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A Purpose-built research device: a case study on a tool built for navigational cues.

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Abstract

This paper aims to develop a research device for a specific case study. This research device is a tool created for an emergency escape team that wants to use a mobile device to help during emergency evacuations. The tool will resemble this mobile device and has specific requirements, the most important of which are that it must have dynamic vibrations, visuals, and sound. Furthermore, it must be used in VR as the initial test to see if the idea works will be done using a VR Unity project. Semi-structured interviews were conducted with three members of the emergency escape team at three separate moments during the development of the tool. The tool can use two separate motors to control its vibrations and has a Vive tracker clipped onto it used to track it in VR. Audio is done in Unity using the built-in 3d special audio and the visuals are also done in the same Unity project. Furthermore, there is a guide on how to set up everything that is needed for the device to function. The guide also includes common problems and how to fix them. In conclusion, a tool for a specific case study can be developed using existing technologies and basic programming skills.

Acknowledgements

I would like to express my deep appreciation to both my project supervisor and my critical observer, who helped me a lot with every step along the way. Their guidance through the project helped me look at specific problems from a different perspective. As well as their knowledge of specific parts of the project I struggled with greatly helped me in continuing development. This endeavour would not have been possible without the emergency escape team who helped me with testing the prototype on numerous occasions. Their assistance helped me develop a greater result with their expertise in emergency evacuation. Thanks, should also go out to my father who helped me with specific parts of the development of the final tool. Lastly, I would like to mention the ethics board of EEMCS at the University of Twente, who approved of the study which made all this possible.

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1. Introduction

Research is done by using specific tools designed to be used for research purposes. Of course, many different tools are being used during research. Examples of technological tools are VR headsets, but also computers and phones. Such a tool has a list of criteria that it needs to adhere to if the tool can be used. This project is about creating a tool that can be used for a specific use case. The development of the tool will be explained. Each step of development, like ideation, specification, and realization will be described. The tool is not a universal tool and will be developed for a specific case scenario. This case is about a research team working on a new way to escape buildings during an emergency evacuation. The current way people escape buildings is by looking at static exit signs. This is something that has not changed in a long time. There are many possibilities to make emergency evacuation safer for many people. Of course, people need to receive feedback to know where to go when leaving buildings, that is why the emergency signs work so well. However, the emergency escape research team had the idea of using phones as dynamic exit signs. Phones have way more feedback options than just visual signals. Phones can vibrate and make sounds as well. This idea first needs to be tested. It is unethical to have people run around buildings with their phones so the first test will be done in VR. This is a good way to simulate a real-life environment while not having to set buildings on fire. Therefore, the goal of this paper is to show the development of a device that can be used in research. This device will be applied in a specific case meaning that it must simulate all the signals phones use to communicate with people in a VR environment. This means that the device needs to vibrate and make sounds and should be trackable in Virtual reality. This way the device can be used for further research to find better ways to escape buildings during emergencies.

1.1 Context and Relevance

Finding a way in an unknown building can be difficult at times. Especially if it's someone's first time in an unknown building [13]. In case of an emergency, people need to be able to evacuate buildings. People unfamiliar with the building layout might not be able to find the emergency exit in time. Using static exit signs works for regular buildings with an outside staircase. However, many more corridors need to be gone through in more complex and bigger buildings. This could result in potential unnecessary casualties which could be prevented with a better way for people to find their way around complex buildings [12].

Currently, there are studies and developments on custom software and hardware solutions [5][7]. However, it might be difficult to implement those solutions on a larger scale. For example, there are multiple studies where Bluetooth beacons are used to determine the position of a custom device. These devices need to be quite close to these Bluetooth beacons for the positioning to work correctly. They come equipped with multiple microchips and some even have cameras. These systems can be expensive to implement in a single building, meaning they will be too expensive to implement in an entire city. If instead of custom devices phones would be used, these systems would become a lot more accessible. Phones are multi-utility tools with the ability to use all these feedback options that almost everyone has nowadays. A phone could use feedback options, like vibrational, auditory, and visual signals to lead people to the nearest exit.

1.2 Challenges

There are many challenges in using a phone as a dynamic exit sign, but this paper will focus on the development of the prototype and therefore will focus more on the challenges regarding the creation of such a prototype. A challenge with creating a device that can be used for research is consistency. The device must be able to reproduce the same output multiple times in a row to compare the results from different test subjects. Another challenge is the longevity of the device, as the tests will be done months or years after the device has been made, it does need to function for that entire time. If the device were to break down after 4 months tests can no longer be done. The last major challenge for this project is the form factor. Since the device must resemble a phone, getting the right components is vital to have a research phone that feels real.

1.3 Research Questions

While keeping in mind the previously explained challenges, the following research questions (RQ) can be stated:

- RQ1: To what extent can hacking/tinkering be used to create a research device?
- RQ2: What are examples of phones being used in research?

2. Background Research

The pre-knowledge needed for this project is to what extent can preexisting technologies be used in an academic setting. Knowing this helps in creating a technology that can be used by researchers to do tests. Hacking preexisting technologies can be an effective way to create a functioning tool that can be used for research. Changing the shape of a device can give different impressions for testers. Therefore, the overall goal of the background research is to gain more insights into what technologies already exist and how they could be used for further research, as well as how tinkering can be used to make a device that can be used for research purposes.

2.1 Literature Review[1]

The first part of this review will be about the preexisting technologies that have already been published regarding emergency escape. Next to this, it explores what these technologies lack and how to potentially use them for further research. The focus of the second part will go into the physical part of creating a tool for academic research. This part will give insights into how preexisting technologies can be used to create systems/devices that can be used in research, with a focus on tinkering.

2.1.1 Preexisting Technologies

For this research, it is important to know what technologies are already out there and how could potentially be used to develop new technology. There are three examples of using a camera to scan a sign or QR code for it to then lead you to the nearest exit. The first development is a flashlight with IR phototransistors that can scan custom-designed tags. The tags contain information from the Indoor Guiding System. With the information, the flashlight can use artificial speech to lead a user to the nearest exit. Tjan et al. [1] developed this magic flashlight which the user must hold and scan DSS tags. Something like this is a tag reader which is connected to a Bluetooth earpiece that can scan custom tags. The tag readers send the information from the tags to a phone that can decode the tag's information into a message. Using a Bluetooth earpiece this message could verbally be told to a user. Legge et al. [3] developed this technology to help visually impaired people with finding their way around buildings. However, custom hardware is not required to make something like this work, as a phone application that can use Augmented Reality (AR) to show users to the nearest exit is also an option. A phone can scan a QR code that contains information about the current location of the user inside a building. The application then uses the database to locate the nearest exit and leads the user thereby displaying arrows on the floor using the phone and AR. Wakchaure et al. [7] developed such a system to reduce the time it takes to escape buildings. However, only using the screen of a phone as information is something that can be improved. These examples show that it is possible to potentially use a device that can lead people in the right direction. However, they do not yet show if this could work during emergencies or with larger groups of people at the same time.

An alternative to using a camera and tags is making use of sensors that can track the location of a beacon. Two examples are using this sort of tracking to find a path to a specific location inside a building. An RFID-based navigation system that uses a grid to determine where the user is located and uses signals to alert the user if there is an obstacle in the way. Furthermore, the grid is divided up into cells which it uses to determine the shortest route to a specific location Tsirmpas et al. [4] used this navigation system to help elderly and visually impaired people find their way around a building. In contrary to this, Delnevo et al. [2] created a system that would make getting around the University of Bologna easier, by using beacons to guide students to their labs, libraries, or lecture halls. The systems architecture includes a server that contains the data of the building's layout, a web application to check the specifics of the Bluetooth beacons, the beacons themselves that emit Bluetooth signals, and a mobile application that can be used to communicate with the beacons via Bluetooth. These examples show how the location of a user can be determined. This could be used in addition to user signals to lead people to the nearest exit during emergency escape situations.

Knowing the location of a person is not only enough to get someone out of a building. A system that can plan effective routes during emergencies is also needed. An emergency evacuation model called dynamic escape route planning (DERP) uses the structure of cellular automata to get information about the structure of the building, the number of people in certain places, and the current situation of a fire. Next to this, DERP uses an algorithm to dynamically adjust the emergency escape route for people still left inside a burning building. Chun et al. [5] experimented with this system and there is an improvement when compared to the standard way of escaping a building. So, using this system could improve the number of people that might escape during an emergency, but the system requires a lot of sensors to function properly, making it difficult to apply to multiple buildings.

To conclude, current developments for the navigation of buildings that could potentially be used for emergency evacuations are cameras scanning tags to show a way out, sensors that track positions and tell people how to get to their destination, and a system that plans the most effective route through buildings. If phones could make use of these systems, there are possibilities to implement this in complex and bigger buildings. More research could be done on the scalability of these systems as most systems do not seem like they could function in all buildings without the right infrastructure. This is a very important part of this research because it should apply to many kinds of buildings with a lot of people inside each building.

2.1.2 Tinkering used for research.

A tool that can be used for research in emergency escape will be made by taking apart existing technologies and putting them together in a new form factor. This is done to make the device accessible for other researchers to replicate the device. As the functionalities are limited to the specific functions needed by the emergency escape team something simple and reliable is important to develop. The tool will be developed over several iterations while observing, reflecting, and testing. This form of development is called tinkering. Mader and Dertien [8] suggest that when using tinkering to create something new over a long period, new designs can be developed. This is supported by Miller [9] as he mentions innovations are made through tinkering. This suggests that developments do not suddenly come from nothing but instead are developed over time by using existing technologies.

There is an example where tinkering was used to develop a coffee table that could show moving pictures depending on the weight distribution of things on the table. The coffee table was created by W. Gaver et al. [10] to research how objects in homes can support activities that stimulate curiosity and exploration. The coffee table went through several iterations and designs. The technologies used are components from a high-end computer as well as a system that calculates the weight distribution of the table. Another example of tinkering is using an Xbox Kinect for purposes that are not intended. This device is a cheap way to track people's position in a space and have a program react to it. It was originally made for games but has been used in many other projects like indoor interactive playgrounds. An example of these uses is using Kinect to incorporate wheelchair controls into games. Kathrin et al. [15] used the Kinect with a newly designed system architecture to use the inputs of someone in a wheelchair and use in in game. This is how cheap components can be used for scientific results. In the end, it is possible to develop a device that can be used for research purposes using tinkering and going through several iterations.

