# MIXED REALITY CPR AND STRESS

*A graduation report*



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# Abstract

This thesis presents the design, development, and evaluation of a Mixed Reality (MR) training application aimed at identifying methods of artificially inducing stress to enhance realism in Emergency Response simulations. Emergency Responders are often in stressful scenarios and require a high stress tolerance to deal with the tense situations they encounter. A higher resilience for stress can be acquired through frequent exposure, which can be achieved through simulations.

In collaboration with SeriousXR, a training application was created that integrates various stressors, tested using Heart Rate Variability (HRV) readings and a survey. Results demonstrated that while the implemented stressors were effective, the severity of stress could not be reliably measured with HRV alone, necessitating the use of surveys. The social stressor of talking virtual humans was found to be the most effective based on survey data. It concludes that while stressors can be artificially induced into MR trainings, their effectiveness can vary significantly between trainees. For the current studies, the sample size was limited to eight participants. Therefore, it is recommended that future experiments be conducted with a larger group and fewer variable changes to better assess specific stressor efficiency on a larger scale.

**Keywords:** Mixed Reality, CPR Training, Stress Measurement, Heart Rate Variability, Simulation, Emergency Response.

# Preface

This thesis marks the end of my studies and the achievement of something I am very proud of. Developing a MR training application focused on stress has been both challenging and a very fun experience.

The idea for this project came from my personal interest in how humans interact with digital experiences, and my curiosity towards stress and its workings. Together with SeriousXR, I created an application that allowed me to learn many new things about CPR, a topic I knew little about, gain valuable insights through testing, and explore various aspects of AR and MR.

I would like to thank my company supervisor, Selwyn Nypels, who provided great support throughout the project, allowing me to deeply focus on my personal interests. His encouragement was incredibly motivating.

Furthermore, I am also very thankful to my graduation supervisor, Yvens Rebouças Serpa, for his guidance and constant feedback throughout the project. His dedication and time made the entire process feel meaningful and made the writing of this paper much more streamlined.

I also want to acknowledge the support of colleagues, friends, and family who helped me throughout the development period with playtests and provided valuable feedback, which was crucial to the application.

Finally, I would like to thank all participants who took part in the testing phase. Their time was extremely appreciated, and their positive remarks gave me a lot of confidence in myself and the project.

# Glossary

**AED** – Automated external defibrillator, a device that can analyze heart beats and deliver an electrical shock in the case of cardiac arrest.

**AR –** Augmented Reality, the addition of virtual elements onto the real world.

**CPR –** Cardiopulmonary resuscitation, the act of manually pumping blood through an organism in an attempt to save their live after cardiac arrest.

**GSR –** Galvanic skin response, a method for measuring stress through skin conductivity.

**HRV –** Heart rate variability, a method for measuring stress from analyzing heart rates and a global indicator for ones health.

**MR –** Mixed Reality, the mix of Virtual Reality and Augmented Reality.

**NPC –** Non playable character, a virtual humanoid the player has no control over.

**RMSSD –** The root mean square of successive differences, a measurement often used for HRV to depict health and stress values.

**Stressor –** Triggers that generate a stress response.

**VR –** Virtual Reality, a completely virtual representation of an environment.

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# 1. INTRODUCTION

Through the eyes of consumers most technological advancements are indicated through changes in realism. Elements such as graphics, computing power and complexity have had substantial developments since the rise of the computer. With the arrival of public Virtual Reality (VR), a technology that immerses users into full 3D environments using near-eye displays, the level of perceived realism has increased drastically (Newman et al., 2022). When increasing the level of realism however, more than just graphics are required to provide an immersive experience. The level of interactivity plays an important role, where even minor disturbances can decrease the level of immersion (van Gisbergen et al., 2019; Weber et al., 2021). One aspect of realism many work-fields aim to achieve is a realistic stress response, which is the response humans have to high amounts of stress (Binsch et al., 2021; Meese et al., 2021).

Stress as defined by the World Health Organization (2023) is as the feeling of worry or mental tension when caused by a difficult situation. Humans experience stress throughout their lives and can build a tolerance for it (Cohen, 1980). Exposing humans to stressful scenarios can build tolerance, but it is often hard to reproduce stressful events without difficult situations such as emergencies. The ability to focus may decrease with psychological stress, thus some work-fields that require workers to have a high tolerance for stress scenarios aim to achieve realistic stress response in their education (Flood & Keegan, 2022; Johnson et al., 2020; Taylor et al., 2011).

SeriousXR, a company that supplies and creates training experiences for all work-fields aims to create the most realistic experiences possible and is thus in search of efficient and proven methods to implement stress in their applications (SeriousXR, 2024). SeriousXR wants to create stressful virtual experiences to expose trainees of emergency response workers to scenarios and prepare them for similar scenarios in real life. Stress is very personal, and it is very dependent on the target group whether certain **stressors**, triggers that generate stress, have effects (Johnson et al., 2005). When general stressors are defined however, user testing can narrow down which have the greatest effect. This paper covers the creation of stress scenarios in a mixed reality experience by defining stressors, and testing them with the target audience, in this case Emergency Response trainees.

## 1.2 Company Outline

SeriousXR is a small company with less than 20 employees in Enschede, the Netherlands. It provides and creates VR/Mixed Reality (MR) training simulations to their customers. They utilize Unity (Unity, n.d.) to re-create real life scenarios in the most realistic way possible to aid the training of several work-fields. Most of their past projects involved the creation of experiences that instruct how to operate machines or perform simple work-related tasks. Their latest projects, however, started involving scenarios that rely on high stress tolerance training such as a battery fire training and the project this paper will consider, the emergency response training.

SeriousXR has no guidelines to create these stressful experiences. To deal with this, they have higher development times or require more user testing to prove the effectiveness of the simulation. This paper aims to provide the company with means to implement stressors more efficiently into their projects, lessening the amount of user tests required and aiding in the setup of future projects.

## 1.3 Problem Analysis

The main objective of Serious XR is to create a realistic MR experience that incorporates stress factors. Stress is to be a core component of the training, as it is different from what competitors do. To achieve this, the company needs to implement methods and triggers for stress and be able to measure these stressors.

To test the factors that trigger stress, a general list of stressors was defined to compare suitability and feasibility, some of which were selected for the training. These stressors were defined based on existing trainings from competitors and pre-defined scientific proven stressor. A stress measuring device was created that can measure stress unobtrusively. Furthermore, an MR prototype was created in which the stressors from the created list were tested. These stressors were then evaluated based on the results of the sensors, and a survey each tester fills in after the experience.

## 1.4 Main & Sub questions

**Main Question:** How to artificially induce stress in emergency response trainees of a mixed reality experience to improve upon the realism?

**Sub Questions:**

(1) What are triggers generating stress responses that affect emergency response trainees in a mixed reality scenario?
(2) How can stress be measured in a mixed reality experience?
(3) What stimuli are the most effective in creating stress in a mixed reality experience for emergency response trainees?

## 1.5 Scope

This study was conducted in a separate project from all other projects from SeriousXR in Unity Engine version 2022.3.19f1. No emphasis was placed the usability of the project for non-engineers (only code documentation was applied), and thus editor tooling was not a priority. Furthermore, the focus of the study was the stress part of realism. Other aspects, such as graphics, were not a focus and could have negatively affected the impact of stress. All 3D models were either supplied by the company or are free to use assets with either MIT license or Creative Commons 0 licenses to allow commercial use. Mixamo (Adobe, n.d.), a platform freely distributing 3D character models and animations, was used for character animations. RenderPeople (RenderPeople, n.d.) was used for commercially usable character models. This project was not something intended for the company to build upon but was an exploration of the topic and a tool for providing the stress guidelines and guidelines for using AR. Performance tests indicated the possibility of having a large number of bystanders possible in the training, possibly increasing the effect of social stressors, but this was not implemented due to a lack of 3D models for virtual humans available.

# 2. THEORY

## 2.1 What is stress?

Stress is a response to worry or mental tension (World Health Organization, 2023). As further stated by Chrousos (1998), stress can be divided into acute and chronic stress. **Chronic stress** is seen as long-term stress and is formed during longer lasting events such as education, work, or large life events. **Acute stress** is short-term stress which is formed in moment-to-moment situations such as emergencies, tests or failing to perform in short activities.

As stated by Cohen et al. (1983) stress can be perceived and non-perceived. **Perceived stress** is the stress a human is aware of and can be measured using the Perceived Stress Scale (PSS). The PSS is a survey in which the degree to which participants find their lives uncontrollable, overloaded, and unpredictable is questioned (Korten et al., 2017). While perceived stress is the stress a human can feel, non-perceived stress is a form of stress humans are not directly aware of. **Non-perceived stress** can still affect humans similar to perceived stress, but can only be measured using the human's physique, either chemically through testing saliva or using sensors designed to measure stress. All forms of stress have one common factor; an outside variable triggers it.

## 2.2 What causes stress?

The formal definition of triggers that generate stress is **stressor** (Cambridge Dictionary, 2023). Similar to stress, the stressor can also be divided into long- and short-term stressors depending on how long they trigger stress. **Long-term stressors** or daily stressors are usually related to how a person lives their life and is influenced by aspects such as work, education, home situations, social networks, having confrontations (or avoiding them) and discrimination (Koffer et al., 2016). Short term stressors or **acute stressors** are a trigger that happens instantaneously or over a very short time. These are the stressors that are applicable to games and training simulations, as they are experienced in suddenly stressful situations such as accidents.

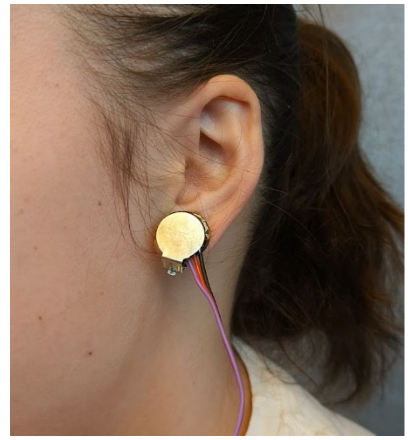
## 2.3 How can stress be measured?

There are many ways to measure stress. The most reliable ways consist of biological chemical tests, in which saliva or sweat samples are tested for hormones (Aschbacher et al., 2013) and the usage of an electroencephalography (EEG) sensor which measures alpha and beta brainwaves (Hamid et al., 2010). There are other methods which are less intrusive and still provide enough data to measure acute stress. The most common way is through a standardized form known as **Perceived Stress Scale** (Cohen et al., 1983; Jiang et al., 2017). This provides insight into the perceived stress level, which is the stress the human is aware of. To measure unperceived stress another strategy needs to be employed.

One method is the measurement of **Heart Rate Variability** (HRV) which is defined by Deepak (2021) as the time in which the heart rate of a human varies. This HRV value is lower under stress and varies between each person (Deepak, 2021). The range for the RMSSD, one measurement used to depict HRV, is 42.9 ± 22.8ms for women and 39.7 ± 19.9ms for men (Voss et al., 2015). Punita et al. (2016) demonstrated in a test with students that values for highly stressed students were 24.60ms while students with no stress had values of 59.50ms. HRV can be measured by using a simple heartbeat sensor and analyzing the data, which makes it an unintrusive method due to the possibility of using finger or ear clips (Figure 1).

**Figure 1:**

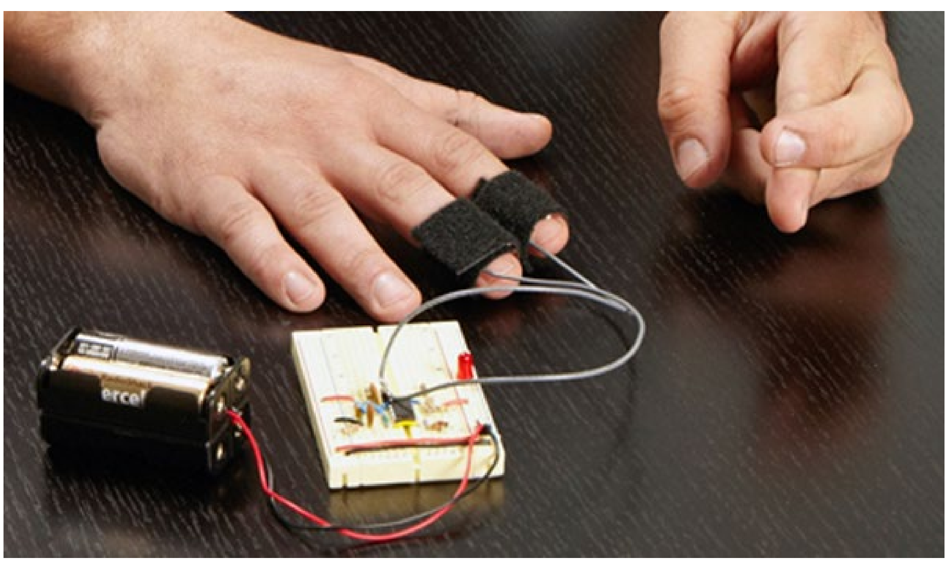
*Example of a HRV sensor*



Besides HRV, **Galvanic Skin Response** (GSR) is another often used method of measuring stress which works by measuring skin conductance (Nagai et al., 2019). When a human is stressed, they start releasing sweat which increases the conductivity of the skin and thus reduces the overall resistance (Markiewicz et al., 2022). By introducing a small pulse on one point and measuring it at another a general skin conductance test can be performed. The GSR can be measured by connecting two wires to fingers and running and analyzing a non-perceivable pulse through them (Figure 2). While unintrusive, it does require to be placed on the hand which can be distracting during hand-focused activities.

