ 1-1 *How is the current user interaction in the social VR spaces and what experiences can be improved?*

The current user interaction in the social VR spaces is dependent on 1) the relationship with the opponent, 2) the type of the social VR platform. Moreover, eleven user behavior patterns, which include the room for improvement, in the social VR spaces were defined.

RQ 1-2 *How is current user attitudes on sharing biofeedback and how can it improve user experience in the social VR?*

Four objectives of sharing biosignals in social VR spaces were discovered; two were focused on making an immersive VR experience and the other two were focused on altering human behavior through VR.

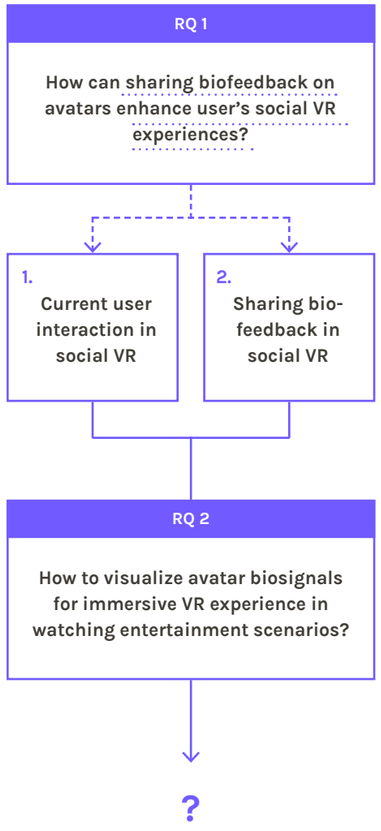


Figure 75. Research questions flow

For this research, it was decided to focus on making immersive VR experiences through biosignal visualization; specifically, based on personal interests and practical reasons, a 'watching entertainment' setting was chosen as a test environment.

Second Research Question

After narrowing down the research scope, a more specific research question, or a design goal, was defined:

RQ 2 *How to visualize avatar biosignals for immersive VR experience in watching entertainment scenarios?*

The co-design session was conducted (Chapter 3) to select an appropriate watching entertainment scenario and ideate biosignal visualization methods to answer the second research question.

The "Live jazz bar" scenario was selected for its half-public and half-private propensity. At a live jazz bar, users were willing to see other people's reactions while enjoying the music in the bar; thus, adding biosignal visualizations on avatars seemed to work in that scenario.

Four different biosignal visualization methods were developed, prototyped, and applied to the VR jazz bar setting (Chapter 4). A user study was conducted with 32 participants to test and compare the effects of each biosignal visualization method in a live jazz bar setting (Chapter 5).

While from the previous user research phase (Chapter 2) that the goal was set to visualize avatar biosignals for immersive VR experience, there were undiscovered objectives beyond the initially set goal. From the suggested four biosignal visualizations, users were able to 1) a better understanding of other people and space, 2) add entertainments, 3) have an immersive and quality VR experience.

Furthermore, the four design methods for biosignal visualization on avatars had their unique advantages and disadvantages; they were dependent on the scenarios, relationship between users, type of signals, and so on. For example, embodied visualizations were suitable for showing accurate biosignal information whereas environment change visualizations were suitable for setting up the mood of the space. Since this research work took an explorative approach, the biosignal visualization concepts can be adopted, varied, and adjusted to achieve their own goals in later applications.

Going back to the first research question, 'how can sharing biofeedback on avatars enhance user's social VR experience?', visualizing biosignals (heart rate, breathing rate) in watching entertainment scenarios showed possibilities of enhancing their VR experiences in three ways. Therefore, the research achieved its suggesting and evaluating avatar biosignal visualization concepts. However, it was still only tested for one scenario under a controlled research environment and should admit limitations, which will be discussed on the next page.

6.2 Limitations and Recommendations

This section discusses the limitations and recommendations of this project. Specifically, the limitation of the research, the recommendations for biosignal visualization, and recommendations on conducting design research (Figure 76).

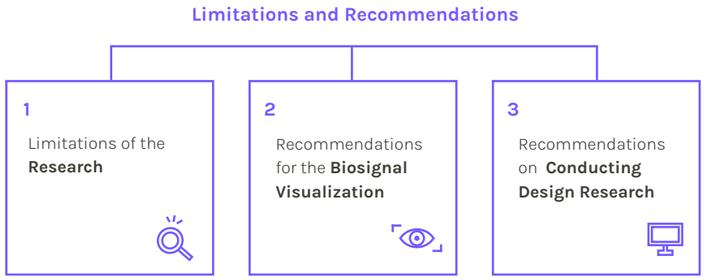


Figure 76. Limitations and Recommendations

6.2.1 Limitations of the Research

This part presents the limitations of the research. Some of them were inevitable due to circumstances; some of them can be improved in later research.

1 Limitations in User Study

Collecting the survey responses

A large number of survey responses had to be eliminated due to their suspiciousness. The link to the survey was posted on various social media platforms to gather participants. It was unavoidable to post the link to the not-verified platforms to collect more responses within a short period. However, many responses showed duplicates in their short-answer question; it indicated that the data was a fraud and all the suspicious ones had to be omitted.

Online User Research Sessions

Due to the Covid-19, both interview and co-design sessions were conducted online. There were some advantages of the online session, for example, recruiting participants from everywhere in the world. However, the variety and interactivity of the co-design session were much limited compared to the offline co-design session. The cognitive fatigue of the participants had to be considered as well since they had to look at the screen for long hours. Moreover, less interaction and collaboration between the participants may have occurred even after the ice-breaking session.

2 Limitations on Final Prototype

Only Visuals, not Other Feedback

This research took the visualization of biosignals into account but not other types of feedback (e.g., sound, haptic, etc). As all the designs were focused on the visualization, the size or the location of the design on the avatar may have influenced how users interpret the impact of the designs. Adding the sound of a heartbeat in the same setting may have resulted in a different conclusion.

Choice of Biosignals

Only two types of biosignals - heart rate and breathing rate - were chosen and tested for the final user research; thus, the conclusion is only limited to the effects of visualizing heart rate and breathing rate, not the other biosignals. Furthermore, some participants raised issues on the need of visualizing breathing rate for the 'live jazz bar' scenario; they could relate breathing rate visualization better with the sports-related scenarios.

3 Limitations in Design Evaluation

Signal Design and Comparison

Four types of biosignal visualization methods - embodied, near-body particles, around-body creature, environment change - were developed and compared; even if the colors - red for heart rate and blue for breathing rate - were controlled for all four types, the size, location, animation, and other design elements couldn't be controlled for direct comparison. They were highly dependent on the designer's artistic style and design capability. Thus, the result may be different if some design elements are tweaked.

Noises from Environment Design

While if the jazz bar environment was set on purpose to create the live jazz bar effect, the environmental factors (e.g., music) influenced participants rating the individual questionnaires, especially for the arousal level.

Not the Real Interaction

On the other hand, the research was conducted in a highly controlled setting, but not in the real jazz bar environment. The participants did not make real conversation with companions, and they were focusing on rating questionnaires under the given VR setting. It was to eliminate other noises so that to focus on comparing four different biosignal visualization methods. Thus, the perceived effects of the visualized biosignals may change when applied in the real VR jazz bar setup.

6.2.2 Recommendations for Biosignal Visualization

There are suggestions for the future biosignal visualization application based on the evaluation results from Chapter 5. In addition, there are also tips for designing the biosignal visualization.

1 Adopting Biosignal Visualization

Understanding the Objectives and Expectations

Before adopting the biosignal visualization concept, the first step is to understand the trait of the space and the people who will be joining that specific environment. The designer should ask: 'what does this space or event provide the users?' 'what are the goals or expectations that the users have from this space or event?' It is because the expected values or gains from users by sharing biosignals vary per scenario and space. The direction of visualizing biosignal can be set after the trait of the users and circumstances are clarified. The followings are the recommended biosignal visualization directions for different needs and purposes.

Controlling the Uncertainty

The fundamental is to control the uncertainty level as a whole. For example, it is easy to associate or assume that the animating visualization is related to a person's breathing in the yoga session. For the marathon, then people might associate the animation with heart rate. However, under the restaurant setting, it is more difficult to interpret the visualizations without further explanation since there's lacking common expectations to associate. While these were examples of different environments, there are much more elements that could be uncertainty factors (e.g., color, speed, size of

visualizations).