2.1.3 Conclusion

In conclusion, there are many systems out there that help with the navigation of indoor buildings that could also be used for emergency evacuations. However, the systems that require custom hardware, like the magic flashlight, are more difficult to implement on a large scale. However, the system that requires a camera to scan a tag could be implemented well in combination with smartphones. Other developments that use smartphones communicate with the user through images or sound, but they don't use multiple senses. All this leaves room for more research on using smartphones that lead people outside with the help of sounds, vibrations, and visuals. For this research, a tool can be created by tinkering with existing technologies by using the examples shown in this chapter as a starting point on how to work on it. The existing technology will go through several iterations to create a system that will create a cohesive prototype.

3. Methods and Techniques

In this chapter, the methods and techniques used for research will be divided into. First, there will be a focus on the methods used to gather knowledge about the prototype and the research device. Secondly, specific techniques used to develop the prototype and concepts will be explained.

3.1 Research Methods

The main way information is collected in this research is through interviews. These interviews will be conducted with research specialists. With multiple rounds of interviews being done throughout the development. This means that after each round of interviews, improvements to the device will be made. The initial questions about the research device can be found in the appendix on page 13. The goal of the interview is to find out if the device is usable for research purposes. Questions about the set-up procedure will be asked, to find possible flaws. Next to this, questions about potential new changes will also be asked. This is done to make sure the device has all the functionalities needed to be used for research.

4. Ideation

In this chapter, a list of preliminary requirements is set up. These requirements are used to develop feasible concepts and allow to creation of tangible/digital prototypes within a reasonable scope. This list was set up with specific stakeholders in mind. These stakeholders will also be discussed in this chapter. Next to this the developed concepts and potential augmentation of said concepts are explained.

4.1 Stakeholder analysis

The internal stakeholders are the first key stakeholder is the project supervisor. This is the person in charge of checking the research methods and progress on development. The focus of this person is on the quality of the tool and the functionalities of the device. The second stakeholder is the problem provider. They are interested in the entire project, as they are the one that has an overview of the project. They know the most about the entire project and the specifics of the research device. While the tool is being developed, they are working with other members of the emergency escape research team on the rest of the project. The third stakeholder is the researchers who will use the tool with random participants to test the idea. The people who will use the research device during tests set up by the researchers will be recruited later in the development process by the researchers themselves. The fourth stakeholder is fellow researchers working on the same project. Currently, these researchers are working on the other aspects of the project like the environment where the tool will be used and the logic the tool will eventually use. This will be people from the emergency escape team who are familiar with the entire system. The external stakeholders are the ethics board which is in charge of determining if the way data is collected for this research is ethically acceptable. In Figure 1 the power of each stakeholder is displayed together with their interest in the project.

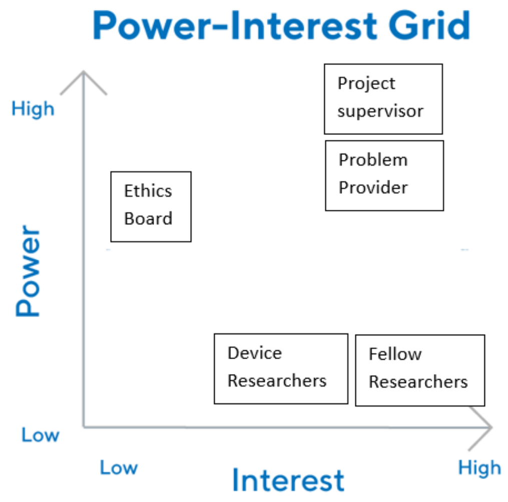


Figure 1 - Graph of the stakeholder power-interest grid.

4.2 Preliminary requirements

There are certain requirements for the device to be useable in the current research setting. The requirements have a description as well as a priority. This priority list is later used to assign values to ideas and determine the best idea.

Requirement ID	Requirement name	Description	Priority
Req. 1	Tracking	The device can be tracked by a VR headset or nearby base stations.	High
Req. 2	User Feedback	The device can send signals using vibrational motors and a speaker	High
Req. 3	Form factor	The shape of the device is roughly the size of a phone. It can fit in an average size pocket.	Medium
Req. 4	Adaptable	The device can change the strength of the vibrational motors and the sounds from the speakers.	High
Req. 5	Compatible	The device can function in combination with an existing setup	High
Req. 6	Long-lasting	The device can function for an unspecified number of years.	Medium
Req. 7	Consistent	The device shows consistent results when it comes to giving feedback and setting up the device.	Medium
Req. 8	Easy to use	The device is easy to set up and software changes should be easy to implement.	Low
Req. 9	Endurance	The device can endure multiple tests over a long period.	Medium

Table 1 - List of preliminary requirements

4.3 Developed concepts

In the beginning three potential ideas were explored. These ideas are explained and shown as pros and cons. These pros and cons are compared with the preliminary requirements to find the best idea to develop further. The ideas will be graded on a score from one to five. Priority will be given to the idea with the highest scores in the more important requirements.

4.3.1- Running the same Unity program on a phone

A phone could run Unity and could communicate with a VR headset using the Unity multiplayer functionality. The phone would need its instance of the program where it must detect if the program is running on a phone or a VR headset. Unity can use all the functionalities of a phone with vibration, sound, and light. The phone could then also be tracked in VR using the built-in gyroscope.

Pros	Cons
In case there is a need for multiple testers at the same time, multiplayer functionality makes it so multiple phones can be used if there is an existing host.	The detection of the program if it's running on a phone or a headset could lead to potential issues.
There is no need to disassemble any existing electronics.	A phone that can run Unity is needed for testing
Phones have all the functionality needed to be used for research.	An external server is needed for the phone and the headset to connect.
Makes the test more realistic as testers are holding a phone.	

Table 2 - Pros and cons of the phone idea

Requirement ID	Requirement name	Score (1 – 5)	Priority
Req. 1	Tracking	3	High
Req. 2	User Feedback	3	High
Req. 3	Form factor	5	Medium
Req. 4	Adaptable	2	High
Req. 5	Compatible	2.5	High
Req. 6	Long-lasting	1	Medium
Req. 7	Consistent	4	Medium
Req. 8	Easy to use	3	Low
Req. 9	Endurance	2	Medium

Table 3- Requirement score phone idea.

Overall, this idea could work in theory, but some aspects make it hard for this idea to work. In Table 3 the endurance and long-lasting requirement score a rather low score. This is because once set up the device could function for some time, however, the inconsistent nature of Unity's networking system makes this idea too unreliable. This means that the device needs to be updated often, the idea becomes too unreliable for a research device. In Table 2 some of the prominent pros and cons can be seen. There are more pros than cons, with this idea being a lot easier to replicate by other researchers if the idea would work.

4.3.2- PS4 controller phone design

A PS4 controller has buttons, a printed circuit board, a mini speaker, an included battery with a charging port, two joysticks, a touchpad, two vibrating motors, gyro meter/accelerometer. These components could be used to create a phone-like device using a 3d printed shell. The controller can be used with Unity over Bluetooth. If a VR tracker were to be mounted on the shell the controller could be tracked in VR.

Pros	Cons
All components are already there for a phone mock-up.	The phone would be likely thicker than a usual phone resulting in an unrealistic feel for the user.
A PS4 controller can be easily disassembled and reassembled in a new form factor	The VR tracker could add even more extra bulk to the device.
A PS4 controller can connect with Unity through existing software	

Table 4 - Pros and cons of PS4 controller idea

Requirement ID	Requirement name	Score (1 – 5)	Priority
Req. 1	Tracking	3.5	High
Req. 2	User Feedback	4	High
Req. 3	Form factor	2.5	Medium
Req. 4	Adaptable	3.5	High
Req. 5	Compatible	4	High
Req. 6	Long-lasting	4	Medium
Req. 7	Consistent	2.5	Medium
Req. 8	Easy to use	2.5	Low
Req. 9	Endurance	3	Medium

Table 5- Requirement score controller idea.

This idea has a lot of potential. With rather high scores in the high-priority requirements. With the tracking, user feedback, adaptability, and compatibility scoring 3.5 or higher as can be seen in Table 5. Furthermore, in Table 4 specific pros and cons can be seen regarding this idea. The device must be designed well to meet the form factor requirement. As the design should be able to fit inside a pocket, the tracker needs to be outside of the main body. In

4.3.3- Custom device with new components

A specially made device could be made with components like an esp32, a mini speaker, vibrational motors, and several buttons. These can be fitted into any orientation or shape making different options available for testing. This would require a VR tracker to be trackable in VR. As well as a 3d printed shell to house all the components.

Pros	Cons
Different shapes can be used to have a more compact system that can be used for testing.	Lots of new components would be needed to make it functional.
A good connection between an esp32 and unity can be made.	There is a high chance of connections being lost due to low-quality products being used.
Only have components that are needed for the system to function.	It is harder to replicate for other researchers.

Table 6 - Pros and cons of custom hardware idea

Requirement ID	Requirement name	Score (1 – 5)	Priority
Req. 1	Tracking	3.5	High
Req. 2	User Feedback	3	High
Req. 3	Form factor	3	Medium
Req. 4	Adaptable	4	High
Req. 5	Compatible	3.5	High
Req. 6	Long-lasting	3.5	Medium
Req. 7	Consistent	2	Medium
Req. 8	Easy to use	2.5	Low
Req. 9	Endurance	1.5	Medium

Table 7- Requirement score custom hardware idea.

While this idea scores relatively high in the high-priority requirements as can be seen in Table 7, it lacks those high grades in all the other requirements. This is mainly because custom components tend to break quite quickly. This means that the device requires maintenance to be used over a long period. Additional pros and cons can be seen in Table 6.

4.3.4 Conclusion

In conclusion, there is potential in all three ideas. However, when looking at the scores there is one that has an overall higher score than the others. That is the idea with the PS4 controller. That is mainly because it is future-proof and has all the other important requirements needed for the device. With a well-designed shell, the VR tracker can be mounted outside of the device, meaning the tracker sits outside of the pocket when the device is inside the pocket.