**Figure 2:**

*Galvanic Skin Response kit, an example of a GSR sensor.*



*Note:* From Galvanic Response Kit by Maker Shed (2011). Makezine(https://makezine.com/article/technology/in-the-maker-shed-galvanic-skin-response-kit/)

# 3. COMPETITOR ANALYSIS

For emergency response VR simulations there are roughly four available competitors: (1) Virtual Life Support (VR Lab, 2022) (Figure 3), (2) RCP (Ludus Global, 2021) (Figure 4), (3) VR CPR Training (Yord Studio, 2022) and (4) CPR Simulator (AATE VR, 2023). Analyzing the competitors, the implemented stressors from each can be sorted into three categories: social, auditive and gameplay. The **social stressors** include having others comment on the trainee's work, stare at the trainee for prolonged times or showing signs of having stress themselves which sets the tone of the situation. The **auditive stressors** are high stimuli background noises such as passing-by cars or dogs barking to distract the user from their task and induce some frustration. Finally, the **gameplay stressors** include aspects such as requirements to fulfill tasks within a time and adding complex tasks.

**Figure 3:**

*Virtual life support CPR training.*


*Note:* Taken within Virtual Life Support by VR lab (2022)

**Figure 4:**

*RCP training.*

*Note:* Taken within RCP by Ludus Global (2021)

While direct competitors show insight into how they approach it, they are not proven to be working. Research into stress for other training simulations gives insight into proven stressors. Eight simulations that stated their stressors gives insight into validated stressors (Abujelala et al., 2021; Binsch et al., 2021; Chaabane et al., 2022; Chang et al., 2021; Finseth et al., 2022; Malta et al., 2021; Nguyen et al., 2021; Tyagi et al., 2023). Table 1 shows the stressors stated by each paper and the work-field simulations were created for. Similar to direct competitors; social, auditive and gameplay are still used as stressors in all researched simulations. Besides these, visual and psychological stressors are used. **Visual stressors** are high stimuli visual cues such as blinking lights and smoke covering up the area. **Psychological stressors** are elements that cause fear or panic such as fire, unstable buildings, children getting hurt or gun shots.

Existing works give five different stressor categories, but general stressors also provide insight into some more generic stressors. The most common method of testing stress currently is the **Trier Social Stress Test** (TSST). TSST is divided into three phases: the preparation of a presentation about yourself under time pressure, presenting with a set presenting time to strangers (5 min) and a mental arithmetic ending (counting back from 1022 in steps of 13). This can thus be divided into two stressors: (1) social stressors and (2) cognitive stressors. **Cognitive stressors** are stressors in which a person is confronted with complex cognitive tasks and most importantly the consequences of failing the task.

Thus, stressors can be defined into six different categories: **social, auditive, gameplay, visual, psychological, and cognitive**. Furthermore, a combination of these stressors is the most effective way to induce stress.

Table 1: *Stressor Analysis*

| Field | Author | Stressors |
| --- | --- | --- |
| Space/Pilot | Finseth et al., 2022 | Alarms, flickering lights, degraded visibility from smoke.<br><br>Method: 3 different levels of stressor intensity |
| Healthcare/Military | Binsch et al., 2021 | Task difficulty, noise, lighting changes, social evaluations, electric muscle stimulation and a simulated attack on the convey.<br><br>Method: 4 phases with increasing stress |
| Police | Nguyen et al., 2021 | Weapon, crowd, unexpected weapons, aggressive dog, blood, darkness, injured people, loud unexplained noise, scream, unknown origin of smoke.<br><br>Method: Poll; results are from most to least stressful |
| Warzone | Malta et al., 2021 | gunfire, bombs, grenades, and improvised explosive devices and seeing vehicle damage, but no human injuries or deaths.<br>*participants had traumas already*<br>Method: Different phases with different stress levels (e.g first patrolling, then an attack phase occurs) |
| Emergency Response | Tyagi et al., 2023 | Explosions, fire, smoke, structural collapse and alarms.<br><br>Method: Randomly assigned groups with different stress levels |
| Ambulance emergency response | Chaabane et al., 2022 | Injured children, school shooting.<br><br>Method: Different experiences for different groups (VR, audio or flatscreen) with the same narrative |
| Resuscitation Training | Chang et al., 2021 | seizure movements, repeated vomiting, and crying or shouting colleagues.<br><br>Method: Two groups; one control group and one with stressors |
| Fire fighters | Abujelala et al., 2021 | fires, alarms, and smoke.<br><br>Method: Two groups; one control group and one with stressors |

# 4. DEVELOPMENT

## 4.1 Design Process

The prototype was developed through an iterative process using git in which feature branches were used. This allowed for simple source control, prototyping and testing. Major features such as AI was initially made outside of the project bounds to be customizable and was later implemented into the actual prototype. During development, elements were tested with colleagues to receive feedback and new ideas on how to approach certain aspects.

Throughout the development cycle a form of the double diamond was followed. The double diamond follows the structure of discover - define – develop - deliver. The first part of development was dedicated to research and **discovering** the different features required for the prototype and the end users. Furthermore, definitions for stress and how to measure stress was researched with the help of a literature matrix. The second part of the cycle, **defining**, was combined with the third which requires **developing**/prototyping and fourth part in which prototypes are **validated**. Features were defined and immediately prototyped individually with colleagues. The cycle would continue until playtests were satisfactory. This process ensured that individual parts would work, which later combined into a full prototype which was also tested again with family and colleagues.

## 4.2 Technology

### 4.2.1 VIRTUAL REALITY

The prototype was designed to work on the Meta Quest 3 (Meta, 2023), henceforth known as the Quest 3. This headset has full color passthrough which allows for AR, and simple hand-tracking which are requirements for the prototype. The company often uses the Quest 3, which currently their main VR headset they use for their services.

### 4.2.2 STRESS MEASUREMENT

The stress was measured through the use of HRV. Both Heart Rate Variability (HRV) and Galvanic Skin Response (GSR) were tested using Arduino and the respective sensors. A simple program was written to use these sensors and display the results on a small screen, which were also sent over Bluetooth or a cable to a laptop on standby. The results were imported into excel after placing the raw data in text files using processing and were later analyzed.

The connection of the different circuits was done using an Arduino Uno (Figure 5). A single 9V battery can supply enough power to run the circuit, when not connected to a laptop. To be able to measure the GSR, an arm band was required with the Arduino attached that would constantly be monitoring the stress levels. The HRV sensor could either be attached to the headset and measured throughout or measure the stress levels before and after each run to test the stress before the training and after the training.

The two methods were tested and HRV was quickly deemed more reliable for this use test. While GSR did work, it only showed stress the moment something occurs and can easily be confused with just taking deep breaths. Furthermore, the finger gloves had to be tight and made hand tracking, a crucial feature of the training, unreliable. HRV could be measured before and after the training itself and is thus a better approach to the measurement of stress, and the readings allow for post-test analyzation which ensures math can be corrected when required.

**Figure 5-0**

*Circuit of the HRV Sensor*

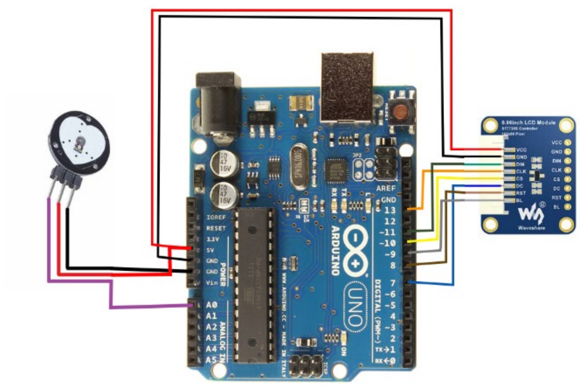


**Figure 5-1**

*Circuit of the GSR Sensor*

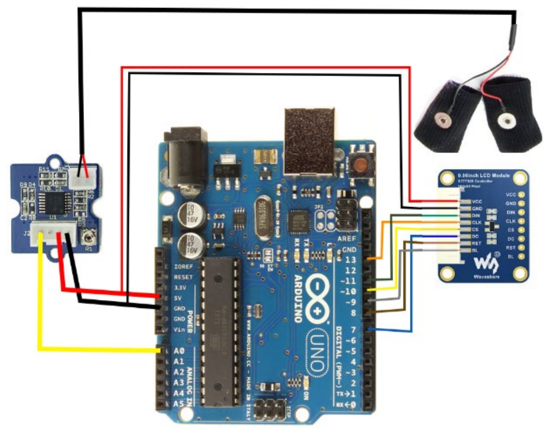
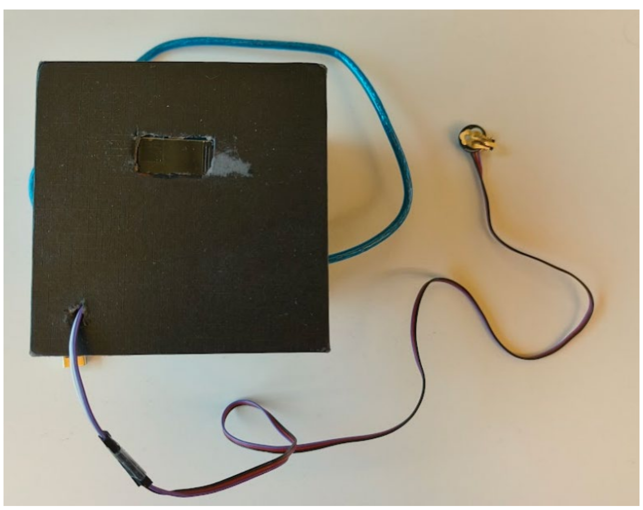


**Figure 5-2**

*Final stress measure box with HRV*



## 4.3 Prototype setup

To artificially induce stress, a blank prototype was created to which stress factors could be applied. The prototype was created using Unity (Unity, 2024). Unity provides the best tools currently available to create MR experiences, as they are in direct collaboration with manufacturers from the headset used for the project, Meta. OpenXR (Khronos, n.d.), a base VR foundation that provides means to port VR games to any platforms, was used for this project in combination with meta specific plugins for better integration of AR.

The base prototype setup consisted of an AR environment (an empty room) with non-controllable humanoid characters and interactable objects added the room. As the prototype was built as an MR application, it had a mix of virtual elements and real-life aspects. The environment was based on Augmented Reality (AR) in which the virtual objects are projected onto the real world. In the base prototype a single NPC walked around until they fall on the location of a physical CPR dummy. The trainee had to follow procedures for CPR as defined by the Red Cross (n.d.) and seen in Figure 6. After a couple minutes an ambulance would arrive which relieved the player of their CPR work. A simple tutorial aided the player in their actions, explaining what the steps are and how to proceed. Based on the actions of the player a score was assigned at the end.

**Figure 6**

*CPR for an Adult*


*Note.* From CPR for an Adult by Red Cross, n.d. Laborposters(https://www.laborposters.org/img/poster-thumbnails/first-aid-fa-poster-cpr-web-large.jpg)

The CPR steps (Figure 6) consisted of chest compressions and giving oxygen. The chest compressions were simulated by using the hand and head positions. The movement values were calibrated with the CPR doll called AmbuMan (Ambu, 2017) and was tested with colleagues. Giving oxygen was simulated by having the trainee place their head near the head of the manikin, requiring no actual breaths to the doll.

## 4.4 Game Design

The prototype design was deliberately kept simple, allowing for the stressors to have more impact. As the base of the training was a resuscitation training, the CPR steps for adults were replicated (Figure 6). To avoid gameplay complications, a simple tutorial was added in the form of an Automated Electronic Defibrillator (AED). The AED is a device used to analyze heartbeats and give electronic shocks, which in real life already instructs responders through the steps required. This decision was made to avoid having players losing focus due to questioning what to do and asking people outside the training how to proceed.

The AED thus served as a guiding aid which is especially important during the first time the player runs through the simulation. The third time the player runs through the simulation, the tutorial and thus AED is completely removed. It spawned in very close to the human and instantly had all the required resources to operate it. It instructed the player through AI generated voice lines and had a small slider bar to indicate the amount of pressure applied to the dummy, allowing trainees to see how much pressure was required for CPR. It instructed when to perform compressions and when to give oxygen or when to give a shock.

Stress design was done conforming to the defined stress categories: social, auditive, gameplay, visual, psychological, and cognitive. Each category has a few simple implementations with variables attached. The implementations are based on competitors and ideas from colleagues and previous research.

### 4.4.1 Social Stressors

The social stressors were designed to give social stimuli to the trainee. These triggers consisted of NPCs talking to the player, giving (invalid) criticism, and displaying a stressed body language as humans often mirror behavior of others (Rizzolatti & Craighero, 2004).

### 4.4.2 Auditive Stressors

Auditive stressors were simple stimuli to distract the trainee and keep them off balance. Elements such as microwave beeps, people talking over important conversations (such as the one with the ambulance) or other sounds associated with something going wrong could trigger the trainee to feel uneasy or frustrated.

### 4.4.3 Gameplay Stressors

Gameplay stressors were stressors baked into the gameplay and are thus dependent on the number of variables in the gameplay. With the current setup, only a few variables exist. There is one large gameplay feature that can be altered however, which is the AED. The removal of features or the complete removal of the AED made it impossible to track whether what the trainee is doing is correct and could make them question themselves. At the end results were shown whether what they did was correct, or incorrect.

### 4.4.4 Visual Stressors

Visual stressors were very similar to auditive stressors where they were implemented to distract the trainee and cause frustration. Elements like flickering lights, dimming the lights, or having smoke limit the view of trainees and could have caused confusion or frustration which was theorized to lead to stress.

### 4.4.5 Psychological Stressors

Psychological stressors were the most personal and could not be defined for a whole target audience. Some general psychological stressors were defined but were improbable to work for all. Elements such as gross or hygienic visuals were applied to disgust the trainee and discourage them from doing their job. This was implemented in the form of vomit, or wound textures applied to the visuals, and a small bit of water being applied to the doll to simulate the liquid effects. Furthermore, other elements such as gender (as victims need to be undressed) or the implementation of children were considered but were not implemented due to the limitations in time and the doll not having the correct proportions.

### 4.4.6 Cognitive Stressors

Cognitive stressors were stressors important to many applications where the user needs to think about their actions. Besides having to follow the steps correctly, which could also be considered a gameplay stressor, no cognitive stressors applied to the training. Some simple elements could have been implemented such as mentally stimulating questions, but the voice recognition it required for trainees to respond is outside of the scope and thus unrealistic. The removal of the AED and thus any indications could be seen as a cognitive stressor, but the choice was made to remove this stressor category from the training altogether.