Sharing visualized biosignal in social VR space is not yet a common concept; thus, people may need to take an extra step to understand what does the visualization refers to unless it is explained in advance. Try not to include multiple design elements as variables but focus on one or two aspects. It will help users to understand the intended meanings without further explanation.

Less Distraction, Better Satisfaction
Unless they are the main event in the social VR environment, the biosignal visualizations should avoid causing distractions for the users. The lower the distraction level, the better the satisfaction level that the users perceive. It was shown in the evaluation that participants chose their favorite visualizations the one they rated as the least distracting visualization (Embodied design for the heart rate; Environment change and embodied design for the breathing rate). It was not a coincidence as one of the design requirements collected in Chapter 2 was 'User find comfort when using the system (R1)'.

2 Sharing Biosignal Visualization to Aim for Specific Effects

It was found in Chapter 5.3.1 that four biosignal visualization techniques had resulted in different effects; hence, each method can be used selectively to create a purposed effect in the social VR spaces.

Design for Accurate Data Delivery
When the precision of delivered data is an important issue, consider an embodied design, which is simple and straightforward. While it might be less creative compared to other techniques, embodied designs are easy to be interpreted by the users.

Although it was not prototyped for this research project, adding direct texts and numbers - one of the six ways to express biosignals in social VR (Chapter 3.2.2) - would add more clarity to transmitting biosignal data.

Design for Atmosphere
Environment change will be the best way to create a mood with biosignal visualizations. There are unlimited possibilities and options to apply environment change in the social VR spaces. In this project for the jazz bar scenario, only the rim of the table and chair head were parts to show the visualizations. They were selected on purpose because they can represent each avatar while still being part of the environment.

The location, object, or area of the environment can be adjusted depending on the desired degree of effects. For the case when it is not important to separate out an individual's biosignal information, showing the general mood with aggregated data would be one way to create the atmosphere. For example, the hue and brightness of the light in a room can represent the average heart rate of the people in that room.

3 Variations and Applications of Biosignal Visualization Design

The followings are the worth mentioning ideas that were raised during the user study. These cover a broader application area than the evaluated biosignal visualization techniques in this research.

Customizable Avatar Biosignal Visualization
Instead of providing a standardized biosignal visualization, each user can have options to customize their biosignal representation as if they are decorating their avatars. This concept may be applicable when the accuracy of data delivery is not necessary. People may have the option to change the colors or even choose different visualization techniques (e.g., moving creature, around body particles); they may choose different characters, like purchasing items from the store. In this way, biosignal visualization can be one way to express themselves to others, to show identity.

Customizable biosignal visualization would make the space more colorful and alive as a result. Moreover, it can work as an icebreaker in social VR spaces that people can start conversations based on other's biosignal visualizations.

P3: "If a person personalize their own way of visualizing their biosignals, I think the space can be more colorful or even more curious for people to talk about. 'I see your little animal, where did you get it? How can he represent you?'"

Blurred Background Effect
The biosignal visualizations can be applied gradually based on the closeness of the physical distance or the actual relationship. For example, a blurred effect can be applied to avatars who are comparatively far away. In this way, users are less distracted from the other's visualization but still can see the overall mood of the space with peripheral sight. As a result, it can lessen the cognitive efforts of the users by reducing the amount of information to be processed.

This concept can extend to applying different types of biosignal visualization based on the relationship or location between people. For example, the user can see a personal biosignal visualization from a friend but can only see the merged, atmospheric visualization from others.

P22: "I'm thinking about the effect that when you are taking a photo, there's a blur in the background, so you can see them but there's no clear focus."

Realistic Biosignal Visualization
A slight, breathing-like avatar animation can reflect the breathing visualization in the social VR spaces. The avatar models in the prototypes were applied 'Idle' animation on the basis; the bodies were pulsating slightly as if the person is breathing. Some participants mentioned that those slight movements gave them the feeling that the avatars were alive even without the extra biosignal visualization techniques.

Only adding a fake pulsating movement of a person can still add value to creating a realistic social VR atmosphere when it is not necessary to deliver accurate biosignal data.

P12: "They're already like, kind of breathing, they have a rhythm. So I think that's already indicating their breathing. I know this is fake data, of course."

6.2.3 Recommendations on Conducting Design Research

Most of the user study sessions were conducted online for this project due to the Covid-19 situation. This section shares the recommendations on conducting design research, especially on the online user study methods.

1 Planning the User Study

Participant Management
Always aim for more participants when recruiting to reach the actual goal. Participants are not as urgent as you; remind them multiple times to inform them about the scheduled time and the necessary details about the research.

Especially for the co-design session, it is crucial to have enough or a fixed num-

ber of participants together at the scheduled time. For example, I had recruited two more participants as a backup for the co-design session; however, it turned out that two of them canceled it at the last minute, and as a result, I had the initially aimed number of participants. It was feasible to conduct the co-design session on the planned date with the planned number of participants only because I recruited an extra number of participants.

Besides, participants tend to show less responsibility in the online environment since it is much easier to cancel the schedule and have less sense of guilt. Hence, participant management is a vital issue to avoid delays in the user study sessions.

Time Allocation

It is better to allocate more time than expected when planning for the user study session. Although there should be a time limit to avoid delays the user study process, it was commonly mentioned from the participants that they were lacking time for the design sessions.

Online communication is comparatively less fluent and slower than live communication. It should be planned ahead that there often occur unexpected technical problems which delay the process.

C: "The session was really nice, but the sensitising booklet took more time than I expected. In addition to that, I think giving more time for ideation phase would be better. I wanted to develop idea further, but because of the time limit, I had to hurry."

D: "It was very very very fun! and it was great seeing so different and cool ideas come to life! I only wish there was more time!"

E: "The duration of each assignment is slightly less; Somehow I feel like I actually spend more time in figure out how to do it."

2 Conducting Online Co-design Session

Use of Online Collaborative Tools (Miro)

Effective use of the online collaborative tool can help to overcome the limitation of the online user studies. In this project, the Miro board was used for two sensitizing booklets and one co-design session. Both non-design and design background participants appreciated and enjoyed the activities with the Miro board for its interactivity and creativity.

However, participants should be educated well on how to use the tools in advance so that they can freely express their ideas during the main design session.

Pair Activity in Co-design Session

Splitting the large group into smaller groups can boost the interactivity in the online design session. The online meeting often results in one person overpowers the conversation and others lose the chance of speaking up. Thus, I paired two participants as a group and created breakout sessions for them for discussion time; in this way, individuals were assigned more time to speak up their ideas within the limited co-design session hours. Moreover, the pair icebreaking activity before the main session helped to add an entertainment feature.

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APPENDIX

A. Design Brief

DESIGN FOR our future

4720

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Lee
initials: S. given name: Sueyoon
student number: 5029872
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): IPD Dfl SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: Medisign / Tech. in Sustainable Design / Entrepeneurship

SUPERVISORY TEAM **
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair:
dept. / section: TUD (IDE)
** mentor: Pablo Cesar
dept. / section: CWI, TUD (EEMCS)
2nd mentor: Abdallah El Ali
organisation: Centrum Wiskunde & Informatica
city: Amsterdam country: Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Maarten Wijntjes date 12 - 2 - 2021 signature

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 21 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 21 EC

List of electives obtained before the third semester without approval of the BoE

X YES all 1st year master courses passed

NO missing 1st year master courses are:

name J. J. de Bruin date 16-02-2021 signature JdB

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: V APPROVED NOT APPROVED

Procedure: V APPROVED NOT APPROVED

- mentor EEMCS already approved

comments

name Monique von Morgen date 2/3/2021 signature MvM

Personal Project Brief - IDE Master Graduation

Sharing Live User Avatar Biofeedback in Social VR Space — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 08 - 02 - 2021 25 - 06 - 2021 end date

INTRODUCTION **
Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

* Context:
Social VR is the application of VR technology in the social field, which allows people to achieve multi-dimensional interaction without meeting each other. It is becoming increasingly adopted in the fields like social media, professional meetings, virtual conferences, and gaming. VRChat, Mozilla Hubs, AltspaceVR, Facebook Horizon are a few of the popular platforms that allow social VR interaction.