Requirement ID	Requirement name	Mobile phone	Controller	Custom hardware	Priority
Req. 1	Tracking	3	3.5	3.5	High
Req. 2	User Feedback	3	4	3	High
Req. 3	Form factor	5	2.5	3	Medium
Req. 4	Adaptable	2	3.5	4	High
Req. 5	Compatible	2.5	4	3.5	High
Req. 6	Long-lasting	1	4	3.5	Medium
Req. 7	Consistent	4	2.5	2	Medium
Req. 8	Easy to use	3	2.5	2.5	Low
Req. 9	Endurance	2	3	1.5	Medium

Table 8- Comparative overview of the three ideas.

5. Specification

This chapter will go deeper into the chosen idea from the previous chapter. The idea will be divided into multiple parts and dive deeper into the implications and how they can be applied to the project. The first part will dive more into the different physical components needed for the device, for example, the difference between the two vibrational motors and how they should impact the design. The second part will be about the software that will support the device, like using Steam and Steam VR to track the Vive tracker. The final part will be about the integration of these parts together to create a functioning device.

5.1 Physical components

The chosen idea in chapter 4.3.4 was idea 2, rebuilding a PS4 controller into a phone. A PS4 controller consists of many parts which can be used for the tool. The first of which is the connectivity to computers. This can be done through Bluetooth and/or a wire directly to the computer. This means the device has the potential to work without needing to be connected by a wire, which gives freedom to potential participants later during the testing phase as users could get tangled up when there are too many long cables everywhere. Using the internal battery of the PS4 controller the device can stay on without having to stay connected to a wire as well. This battery can keep the tool on when testing for an extended period. Next, are the buttons needed to connect the PS4 controller to the computer, these are the home button and the share button. This means these buttons need to be pressable if the device must be connected wirelessly. The PS4 controller also has two different vibrating motors. These motors can be seen in Figure 2 with the motor with less weight located in the right grip on the left side of the image and one with more weight located in the left grip on the right side of the image. The motor with more weight should therefore be located near the middle of the tool whereas the motor with less weight should support it near the top or bottom. These motors can be controlled separately through software and thus can be used to create more dynamic signals for the tool. Furthermore, the PS4 controller is compact enough and weighs about the same as a standard smartphone.

Figure 2 - The vibrational motors found in a PS4 controller

Next to the PS4 controller, the device will have a VIVE 3.0 tracker attached to it as well. The tracker weighs around 75 grams and can be seen in Figure 3. This tracker can be used to track the device in VR, which makes it possible to see the device in your hand in virtual reality. The distance and location between the device and the headset can then be used to play sounds louder when the device is close to the headset. As well as less loud when the device is further away. The device that will be shown in VR will also be able to show flashing lights on the screen as another form of signal to the user. For the VIVE tracker to work, base stations must be present in the room. These are used by the tracker to determine its position in the room.

Figure 3 - HTC Vive 3.0 tracker

5.2 Software components

The software side of the device changes depending on which headset is used for testing. The tests done during the development of the device were done using a Meta Quest 2 headset. Not all the software that is required for this is also required for other headsets. However, no matter which headset the test happens with, the following software components are needed for the device to work for this research project. Firstly, the emergency escape unity project. In this project, the logic for the device will be present, which is required as the device cannot function without it. Secondly, the VIVE tracker requires Steam and Steam VR to be active and running. The tracker uses these programs to give the position to the unity project.

For the calibration of the device, it is important to know which VR headset will be used for the tests. When using HTC or Valve headsets following the standard tracking software, calibrating the tracker will be possible. However, when using a Meta headset the software OpenVR-SpaceCalibrator will be needed. This software can be used to calibrate the position of the tracker this is normally not possible.

5.3 Combining the components.

To combine everything into a single device, a shell needs to be made to house everything. The components of the PS4 controllers need to fit within this shell. The shell also needs to have a separate attachment to which the VIVE tracker can be attached. The tracker must be visible by the base stations and thus cannot be put inside the device. This attachment needs some space between the main tracker and the device, for people to put the device in their pockets as well as be able to hold the device in their hands.

6. Realisation

6.1 Pre-VR testing/development

The development started with creating a unity project to test the limitations of the PS4 controller, such as testing the vibrational motors and looking into sound. In addition to this, the extent to which audio works in unity was also tested. The audio in Unity and the vibrational motors were tested with a user test with the emergency escape research group to see if they were up to standard. Before transferring the components to the shell, this was done to check if everything worked.

6.1.1 Functionalities of the PS4 controller

Testing all the functionalities of the PS4 controller is easier to do when the controller is not broken down yet. To test the functionalities of the PS4 controller a simple unity project was made together with a C# script. The script was used to test the vibrational motors of the PS4 controller. As mentioned in Chapter 5.1, the PS4 controller has two separate vibrational motors, 1 with a heavier weight attached to it and one with a lighter weight. In Figure 4 both motors and weights can be seen in the controller's handles. These motors can be controlled separately through script to create the desired effect. When testing the strength of each motor, the motor with heavier weights does make the controller vibrate more vigorously, whereas the other motor creates more micro-vibrations which can be used as supporting vibrations to the heavier motor.

Figure 4 - Motors of the PS4 controller.

The controller can be connected to a computer in two ways, a simple way and a preferred way for the project. The simple way is to use a USB A to micro-USB cable to connect the PS4 controller to a computer Using a cable is better for stand-by usage, as the battery charges while connected. However, the cable could block users from doing what they want to do which is not desired during testing. The preferred way for this project is to connect the controller to the computer via Bluetooth. This can be done with a PS4 controller as it does have the functionality to connect to a computer using Bluetooth. The controller can also still receive information from Unity. There are two downsides to using Bluetooth, namely battery usage and connectivity. The battery only becomes a problem if the controller is not fully charged before a test. The connectivity is quite stable when close to the computer, but it can time out if the device is not used for two to three minutes. This is a common problem with Bluetooth controllers and can be fixed by reconnecting the controller to the computer.

6.1.2 Audio solution of the tool

Audio is an important part of the tool. It would be great if the sound comes from the tool in real life as it creates more emersion for the testers. The PS4 controller has a speaker which is used by developers. This speaker is used during games when the developer needs it. However, the audio output of the PS4 controller could not be selected by normal means on a computer, which is the platform on which the system will be used. Using third-party software like Wwise, which is software that enhances the audio functionalities of Unity, it was also not possible to use the speakers of a PS4 controller. The second software DS4Windows was promising as it allows you to change many aspects of the controller, like the lights, and button mapping, but not the speakers. It is possible to use the speaker of the PS4 controller but a PS4 development kit is needed for this, which is outside the budget of this project. This led to the conclusion that after looking for multiple ways to use the speaker as an audio output the decision was made to use Unity's built-in 3d audio system instead of the speaker. This is because by using Unity's 3d audio system with the location of the tool in VR a realistic enough sound can be produced.

6.1.3 Testing the functionalities outside VR

Two scenes were made for testing the functionalities of the controller with the emergency escape research group. The first was to show the capabilities of the vibrational system and the second was to show Unity's 3d special audio. The vibrational system was demonstrated by letting the tester hold the controller while a red capsule walked toward a blue checkpoint, see Figure 5. This was done to simulate a potential experiment in VR. The controller would start vibrating stronger when the capsule came closer to the checkpoint. Once the capsule reached the checkpoint the controller would either vibrate once or twice depending on where the user should go next. The direction was indicated using the circles on the walls near the blue checkpoint in Figure 5. This system of determining the direction of where to go depending on how many vibrations there were, was later scrapped.

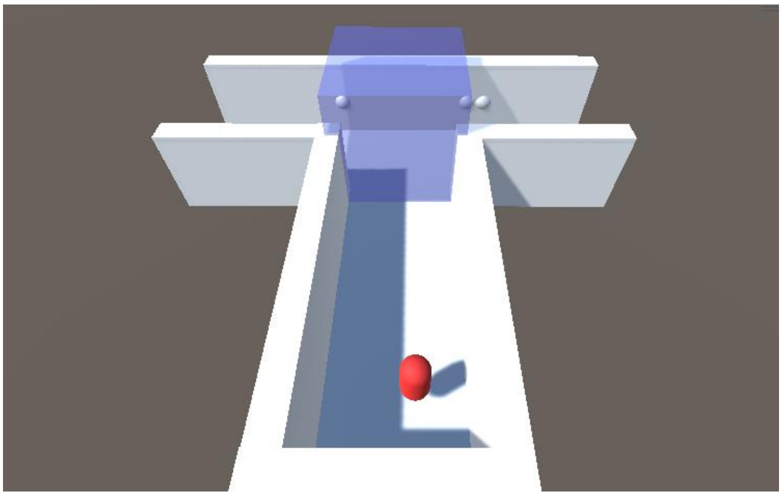


Figure 5 - Vibrational testing scene

The second testing scene included a yellow stationary audio listener, which would later become the headset of the user, and a red moving audio source, see Figure 6. The audio source would emit constant audio which the tester could listen to. The direction of the audio depended on the position of the red sphere compared to the position of the yellow sphere. The goal was that if the red sphere was on the left of the yellow sphere the tester should be able to hear the audio come from the left.

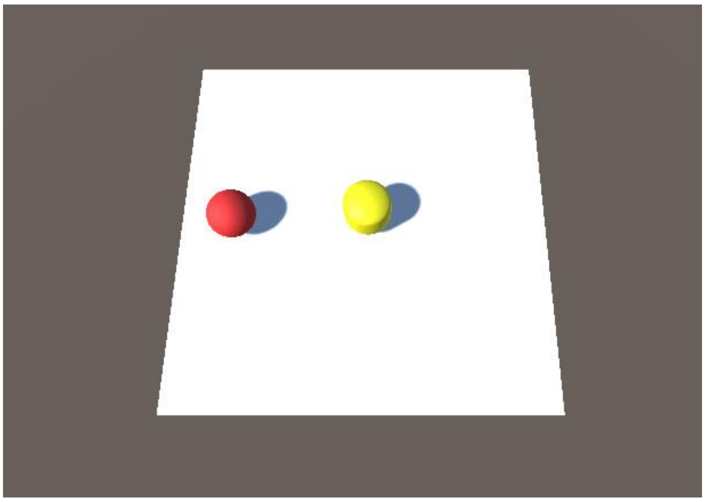


Figure 6 - Audio testing scene

The tests were done on three separate occasions with three members of the emergency escape research team. However, because of the corruption of two audio files, there is only data on two participants for tests one and two. The remaining transcribed interviews can be found in Appendix 10.2. Firstly, the vibrational scene was tested as explained before. The consensus is that the logic for the system made sense, as Participant A mentions: “It seemed to work. I was surprised by how well the audio worked. That it’s actually recognizable where the noise is coming from”. To which Participant B added: “I really like it, like the gradual increase of the vibration especially.” Another suggestion was made by Participant B for the vibration when reaching a checkpoint, the tool could use a single vibration to let users know they reached a checkpoint. Sound and/or visuals can then be used to indicate the next direction instead of vibrations. This suggestion makes more sense when there are more than two directions to go into which can happen and was therefore later implemented in the testing project.