## 4.5 Prototype Iterations & Feedback

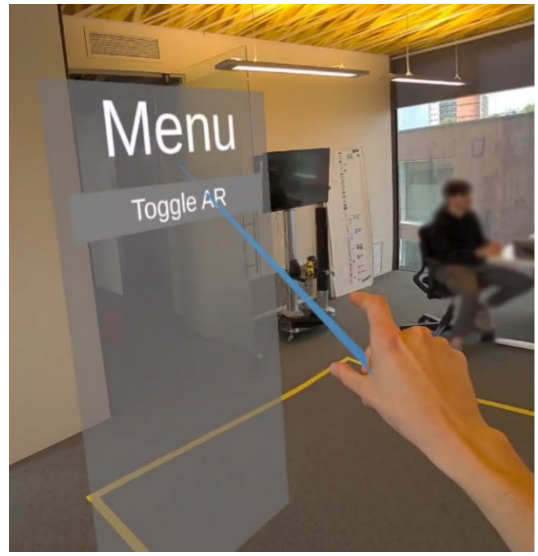
### 4.5.1 The MR base prototype

The first prototypes to be created implemented simple AR with some depth possibilities and the switch between AR and VR. The prototypes were tested with both OpenXR and the Meta Quest platform plugins, and OpenXR was ultimately used on request of SeriousXR. These first prototypes had no real interactivity aside from menu interactions, hand tracking and depth calculations.

The first feature to be implemented was the handtracking, which was implemented with the XR Hands plugin from OpenXR. This plugin allowed for simple hand recognition, input (position, rotation, finger position, pinching) and hand gestures, which covered all the features required for the training. To install it, it simply required activating a plugin in Unity and the installation of a sample pack. The initial menu selection tool was built after experimenting and learning how to properly use gestures and input using the XR hands plugin (Figure 7).

**Figure 7**

*Hand recognition and menu interaction with gestures.*




AR is implemented into Unity by transforming the skybox into the camera feed picked up by the headset. This causes a problem, as all virtual objects are always in front of the skybox, and are thus always fully visible even when in reality they should be obstructed. To increase realism, virtual objects could be assigned a material that would help to percieve them better in relation to real-life objects. This material was transparent, and made objects behind them transparent as well, thus showing the skybox or real-life objects. The material was assigned to objects such as pre-positioned tables and chairs, and the hands to allow real-life objects to show in front of virtual objects. An example of this can be seen in Figure 8, where the cat is not occluded on the left and is occluded behind the physical object on the right.

**Figure 8**

*Depth occlusion example*

*Note.* From ARCore depth API by Android Community, n.d. AndroidCommunity (https://androidcommunity.com/wp-content/uploads/2019/12/ARCore-Depth-API.jpg)

This prototype was a base for future prototypes, which was often play tested. While this base version itself did not have many iterations from feedback, many features were added over time such as the ability to switch between AR and VR and custom behaviors for certain furniture objects.

One major feedback point that was implemented however was the sensitivity of the menu selection beam. It was unreliable to trigger it when not experienced with the project, thus extra gestures were added to ensure more reliable trigger mechanism.

### 4.5.2 The doll positioning prototype

The doll positioning prototype was the first interaction in progression towards the final goal of making the CPR prototype. The problem when creating this prototype consisted of how to calibrate the positions of a real-life doll into AR reliably. For this problem to be solved, a virtual human would have to end up falling exactly on top of the doll. This would increase immersion over the fake doll that is there in real life.

To solve this issue, first competitors were analyzed to view their solutions, as all CPR trainings encountered this problem. While many do not demonstrate how they calibrate the doll, Virtual Life Support (VR Lab, 2022) solved this issue by requiring the user to carry over a virtual outline to the real doll. After testing this, it was found to not reliable as the outline would sometimes show up far from the actual doll.

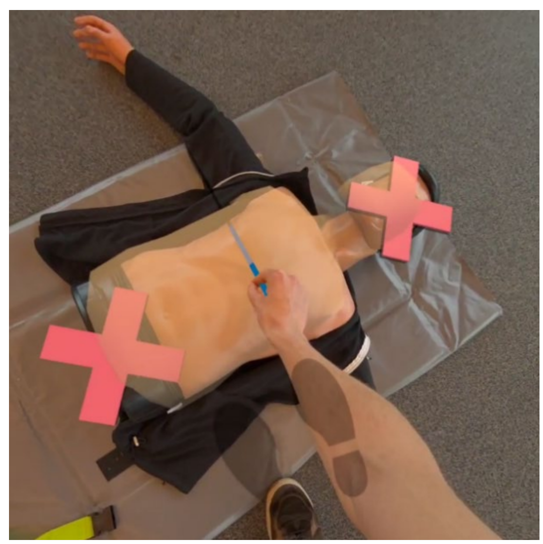
**Figure 9**

*Calibration anchors to define the doll position.*

Next, a completely new approach was designed and tested. Instead of dragging the object, the menu interaction beam was altered to allow the placement of crosses on objects labeled as floor which allowed users to aim at the top and at the bottom of the dummy to calibrate the positions (Figure 9). Undocumented playtests had shown it was a promising way of calibrating the body. The positions of the anchors could be saved, which allowed testers to set it up once and remember the position of the doll.

**Figure 10**

*Calibration hybrid solution with an outline that can be moved by picking it up.*



Later from feedback this was changed into a hybrid version from the competitor and the current prototype. This change was made based on tests, after which instead of only offering the option of placing crosses, a drag feature like the competitor was added after the anchors had been set. This makes it so the body spawns in approximately the correct position, after which it can be fine-tuned with proper placement. This was play-tested often, and it was intuitive to use after learning how to use it once. This implementation can be seen in Figure 10.

Finally, the saving of positions was removed as it was not reliable. The headset would often detect a room change, even when staying in the same room. As the doll position was bound to the room, changes made it random to where the virtual doll would appear, and it was thus opted to remove the feature.

### 4.5.3 The falling human prototype

The next prototype to be created was the falling human prototype. Once the doll had been calibrated, it was required for the program to have a virtual human walk around and fall precisely onto the calibrated doll. To create this, AI had to be created with the ability to receive a trigger to fall, after which it would walk to the perfect position and start falling.

**Figure 11**

*Early version of "sick" falling NPC human that randomly walks around in AR.*

First, the base AI had to be made which could be expanded to incorporate the requirements. A simple state machine was created which initially used non-inherited classes. These classes had AI state interfaces which allowed them to have specific instructions for each state. Behavior was added to these classes, creating three states: random walk which determined whether to wait or where to walk to, destination walk which was the walking itself and a falling state which would trigger the NPC to fall down at a specific location (Figure 11).

The state machine was later changed to use an abstract class system. This made for better and easier casting to different states while adding the option to synchronize variables and serialize the classes. An extra state was also added: a rotation state which rotated the AI to a desired rotation over time to make the falling more reliable.

**Figure 12**

*The NPC human once it has fallen down on top of the anchors*

The final solution to the problem was the creation of an NPC human that could randomly walk around until a trigger for falling was received after a random number of seconds. Upon receiving the trigger, the virtual human would walk to a spot that was based on the position of the calibrated doll and would proceed to rotate to the perfect rotation and fall (Figure 12). When exiting any of the states, everything would be reset to ensure the possibility of recalibration.

### 4.5.4 The bystander prototypes

Based on the stressors defined earlier, social stressors would be a large part of this application. To create these stressors, virtual bystanders had to be created. In the first bystander prototype, they were simple and only rotated their head to the human without adding any interactivity. They were based on the falling human AI (Figure 13). To make them more realistic however, they required the ability to speak, wink and perform different animations when talking.

The speaking was achieved by analyzing the audio waves from audio clips and moving the mouth from a closed point to an open point based on the wave value. Values from zero to one opened and closed the mouth to generate a primitive lip-synchronization. This required the virtual humans to have proper bones for mouths, which removed the possibility of using Mixamo (Adobe, n.d.) characters. RenderPeople (RenderPeople, n.d.) offered four free commercially free to use fully rigged 3D humans that had the proper bone setup.

These more customizable virtual humans allowed for the addition of winking as well. They got the ability to wink and look at targets to increase realism.

Based on user tests the humans were still found to be very static, thus in a later version they also played random animations (retrieved from Mixamo) when selecting a voice-line to play. These actions ranged from taking photos, showing worry, kneeling or performing simple hand moving animations.

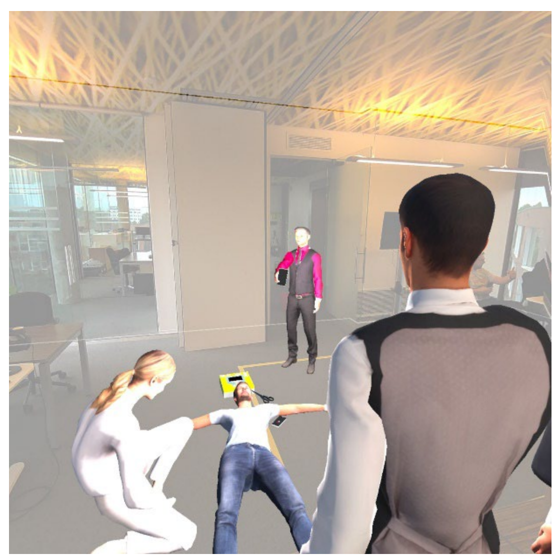
Finally, the humans were changed to pick from pre-determined places to watch from based on the calibration of the doll. The humans would often stand too far away from the doll or stand within each other which decreased the realism or feeling of being watched. This change was made based on feedback from one of the playtests. The final solution can be seen in Figure 14 where one of the characters is taking a photo with flash.

**Figure 13**

*Early bystander AI using Mixamo characters. One character idles and the other takes pictures while idling.*

**Figure 14**

*Final bystander AI with custom animations (& phone flashing camera) using RenderPeople models.*



### 4.5.5 VR mixed environment prototype

One of the initially important features was the possibility to switch between VR and AR. To create this, a spyglass was created to see if AR could be brought into VR. This led to the possibility of making the head of the dummy an AR sphere which meant that the user could still properly give oxygen to the doll even in a full VR environment (Figure 15). More immersion was created with the ability to bring real chairs and tables into the VR (Figure 17).

Other MR aspects included the changing of light. A shader enhancement was created to besides changing light levels of AR environments, add the possibility to add point lights (Figure 16). These could be placed on top of walls and with the coordinates of a point light and a radius could look like light was added into the scene.

One change that occurred later in the project was the complete removal of the VR version. While this version was initially high on the priority list, it was later deemed unnecessary for the project and due to time constraints removed altogether. The final version is thus still MR, but the environment is always AR on top of which virtual elements are added.

**Figure 15**

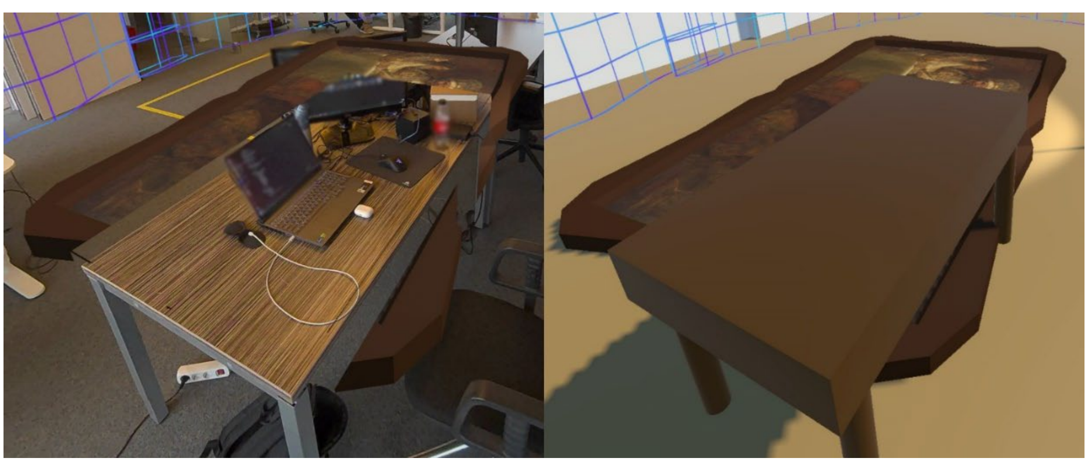
*Weirdly proportioned falling human with a transparent/occlusion head*

**Figure 16**

*Point light at the microwave with low lighting in the back.*

**Figure 17**

*Comparison between VR and AR environment. The Table is automatically generated and occludes objects behind it.*



### 4.5.6 The start of the real prototype

Combing the previous prototypes created a base prototype on top of which gameplay was added. The steps of CPR had to be recreated into a gameplay loop. The first problem that arose was the analogue nature of the dummy, which did not have the possibility to send data such as compression depth to the headset. The solve this, the position of the hands and head were used to recreate an approximation of compression depths. A slider indicated how deep compressions are which can be seen in the back of Figure 18.

**Figure 18**

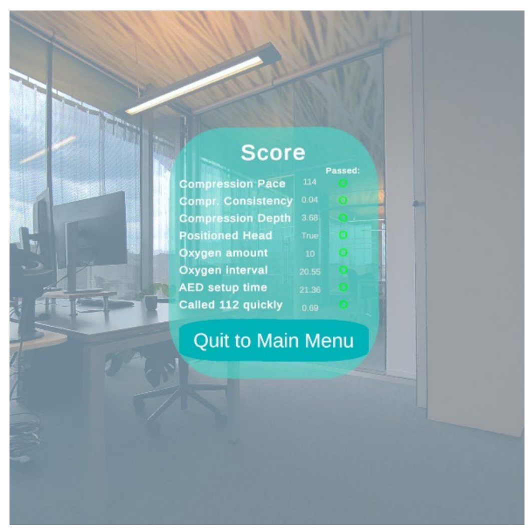
*Compressions with AED in the back displaying the current depth (slider in white)*


Giving oxygen was done by using a collider to check the head position. Oxygen was later changed to only work when the head was positioned correctly by holding a hand near the chin of the virtual human. The main issue with this approach was that when listening to see if the person was breathing, the oxygen giving sound would play. From playtests this was not really an issue, and stayed in the final version as other solutions would require more time. With this performing each of the CPR steps was possible.