Avatars are virtual anthropomorphic characters whose goals are to represent humans in virtual worlds. Such avatars are frequently used in personal applications such as video games, or collaborative scenarios [Pan and Steed 2017, Piumsomboon et al. 2018]. They allow their users to be virtually present in a personal or shared 3D synthetic world. (Figure 1) Due to the massive dissemination of consumer-grade Head-Mounted Displays, avatars have become a major requirement on immersive applications, leading to improvements in their visual quality. It is now possible to personalize the avatar representation to the user, which impacts immersion [Waltemate et al. 2018], as well as to display onto these avatars accurate motions of users through the use of lightweight motion capture systems, and even to display believable facial expressions.

While it is possible to be personalized and adopt motions and facial expressions, the avatars yet do not reflect the user's real psycho-physiological state. These gaps between the real and virtual world often degrade the immersion of the users in virtual spaces, even with the constant improvement of visual representation.

* Project Direction:
With the advances in sensor technology and real-time processing of neurophysiological data, a growing body of academic literature has begun to explore how live biofeedback can be integrated into information system for everyday use [Lux et al. 2018]. For example, one research investigated the multi-sensory heart rate feedback in VR. (Figure 2) Adopting biofeedback (e.g. heart rate, galvanic skin response) to avatars in understandable manner could be a way to improve user experience in virtual space.

The graduation project offered by CWI (Centrum Wiskunde & Informatica) aims to explore approaches to better reflect the current state of users by adapting their avatar's visual appearance to their own physiological signals.
In this project, I will explore how to visually map the user's bio-signals on the avatars in the virtual space. It is crucial to consider both the users' self and other's interpretation of biofeedback, as the ultimate goal is to enhance the user-experience with avatars in the virtual setting. The result will be evaluated via the user studies.

* Project Outcome:
The outcome of this project will be a set of VR prototypes or methods that provides a visual representation of the user's biofeedback on the avatar, that solves the current limitation and enhances the user experience in virtual space. The user experience will be tested and analyzed with the VR prototype to evaluate the achievement of the goal. CWI will provide technological support, facilities of VR and biosensors, and the guidance of research methodologies.

space available for images / figures on next page

introduction (continued): space for images

image / figure 1: Personalized Avatars in Facebook Horizon

image / figure 2: Multi-sensory Heart Rate Feedback in VR [Chen et al. 2017]

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

* Problem definition:
- The current appearance of avatars in social VR platforms doesn't reflect the user's real psycho-physiological state; the gaps between the real and virtual world degrade the immersion of the users in virtual spaces.

* General goal:
- Design, propose and evaluate a biofeedback visual representation system on animated avatars in virtual space.

* Experience:
- Understand the current avatar experience in the social VR space.
- Plan and apply various design methodologies to create biofeedback visual representation.

* Technology:
- Explore different biosensors and development tools of virtual spaces, while the main focus will be a design-oriented approach instead of a technology-oriented approach.

* Prototype:
- Develop a set of VR prototypes in Unity3D which provides visual representations of the user's biofeedback.

* Evaluation:
- Test the experience of users with the proposed system and evaluate the added-value to the current technology.
- Consider the controllability of biofeedback, effects, and limitations of the proposed system in different scenarios (self, foreign live biofeedback, and the relationship between the users)

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Design a social VR biofeedback visualization system that reflects the real-time user bio-signals for enhanced avatar communication in virtual space. The goal is to create an appropriate representation of the biofeedback on avatars so that can offer immersive experience to the users.

* Research:
- Literature review on social VR, bio-signals, and visualization of emotions on the avatar.
- Explore different bio-signals and select the appropriate techniques for the design (e.g. heart rate, electrodermal activity) to solve the current limitations on avatars in VR space.
- Conduct user research to investigate 1) social VR usage, 2) privacy aspects/perception on visualizing biofeedback, and sharing it with other users, 3) undiscovered problem and needs.

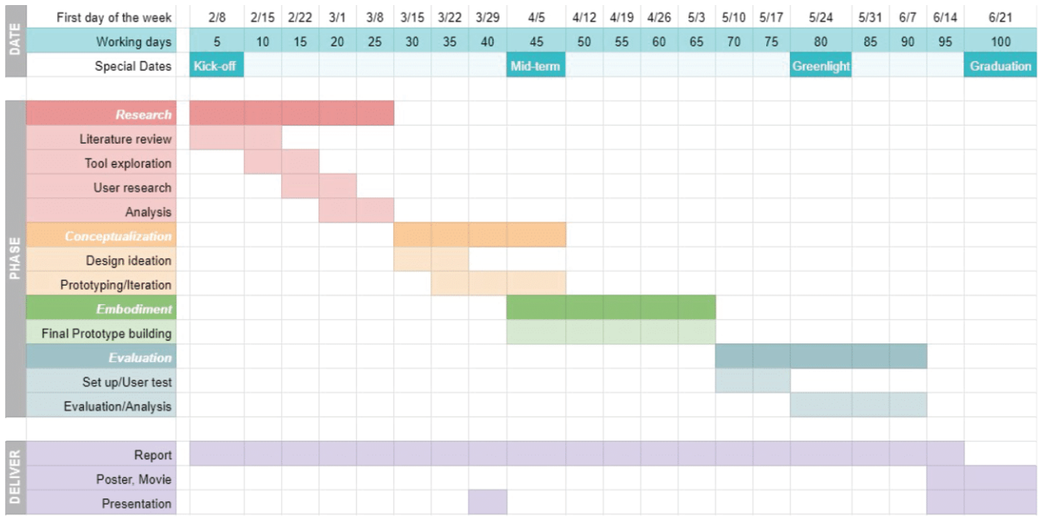
* Design:
- Generate ideas on how to visualize biofeedback into an avatar (e.g. run online co-design session).
- Multiple iterative design and testing to finalize the design concept.
- Final digital prototype will be built in Unity3D.

* Evaluation:
- Evaluate the interaction experiences of the final design outcome (quantitative, qualitative).
- Participants will be invited for the testing.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 8 - 2 - 2021 25 - 6 - 2021 end date



The project consists of 4 phases: research, conceptualization, embodiment, and evaluation.

* Research (5 weeks):
- Literature review: literature review on social VR, bio-signals, avatars and explore current VR platforms.
- Tool exploration: familiarize with biofeedback concept and different devices for bio-signal measurement.
- User research: secondary research, semi-structured interview (around 5 ppl, a mix of different purpose/platform users - on 1) social VR usage, 2) privacy aspects/perception on visualizing biofeedback, and sharing it with other users, 3) undiscovered problem and needs)
- Analysis: summarize and analyze findings and insights from the research phase.

* Conceptualization (4 weeks):
- Design ideation: explore possibilities and generate ideas, and select potential directions.
- Prototyping / Iteration: prototype and iterate (involve participants for testing and iterating process).

* Embodiment (4 weeks): - Final prototype building: build final prototypes in Unity3D.

* Evaluation (5 weeks):
- Set up / User test: plan, set up and conduct user tests with the prototype.
- Evaluation / Analysis: A/B test (compare with/without the added measure the effect in scale - e.g. trust scale, presence, attitude, bio-signals measuring, proximity), system usability scale, privacy test

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

* Competences:

As a designer, I am interested in new technology and creative content, as well as reflecting and gaining insights from human behaviors and everyday activities. Within the technical domain, I was particularly interested in XR technology; that I had prototyped a simple Unity AR application that reflects the user's emotion via dancing avatars, during an individual design project course.

The topic of avatars in the social VR space - the graduation project offered by CWI - aligns with my personal interests and the skills I have acquired.

With a background in Industrial design at engineering school, I gained sufficient experience in both conducting design research and building appropriate physical and virtual prototypes based on the research outcome.

Courses from DFI master provided various, structured design methods and approaches that I can apply when carrying out design researches. In addition, the theoretical knowledge and practical skills I gained from the elective semester will be adding value to this project. I learned how to approach, plan and interpret user studies in regards to emotion during the [Design for Emotion] course; it can be applied in understanding user's emotions when perceiving avatars of their own, as well as the other's. 3D drawing skills from [Computer sketching] and color-using skills from [Basic Color skill] will be helpful in developing an aesthetic VR environment.