There were some concerns about the strength of the motors. This is because there are two types of vibrational motors in a PS4 controller, see Chapter 6.1.1. Participant A adds to this by mentioning that louder motors might surprise the user when using the tool as they said: “in a controlled experimental environment you may not want to put it on the absolute maximum setting, because then you hear the motor so loud. That it may be distracted. And it may be so sudden that it may be, you know, surprising or shocking that the first reaction may be jumping.” With this concern in mind, Participant A recommends having an option to control the vibration just in case is a good option to have. This was something that should be kept in mind during the creation of the shell and programming of the tool.

Secondly, the audio scene was tested, and using Unity’s 3d spatial audio is above the expectations of testers as mentioned before. Users were able to distinguish between left and right when wearing simple headphones. However, Participant B mentioned an issue with the audio system saying you can only hear it from the left or right, but then lack sound from the other side. The system is not sophisticated enough to create reverberations in a room. In general, the audio test was not foolproof as the test only tested the difference between left and right but not up and down. Up and down sounds are important as these would be needed if a participant needs to walk up and/or down a floor.

Lastly, some recommendations were given regarding the size of the device. When asking Participant A for their recommendations for the size they mentioned this: “You know these like Donald Duck funny pocketbooks. I think that would be sort of the max.” as well as “Ideally it wouldn’t be all too heavy. So, you could have it comfortably in one hand for the duration of an experiment.” Participant B adds to this by saying: “I think it would actually be better to have it be a bit thicker than to have it thinner. Because people are like if you don’t hold your own phone, it’s more difficult to grab.” The size of the tool should be about the size phone on the larger side and can be quite a bit thicker than a phone. Normally a phone weighs around 200 grams, so the goal is to have the device weigh between 150 and 250 grams. Eventual users of the tool should be able to hold it for an extended period without it becoming too exhausting.

6.2 VR development

With all the features outside of VR working, bringing the tool into VR is the next step. This started with working on a simple VR unity project to walk around in. Next, the Vive tracker was brought into VR to visualize the device's location as the tracker will be connected to the tool. Specific software that was needed for this was also found.

6.2.1 Types of VR trackers

A requirement for the research team is that the tool must be trackable in VR. This can be done using a VR tracker. Two types of tracking technologies are important to this project that a tracker can use. It is important to choose the right tracker as there are significant differences between the two technologies. There is lighthouse tracking and IMU (inertial measurement unit) tracking. lighthouse tracking is a laser-based tracking system developed by Valve. It uses two base stations which are placed in the tracking area and are used as reference points in the room by the tracker [16]. This gives the tracker information about the location in the room which it can then transfer to unity. From unity assigning an object to this position is easy by using a C# script.

IMU trackers are often smaller than lighthouse tracking. In Figure 7 a Slime VR IMU tracker can be seen which weighs 50 grams, 25 grams lighter than the Vive tracker 3.0. IMU trackers also do not need base stations to determine their position in a room, as these trackers work by using orientation and speed to determine their position. This would be perfect for the tool, as these trackers are small enough to fit inside the tool and require less setup compared to lighthouse tracking. However, the issue with IMU trackers is that they are difficult to use with Unity, as there is no package for these trackers yet, and creating the logic is outside of this project’s scope. That is why for this project lighthouse tracking is used with the Vive tracker (3.0) and two base stations.

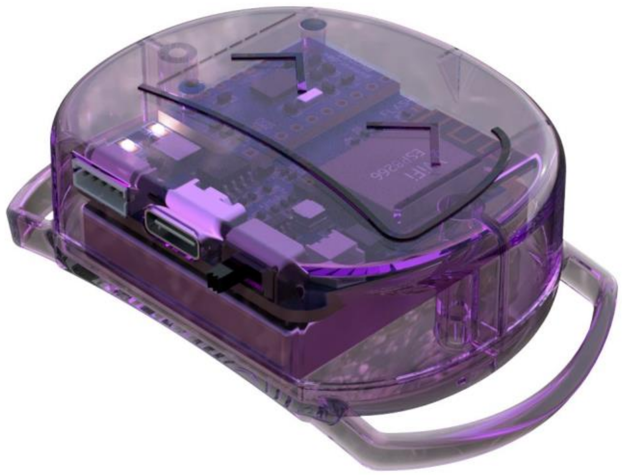


Figure 7 - Slime VR IMU tracker [17]

6.2.2 Tracking an object in VR.

To track an item in Unity, a new project was made. By implementing a simple movement system using the open XR unity package the basics of unity development can be made. This movement system lets the user walk around as well as track the location of the headset and controllers. Open XR uses Steam VR to display the scene to the user. To get the tracker into the project, the tracker and the base stations first had to connect to Steam VR. Once this is done an object can be attached to the location of the tracker. However, the location of the tracker in real life is not the same as the location of the object in VR if the tracker is not calibrated. When connecting a tracker using a Vive headset, the default calibration process works. But when using a headset from Meta a program called OpenVR-SpaceCalibrator can be used to calibrate the tracker. How this can be done can be found in the tool guide found in the appendix.

6.2.3 The tracked tool in Unity

Getting the tool to track in Unity starts with assigning an object to the tracker's location. This can be done by assigning the Vive tracker to a specific body part using Steam VR. Unity can now use the specifics from Steam VR and a custom input system to use the tracker's position. By assigning an object to the location of the tracker, the tool can appear in your hand.

Now that the tool can be tracked and seen in VR, the vibrational and audio systems' logic needs to be improved. This is done by adding onto the existing vibrational system explained in section 6.1.3. Some changes to the vibrational system explained in that section are a stronger vibration once a checkpoint is reached. As well as using both vibrational motors instead of only the stronger motor. A complementary system for the audio was made, where the time between beeps decreases the closer the user is to the next checkpoint. There is also an option to play a different sound effect if the user reaches a checkpoint in addition to the vibration. An alternative logic was made where there is a stronger vibration and a weaker vibration. These vibrations play on a specific interval that can be changed. The user would feel the stronger vibration when they are moving in the right direction, e.g. when their current distance to the next checkpoint is smaller than their distance to the next checkpoint a few moments before. The same is true for the weaker vibration but then in reverse. This specific system was also made for the audio system. However instead of using different volumes, different sound effects were used to indicate if a user is moving closer to the checkpoint.

After creating the logic for the tool, a testing scene was made to test this logic. Corridors were made with three exits after a specific number of checkpoints. The checkpoints work as positions in the world. The tool tracks a specific object which is located at the first checkpoint. Once the tool enters the radius of the object, the object moves to the second checkpoint. Using this system, the checkpoints can be moved to a specific location and additional routes can be added later.

6.2.4 Testing the set-up procedure

The set-up of the device was tested to find out if it is usable for the average researcher. Two members of the emergency escape team were asked to follow specific steps to set up the VR base stations and Vive tracker. Some confusion was found by Participant B “I didn’t know if I had to put the clip at the bottom or the back of the device.” This was a comment regarding attaching the clip to the base station itself. The steps explained that the clip must be screwed into the tool, however, there are two spots where this can be done on the base station. This led to confusion for the researcher. Other unclear steps were improved to be more specific or say what the difference is between the two options. After suggesting the option of video guides Participant A responded with a positive reception saying: “I think just having a second sort of channel of information would be helpful.” This is something that was therefore later implemented into the tool guide.

Before the tests, specific rooms were not considered, however, this is important as the tool will not always be used in the same room. Participant A supports this by saying: “I think the most tricky thing at the start would be the setup of the trackers. If the room is not workable you need to have at least two outlets or a connection extension or something.” Knowing which room to be in before future tests will make it possible to see if there are enough outlets for the base stations. After the test, the steps were updated and added to the tool guide, which can be found in Appendix 10.1.

6.3 Writing the guide

The guide consists of the required components needed to use the tool. In the guide, there is a section about the software needed to use the tool and where and how to install it. Next to this, there are explanations about the various set-up procedures for example how to set up the base stations or how to turn on the tool. There is also a section about common problems and what to do to fix them.

6.3.1 The tool guide

Next to the tool, there is also a guide that explains how to set up everything. This guide can be found in Appendix 10.1. Next to a setup explanation the guild also what other components are needed to test with the tool, like the base stations and a VR headset. At the end of the guide, there is a chapter about common problems and fixes that are found. The guide will be updated once more problems are found. It can be found in the appendix and contains instructions on the tool itself, the tracker, and base stations. There are instructions on how to turn them on, how to connect them to the computer, and how to operate them. The guide is written with steps, so it is easy to follow. There are pictures of the steps where these could prove useful.

The tool guide also contains videos of the more difficult steps or parts that are important to get right. The videos go through each step and show what must be done, as well as provide more information about why it must be done that way. These videos are available in the guide at the beginning of each part if there is a video guide for that part. In the videos, each step is also demonstrated, and an example is shown which the researcher can use.

6.4 Shell design

The shell is designed to house the PS4 controller on the inside and the Vive tracker on the outside. The components that are not needed for the tool are removed from the PS4 controller and a design is made to house the remaining parts. There are 2 spots for the vibrational motors at the bottom and a space for the charging port with the motherboard and battery located centrally in the device.

6.4.1 Specifications of the shell

The shell of the tool is designed to resemble a phone. Therefore, the shape is rectangular and can fit inside a pocket. It is roughly 9 cm wide, 15 cm tall, see Figure 9 and 4 cm thick, see Figure 8. The width and height of a phone resemble the same size as a larger phone, but the thickness is roughly three times as thick as a phone with a case. Attached to the shell is a small clip to which the Vive tracker can be attached. When everything is assembled and put together the tool weighs 360 grams. This is heavier than a normal phone, which weighs around 200 grams and could be cut down.