To complete a gameplay loop, linearity was added in the form of the AED. The AED was simultaneously a simple tutorial which instructs users on what to do. Combined with a simple phone which played five pre-determined voice lines, the user could now follow steps and reach a point where they would infinitely give CPR.

**Figure 19**

*Score given at the end of the training*




Finally, an ending was required. For this, an ambulance was added that would show up after a predefined number of seconds, 150 in the case of this training.  The timer would start after a call with the phone had been placed. The choice was made to make the ambulance purely a sound that increases over time with no actual graphics as modelling is outside the scope of this project.

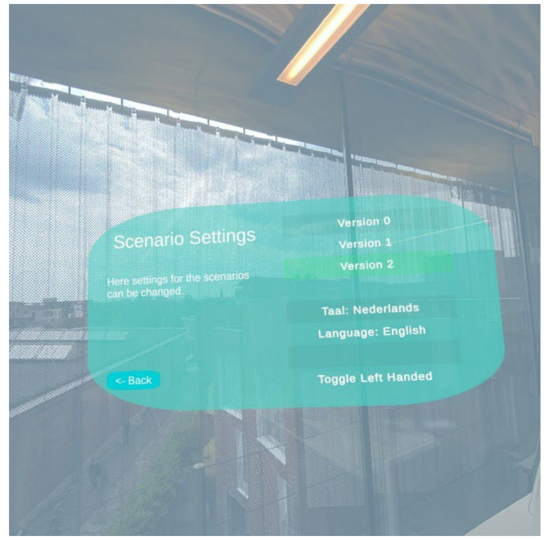
With a gameplay loop prototype completed, a primitive score was added that calculates performance based on the actions done throughout the training (Figure 19). This was found to be one of the most important features of the training, as all testers were very interested about their performance throughout the training.

### 4.5.7 Stressors & other feedback

The base gameplay loop offered a base version of the prototype. It was tested thoroughly and often and many minor tweaks such as the positioning of the AED, language options, left-handed mode, and changes in interactions with pads and scissors were suggested. This was all placed in a to-do list and worked out throughout the development of the stressors and other features.

**Figure 20**

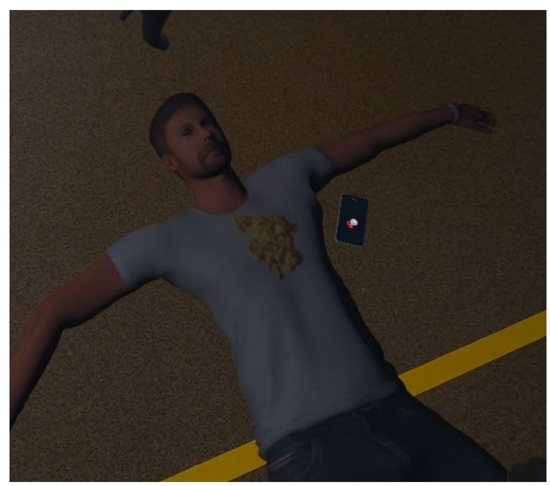
*Scenario settings. Each version is a different stress preset*




The implementation of stressors was done based on the design made in the design phase and only required implementation at the correct positions, as implementation methods were already defined. The stressors were subdivided into presets as seen in Figure 20 and Table 2. The stressors were play-tested thoroughly with colleagues and family. Based on tests, changes were suggested such as: a change in volume from talking humans, the presence of humans and the option to interact with some things such as the microwave to turn them off. It was also opted to not implement some of the higher difficulty stressors at this point. One feature initially planned was smoke. However, smoke was found to be hard to implement and the smoke used previously by SeriousXR was impossible to transfer. Furthermore, voice recognition was also not practical due to the Dutch language requirement and was thus scrapped.

**Figure 21**

*Throw up in stress preset 2. This preset also incorporates dimmed lighting.*



While implementing the psychological stressors, further problems arose with the requirement of a shirtless version, wounded version and a throw-up version of the victim (Figure 21). These would require 3D models to either have shirts that are separate from the body or a complete re-work. As both options were impossible without 3D modeling skills, a different solution to this issue was to alter the body instead in photoshop and add a fake shirtless version on top of the existing shirt. While hypothesized to be distraction, based on feedback from testers the shirt outlines went unnoticed, possibly due to stress.

In general feedback was positive. Many ideas arose with the testers which usually indicates high interactivity with the project. Most features were outside of the scope of this project, but many were implemented and made for good improvements. In total around eleven prototype/iterations were created and tested throughout development. This made the final testing to be without many surprises on the bug side of things, although some minor things were changed even during the tests such as the placement of certain objects.

# 5. TEST SETUP

Before stress-tests were completed, a benchmark was done to test performance and to reduce the change of motion sickness. After, tests with the prototype were performed with in total eight different testers, of which three tests were taken in pre-determined fully replicable conditions and five in slightly less perfect conditions which are denoted as extra tests. The trainees were told the stress measurement devices gave insight into other data for the simulation, but are aware stress is a factor implemented into the application.

To compare measurements of stress with sensors, a baseline was first set. Users were first introduced to a relaxing environment in which they got the opportunity to calm down completely, during which a baseline stress level was calculated. After a baseline was set, the first playthrough was done which had no stressors applied. This served as both a tutorial and a baseline for gameplay related stress. A stress measurement was done after the first playthrough, and the second playthrough settings were configured with stressors applied. After the second playthrough stress was again measured, and the settings for the final playthrough were configured. A final stress measurement was done, and the stress survey was given to get a measurement on the perceived stress levels. The stressors for each preset can be seen in Table 2.

**Table 2:** *Settings for the stress test*

| First run | Second run | Third run |
|---|---|---|
| No social stressors | 4 NPCs that talk to the player | 4 NPCs that comment on the player and give criticism |
| No auditive stressors | Microwave beeps (90bpm), car alarms & honking | Microwave beeps (90bpm), car alarms & honking, loud people talking over the emergency response call |
| No additional gameplay stressors | No additional gameplay stressors | No AED (no indication of progress or pressure) |
| No visual stressors | Flickering lights | Flickering lights, low light levels |
| No psychological stressors | Small wounds on the victim chest | Vomit on the victim |

## 5.1 Performance Benchmarks

To allow proper testing and to minimalize the risk of motion sickness which a common factor in VR (Chattha et al., 2020), the performance had to be benchmarked. This consisted of running reproducible tests with different variables to get a reading on the performance. This was done using the Meta Developer Hub built-in performance measuring tool called Perfetto. Perfetto measures all data generated by the VR headsets in a given timeframe and outputs a file which can be read from their webpage containing all different analytics. It outputs frame times, weighted averages, min and max frame times which was used to find out the limits of the application.

For performance to be considered good it has to be capped at 72 frames per second (FPS) (Wang et al., 2023). The FPS on headsets is variable, and the Quest 3 supports 72, 90 and 120 hertz modes. 72 is considered the minimum for an application to be well optimized, and is thus the target of this test. The framerate is in the application capped to this amount, as OpenXR does not offer settings to increase it further for Quest builds.

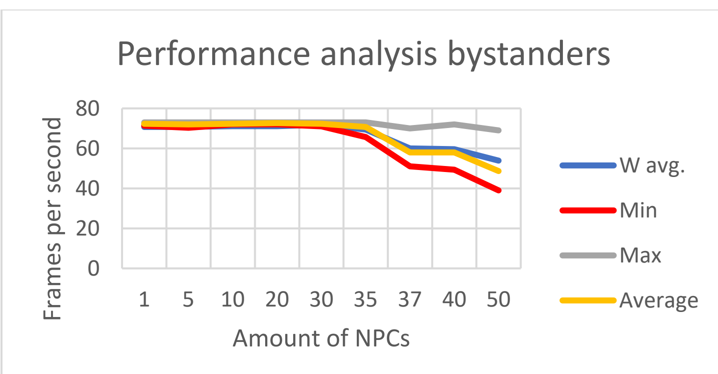
The application was tested with the variable of NPC bystanders. The full final version of the application was used, and performance was tested at the point where all NPCs (including the victim) are still walking. Each test consisted of 3 readings of the same number of NPCs, which were averaged into the results. A bystander has 12.000 ± 500 triangles; the uncertainty is due to each model having a slightly different triangle count.

**Table 3:** *Performance benchmark results*

| Amount of NPCs | Triangle Count (*1000) | Weighted average (FPS) | Min (FPS) | Max (FPS) | Average (rounded) (FPS) |
|---|---|---|---|---|---|
| 1 | 12 ± 0.5 | 70.68 | 71 | 73 | 72 |
| 5 | 60 ± 25 | 70.78 | 70 | 73 | 72 |
| 10 | 120 ± 5 | 71.07 | 72 | 73 | 72 |
| 20 | 240 ± 10 | 71.13 | 72 | 73 | 73 |
| 30 | 360 ± 15 | 71.86 | 71 | 73 | 72 |
| 35 | 420 ± 17 | 69.44 | 66 | 73 | 71 |
| 37 | 442 ± 18 | 59.99 | 51 | 70 | 58 |
| 40 | 480 ± 20 | 59.59 | 49 | 72 | 58 |
| 50 | 600 ± 25 | 53.88 | 39 | 69 | 49 |

**Figure 22**

*Performance analysis graph*




As seen in Table 3 and Figure 22, the performance is capped at the maximum with minor dips starting to happen around 35 NPCs. This is further amplified at 37 after which the performance is unacceptable. The limit for the sheer number of NPCs is thus 35, equating to 420.000 ± 17.500 triangles, after which nothing else requiring large performance can be added. In practice, this is not viable as only 4 different character models are available for free to be used without commercial constraints which includes the victim 3D model. One other variation on one of the models has been made using Photoshop, which makes the total bystander amount 4. This proves that the application has enough performance to minimize motion sickness.

## 5.2 Survey

The survey was created with the intention of finding the perceived stress levels of testers. It is based on the generalized test named the Perceived Stress Scale which aims to find these levels, which is focused on a large amount of time and is more centered towards life questions as seen in Figure 23. To get a view on the acute perceived stress levels a custom survey was made.

The first questions were to find out the situation of the tester and how experienced they were with CPR. These questions consisted of the following: (1) “What is your job title”, (2) “Have you ever completed a CPR/resuscitation training?” and (3) “Why did you require CPR” in the case question two was answered with a yes. Finally, the question (4) “Had you ever experienced a virtual reality simulation before this” allows for a filtering of people who had experience with VR or none, the latter of which could introduce stress or amazement with the technology instead of the application.

**Figure 23**

*Perceived Stress Scale test*

**Perceived Stress Scale (PSS-10)**

Instructions:

The questions in this scale ask you about your feelings and thoughts during the last month. In each case, you will be asked to indicate how often you felt or thought a certain way.

In the last month, how often have you...

| | | Never | Almost Never | Sometimes | Fairly Often | Very Often |
|---|---|---|---|---|---|---|
| 1 | been upset because of something that happened unexpectedly? | 0 | 1 | 2 | 3 | 4 |
| 2 | felt that you were unable to control the important things in your life? | 0 | 1 | 2 | 3 | 4 |
| 3 | felt nervous and "stressed"? | 0 | 1 | 2 | 3 | 4 |
| 4 | felt confident about your ability to handle your personal problems? | 4 | 3 | 2 | 1 | 0 |
| 5 | felt that things were going your way? | 4 | 3 | 2 | 1 | 0 |
| 6 | found that you could not cope with all the things that you had to do? | 0 | 1 | 2 | 3 | 4 |
| 7 | been able to control irritations in your life? | 4 | 3 | 2 | 1 | 0 |
| 8 | felt that you were on top of things? | 4 | 3 | 2 | 1 | 0 |
| 9 | been angered because of things that were outside of your control? | 0 | 1 | 2 | 3 | 4 |
| 10 | felt difficulties were piling up so high that you could not overcome them? | 0 | 1 | 2 | 3 | 4 |

*Note.* PSS-10 by NovoPsych, n.d. NovoPsych(https://novopsych.com.au/wp-content/uploads/2022/02/pss-10-picture-blank-form-PDF-1.png

The following questions were related to the actual application. The next question was (5) “Throughout the experiences, did you feel surprised that something happened unexpectedly” which could be answered from in a 5-likert scale, where 1 meant “never” and 5 meant “often”. Surprises are a large part of stress, and new situations require focus and attention. The following questions was (6) “From the playthroughs, which one was considered as most stressful” which gave a direct reading on which of the settings combined to be the most stressful. None was also an option in case none of the experiences were considered stressful. Question 6 could be elaborated on in a text field.

The following questions (7-15) had 5-likert scales. The questions 7 to 9 were to find the personal opinion on how focused the testers were during each of the playthroughs with 1 meaning “no focus” and 5 meaning “full focus”. Questions 10 to 15 were related to the individual stressors with 1 meaning “did not notice” and 5 meaning “was not able to focus”.

The final questions allowed for some general remarks and feedback which could offer improvements to the application, or ideas on how to approach things differently. These will be discussed in the discussion as well.

The full survey is available in the full report. Results from the survey will be discussed in Chapter 6 Results.