*Ambitions:
- Explore various types of biofeedback collected from biosensors and select appropriate ones to solve the current limitations.
- Design and suggest a biofeedback visualization system that considers the user in revealing their biometric data.
- Improve prototyping skills and obtain confidence in developing a VR environment, using Unity.
- Manage to plan and conduct user research under the restricted, Covid-19 situation.
- Learn to ask for help, make full use of resources that I can get support from.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

B. Survey Questions

Title: My Life in Social VR: Understanding Social Virtual Reality Experiences

Introduction

Hello! Thanks for your participation!

This survey is a part of a master's graduation project on avatar interaction in the social Virtual Reality (VR) space at Centrum Wiskunde & Informatica (CWI) in the Netherlands. The goal of this survey is to understand current social VR experiences on different platforms (e.g., AltspaceVR, Mozilla Hubs, VRChat, etc.), and their use for different purposes. Please share your social VR experience with us, if you have any! (It includes experiences using Head-Mounted Displays or browser-based)

It will take around 10-15 minutes to complete the survey. If you complete the survey, there is a chance of winning a €30 (thirty euros) worth gift card voucher! At the end of the survey, we also ask if you are willing to participate in the next round of user studies.

The data that is collected here will be used solely for research purposes by only researchers at CWI, and will not at any point be shared with any third-party individuals or institutions.

If you have questions about this survey, please contact: Sueyoon Lee <sueyoon@cwi.nl> or Abdallah El Ali <aea@cwi.nl>

0. Demographic

1. What is your age?

2. What is your gender?
- Woman
- Man
- Non-binary
- Prefer not to disclose
- Other

3. What is your ethnicity?
- Caucasian
- African-American
- Latino or Hispanic
- Asian
- Native American
- Native Hawaiian or Pacific Islander
- Prefer not to say
- Other

4. Which country do you live in?

5. What is the highest degree or level of school you have completed?
- Less than a high school degree
- High school degree or equivalent
- Bachelor's degree
- Master's degree
- Doctorate
- Other

1. VR Experience

1. Do you own a VR device/headset?
- Yes
- No

2. Whether you own a VR headset or not, how frequently have you used a VR device?
- Everyday
- Several times a week
- Once a week
- Twice a week
- Once a month
- Less than once a month

3. Which social VR platform(s) have you used? (multiple choices possible)
- Altspace
- VRChat
- Mozilla Hubs
- Rec Room
- NeosVR
- High Fidelity
- Engage
- Big Screen
- Oculus Venues
- Other

2. Platforms

For the next questions, we would like to ask about your experience on a specific social VR platform of your choice. Please choose one social VR platform that you have a reasonable amount of experience with (at least 2 hours), and would like to share your experiences about. If you have experienced multiple platforms, then you are free to leave comments in a later part of the survey.

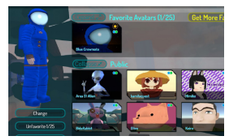
1. Select one social VR platform that you have reasonable experience with (at least 2 hours), and want to base your next responses on.
- Altspace
- VRChat
- Mozilla Hubs
- Rec Room
- NeosVR
- High Fidelity
- Engage
- Big Screen
- Oculus Venues
- Other

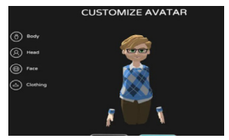
2. Based on the platform you selected, what was your purpose of using the platform?
- Making new friends
- Meeting with friends remotely
- Attending events
- Hosting events
- Networking
- Learning
- Working
- Exploring technologies
- Gaming
- Entertainments (e.g., watching movies)
- Health related (e.g., therapy)
- Other

3. What is the type of experience you normally had with that platform?
- HMD-based (e.g. wearing an oculus quest)
- Browser-based
- I have used both

4. How many times have you used this specific social VR platform?
- Once
- Less than five times
- Less than ten times
- Over ten times

5. Were you able to customize your avatar?
- Yes, Fully (e.g., VRChat - creating or uploading personal avatars)
- Yes, Partially (e.g., AltspaceVR - changing the hair color)
- No (e.g., Spatial.io - auto-creation)





-> Different path based on the selection

3. Avatars

3-1. Yes, fully

Please answer these questions based on the social VR platform that you selected in the previous section.

1. How did you choose and decorate your avatar?
- Use the default setting
- Choose from existing settings
- Take a readymade 3rd party avatar
- Create and upload own avatar
- Other

3-2. Yes, partially

Please answer these questions based on the social VR platform that you selected in the previous section.

1. How did you choose and decorate your avatar?
- Use the default setting
- Customize some parts
- Customize all the detailed components
- Other

3-3. Avatar appearance

Please answer these questions based on the social VR platform that you selected in the previous section. Indicate your opinion about the following statements. (1- Strongly Disagree, 5 - Strongly Agree)

<5-Points Likert Scale>

1. The avatar I use the most represents my identity in the social VR space.

2. I (want to) put effort into customizing avatars to reflect my identity in the social VR space.
3. I prefer to customize my avatar as an 'ideal' version of myself instead of reflecting how I look like in real life.
4. I worry about revealing my real-life identity through my avatar.
5. I am satisfied with the current avatar representation options.

<Open-ended question>

6. I find current avatars to be missing ...

3-4. Avatar interaction

Please answer these questions based on the social VR platform that you selected in the previous section. Indicate your opinion about the following statements. (1- Strongly Disagree, 5 - Strongly Agree)

<5-Points Likert Scale>

1. Interacting with avatars in the social VR space feels natural to me.
2. It is easy to recognize other avatars' emotions.
3. The movements of the avatars are believable to me.
4. The facial expressions of the avatars are believable to me.

4. Interaction

Please answer based on the social VR platform that you selected in the previous section.

In the social VR space, there is a chance of interacting with people who have different relationships with you. This could be categorized into:

(a) Actual real-life friend that is now in social VR
(b) Virtual friend that you now meet in social VR
(c) Stranger in social VR

4-1. Interaction

1. Have you interacted with an "actual real friend" in the social VR platform that you chose?

- Yes
- No

-> Different path based on the selection

4-2. Interaction

1. Have you interacted with a "virtual friend" in the social VR platform that you chose?

- Yes
- No

-> Different path based on the selection

4-3. Interaction

1. Have you interacted with a "stranger" in the social VR platform that you chose?

- Yes
- No

-> Different path based on the selection

4-1. Interaction - a) actual real-life friend

This part is about the experience you had with an "actual real-life friend" that is now in social VR.

1. Choose the top three interactions you performed.

- Talking (leading the conversation)
- Listening
- Body movement
- Texting
- Watching media
- Sending emojis
- Others

<5-Points Likert Scale>

2. In general, I would like to hide my real visual representation (e.g., face, body) when interacting with an 'actual real-life friend' in the social VR space.
3. In general, I want to hide my real audio (e.g., voice, coughing) when interacting with 'actual real-life friend' in the social VR space.
4. In general, I want to hide my real biological signals (e.g., heartbeat, breathing rate) when interacting with 'actual real-life friend' in the social VR space.

4-2. Interaction - b) virtual friend

This part is about the experience you had with a "virtual friend" that is now in social VR.

1. Choose the top three interactions you performed.

- Talking (leading the conversation)
- Listening
- Body movement
- Texting
- Watching media
- Sending emojis
- Others

<5-Points Likert Scale>

2. In general, I would like to hide my real visual representation (e.g., face, body) when interacting with an 'actual real-life friend' in the social VR space.
3. In general, I want to hide my real audio (e.g., voice, coughing) when interacting with 'actual real-life friend' in the social VR space.
4. In general, I want to hide my real biological signals (e.g., heartbeat, breathing rate) when interacting with 'actual real-life friend' in the social VR space.

4-3. Interaction - c) stranger

This part is about the experience you had with a "stranger" in social VR.

1. Choose the top three interactions you performed.

- Talking (leading the conversation)
- Listening
- Body movement
- Texting
- Watching media
- Sending emojis
- Others

<5-Points Likert Scale>

2. In general, I would like to hide my real visual representation (e.g., face, body) when interacting with an 'actual real-life friend' in the social VR space.
3. In general, I want to hide my real audio (e.g., voice, coughing) when interacting with 'actual real-life friend' in the social VR space.
4. In general, I want to hide my real biological signals (e.g., heartbeat, breathing rate) when interacting with 'actual real-life friend' in the social VR space.