Figure 8 - side view of the tool

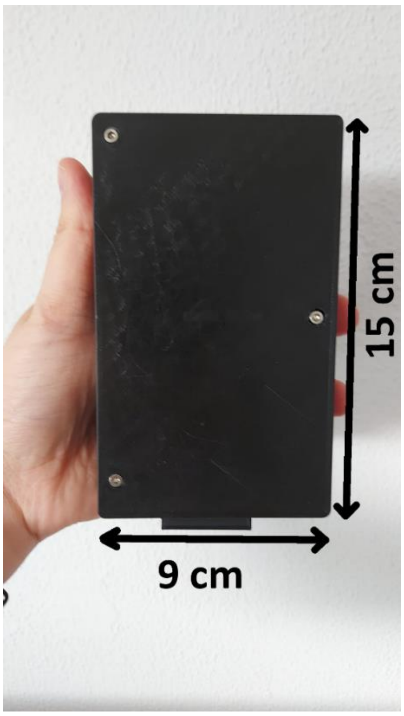


Figure 9 - front view of the tool

6.4.2 Functionalities of the tool

The tool consists of three parts, the body, the lid, and the clip. The body is the thing that houses all the components of the PS4 controller. The lid can be screwed onto the body to keep components properly secured and protected. The clip can be attached to the body and has a small screw onto which the Vive tracker can be screwed.

The shell was first designed using Blender, a 3d modeling software. There are a few noteworthy parts of the design. In Figure 10 a top-down view of the design can be seen. On the left, there is a space where the charging port can be mounted down using two screws. There are two holes where the screws can be mounted. Next, the two cylinders at the top keep the PS4 controller components aligned and stops the components from moving. The two cubes with circular holes are for mounting the vibrational motors. They are attached to the side and bottom of the device as that will be where the tester will hold the tool. Additionally, there are 3 more pillars, two in the top corners and 1 in the bottom middle. Those are there for mounting the lid to the body.

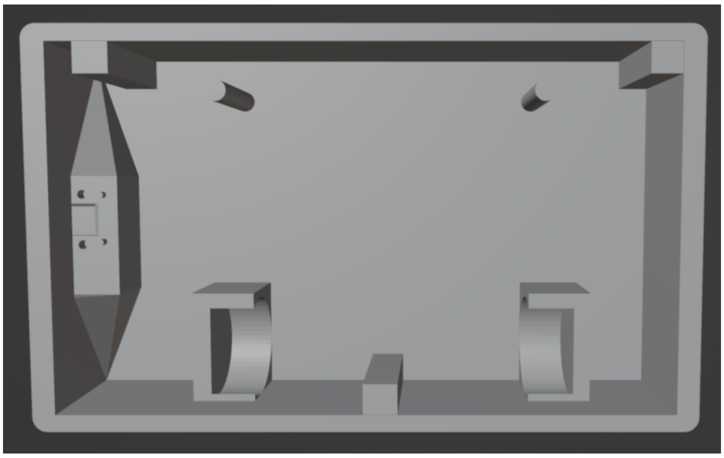


Figure 10 - 3D model of the body

Additionally, at the bottom of the body, where the charging port is located there is a small hole to see the charging port light, see Figure 11. This hole was made using a drill but could be incorporated into the next design. This light indicates when the device is charging and when it turns off when the device is fully charged. This is also where the clip can be attached to the body. By pushing the clip into the socket, it becomes secured to the body. The clip can be seen mounted to the body in Figure 8.

Figure 11 - Bottom side of the tool

The lid of the tool is secured by 3 screws, which can be seen in Figure 12. This was done by first drilling holes into the cube pillars, Figure 10. These holes could also be incorporated into a new design which minimises the need for additional tools. The holes were 3.5 mm wide and deep enough to fit a small screw into. After drilling the holes, a small metal screw holder was melted into the holes. Now the screws can screw into metal instead of plastic. The screws can be screwed on by using a 3mm hex key. This increases the durability of the tool and the security of the lid. Once the lid is secured there is a small gap between the lid and the body. This gap could be minimized by improving the current design.

Figure 12- Lid screws and socket

The clip can be attached to the body at the bottom underneath the charging port. It can be removed and attached by using some force but once secured it is sturdy and will not detach easily. On the other side of the clip, there is a screw, which is melted into the plastic to keep it secured. It is a special screw, often used in selfie sticks, which is where this screw comes from. The Vive tracker can be screwed onto the clip and will be secured during testing, this can be seen in Figure 13.

Figure 13 – the Vive tracker attached to the clip

6.4.3 Insides of the tool

There are many parts to a PS4 controller. Many of these parts are needed for the controller to function. However, some parts are not needed when only using the home button to connect the controller via Bluetooth and the vibrational motors. Firstly, the outer shell can be fully removed by unscrewing 4 screws at the back of the controller and using prying tools to pry open the controller. A wire that connects the charging chip and the motherboard can now be disconnected and the front and back can be separated. The charging chip can be seen in Figure 14 and can be removed using a screwdriver, as it too needs to be transferred to the tool.

Figure 14 - The charging chip

Secondly, the touchpad can be removed, since it is connected by a cable to the motherboard that can be disconnected. After it is disconnected the front plate can be removed from the internal components seen in Figure 15. Thirdly, the rubber parts for the buttons that are settled in the front part of the housing are also not needed and therefore are not in the tool. An exception is the rubber contact point for the home button, which is an important piece to connect the controller to a computer. All the removed components, including the touchpad, can be seen in Figure 15.

Figure 15 - Removed parts from the controller, Except the home button contact point

Lastly, most of the plastic housing can be removed. The outer shell can be fully discarded. The vibrational motors are glued into the internal housing. That part of the housing is cut off the rest and the motors were removed from the plastic. The specific plastic part that was removed can be found in Figure 16. The remaining internal plastic housing is used to keep specific parts of the controller aligned. Specifically, the flimsy foil with wires needs to make contact with a specific point on the motherboard for the home button to work.

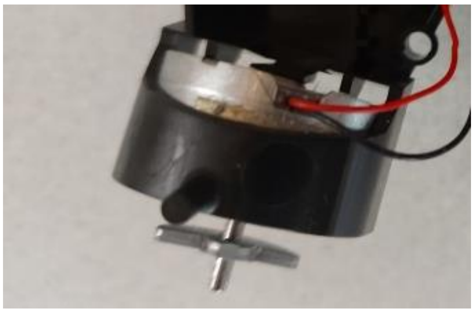


Figure 16 - Plastic housing around the vibrational motors

After removing the unnecessary components, everything that is left is the motherboard with internal housing, the vibrational motors, the charging chip, and the internal battery. Now these components can be inserted into the tool shell which can be seen in Figure 10. The charging chip can be secured using two screws onto the shell which can be seen in Figure 17 on the left side. A white clip between the motors and the motherboard was installed such that the motors could be glued onto the shell. This must be done because they could otherwise vibrate out of their position. The clip can now be used to separate the vibrational motors and the motherboard such that the motherboard can be removed from the tool if that is needed. The plastic part above the motherboard is connected to the motherboard using a nut and a bolt. The hole for this is normally used by the outer shell of the controller to keep the motherboard and plastic housing aligned. However, as the outer shell is removed a nut and bolt can be used for the same purpose. The nut and bolt can be seen in Figure 17 in the center of the motherboard just above the joysticks.

After everything is attached to the motherboard the remaining parts can be inserted into the shell in the following order: first the battery at the bottom, then the battery spacer which also keeps the battery aligned with the motherboard, and after that, the motherboard with plastic housing attached can be put on. Everything is kept in place using the two plastic aligners found at the top of Figure 17. Furthermore, once everything is inserted into the shell the rubber contact point can be put on top of the foil. This can be kept in place by using a rubber band as using tape or glue does not work on silicone without proper preparation. If the home button now needs to be pressed all that needs to be done is press slightly on the black part of the silicone. Lastly, some extra padding can be added between the motors to fill up the space between the motherboard and the side of the device. This can be done to keep the motherboard extra-secured.

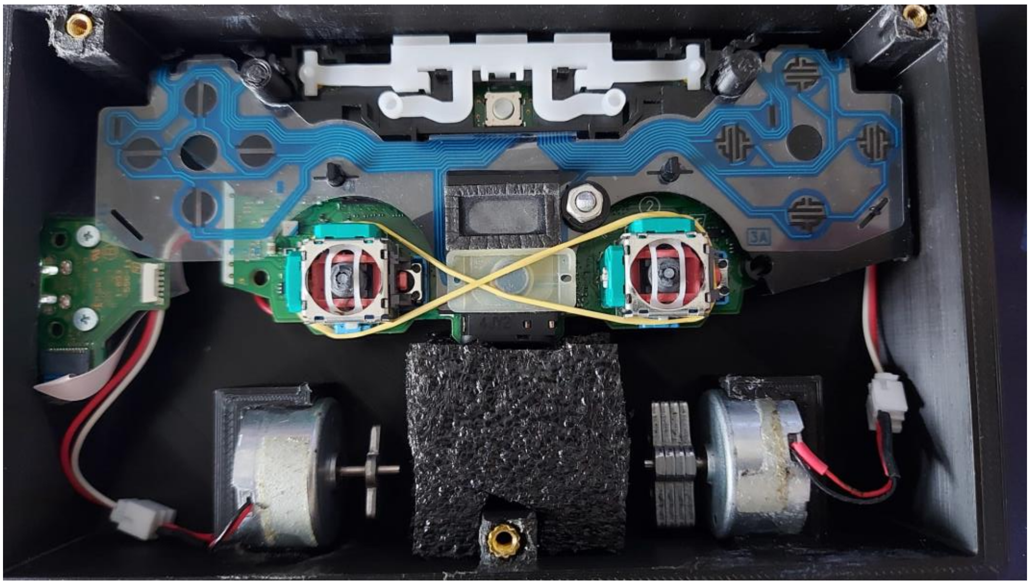


Figure 17 - Internal components of the tool

6.4.4 Optimizations to the design

Several future optimizations can be made to the design. Firstly, the two plastic aligners that can be found at the top of Figure 17 are quite weak. That means that they can break quickly if not handled with care. A potential way to improve this is by removing them and drilling two holes where they are located. After that two large screws can be inserted from the bottom of the device such that they stick inside the device. Metal is a lot stronger than 3d printed plastic and thus will be more reliable for testing. A second optimization is reducing the wasted space that can be found in the device. There is quite some space between the motherboard and the motors which allows the width to be reduced.