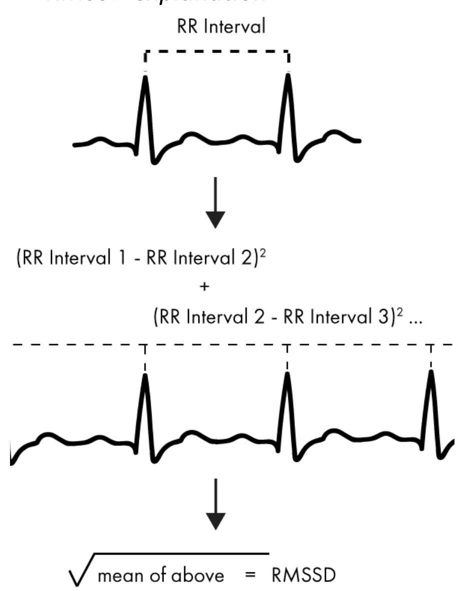
## 5.3 Results setup

The tests were done in different phases. HRV was used to measure stress, which required a baseline and a measurement after each test. The first phase, or the baseline phase consisted of a meditation app that was selected called Nature Treks VR to get a baseline of the stress levels. The participants had to attach an ear clip after which they would relax in a meditative environment. After two minutes the measurement was started, which lasted 2.5 minutes. The results were noted down and a file was created with all the raw heartrate results which can be re-analyzed after the tests were completed. The ear clip would be removed after a measurement was performed.

The second, third and fourth phase were playthroughs of the prototype. The VR headset was set up with the correct settings (presets were created to follow the stressors as defined earlier), and participants played through the application. Throughout the experiences, only the first playthrough required a little outside guidance as no one had ever used hand tracking before which made the body setup non-intuitive. After the first playthrough, participants were again connected to the HRV sensor, and the heart rate variability was again calculated. After the calculations, results were noted down and the next stress preset was selected. This was done until all three versions had been tested, after which the participant would fill in the survey.

**Figure 24**

*RMSSD explanation*




*Note.* Heart rate variability by Bryn Farnsworth, 2019. imotions(https://media.imotions.com/images/20190411122521/RMSSD-walkthrough.png)

The data can be analyzed based on the heart rate readings. A heart rate is the amount of time between pumps of the heart, and the interval between each heartbeat is called the R-R interval, which is the time between peaks from heart beats. These R-R intervals can be analyzed further to determine the RMSSD as seen in Figure 24.

The RMSSD values can be interpreted as direct stress factors, where the baseline allows for a base level without any stress and further values can be compared to the baseline. Lower values mean higher stress, and higher values thus mean less stress.

One of the factors that can introduce errors in this setup is the fact that physical exhaustion also changes the RMSSD values. An attempt was made to minimize the amount it would affect the HRV values by taking around two minutes before starting the measurement after the training was completed. This was done by adding a results screen and discussing the results of the training.

# 6. RESULTS

## 6.1 Results Tests

In total eight tests have been conducted, of which three with the full testing procedure and five with minor alterations. Results of the survey are given in the respective score-based form to allow for comparison in the analysis. Only the comparable survey results are reported in this section, the full list of answers can be found in the full version of the paper.

The full analysis of the tests is done in 6.2 Analysis. Data is presented in three different ways: (1) A Table with stress values, (2) a graph based on the stress and (3) survey results. The stress Table contains two values of which the RMSSD is most important. Lower values of the RMSSD indicate more stress, as the heart rate is more stable under stress.

Four tests were conducted as stated previously in the test setup. The base represents the RMSSD value with no stressors applied at all in a relaxing VR game. This measurement allows for comparisons with the other measurements, which are taken after each stress preset from Table 2.

The survey data will be presented with abbreviations for each question and a color indicator whether it means they were stressed or not as displayed in Table 4. The range indicates the possible range or options of the answer (with 1-5 indicating a likert scale). The last two empty cells indicate the color range, where warm colors indicate more stress (orange/yellow) and higher focus/less stress is indicated in colder colors (green/blue). As there are two different scales there are two different color types.

The first scale goes from “no focus” (yellow) until “completely focused” (blue). The second scale goes from “did not notice the distractions” (green) until “could not focus due to the distractions” (orange).

**Table 4:** Survey colors & range

| Question | Range | | |
|---|---|---|---|
| CPR experience? | No/yes | | |
| VR experience? | No/yes | | |
| Most stress preset num | 1-3/none | | |
| Focus for preset 1 | 1-5 | | |
| Focus for preset 2 | 1-5 | | |
| Focus for preset 3 | 1-5 | | |
| Occurrence of surprises | 1-5 | | |
| Distraction: Human presence | 1-5 | | |
| Distraction: Human talking | 1-5 | | |
| Distraction: microwave | 1-5 | | |
| Distraction: background noise | 1-5 | | |
| Distraction: Camera flashes | 1-5 | | |
| Distraction: Psychological | 1-5 | | |

### *6.1.1 Full procedure tests - official*

*Results Martijn – CPR instructor at Velco*

**Table 5:**

Results from Martijn

| Stress Preset | RMSSD (ms) | Heartrate (BPM) |
|---|---|---|
| Baseline test | 54.34 | 84.39 |
| Preset 1 | 44.79 | 87.01 |
| Preset 2 | 42.23 | 87.63 |
| Preset 3 | 45.83 | 87.4 |

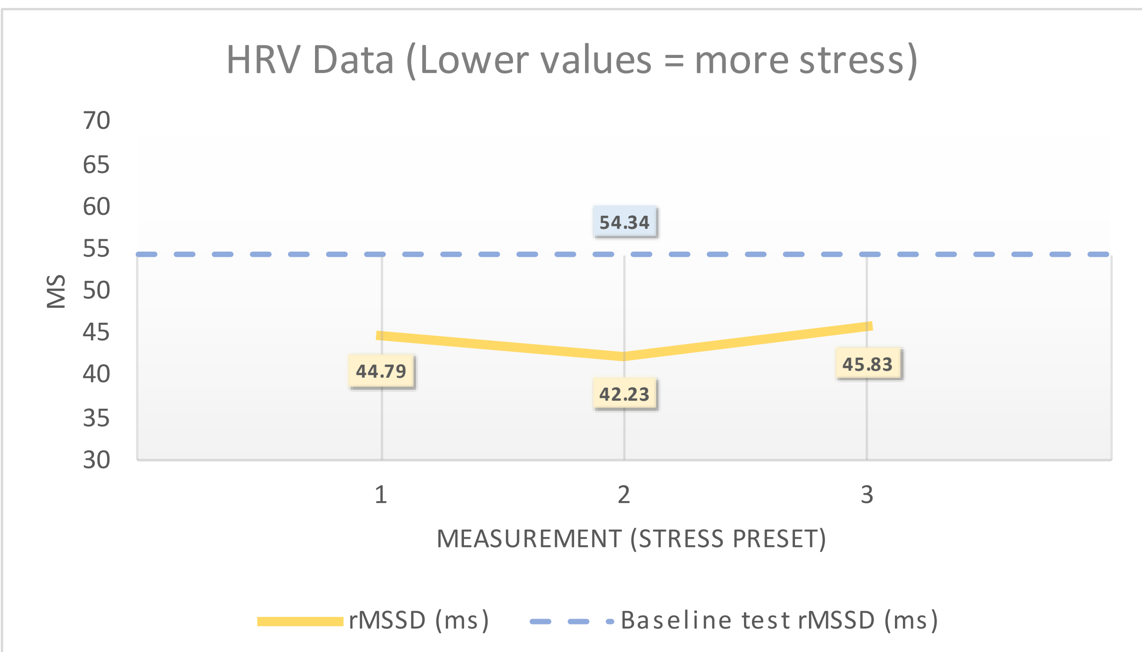
**Table 6:**

Measurable survey results from Martijn

| Question | Answer |
|---|---|
| CPR experience? | 1 |
| VR experience? | 1 |
| Most stress preset num | 2 |
| Focus for preset 1 | 5 |
| Focus for preset 2 | 4 |
| Focus for preset 3 | 4 |
| Occurrence of surprises | 3 |
| Distraction: Human presence | 3 |
| Distraction: Human talking | 4 |
| Distraction: microwave | 2 |
| Distraction: background noise | 3 |
| Distraction: Camera flashes | 1 |
| Distraction: Psychological | 3 |

**Figure 25:**

HRV Data (yellow) graph compared to the baseline (blue)



*Results Mirza – Barista at Starbucks*

**Table 7:**

Results from Mirza

| Stress Preset | RMSSD (ms) | Heartrate (BPM) |
|---|---|---|
| Baseline test | 51.65 | 84.39 |
| Preset 1 | 48.65 | 87.01 |
| Preset 2 | 45.77 | 87.63 |
| Preset 3 | 48.19 | 87.4 |

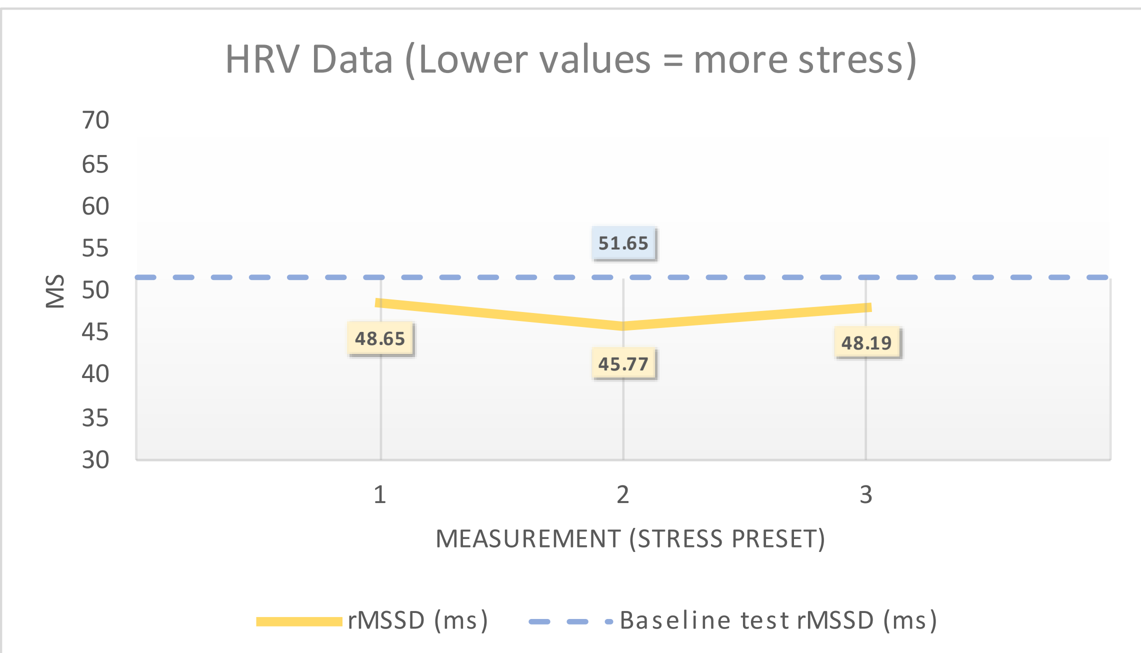
**Table 8:**

Measurable survey results from Mirza

| Question | Answer |
|---|---|
| CPR experience? | 1 |
| VR experience? | 1 |
| Most stress preset num | 2 |
| Focus for preset 1 | 4 |
| Focus for preset 2 | 2 |
| Focus for preset 3 | 4 |
| Occurrence of surprises | 3 |
| Distraction: Human presence | 2 |
| Distraction: Human talking | 4 |
| Distraction: microwave | 1 |
| Distraction: background noise | 2 |
| Distraction: Camera flashes | 1 |
| Distraction: Psychological | 1 |

**Figure 26:**

HRV Data (yellow) graph compared to the baseline (blue)



*Results Bart – Previously CPR certified at Saxion*

**Table 9:**

Results from Bart

| Stress Preset | RMSSD (ms) | Heartrate (BPM) |
|---|---|---|
| Baseline test | 61.49 | 57.88 |
| Preset 1 | 62.58 | 60.07 |
| Preset 2 | 55.96 | 54.77 |
| Preset 3 | 57.01 | 55.97 |

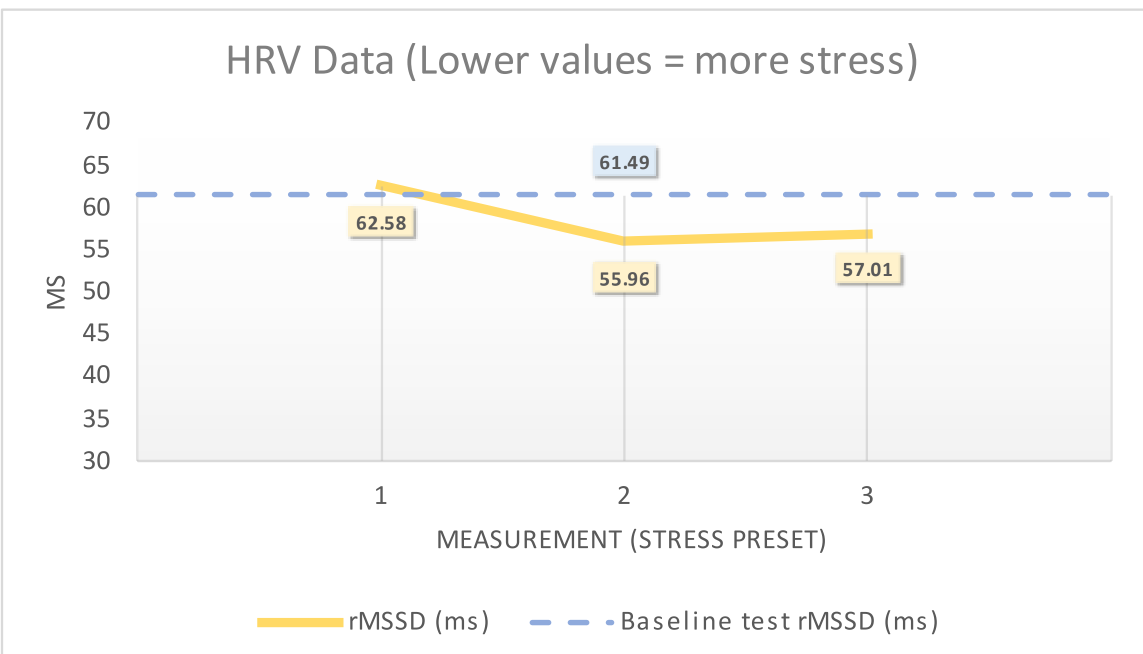
**Table 10:**

Measurable survey results from Bart

| Question | Answer |
|---|---|
| CPR experience? | 1 |
| VR experience? | 1 |
| Most stress preset num | 2 |
| Focus for preset 1 | 4 |
| Focus for preset 2 | 4 |
| Focus for preset 3 | 4 |
| Occurrence of surprises | 3 |
| Distraction: Human presence | 3 |
| Distraction: Human talking | 4 |
| Distraction: microwave | 2 |
| Distraction: background noise | 4 |
| Distraction: Camera flashes | 2 |
| Distraction: Psychological | 3 |

**Figure 27:**

HRV Data (yellow) graph compared to the baseline (blue)



### *6.1.2 Tests without perfect setup - extra*

Throughout the testing period some tests were conducted which do not have the perfect conditions. This includes testing with colleagues who had previously tested the experience, family members which could have biases and testing without the doll and the use of a pillow instead. These tests however are still full tests, and the full procedure was applied when performing the tests. As they are not easily reproducible, they are separated in the analysis. Each of the results have their respective conditions for being unofficial tests in their respective titles.