5. Experience in Other Platforms

1. If you want to leave any comments about your experiences on different platforms (e.g., you act differently in platform X than platform Y), please share them here!

6. Practical Questions

1. Are you interested in participating in the next session? (with gift card compensation, 10 euros per hour)

- Yes
- No

2. Please enter a valid email address for further notice about followup user studies on social VR (your email address will not be saved or used for any other purpose beyond inviting you for participation)

3. Check the choice of your interest (multiple allowed)

- (Online) Interview
  Estimated Date: Feb 24th - March 3rd
  Estimated Hours: 1.5- 2hours

- (Online) Co-design session
  Estimated Date: March 17th -March 24th
  Estimated Hours: around 2hours

Closing

THANK YOU!

Thank you for your time and participation!
Please provide a valid email address if you want to enter a draw to win a €30 (thirty euros) gift card voucher for filling in the survey. The type of voucher will be tailored according to the country you reside in. (your email address will not be saved or used for any other purpose)

C. Interview Questions

Introduction

- **Intro**: Hello, I am Sueyoon, a design student working on my graduation project at CWI, in the Netherlands. The goal of this research is to enhance the social VR experience by adopting biosignals to the avatars in the social VR spaces.
- **Aim**: I want to know about your current experience in the social VR space
- How you interact with others (friends, strangers)
- What is the purpose of those interactions?
- What were the difficulties?
- How successful or unsatisfied with the current interaction (visual) methods - e.g. facial expression, emojis
- Under different environments?
- Concern about the privacy regarding sharing your biosignals
- **Privacy**: I want to make a Zoom recording of this interview for future analysis in this project. Your face will never be exposed and data collected from today will remain confidential. Your user profile will be coded for analysis. Would you give me permission to record this interview?

Miro Board

Part1: About me

- Could you elaborate on your self-drawing?
- When do you play social VR?
- What time of the day / where?
- Do you plan ahead to participate in a specific event?

Part2: My body signals (Friend)

- Did you have someone in mind when answering these questions?
- Could you explain what are the main differences between the 'real' and 'ideal' look?
- Why would you show this biosignal?
- Why would you hide this biosignal?

Part2: My body signals (Stranger)

- Did you have someone in mind when answering these questions?
- Could you explain what are the main differences between the 'real' and 'ideal' look?
- Why would you show this biosignal?
- Why would you hide this biosignal?

Part 4: Current interaction in the Social VR space

- When / Which platform / what purpose?
- Could you explain your journey from the start?
- Why was the first green dot the positive interaction moment to you?
- Did you have a particular aspect that you liked? (e.g., Interface)
- Is it due to VR technology?
- What was the first red dot the negative interaction moment to you?
- What were the barriers to this interaction?
- Is it because it's the virtual environment?
- What would be an ideal way to improve?

Part 5: Interaction in different social VR spaces

- How satisfied were you with the current interaction?
- What if the same thing happened in the real world, not in VR space? What would have been different?
- Better? Why?
- Worse? Why?
- If anything is possible in the VR world, how would you want to make improvements here, for better communication?

Additional Questions

Part 2&3: Go back to biosignals

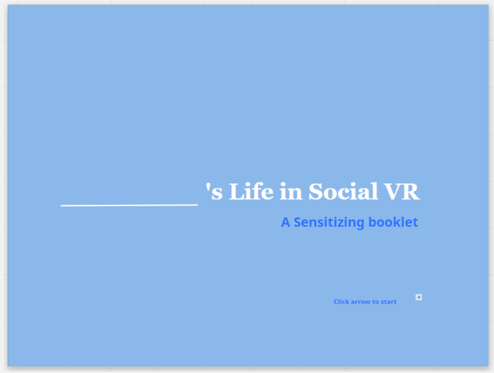
- You shared some experiences about how you interacted with people in the social VR spaces. Do you think that your answer will be different if I asked the same questions about these body signals, in virtual reality?
- If you can be selective when choosing what to share, how would you do?
- Do you want to see your own biosignals during the gameplay?
- It could be directly on your avatar
- It could be on the setting menu or on the screen?

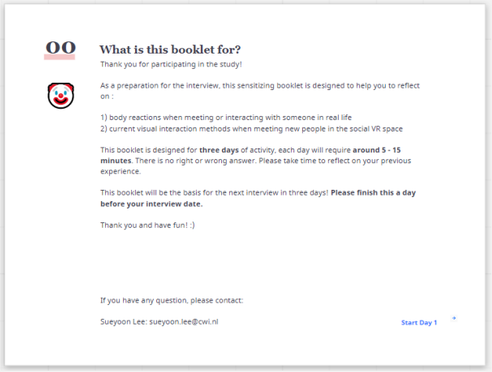
Wrap up

Thank you for sharing your experience! The interview part is done, and I have a short personality questionnaire and a form to fill in your experience about this user study, as well as the information about the gift card.

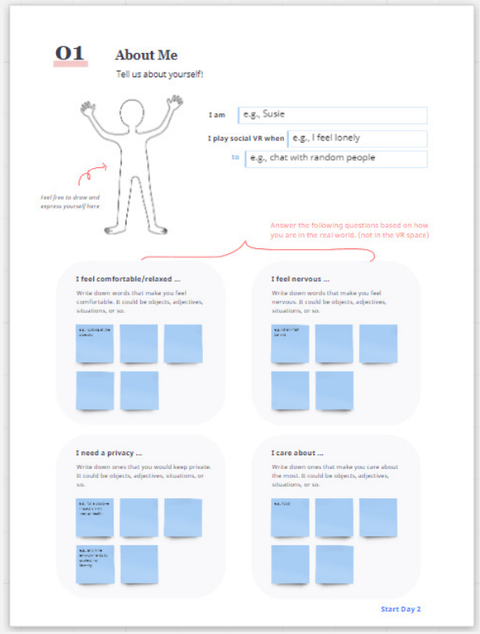
D. Interview Sensitizing Booklet

Introduction





Day 1



Day 2

02 My body signals 1 (Friends and Family)

Reflect on the situation when you met someone with who you **feel comfortable** (e.g., friends, family) in real life. Based on the reflection, use drawing tools on the left bar to **draw your biosignals on the body** below.

Help!

This is real me!

When I meet someone with who I feel comfortable, my body reacts like ...

Any comment?

1 e.g. heartbeat increases because I am
2 Type something
3 Type something
Type something
Type something

Maybe the above representation is not how you want to look. If you could **alter the biosignals**, how would you want to be?

How I want to look like!

I would show ...
Type something
because ...
Type something
I would hide ...
Type something
because ...
Type something

Next Step

A cheat sheet for Day 2 activities

I am not familiar with biosignals. Which ones should I be using here?

It could be something like...

heartbeat | sweat from the hand, foot... | contracting muscle | brain activity
breathing | body temperature | eye gaze pattern | Pupil dilation
... | ...

So what should I be drawing on the body?

This is just an example. You can draw in any form!

03 My body signals 2 (Strangers)

Reflect on the situation when you met someone with who you **don't feel comfortable** (e.g., stranger) in real life. Based on the reflection, use drawing tools on the left bar to **draw your biosignals on the body** below.

This is real me!

When I meet someone with who I don't feel comfortable, my body reacts like ...

Any comment?

1 Type something
2 Type something
3 Type something
Type something
Type something

Maybe the above representation is not how you want to look. If you could **alter the biosignals**, how would you want to be?

How I want to look like!

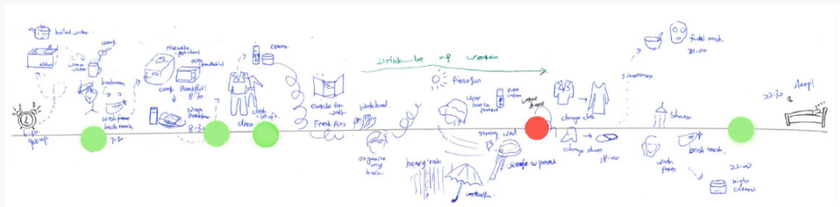
I would show ...
Type something
because ...
Type something
I would hide ...
Type something
because ...
Type something

Start Day 3

A. Timeline example

Go back to the exercise

- The image below is an example of a timeline made by a participant in a previous study, describing her typical daily activities.
- The green and red dots indicate the positive and negative moments on her timeline.