The same is true for the space between the motors and the charging chip. This space can be reduced to make the height of the device smaller. Furthermore, there is extra space between the highest point of the components and the lid of the tool. This was done to add extra padding to keep the internal components safe. The extra padding can be seen in Figure 18. However, this padding is not needed if a thinner device is needed.

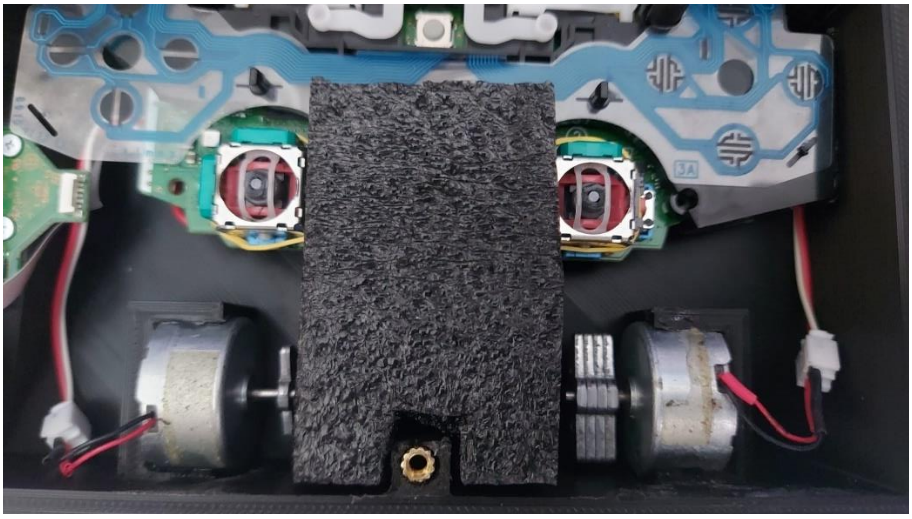


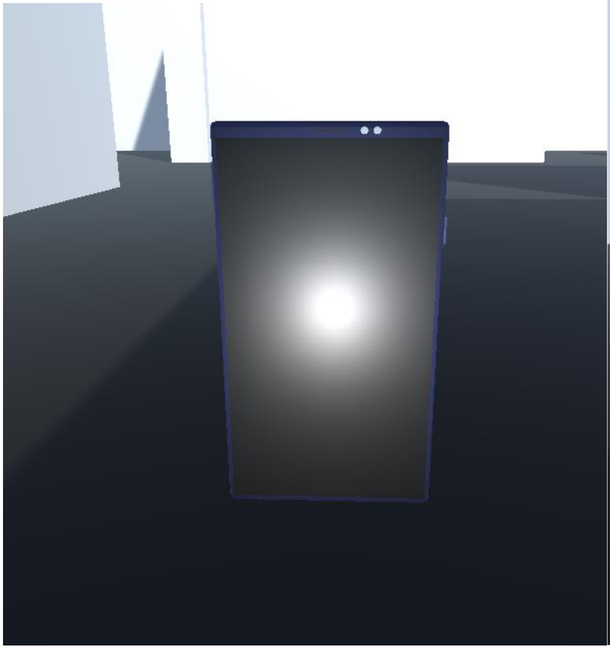
Figure 18 - Internal components with extra padding

Additionally, the weight of the tool can also be reduced in numerous ways. For example, by reducing the thickness of the walls or top, the tool will become lighter. Alternatively, using different/lighter components from a PS4 controller will also reduce the weight. The two joystick modules can also be removed which slightly reduces the weight. However, the biggest weight reduction can be made by switching from lighthouse-based tracking to IMU tracking. As an IMU tracker does not need any vision of the outside it can be put inside the device. Therefore, the clip can be removed and in general, an IMU tracker is often lighter than a lighthouse-based tracker.

Another improvement point for the design is an additional point to which the lid can be secured. There was no specific reason why three contact points for the lid were made, but increasing this from three to four will increase the sturdiness of the tool. It is recommended that there is the lid be secured in each corner to reduce the possibility for one side to lift and let objects like dust and debris come inside the tool.

6.5 Final testing/development

The final test was held with the tool fully built as well as an updated version of the Unity project mentioned in section 6.2.3. The changes for the project are regarding an additional signal to the user in the form of visual signals. The virtual phone now uses its “screen” to blink in synchronization with the audio and vibrations. How the tool is seen in VR can be seen in Figure 19. The first system flashes a green screen, which can be seen in Figure 20, when moving in the right direction, and a red screen when standing still or moving in the wrong direction. The second system always flashes a green screen but the time between the flashes depends on the distance from the tool to the next checkpoint. The further away the device is the longer the time between the flashes is.



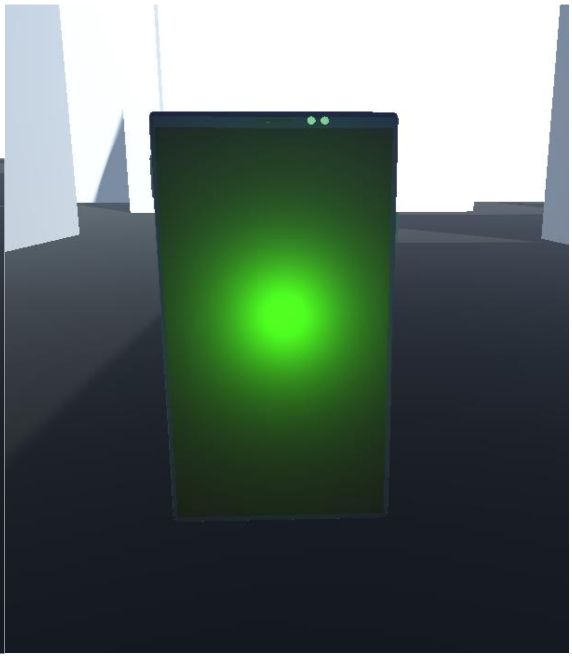


Figure 19 - The tool as seen in VR

Figure 20 - The tool flashing green

Firstly, the feedback on the shape of the device is mixed by users. User A first put on the VR headset and was then given the tool. Once they started forgot they were holding the tool and since the tool looked like a phone in VR began to feel like they were holding a phone. Participant A supports this by mentioning in his interview: “I knew how big this thing is before you put the VR headset over my head. But if this would be an experiment, I honestly like the idea of putting it into people’s hands when they are already in VR because then they don’t have this preconceived notion of how big the device is.” user C is normally used to smaller phones and was because of that not convinced they were holding a phone, they mention the following when asked about if the tool feels like a phone: “ It felt like a device that is a prototype for one. It wasn’t uncomfortable to hold, but it felt like a good approximation for it. It required a bit of a suspension of disbelief.” This indicates that the feel and texture of the tool are important for any possible next iterations. User B was sadly holding the tool incorrectly and therefore was not fully convinced they were holding a phone. They mentioned the following: “I’d say that in VR it kind of looked like a phone. It didn’t feel that much like a phone probably also because I wasn’t holding it like a phone.” They recommended telling testers to hold the device like a phone as that will probably improve emersion

Secondly, out of the three signals used to communicate with the user, vibrational systems were noticed the least. Participant A mentioned the following regarding the vibrations when testing with the red and green system: “Maybe I was focusing too much on the red and green, but I guess the vibration is not that important when the colors are there. Maybe it could also be because they were so consistent that I ended up zoning them out” Vibrations during the red and green system do vary between stronger and weaker vibrations, but because the contrast between red and green is more than weaker and heavier vibrations it will be easier to focus on the visuals. In the second test where the strength of the vibrations ramps up and reset once a checkpoint is reached, Participant A noticed the vibrations more. Participant B supports this by saying the following when asked in which system they noticed the vibrations more: “In the second one. The first one I didn’t notice it at all. I think because in the first the lights were way more prominent, so the other ones I didn’t need to focus on. And then the second one, the light was less prominent. So, I had to rely a bit more on the other two”. It is unclear if the vibrational part of the tool is needed for users and how it can be improved when testing with real participants.

Lastly, the tracking of the tool was perceived as relatively standard. Some hiccups were noticed like the tool losing tracking for a split second and thus flying away. Participant A mentions the following regarding this: "They were once or twice where I put it, the phone down to my side. Where I saw it disappear. And that could be because I was blocking one of the cameras." Participant C adds to this: "There were a couple of hiccups. I'm personally not working so often with VR, but often enough that I don't pay attention to it. So, for me, it was not super distracting." These issues were common when tracking anything in VR and therefore don't require any more problem-solving. Additionally, during the test, there was one instance where the tool in VR and the tool in real life were desynced, as there was a meter distance between the two. This was easily fixed by resetting the tracking.

7. Discussion

Numerous discussion points were mentioned during the user tests with the emergency escape team. These include problems encountered during the development and their implications for the project and further research. Specific discussion points are the vibrational components of the tool compared to the other stimulations, the perception of the tool as a phone in VR, and what the test should look like when testing with real participants. Next to this, it is important to mention the possibility of optimizations for the design in both weight, shape, and size. The initial discussion point is about the number of tests done at each point in development. Data from two participants for the first two tests and three participants for the last is not a lot to develop concrete conclusions. However, it is enough to find major flaws and speculate on potential improvements. The upcoming discussion point should be reevaluated in case there are any additional tests and/or developments.

The next discussion point is about the vibrational component of the finished tool. Since the tool has two different vibrational motors which can each be separately turned on, there is some option for customisability. The motors have different weights attached to them making one motor vibrate the tool more than the other. When focussing on the vibrations they can be noticed quite clearly, as the combination of both motors creates roughly the same vibration as a regular phone. However, during the tests, vibrations aren't the only signal used to communicate with the user. This is because we trust sounds and visuals more than vibrations as we are more used to them in daily life. This leads to testers zoning out the vibrations and focussing on either sound or visuals when all three signals are used together. This is not necessarily a bad thing as it can be used as supporting information, which might prove useful in a high-stress environment like an emergency evacuation. It is recommended that vibrations are still used in the tool and additional tests should be done to determine the ideal strength of the vibrations.