*Results Selwyn – Company Coach*

**Table 11:**

Results from Selwyn

| Stress Preset | RMSSD (ms) | Heartrate (BPM) |
|---|---|---|
| Baseline test | 48.78 | 60.82 |
| Preset 1 | 47.94 | 64.85 |
| Preset 2 | 41.36 | 74.27 |
| Preset 3 | 43.51 | 66.44 |

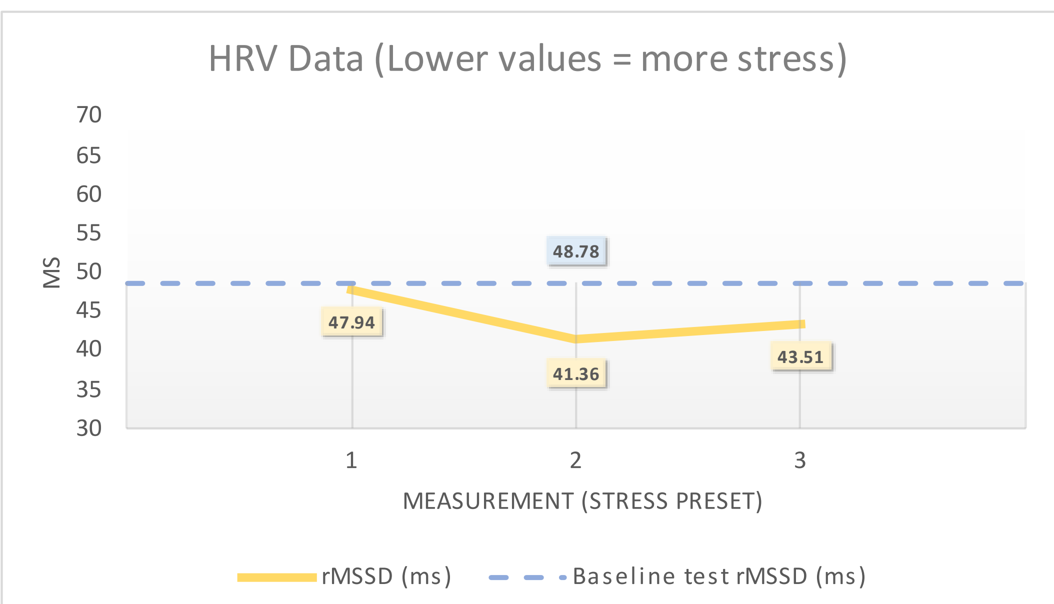
**Table 12:**

Measurable survey results from Selwyn

| Question | Answer |
|---|---|
| CPR experience? | 1 |
| VR experience? | 1 |
| Most stress preset num | 2 |
| Focus for preset 1 | 5 |
| Focus for preset 2 | 2 |
| Focus for preset 3 | 2 |
| Occurrence of surprises | 4 |
| Distraction: Human presence | 4 |
| Distraction: Human talking | 4 |
| Distraction: microwave | 3 |
| Distraction: background noise | 3 |
| Distraction: Camera flashes | 4 |
| Distraction: Psychological | 3 |

**Figure 28:**

HRV Data (yellow) graph compared to the baseline (blue)



*Results Erwin – Father, CPR certified, pillow used instead of CPR dummy*

**Table 13:**

Results from Erwin

| Stress Preset | RMSSD (ms) | Heartrate (BPM) |
|---|---|---|
| Baseline test | 50.97 | 72.48 |
| Preset 1 | 45.91 | 74.71 |
| Preset 2 | 47.86 | 78.16 |
| Preset 3 | 43.67 | 79.46 |

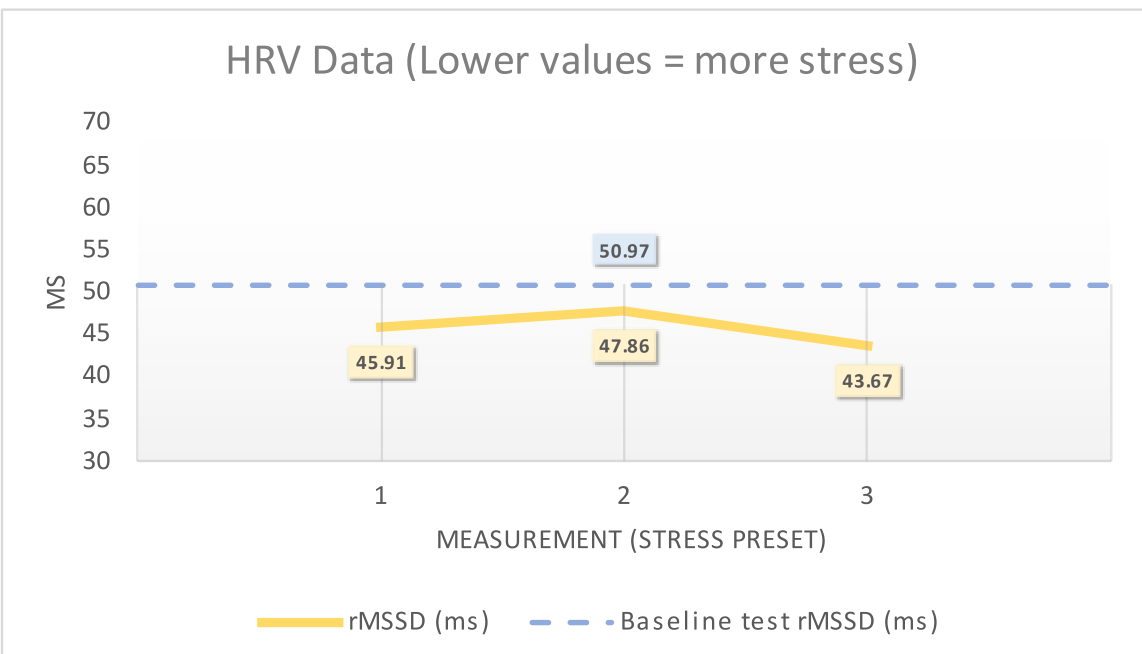
**Table 14:**

Measurable survey results from Erwin

| Question | Answer |
|---|---|
| CPR experience? | 1 |
| VR experience? | 1 |
| Most stress preset num | 1 |
| Focus for preset 1 | 4 |
| Focus for preset 2 | 4 |
| Focus for preset 3 | 4 |
| Occurrence of surprises | 3 |
| Distraction: Human presence | 2 |
| Distraction: Human talking | 2 |
| Distraction: microwave | 2 |
| Distraction: background noise | 2 |
| Distraction: Camera flashes | 3 |
| Distraction: Psychological | 1 |

**Figure 29:**

HRV Data (yellow) graph compared to the baseline (blue)



*Results Else – Mother, non-CPR certified, pillow used instead of CPR dummy.*

**Table 15:**

Results from Else

| Stress Preset | RMSSD (ms) | Heartrate (BPM) |
|---|---|---|
| Baseline test | 58.26 | 63.36 |
| Preset 1 | 55.05 | 64.40 |
| Preset 2 | 49.55 | 67.94 |
| Preset 3 | 48.21 | 67.22 |

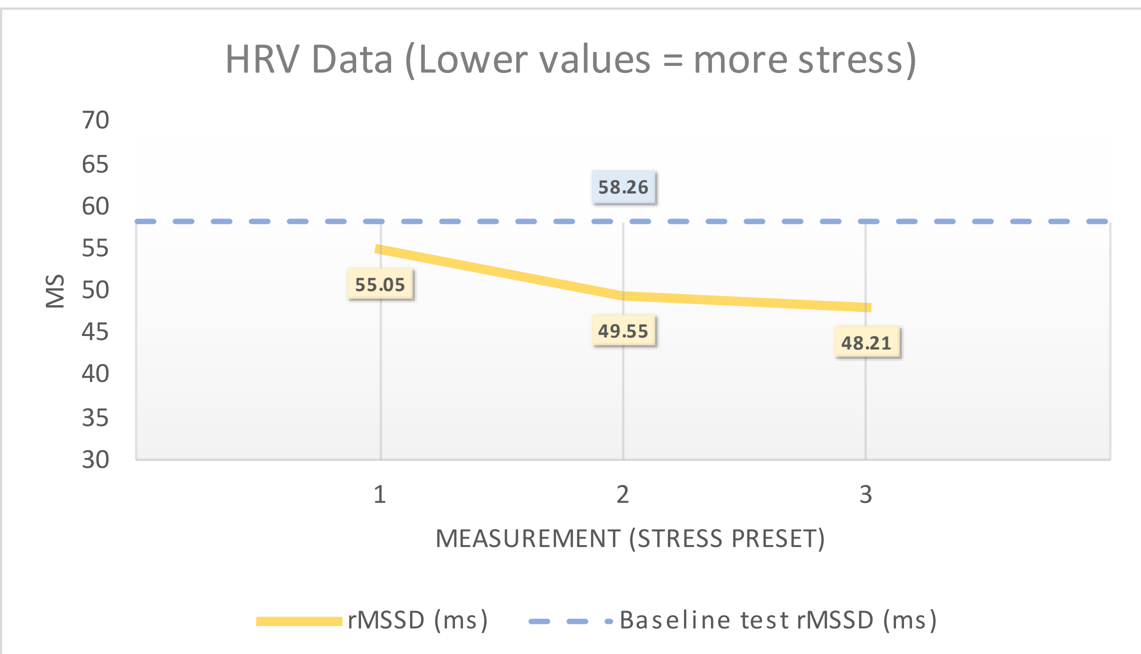
**Table 16:**

Measurable survey results from Else

| Question | Answer |
|---|---|
| CPR experience? | 0 |
| VR experience? | 1 |
| Most stress preset num | 3 |
| Focus for preset 1 | 5 |
| Focus for preset 2 | 4 |
| Focus for preset 3 | 2 |
| Occurrence of surprises | 4 |
| Distraction: Human presence | 3 |
| Distraction: Human talking | 5 |
| Distraction: microwave | 4 |
| Distraction: background noise | 4 |
| Distraction: Camera flashes | 4 |
| Distraction: Psychological | 5 |

**Figure 30:**

HRV Data (yellow) graph compared to the baseline (blue)



*Results Sedat – previously CPR certified, pillow used instead of CPR dummy*

**Table 17:**

Results from Sedat

| Stress Preset | RMSSD (ms) | Heartrate (BPM) |
|---|---|---|
| Baseline test | 40.78 | 59.34 |
| Preset 1 | 38.74 | 59.70 |
| Preset 2 | 39.26 | 60.21 |
| Preset 3 | 36.27 | 60.03 |

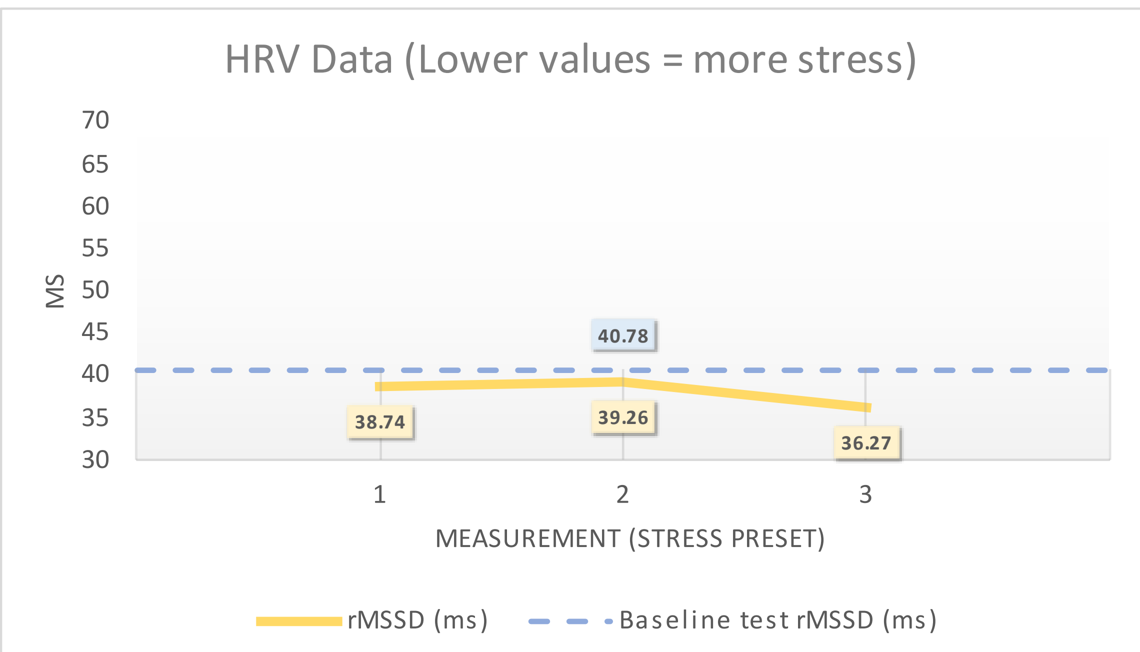
**Table 18:**

Measurable survey results from Sedat

| Question | Answer |
|---|---|
| CPR experience? | 1 |
| VR experience? | 0 |
| Most stress preset num | 3 |
| Focus for preset 1 | 5 |
| Focus for preset 2 | 4 |
| Focus for preset 3 | 3 |
| Occurrence of surprises | 3 |
| Distraction: Human presence | 3 |
| Distraction: Human talking | 4 |
| Distraction: microwave | 2 |
| Distraction: background noise | 4 |
| Distraction: Camera flashes | 3 |
| Distraction: Psychological | 4 |