Day 3

04 Current interaction in the Social VR space

a. Reflect on a social VR experience when you had previously.
b. Write down / visualize the activities you did in the social VR space on the timeline, **from entering until exiting the social VR world.**
c. Include **at least three** actions that happened when **you interacted with someone in the social VR space**. (It could be both active or passive)
d. Use green dots to mark the positive interaction moments. (It could be a pleasant surprise or the moments that you achieved your goal.)
e. Use **red dots** to mark the negative interaction moments that you want to alter or improve the way you interacted.

See example

entering — existing

Use these dots! XD

- If drawing here is challenging, you can hand draw on any white paper, take a photo and upload it here.

Next Step

05 Interaction in different Social VR spaces

- Reflect on your experiences in different social VR spaces. It can be different platforms, different worlds, or different purposes (e.g., meeting new friends, gaming, watching, meditating, etc).
- Were there differences in the way you interacted between these different situations? (e.g., I send emojis to a lecturer at a conference in Altspace, and I run around at VRChat to get attention, etc)
- **Pick** different situations you interacted with new people, **draw,** or **describe** each of your experiences below.

 # Situation 1

e.g., I participated in an online conference at Altspacevr for the first time. The lecturer was presenting on the stage, and everyone else was muted. I wanted to discuss one topic with someone in the audience while on muted, so I sent a friend request to a person next to me and texted him.

The platform was ...
e.g., AltspaceVR
The purpose was...
e.g. to share my thoughts with
I used ....
e.g. texting to the person next to
because
e.g. I didn't want to interrupte

 # Situation 2

Draw or describe here

The platform was ...
Type something
The purpose was...
Type something
I used ....
Type something
because
Type something

 # Situation 3

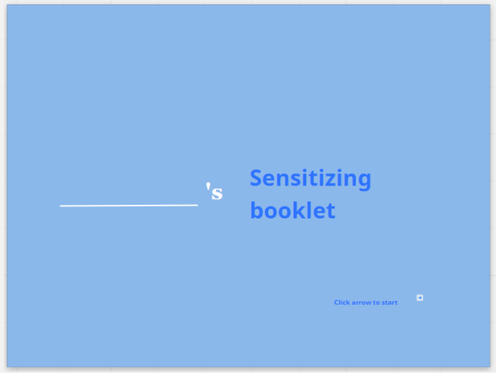
Draw or describe here

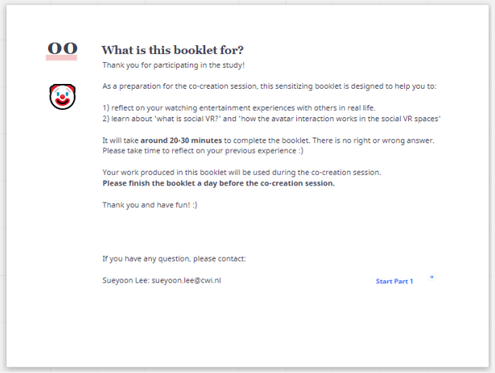
The platform was ...
Type something
The purpose was...
Type something
I used ....
Type something
because
Type something