Another discussion point is regarding the perception of the tool as a phone in VR. As the size of the tool is larger than an average-sized phone, most people will not perceive the tool as a phone when showing it in real life. However, it is possible to trick the mind into thinking that users are holding a phone, which is the goal of the tool. If the user gets the phone handed in VR they don't have any preconceived notion of what the tool looks like and are more likely to believe that the tool is a phone. This is harder for users who are used to a smaller phone, as the width and height are quite a bit bigger than a small-sized phone. Because of this, it will take more time for them to think of the tool as a phone. Furthermore, the user should hold the tool like a phone to increase emersion as the thickness is the part that deviates the most from a regular phone. Specific improvements to the design are already mentioned in Chapter 6.5. However, some additional improvements can be found by changing the material of the tool to common materials found on phones or phone cases. This will make the tool feel more realistic as 3D-printed plastic feels different than a leather or plastic phone case.

Furthermore, next to the tool, some important things to keep in mind during further tests are the reach of cables. It is recommended to keep any real-life issues to a minimum during testing. That implies that the user should not struggle with cable management while turning in VR. Using spools to keep the wire hanging from above helps with this issue. Furthermore, to minimize desynchronization between the tracker and phone in VR, it is recommended to use a well-lit room without any sunlight. As base station emits the same type of light found in sunlight.

Lastly, as mentioned in Chapter 6.4.4 the use of an IMU tracker will reduce the overall weight of the tool. In general, IMU trackers are lighter than lighthouse-based tracking. Using an IMU tracker will also reduce the need for the base stations as those are there only for the tracker because when using a meta headset, base stations are not needed. This also makes the set-up of the tool a bit easier as setting up the base stations in a new room can take up quite some time. The biggest issue with using IMU trackers is that there are little to no guides to use those kinds of trackers in Unity. Therefore, it is only possible for an advanced user who is used to working with advanced coding with Unity and VR.

8. Conclusion

In conclusion, this research aims to provide a foundational research tool for other researchers to use and shows steps in how to possibly develop a specific tool needed for other kinds of research. research devices do not have to be expensive pieces of equipment as demonstrated by the capabilities of this tool. The tool can be replicated by other researchers and its functionalities can be applied in many more circumstances. Using VR, the tool can vibrate using the two different vibrational motors located inside the tool. Furthermore, using the technology of VR and an HTC Vive tracker the tool can be tracked and located in VR and given any look needed by researchers not limited by specific phone types. Using simple unity code and systems, using audio and visuals are also a possibility when using the tool. The tool guide provides information about the setup, requirements, problems, and fixes to aid other researchers in using this tool. To better understand the implications of the tool, future studies could address enhancing the current design and looking for possible ways to upgrade certain parts of the tool, like the tracker or specific hardware components. As well as look for alternative ways to use widely accessible research tools.

9. References

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10. Appendix

[1]This literature review was made as an assignment for the EEMCS Creative Technology Bachelor course “Academic Writing” and was made by Mitchell van Poecke.

10.1 Set-up and device explanation:

List of items needed for device set-up.

Hardware:

- VR headset with controllers (Oculus or Vive)
- Cabel to connect headset to PC (for quest 2 usb c to usb a, 5 meters preferred)
- 2x Vive Tracking Base stations + Base station clip.

- 2x Vive Tracking Base stations power cable.
- The tool
- Vive tracker + dongle (should be included in the box)


- A PC good enough to run VR.

Software (for on the pc, 1 time set up for a new PC):

- The emergency escape unity project.
- Steam (https://store.steampowered.com/)
- Steam VR (can be found in the steam store, https://store.steampowered.com/app/250820/SteamVR/)
- Oculus software (Meta headsets only, https://www.oculus.com/download_app/?id=1582076955407037)
- OpenVR-SpaceCalibrator (Meta headsets only, https://github.com/pushrax/OpenVR-SpaceCalibrator)

Preparation:

1. Make sure the VR Headset (in case of using a quest (2)) is charged.
2. Make sure the VR controllers have batteries in them that are charged.
3. Make sure the Vive tracker is charged before the test begins.
4. Make sure the Device is charged before the test begins.

Hardware Set-up:

Setting up the base stations

For a video demonstration click here: https://youtu.be/Uc0yg7jfPqM

When setting up the base stations have them on opposite sides of the room facing each other. That will be the area that is being tracked. The Vive tracker should always stay visible to one of the base stations.

1. Attach the Vive base stations to the clips.

2. Plug the power cable into the Base Station.

3. Find a spot for the Vive Base stations, they must face each other (preferably as high as possible and facing slightly down 10-20 degrees. They do not have to be equal hight, but it is preferred if possible)
4. Attach the clip to a sturdy object either horizontally or vertically. (Make sure the HTC logo will face up when it is attached
5. Plug the power cable into a socket.
6. If done correctly there should be a green light and one base station should show a B and the other a C.
7. If one or both show an A, hit the channel buttons until it shows a B and a C.

Setting up the VR headset

1. Turn on the VR Headset.
2. Plug the headset into the computer.

3. Follow the instructions in the headset to set up the play area.
4. Boot up steam VR when the headset is connected and ready.

Setting up the Device

1. Add the device to the PC via Bluetooth.
2. Hold the ps4 button and the share button.
3. Go to the settings menu of the computer.
4. Click on Devices and add a Bluetooth or other device.
5. Click on Bluetooth.
6. The controller should show up, if not repeat step 2.
7. Select the controller in the list of devices to pair/connect the device to the computer.
8. The Device is now connected.

if the computer does not have Bluetooth the only option is to use a wire directly to the computer. The device should connect automatically that way, but it does require to be connected by the wire.

Setting up the tracker

First set up the base stations and stating up Steam VR before doing this step.

1. Plug the dongle into the computer.

2. Add the connector to the dongle.

 

3. Turn on the VR Tracker by holding the button in the middle for 2 seconds.

4. If the light turns green you are done! Otherwise continue steps 4 - 9
5. Right click on the little steam VR window
6. Click on devices -> Pair Controller
7. Click on HTC Vive Tracker
8. Hold the button of the VR tracker for another 2 seconds.
9. The tracker should start blinking and eventually turn green.

10. The Tracker is now connected.

Calibrating the tracker

This must be done for quest headsets only.
First follow the First time Software Set-up, setting up VR headset and setting up device before following this part. This needs to be done each time you restart steam VR, or if the tracker turns off/becomes inaccurate.

1. OpenVR-SpaceCalibrator should be open when steam VR is running.
2. Select the left controller in the top left corner of the window.
3. Select the tracker in the top right corner of the window.
4. Select the slow calibration speed for more accurate tracking.
5. Put on the VR headset.
6. Grab the left controller and hold it in your hands.
7. Hold the tracker close to the device.
8. Click Start Calibration.
9. Move the device and tracker in a figure infinite motion until calibrating is complete.

Pairing the tool to the computer

For a video demonstration click here: https://youtu.be/qVIAEqgORrA

The tool is a PS4 controller and thus needs to be connected to a computer via Bluetooth. If the computer does not have Bluetooth go directly to Connecting the tool to the computer. If the computer does have Bluetooth, follow these steps:

1. Open the tool, by carefully removing the screws using the included hex key.
2. On the computer go to settings → Devices → add Bluetooth device → Bluetooth
3. While the computer is looking for Bluetooth devices, press and hold the home button (the black part of the rubber in the red circle) and the share button (the elevated white part inside the yellow circle).
4. The tool should show as gamepad, or wireless controller or something similar.
5. Click on it to pair the controller to the computer.

Connecting the tool to the computer

If the computer does not have Bluetooth as an option, use a USB A to Micro usb cable to connect the device to the computer. Only do this if the tool is already paired to the computer.

follow these steps to connect the controller to the computer:

1. Open the tool if it is not already opened
2. press the home button once.
3. The wireless controller should show connected instead paired in settings → Devices
4. Close up the tool with the hexagonal key

Attaching the tracker to the tool

1. Attach the clip to the body by using a little force to click it in place
2. Slot the safety strap over the clip and the screw
3. Screw the tracker onto the clip.
4. The clip is not attached to the body!

First time Software Set-up

This only has to be done once but does need to be done each time you use a new PC.

Meta Software

This step only needs to be done for meta headsets, but should be done before Steam/Steam VR

1. Download and open the Meta software, link in the software requirements.
2. Log in using a google/meta-account.
3. Click on devices and Add Headset.
4. In your VR headset, click on quick settings.
5. Click on Quest Link
6. Press Launch.
7. If the headset is plugged in it should show the headset in the software on the PC.
8. Select link cable and continue through the prompts.
9. The headset is now connected to the PC.

Steam/Steam VR

1. Download steam using the link in the software requirements.
2. Make a steam account and log in.
3. Download steam VR from the steam store. (it's free 😊)
4. If you start Steam VR and use Vive headsets should prompt you with a set-up wizard for the play area, complete it.
5. If you start Steam VR and use a Meta headset you should open steam VR and end up in a house inside the headset. This means steam VR is running successfully!

Transcripts

All transcripts are automatically generated by Microsoft teams. When text is referenced in the report the audio file is used to get the correct intentions.