**Figure 31:**

HRV Data (yellow) graph compared to the baseline (blue)



*Results Yvonne – CPR certified, pillow used instead of CPR dummy*

**Table 19:**

Results from Yvonne

| Stress Preset | RMSSD (ms) | Heartrate (BPM) |
|---|---|---|
| Baseline test | 55.72 | 72.52 |
| Preset 1 | 56.11 | 74.35 |
| Preset 2 | 48.76 | 72.19 |
| Preset 3 | 48.99 | 74.54 |

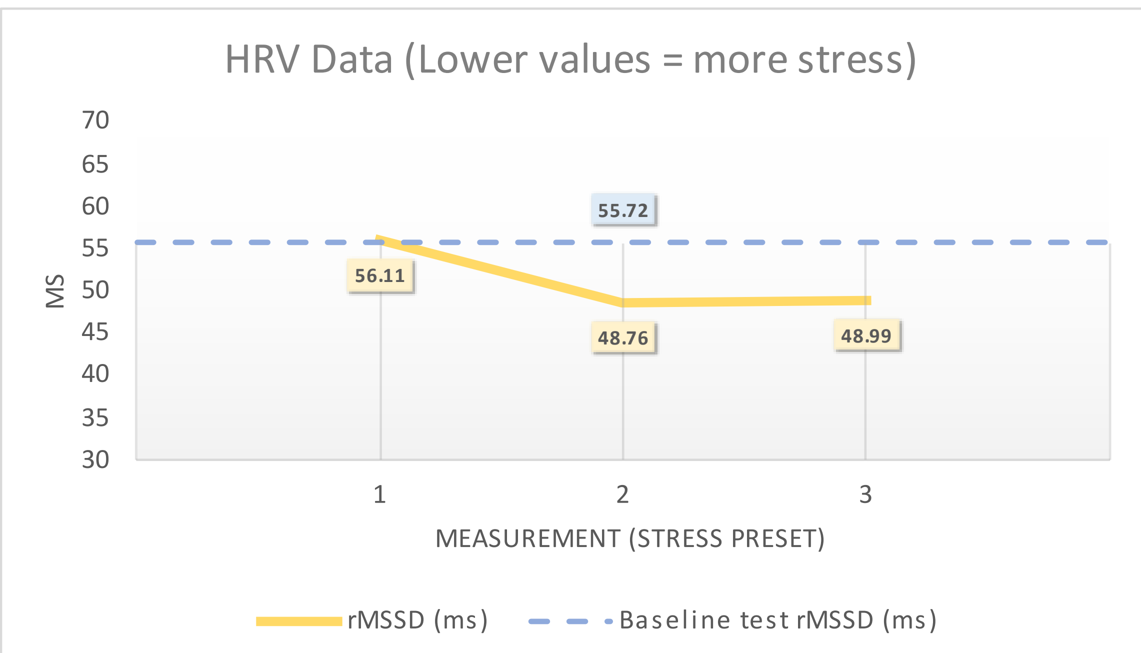
**Table 20:**

Measurable survey results from Yvonne

| Question | Answer |
|---|---|
| CPR experience? | 1 |
| VR experience? | 0 |
| Most stress preset num | 3 |
| Focus for preset 1 | 5 |
| Focus for preset 2 | 1 |
| Focus for preset 3 | 4 |
| Occurrence of surprises | 3 |
| Distraction: Human presence | 2 |
| Distraction: Human talking | 4 |
| Distraction: microwave | 2 |
| Distraction: background noise | 2 |
| Distraction: Camera flashes | 2 |
| Distraction: Psychological | 2 |

**Figure 32:**

HRV Data (yellow) graph compared to the baseline (blue)



## 6.2 Analysis

### 6.2.1 Sensor Data Analysis

Throughout the testing phase two different methods of measuring data was applied: sensor data and a survey. Each method provided different insights into the main and sub questions. First the sensor data was analyzed which is compared to the survey data in the second chapter to be able to answer whether the sensor picked up stress. The comparison of the different presets gives insight into whether the stressors were effective, and the survey provides further insight into which specific stressors triggered perceived stress.

First, combining all data into averages demonstrates how stress was perceived by the sensor. RMSSD values are indicators of stress, and comparing the different presets to the baseline shows how each preset influenced the stress levels. Table 21 and Figure 33 show the baseline, where each preset measurement is below the baseline and thus had some form of stress. The RMSSD is lowest for the second preset, which does not have all stressors applied. Here the most prominent stressors are social and auditive stressors, whereas preset 3 focusses more on the visual stressors while keeping the social and auditive stressors from preset 2. This thus indicates that, on average, users found the second preset the most stressful.

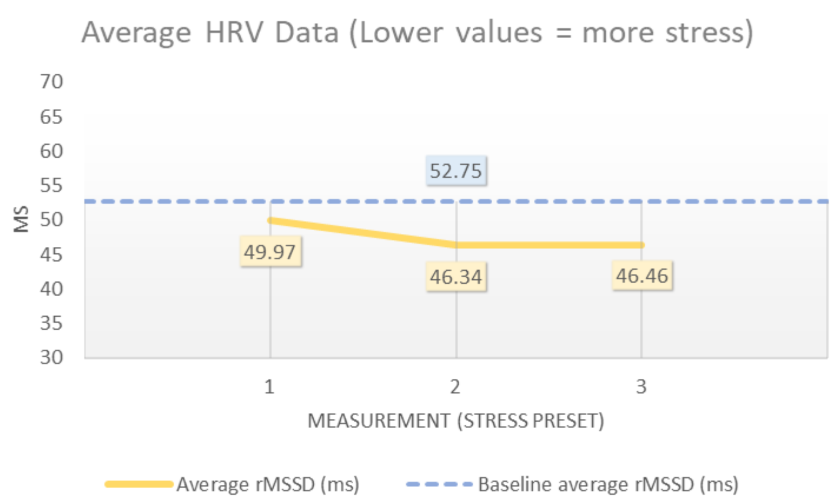
**Table 21:**

Average RMSSD per preset (Lower = more stress)

| Stress Preset | Average RMSSD (ms) |
|---|---|
| Baseline | 52.75 |
| Preset 1 | 49.97 |
| Preset 2 | 46.34 |
| Preset 3 | 46.46 |

**Figure 33:**

Average RMSSD graph



By analyzing the average changes compared to the baseline, it can provide a different view how stress was generated based on sensor data. Each individual RMSSD value was compared to the respective baseline and averaged to retrieve the average change (Table 22 & Figure 34). The min and max change values demonstrate that there is a large difference in change throughout the samples, which indicates that not everyone experienced stress as significantly as the other. Again, averaging the change demonstrates that preset 2 was found to be most stressful.

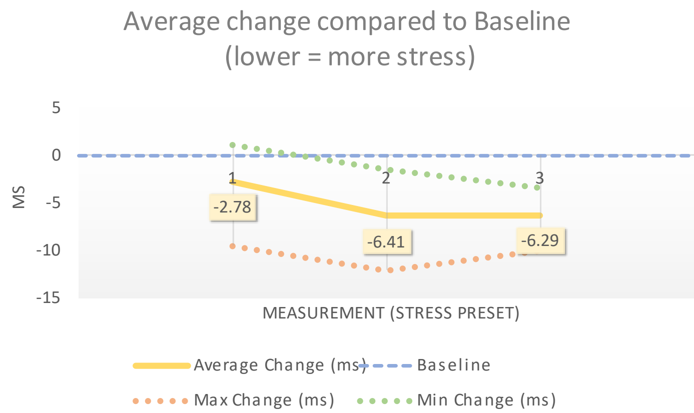
**Table 22:**

Average change in RMSSD compared to the baseline per preset (Lower = more stress)

| Stress Preset | Average change (ms) | Min change (ms) | Max change (ms) |
|---|---|---|---|
| Preset 1 | -2.78 | 1.09 | -9.55 |
| Preset 2 | -6.41 | -1.52 | -12.11 |
| Preset 3 | -6.29 | -3.46 | -10.05 |

**Figure 34:**

Average change of RMSSD graph




Both the average and the average change indicate that there indeed was a form of stress, as the first preset with no stressors had the least amount of change. This does not however indicate the severity of stress. Normal ranges for the RMSSD for unstressed and healthy people lie between 40 and 65 milliseconds. Quick repeated tests do not cause enough fluctuations in the RMSSD to trigger values that fall outside the calm range, and instead only decrease the RMSSD by a little. This indicates that, if the sensor data is reliable, it only shows whether there was stress and which test was found to be most stressful and not necessarily the amount of stress in a value between 0 and 100 for example.

Some tests were done with all perfect conditions, and some were not. All previous data was shown with all tests included, but other variables such as needing to perform on a pillow might increase or decrease the amount of stress.

From the data from solely the three perfect conditions testers, the average RMSSD values were higher than the tests from all data combined. This could be due to the age from the testers (the older the person, the lower their RMSSD values usually are) and the experience level (each person was CPR certified). Average values (Table 23 & Figure 35) still indicate that the first preset had the highest RMSSD values, and the second preset the least, thus supporting the second present to be found the most stressful.

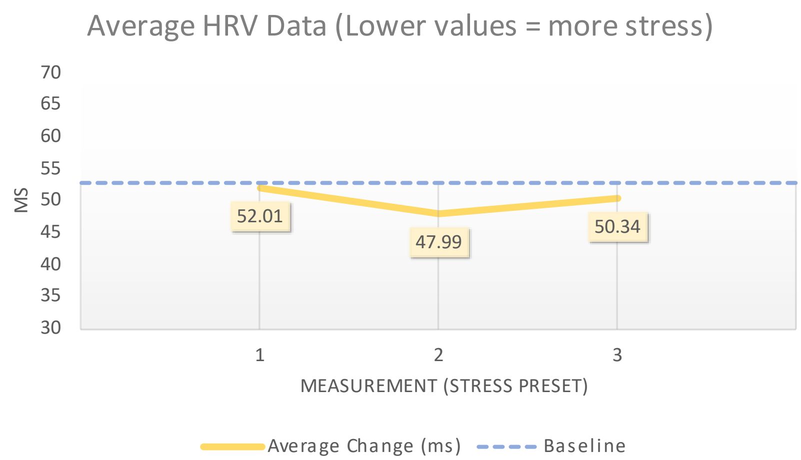
**Table 23:**

Average RMSSD per preset from full procedure tests. (Lower = more stress)

| Stress Preset | Average RMSSD (ms) |
|---|---|
| Baseline | 55.83 |
| Preset 1 | 52.01 |
| Preset 2 | 47.99 |
| Preset 3 | 50.34 |

**Figure 35:**

Average RMSSD graph from full procedure tests




While the average data is closer to the baseline, taking the average change in RMSSD (Table 24 & Figure 36) shows that the overall range in possible values again is high. Even though the sample size is low, the range is still high which gives an interesting view on how individuals might experience stress more significantly than others. Only one individual had a high change in RMSSD, thus no conclusions on whether the doll is more stressful than a pillow can be drawn. This data does however reiterate that the second preset was the most stressful, which was true for all individuals.

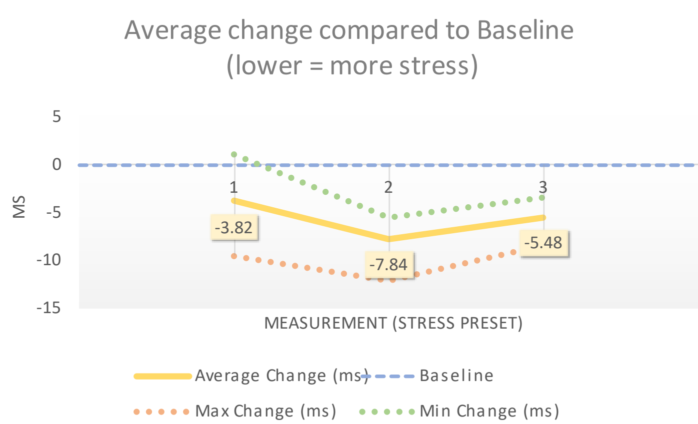
**Table 24:**

Average change in RMSSD compared to the baseline per preset for full procedure tests (Lower = more stress)

| Stress Preset | Average change (ms) | Min change (ms) | Max change (ms) |
|---|---|---|---|
| Preset 1 | -3.82 | 1.09 | -9.55 |
| Preset 2 | -7.84 | -5.53 | -12.11 |
| Preset 3 | -5.48 | -3.46 | -8.51 |

**Table 36:**

Average change of RMSSD graph for full procedure tests




While RMSSD has been proven to indicate stress, the raw heartrate, which some might argue is linked to stress, seems to not indicate direct stress values. To proof this, the ratio between heartrates and the RMSSD were compared, and changes relative to the expected can indicate how much difference there is between the readings. For this, the ratio was calculated for each reading (Table 25). The ratio is calculated for each test, from which the average is taken. The heartrate is divided by the RMSSD to get a ratio, which is than subtracted by the average. The absolute values are averaged to retrieve an average ratio change.

If the heartrate would scale with the stress, and thus the RMSSD, the change in ratio would be 0. From the data, almost all have significant changes in the ratio. Only Bart had a change of 1%, and all the others had values ranging from an average of 8% difference to 16%.