Next Step

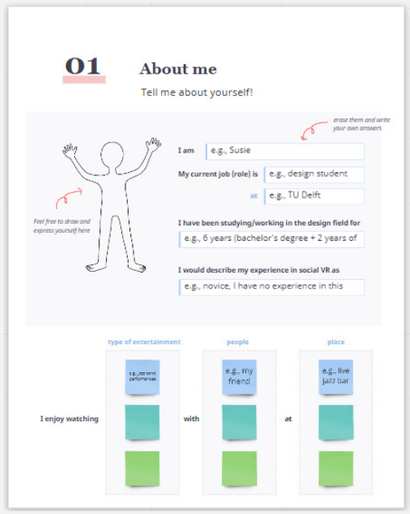
E. Co-design Sensitizing Booklet

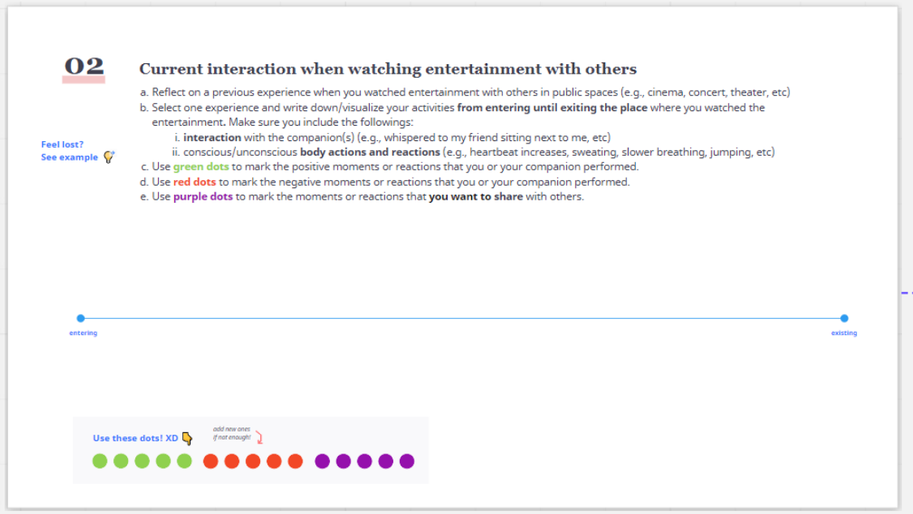
Introduction

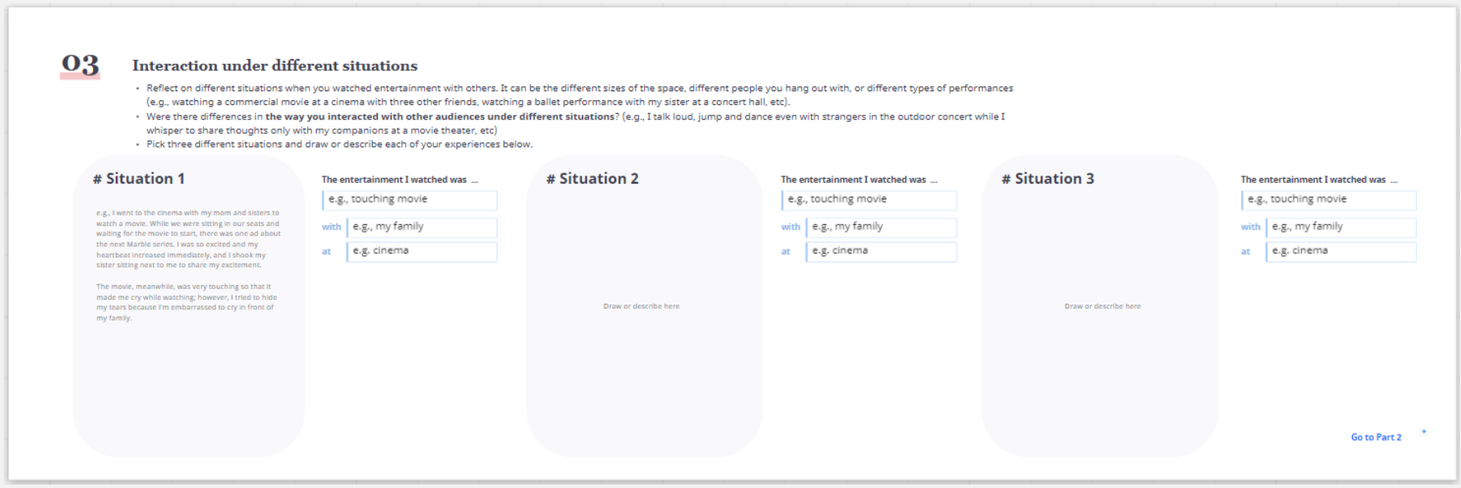




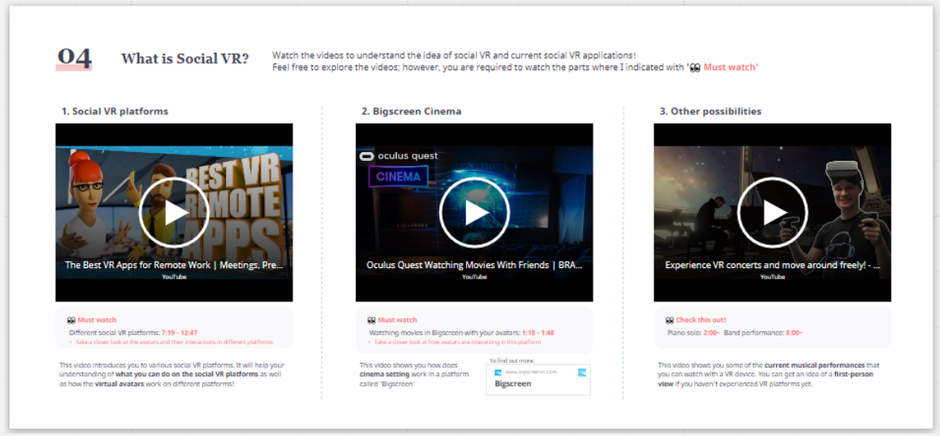
Day 1

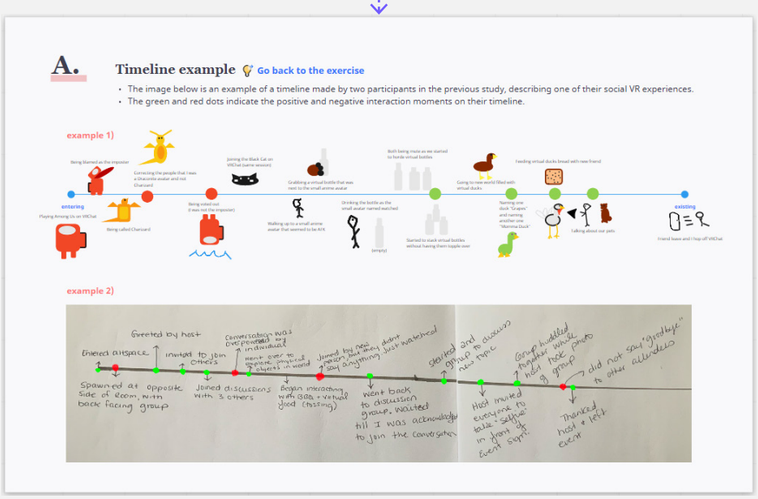






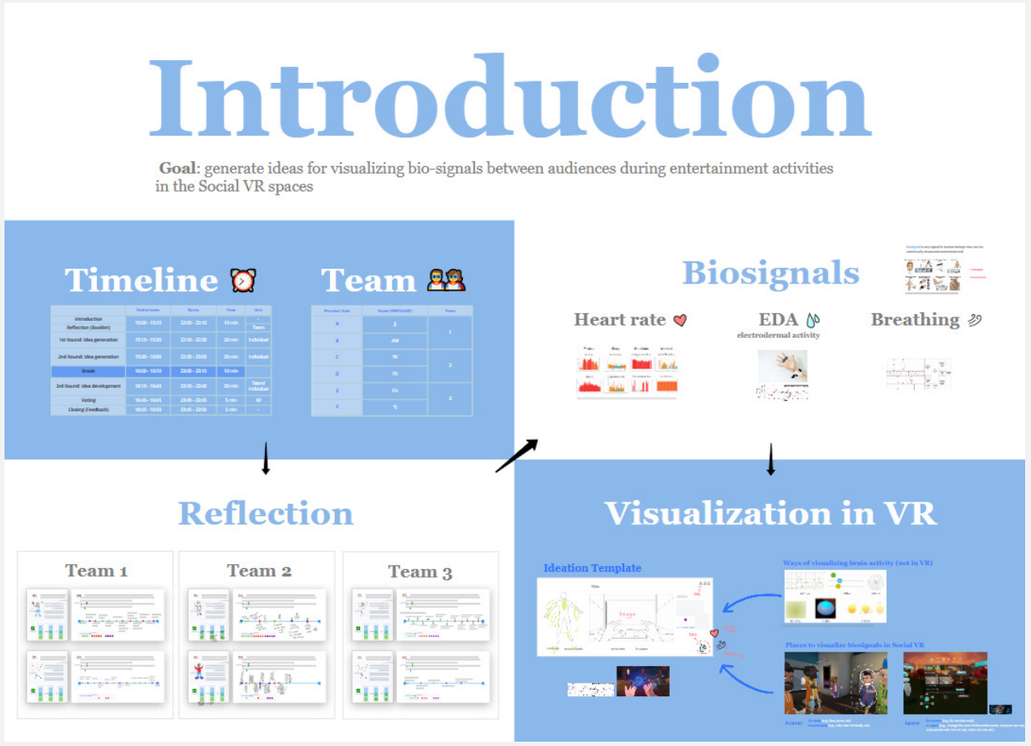
Day 2





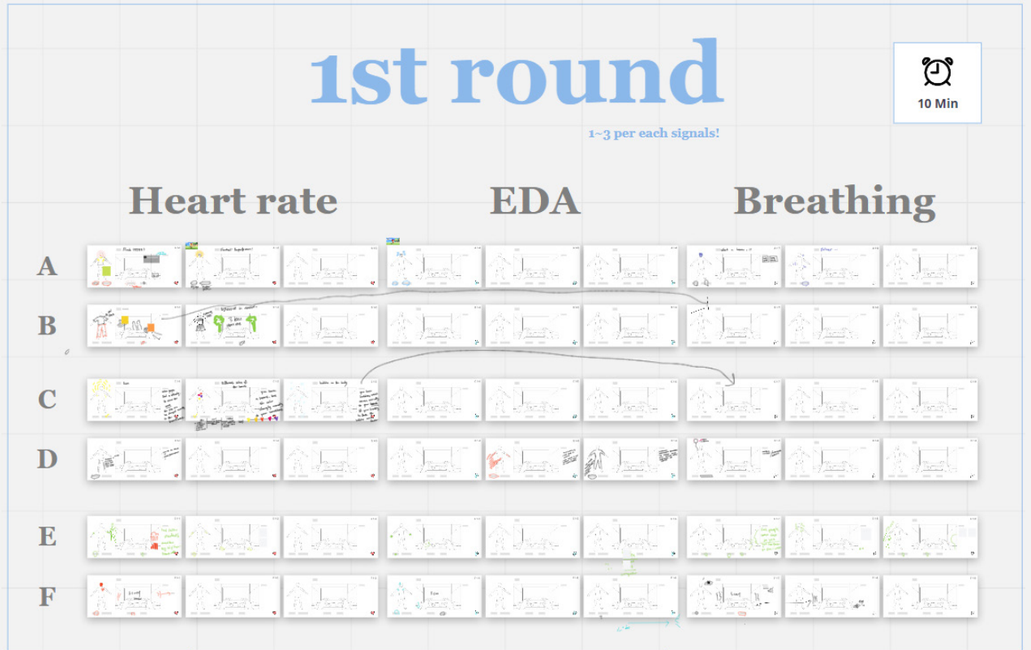
F. Co-design Main Board

Introduction

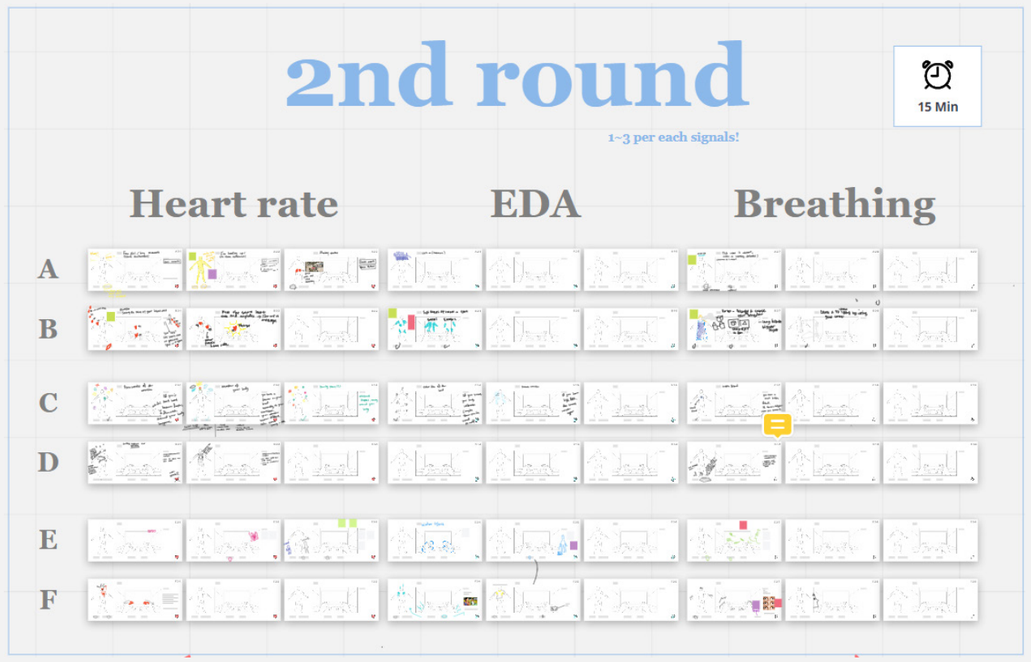


Scenarios (from Sensitizing Booklet)

1st Round

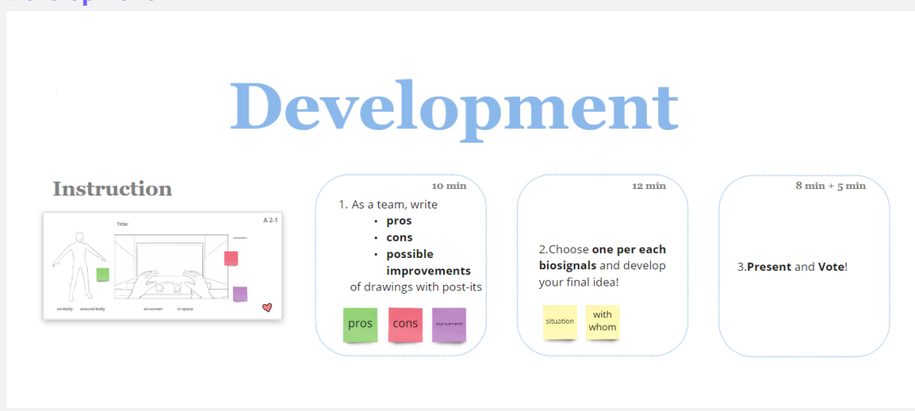


2nd Round

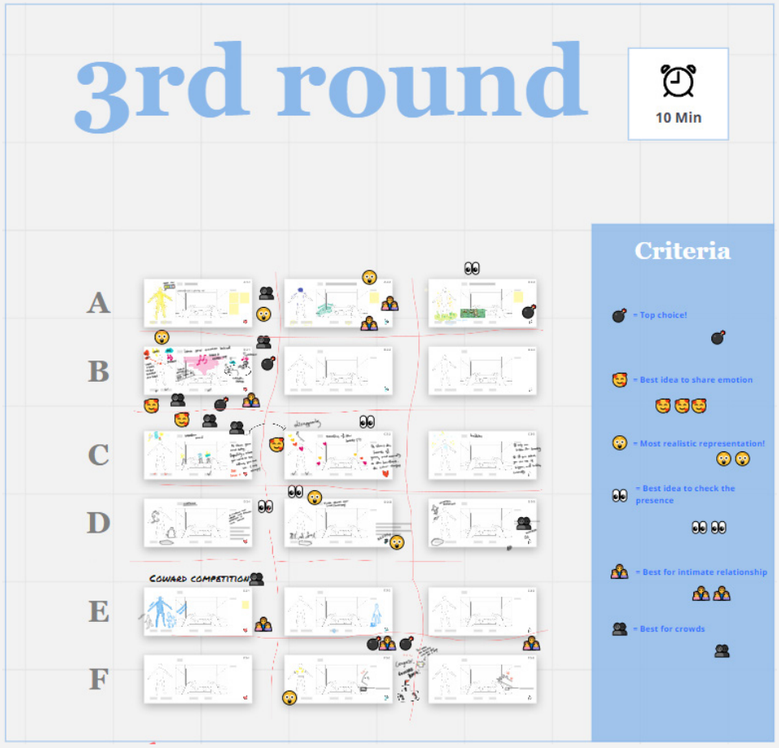


Requirements and Examples

Development



3rd Round



G. User Study Materials

1. General Information Form

User Study Participants: General Information

Participant ID. _____ Laptop ID. _____ Date ___ - ___ - _____

1. What is your age? _____

2. What is your gender?

   ☐ Woman ☐ Man ☐ Non-binary ☐ Prefer not to disclose

3. What is your current occupation? _____

4. How many times have you used VR devices?

   ☐ Haven't tried before ☐ Once ☐ Less than five times ☐ Less than ten times ☐ Over ten times

5. How many times have you visited social VR platforms (e.g., VR Chat, Mozilla Hubs,... etc)?

   ☐ Haven't tried before ☐ Once ☐ Less than five times ☐ Less than ten times ☐ Over ten times

6. Do you have a visual impairment?

   ☐ Yes ☐ No

7. Do you wear contact lenses or glasses at the point of the user study?

   ☐ Yes ☐ No

8. Color Vision Test

   Write top three numbers from the color vision test:

   ____ ____ ____

   Write the bottom three numbers from the color vision test:

   ____ ____ ____

2. Consent Form

User Consent Form

This research is a part of a master's graduation project on avatar biosignal visualization in the social Virtual Reality (VR) space at Centrum Wiskunde & Informatica (CWI) in the Netherlands.

The purpose of this study is to test and compare the effect of different avatar biosignal visualization methods in the VR jazz bar setting in the VR environment.

We will voice-record the session and take some footage if needed. By signing this consent form, you are giving us consent to use the verbal statements and questionnaires you submitted, but not your other personal information, for the purposes of analysis. The data that is collected here will be used solely for research purposes by only researchers at CWI, and will not at any point be shared with any third-party individuals or institutions.

You are free to refuse to participate, take a break, or withdraw from this study at any time. Please let us know if it is needed.

Data Protection Privacy Notice

The data controller for this project will be Centrum Wiskunde & Informatica (CWI). The CWI Data Protection Office provides oversight of CWI activities involving the processing of personal data. CWI's Data Protection Officer is Carl Schulz and he can be contacted at carl.schulz@cwi.nl.

Legal basis for processing is the General Data Protection Regulation (GDPR) [1] and specifically Article 89. Your personal data will be processed for the purposes outlined in this notice. The legal basis that would be used to process your personal data will be the provision of your consent. You can provide your consent for the use of your personal data in this project by completing the consent form that has been provided to you.

If you are concerned about how your personal data is being processed, please contact Abdallah El Ali in the first instance at aea@cwi.nl or Pablo Cesar at garcia@cwi.nl. If you remain unsatisfied, you may wish to contact CWI's data protection officer Carl Schulz at carl.schulz@cwi.nl.

[1] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation)

I hereby acknowledge that I have read and understood the information above:

Name: **Date:**

3. Participant Manual

Participant Manual

Hello! Thanks for your participation 😜

Today's test consists of three parts:
1) Questionnaire within VR
2) Questionnaire via Google Form
3) Focus Group within VR

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1) Questionnaire within VR (Individual)

How to:
You are in a jazz bar with your friend sitting at a table. A jazz band is playing on your right side.
You will see a **questionnaire panel** in the front; click the start button to start.

Observe the visualized biosignals of your companion. Use your VR controller to click the blue dot and relocate it into an appropriate Likert scale.

If you click next, then the scene will change. You cannot go back.

Image 1. Jazz bar example environment

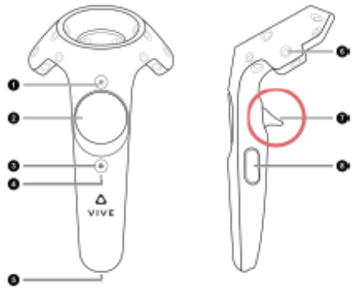

Image 2. VR controller (source from Unity)

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2) Questionnaire via Google Form (Individual)

One page, short questionnaire in Google Form.

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3) Focus Group within VR (Team)

Discuss and share your opinion about the biosignal visualization with your fellow and moderator!