**Table 25:**

Average change in RMSSD compared to the baseline per preset for full procedure tests (Lower = more stress)

| Tester | Average change in ratio | Average Ratio | Ratio baseline | Ratio test 1 | Ratio test 2 | Ratio test 3 |
|---|---|---|---|---|---|---|
| Martijn | 0.16 | 1.87 | 1.55 | 1.94 | 2.08 | 1.91 |
| Mirza | 0.08 | 1.79 | 1.63 | 1.79 | 1.91 | 1.81 |
| Bart | 0.01 | 0.97 | 0.94 | 0.96 | 0.98 | 0.98 |
| Selwyn | 0.18 | 1.48 | 1.25 | 1.35 | 1.80 | 1.53 |
| Erwin | 0.10 | 1.63 | 1.42 | 1.63 | 1.63 | 1.82 |
| Else | 0.13 | 1.26 | 1.09 | 1.17 | 1.37 | 1.39 |
| Sedat | 0.11 | 1.55 | 1.46 | 1.54 | 1.53 | 1.66 |
| Yvonne | 0.09 | 1.41 | 1.30 | 1.33 | 1.48 | 1.52 |

Taking the average heartrate however (Table 26), does still indicate that the second preset had the highest heartrate on average. So, while heart rate may not be a reliable tool for measuring stress, and while high or low heart rates might not indicate high or low RMSSD, on average during these tests the heart rate did have a correlation with the most stress measured or not.

Thus, sensor data shows that the second preset is the most stressful, closely behind the third preset. These values are hypothesized to demonstrate the overall stress values. To compare the values, the perceived data was measured using a survey. This survey is compared to the sensor data to contradict or proof the data measured. From the data so far, the second preset is the most stressful.

**Table 26:**

Average heartrates per test

| Stress Preset | Average Heartrate (BPM) |
|---|---|
| Baseline | 69.40 |
| Preset 1 | 71.51 |
| Preset 2 | 72.85 |
| Preset 3 | 72.31 |

### 6.2.2 Survey Data Analysis

The survey data gave an indication on the perceived stress experienced by the testers. This was compared to the measured stress from the stressors, and answered the sub questions of whether sensors can be used to measure stress, whether there was stress in the first place and what the most effective stressors are. All survey data is shown side by side in Table 27.

**Table 27:**

Survey data side-by-side

| Question | Martijn | Mirza | Bart | Selwyn | Erwin | Else | Sedat | Yvonne |
|---|---|---|---|---|---|---|---|---|
| CPR experience? | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| VR experience? | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| Most stress preset num | 2 | 2 | 2 | 2 | 1 | 3 | 3 | 3 |
| Focus for preset 1 | 5 | 4 | 4 | 5 | 4 | 5 | 5 | 5 |
| Focus for preset 2 | 4 | 2 | 4 | 2 | 4 | 4 | 4 | 1 |
| Focus for preset 3 | 4 | 4 | 4 | 2 | 4 | 2 | 3 | 4 |
| Occurrence of surprises | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 3 |
| Distraction: Human presence | 3 | 2 | 3 | 4 | 2 | 3 | 3 | 2 |
| Distraction: Human talking | 4 | 4 | 4 | 4 | 2 | 5 | 4 | 4 |
| Distraction: microwave | 2 | 1 | 2 | 3 | 2 | 4 | 2 | 2 |
| Distraction: background noise | 3 | 2 | 4 | 3 | 2 | 4 | 4 | 2 |
| Distraction: Camera flashes | 1 | 1 | 2 | 4 | 3 | 4 | 3 | 2 |
| Distraction: Psychological | 3 | 1 | 3 | 3 | 1 | 5 | 4 | 2 |

The first important data is the stress preset most of the participants found most stressful. The mean from this data is 2.25 and the median is 2. Thus, like the sensors measured, the second preset was found to be most stressful.

The amount of stress people perceived is however very variable. As seen in Table 28 the total range of values for the presets was varied. The first preset had no results below 4, which means that none of the users were even a little distracted and a mean and median value rounding to five which means full focus. The second preset however had values ranging from “not being able to focus at all”, corresponding to 1 and 4 which means “good focus, but not fully”. The mean for the second preset rounds to being slightly distracted which is the lowest of the presets. The range is the highest, and thus people had different experiences with stress levels. Finally, the third preset was close to the second preset in mean while having a slightly lower range. Both the second and the third preset had the most common answer of 4 which means they were very focused, but not fully.

**Table 28:**

Answers of the survey for presets

| Question | Mean | Median | Min | Max | Range (max-min) | Most common |
|---|---|---|---|---|---|---|
| Focus for preset 1 | 4.625 | 5 | 4 | 5 | 1 | 5 |
| Focus for preset 2 | 3.125 | 4 | 1 | 4 | 3 | 4 |
| Focus for preset 3 | 3.375 | 4 | 2 | 4 | 2 | 4 |

This thus indicates that there was some stress, but not much. The data does however confirm the sensor data, which had similar results. The main difference is that most people found that the focus for the first playthrough was full, while sensor data demonstrates that there was still some stress. This could be due to playing a VR game or the physical exercise required for CPR.

The individual stressors in Table 29 have large differences in whether they were seen as stressful or not. The most stressful distraction by far is the Human Talking stressor, which are the voice lines played by the NPCs that comment on the actions of the player. They were on average seen as Very Distracting, with the median, mean and most common value all agreeing that they were very distracting.

The other stressors however were not seen as too distracting. Most have both an average and mean of 3 which indicates mild distractions, and the microwave was the worst distraction with an average, mean and most common value of 2 which indicates no distraction. The second highest distraction was the background noise, which had a joined most common value of 4 and 2 and an average of 3 indicating being a mild distracting.

Overall, the most stressful types were thus humans talking and background noise. The first can be categorized under both social and auditive, and the background noise is purely an auditive stressor. The mere presence of humans was not too distracting, but this could be due to the virtual nature which makes it so they can not touch you nor try to help in bad ways.

**Table 29:**

Answers from the survey for individual stressors

| Question | Mean | Median | Min | Max | Range (max – min) | Most common |
|---|---|---|---|---|---|---|
| Distraction: Human presence | 2.75 | 3 | 2 | 4 | 2 | 3 |
| Distraction: Human talking | 3.875 | 4 | 2 | 5 | 3 | 4 |
| Distraction: microwave | 2.25 | 2 | 1 | 4 | 3 | 2 |
| Distraction: background noise | 3 | 3 | 2 | 4 | 2 | 4 & 2 |
| Distraction: Camera flashes | 2.5 | 2.5 | 1 | 4 | 3 | 1 & 3 & 4 |
| Distraction: Psychological | 2.75 | 3 | 1 | 5 | 4 | 3 |

Other results from for example the optional fields reveal that stress is very personal. Else had results that indicated that she was most distracted by the throw up, causing her to completely lose focus. She was the only tester without any CPR experience and had a relatively high stress amount compared to the others, maybe indicating that having no CPR experience leads to higher stress, but with the sample size this cannot be concluded. When looking at people without VR experience, results are still very varied. This might indicate that whether VR was experienced before the training does not give an indication on whether the training is perceived as stressful.

Furthermore, from looking at why people responded their most stressful preset, the lack of the AED was the most common factor of why preset 3 was chosen. This stressor was missing from the survey, and is thus not proven, but can indicate that gameplay or cognitive stressors can in fact still affect the total stress levels.

Thus, the survey data indicates that while there was some stress, the amount perceived was not too much. It further demonstrates that the sensor data does indeed have some correlation with the perceived stress levels. Finally, it shows that there is a large variety in the different perceived stress levels from everyone, and that VR experience plays no role in extra stress levels experienced.

# 7. CONCLUSION

## 7.1 Conclusion

The goal of this project was to find out how to artificially induce stress in emergency response trainees of a mixed reality experience, which increases realism. To answer this, sub questions were devised to find the stressors that affect trainees, how stress could be measured and what stressor works the best. A mixed reality training application was created, with stressors implemented to test which work best. In total eleven different iterations were made and tested using a git feature-branch approach, each adding new features and stressors. The final version was tested with eight different testers, of which three followed the perfect pre-defined procedure.

The stressors in the prototype were designed based on categories defined through research and competitors, which are: social, auditive, visual, gameplay, psychological and cognitive. From these categories, the most effective stressors based on survey data are the social and auditive stressors. The sensor data reveals the second preset to be most stressful, which focusses on the social and auditive stressors, thus confirming the perceived stress from the survey. Other categories such as visual and psychological stressors did affect stress levels to some degree, but significantly less and were more varied between each test. Thus, while all categories affect trainees by at least a little, the best stressors are social and auditive stressors.

To measure stress using sensors, two solutions were created using Arduinos and tested. After evaluation, HRV was found to be the most practical approach, and was used throughout testing. Stress was measured using a heart rate meter connected an Arduino and analyzed in Excel to calculate the HRV values. The values measured correlate well with the self-perceived stress levels and can thus indicate stress. While the existence of stress can be measured, the severity is not measured with the HRV method to a degree where solid numbers can be attached. Thus, HRV is a valid method for testing stress, but still requires survey data to confirm the amount.

The stressor that worked best was the NPCs that talk to the trainee. The survey data shows that almost all testers found the NPCs talking the most contributing factor to the stress. This is also supported by the second preset to be found the most stressful by both the survey data and the sensor data. No one could fully focus on both the second and third preset, indicating that distractions make users lose focus and thus resulting into stress.

Thus, to artificially induce stress, social and auditive stressors are a crucial factor. Written feedback demonstrates that testers found the training to increase the realism, and stress was higher when these factors were applied. There is still a lot of variety between all testers, with some barely having any perceived stress. Thus, while stressors may work for most, it might never work consistently for all users.

## 7.2 Discussion

Throughout development, time was a crucial part of what could be done. One of the main consequences of this is the number of stressors that could be implemented and represent the devised categories. The method for testing the different stressors was not perfect as many variables were changing at once, thus not having any usable sensor data for individual stressors. With the current setup, tests took a full hour which was considered long by most participants. Future research could thus focus more on in-depth categories instead of creating presets out of all and could determine more precisely what works and what not.

The sample size of this research was relatively low. Currently, a focus was placed on participants having CPR experience. While this gives one view, having non-experienced participants would also give a good view on how stressors can be used in the education of CPR. Furthermore, more non-VR experienced testers might show a correlation between stress and experience. These were factors that were not considered. Also, the sample size of eight is low and is not sufficient to draw strong conclusions. This research demonstrates the possibilities of stressors and can be used as a groundwork for future works on similar topics.

HRV is known to give a depiction of health and stress. One of the aspects that could have influenced the stress levels was the fatigue of participants. After performing physically intensive CPR, testers might experience fatigue, which is also known to affect the HRV values. This was minimized by having time between the tests and the measurements, but this might have still influenced data. The severity of this could be a good topic for future research, by incorporating a placebo group which performs similar activities without any of the stressors.

Furthermore, in other future work, more stressors can be tested and analyzed with people, and applied on different project types. This project was developed from scratch, but stress data on existing projects might reveal that other stressors might work differently in different applications. Other stressors might have larger effects on stress, and if other aspects of realism are better (for example graphics & audio design) stressors might have an increased effect. Future work could furthermore investigate more psychological stressors such as operating on females or children, having actual blood effects or with a more realistic implementation on the doll besides making it wet. Other gameplay aspects such as pacemakers or chest hair might make the gameplay more varied, increasing the gameplay stressors. Additionally, implementing voice recognition would solve many issues with the current lack of interactions with the phone and bystanders.

Finally, having a VR environment was initially a large factor of this research and was removed throughout development due to time constraints. Being able to change the actual environment where the CPR takes place can give a totally different experience and immerse trainees even more in the training. Future work could fill that hole and focus on the environment besides just the training, increasing realism and possibly influencing stress.

# 8. REFLECTION

When starting the project, I had a hard time grasping the entire scope and size of the project, and was anxious to get started. Now at the end, I feel like the project went extremely well and I am very proud of what I managed to achieve. There were many hurdles, but due to knowledge from previous projects I managed to stay away from most pits I used to fall in often.

I feel like one of the largest contributors to the relatively (compared to previous projects) smooth progress was the help of my Saxion coach Yvens, and the freedom given throughout development from SeriousXR. I worked independently for most of the project, mainly cooperating when asking for feedback or asking whether certain implementations or features were satisfactory. This made it to where I could set personal deadlines, and work at my own pace without relying too much on others. Furthermore, with the quick feedback from Yvens I always felt like I was on track and was never discouraged due to continue working.

Of course, it was not all smooth sailing. I did encounter many motivational issues, especially with the writing of the theory, and tried to combat this by adding more variety to my schedule. While I initially focused on getting more research before starting actual development, this was very demanding on my enjoyment, and I found it more fun to separate my days of working into days where I would work Unity prototypes and days reserved for the theory. By making the switch I was able to focus more effectively on both tasks, which is something I will remember in the future such as when following my masters.

I furthermore ran into some time issues as I am still unable to properly assess how much time certain tasks take. While relatively accurate 80% of the time, the 20% made up a large part of the final half of the development which made progression slow. This made the last weeks of development relatively stressful, as the deadline for doing tests drew closer. Luckily it all managed to work out, and by asking much feedback throughout the development of the stressors I managed to get something that was close to what I aimed for relatively quickly.

My main weakness lies in the time I give myself to work on features, which I then fill with empty spots making me work less. While already improving, I still need to set tighter personal deadlines to prevent myself from slacking off when time feels abundant. I personally really liked the scrum sprint workflow that SeriousXR uses for working weeks, as this allowed me to work on this skill a lot. In future jobs I will look for a company that employs this working strategy, as I feel like it supports my method of working effectively.

I honestly thoroughly enjoyed this project. I feel like I learned many new things, I loved working at SeriousXR, and I feel like I made something I can be proud of. I got a ton of positive feedback, and these last few months made me realize I made the correct decision of following this study and going through this career path. I can’t wait to start my masters, and to have the skills necessary to do this kind of work on a daily base. I want to reemphasize my thanks to Yvens and SeriousXR for their help throughout the project, you made it enjoyable. Thanks for reading this paper!

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