10.2.1 Transcript first test participant a

1. What were your overall first impressions of the functionality so far?
2. It seemed to work. I was surprised by how well the audio worked. That's actually recognizable where the noise is coming from. So that was surprising to me because I didn't know that it there can be that good, but for the vibrations. I felt it mostly in the left hand. So I think it would be ok if I even hold to tell the controller only in one hand because there was not really coming anything on the right hand. Umm well, I did feel that much weaker. But in both cases it seemed to me that the vibrations got stronger and stronger and the sound got louder and louder the closer we came to the target, and it got weaker and the further we were away. So A that was the intended thing, then that worked. I guess I I'd have questions like how right now in the in the tactile condition, we had a sort of fixed Max distance. And as you pointed out out earlier that there was no reset after you hit the trigger zone, which is fine. But I was wondering, do we need to consider sort of maximum distance because it can't go infinitely low. In regards to sound or vibration so that there needs to be a sort of lower limit of what the minimum. You know, noise level or vibration level, is that a person can recognize? And I was wondering what that would be, because then that would have implications on what the navigation could look like.
3. Umm so then also the question will be the what would be the the ideal distance between the nodes for it to? Basically that that a person would know, OK, I need to go this direction.
4. Yeah, I guess so.
5. If the if the distance is too big, then you wouldn't know if you were walking the the right way because the vibration doesn't go up or down as much as you.
6. Yeah, I guess so.
7. And is there anything you would like to see added onto these functionalities that you were missing?
8. We've got to functionality. So what we just talked about that being reset in the trigger zone, I think that would be nice to have, but that's already implemented in other systems, so. There is the form factor that that will change I guess from the device. Umm for testing purposes it would be nice to have a. Have the way that you can do both audio and haptics. And. Yeah, I think I think that would some be something that I'd add. And then. And maybe that's more of a mechanical our consideration then a sort of software functionality consideration. The problem of vibrations is always that you hear them. And maybe that's more of a mechanical our consideration then a sort of software functionality consideration. The problem of vibrations is always that you hear them. How much would the noise have to be in relation to the vibration so the navigational noise need to be in relation to the motor noise that the vibration make. In order for this, for the sound to be noticeable over the vibration of the motor. If you want those two things to be somewhat similar in there, they're push to move certain way, but I guess minor things. But with that being said, I think the main functionality is there in that it is vibrating in a handheld device and it is emitting sound in a 3D way. So. So that's good. So that's great. Now, I'd be very curious to see if that can be packaged in a yeah, in a phone shaped device. I guess.
9. So for me as well the the next step is this is all basically 2 dimensional functionality as in it's using virtual space but we need to the next step is using VR to let it all come together.
10. Basically, yeah. And does the umm so when you said 2D space. It's also quite interesting because we were only moving horizontally.
11. Yeah.
12. And when I was now thinking of having this as a phone, then I could also hold the phone up or down in in 3D space on the Y axis as well.
13. Yeah.

14. Would that be something that and that the audio system can handle?
15. Uh, I mean it in general, if you have it here, it will come from the right. Yeah, same with up. It will still mostly come from the right, so it's basically since you're holding it, you will also. When you think about it, ohh it's over there and then especially. Ohh it's coming from there. You can kind of fill the blank in yourself, right? Yeah, but I think in general it does also take in the the Z direction.
16. Yeah, OK.
17. What are the parameters that need to be able to change in regards to the audio? As in, is it volume? What kind of sound file?
18. Yes, all of those, so I think. When I think research, I think very strictly controlled environments. So the first sound that I'd use is probably. Is like just a beep or a series of beeps and then I would need to define the the amplitude of the beep and the frequency in which the beep occurs and the sort of spacing between the beeps. Uhm, so that but then. So that that would need to be adjustable, the loudness, the frequency, the type of sound in the your example that you showed you had this sort of, you know, elevator waiting. Yeah, music as a demonstration. And it's a very nice nice for demonstration, but it probably wouldn't be used as such for.
19. Yeah.
20. Well research setting because when I think navigation I'd want the ability to have different sound stimuli, but also probably short ones because it needs to be adaptive. Yeah, so pitch frequency, amplitude, the type of sound file. The I guess the updating rate, I mean that the guests that's partially controlled by the the sort of distance between checkpoints. And but what I mean is, so let's imagine we have sort of checkpoint 10 meters apart. If the sound clip is too long then it will still play, while actually shouldn't be. One should start over again, so software wise there would need to be sort of cut once the next.
21. How unity does it is if you play sound and if it still playing you hit play again, then it just resets.
22. OK, so there is no layering on the audio like an old video games where if you select 20 units of the same type no amplifies the amplitude and it's super large, right? That's good.
23. I also have the same question for vibrations cause now the headset player moves to the checkpoint and that's linear, yes. So when you move to it, it linearly becomes higher and higher.
24. Yeah.
25. How would that eventually look like?
26. Well, it be in pulses.
27. So it's like uh, because now it's constantly vibrating.
28. Yeah.
29. Would there need to be an option where it's like BOOP, boop, BOOP and then it gets faster or?
30. Umm. My first inclination would be that. So that the amplitude of vibration that I need to make sure that the person gets it. Umm is different? Yeah, because there is more artificial noise. Having the option to change it is good and I rather sort of in an emergency situation. I would, I guess put it on whatever the Max is and to make sure that it's always working. Umm, but in a controlled experimental environment you may not want to put it on the absolute maximum setting, because then you hear the motor so loud. That it may be distracted. And it may be so sudden that it may be, you know, surprising or shocking that the first reaction may be jumping. You're scared about it, but in emergency, I guess that wouldn't be the case because you have primarily concern is not to get burned to death. So having a strong vibrating device is not your biggest worry. But yeah, so I think This is why having the option to control the loudness in the case of the audio or just strength of the vibrations. Hmm is a good option to have, although I would probably for experimental settings keep it rather low. Yeah, and rather controlled. Umm plus I think you know software wise it would be nice to have a specific knowledge about the like how much it is like how loud it is and decibels or how sort of you know strong it is and how many Hertz

the vibrations are and the aptitude is what the P to peak frequency is and whatnot, because then you can compare this to a device that you want to sort of mirror.

31. So when I was thinking about maybe we can use this to put the phone into people's pockets. I have honestly no idea how loud the phone can be and I have no clue of how. I strongly affirmed vibrates, so having the the technical knowledge and information to be able to relate it to something that we sort of have an intuitive feeling for would be good, yeah. But then you know, not all pants have actually pockets, and they are very different sizes and it depends on what the person actually wears and how tall the person is. Like you're quite a tall person, so you are pockets will naturally be much bigger than a person. That's just the medium pockets fit. So I guess, yeah, I think at the largest it should be. Like. Umm, sort of. I'm looking for a looking around for a book that is kind of the the form factor that I'm thinking of. Yeah, but maybe, you know,
32. maybe over there are more.
33. Yeah, maybe you know, these of those are good. You know these these like Donald Duck comics that you have like, goes Donald Duck, funny pocketbooks like, I think that that would be sort of the the Max yeah. Because they are. When I think back when I read them, when I was a kid, they could be like sort of bent a bit and put into the pocket quite comfortably and we carry them around quite easily. So I think that size. And I think ideally it wouldn't be all too heavy.
34. Mm-hmm.
35. So you could have it comfortably in one hand. For the duration of an of an experiment. So when I think about a study that I were to do in a lab, it may be that it it could take an hour, could take 1.5 hours and maybe you wouldn't have to hold it in your hand for that duration. But let's say it would be possible to hold it. In your hand for an hour. So like, I don't think it should be much heavier than let's say like 200 grams or 250 grams, cause everything above that gets kind of heavy if you hold it for long enough.
36. OK.

10.2.2 Transcript first test participant b

1. My first question is what are your overall impressions of the functionalities right now? So anything that sticks out
2. I really like it, like the gradual increase of the vibration especially. I like that it shows where it's where it goes left.
3. Alright, so you said that if it's, if you have to go left it, but it's once and if.
4. Yeah, so basically right now that's hard coded. But eventually, like a system, needs to be made for that.
5. OK.
6. That's, I don't know if you have any suggestions for that. Of all it could work. I don't know if like I'm thinking if you do this in a more stressful situation or if it's tested, then maybe people could forget what one vibration and two vibration would mean.
7. Ohm, but I don't know how you could fix it. And also I think some people have difficulty with letting reads and writes associate one with left or right or something.
8. So, but yeah, you're also only holding it in one pence and can't really change it. Hmm, depending on the size.
9. Something that could maybe work is having a so like when you reach a checkpoint it's always just vibrates twice so you know you reach a checkpoint and then the audio is just like OK, turn right or turn left that would be possible.
10. Yeah, country is single another way right now.
11. is that like from my Study, we are trying to see the difference of between having like vibrations having auditory signals and having visual signals, lights, flash or something. So then if you tell them go left or right, it kind of defeats the purpose of the vibration, you know, because then you don't have the difference between auditory and vibration. And so, like, just from the perspective of my Study, I'll keep the vibration, but then add probably has to do it like one of our personal versions.

12. I mean basically all functionalities can be turned on and off if they only so.
13. Or you just let them figure out which way they have to go.
14. They could also do possibility, yeah.
15. Actually, the vibrance once that's really good.
16. Yeah.
17. And yeah, for the for the auditory there also really like it because it's cool that it only only here it's on the left side or the right side maybe. I don't know if it's possible that you because now I think you only hear it on the right side if it's on the right.
18. So because I don't think that's really how it works and real life, it's still kind of here on the left side, just work, right?
19. So maybe if you can.
20. Yeah, the crease the, the, the, the volume just a bit so that you actually hear that's on the right side but not the the left side of the people turned off.
21. Yeah, OK. Yeah.
22. Alright.
23. Umm are there any functionalities that were missing in your van?
24. Umm. I mean for now, because they didn't do it yet. Is the the flashlight or something the the visual thing?
25. So, umm, but there's actually like an interesting point because I couldn't imagine that if you have like, it's probably like a flash that increases. So it gets, it gets faster and faster.
26. Some people might find it super disturbing if it flashes super quickly. Umm, so that's something that you have to keep in mind.
27. Ohm, I don't know if you have any ideas yet. So for the the actual flashing lights, it will most likely be done in VR, since if you have a headset you can't see the device.
28. That you're holding, but how exactly?
29. I will do that as a script. Like flashing lights might be a bit difficult. Also with like epilepsy and yeah yeah.
30. Yeah, that's true. The functionalities that you have until now, I don't think I'm I'm missing anything. I mean, yeah, the left and right is still something that might be difficult for people.
31. Umm for the auditory parts. And then it would just be like umm, so there's something like and maybe even an option for go left, go right, go straight auditory.
32. Yeah, sure.
33. That's that's actually super helpful. And if there was a voice, something like kind of like Google Maps or something. Where you where the checkpoint reached. So that's an option that also still want to add because I think that might be useful for testing too, because it would be it.
34. Were there any for for the the vibrational functions?
35. In the end, as in the controller, cause for now it's. It's like a good intensity. I would say, but I don't know how you're gonna build it, so maybe it's gonna be too weak or too.
36. Yeah. Also, don't know that yet because it's very dependent on the build as well. Uh, But I'll still need to do research on how to basically use a vibrational motor to get it in a device and let it vibrate.
37. But yeah, if you think about it, then in the end it should be something like a phone or something. hen the web version is probably not that strong strong, so it doesn't vibrate that strong. So yeah, I mean from the left and right, that's it.
38. What would be the the ideal form factor of this device in in your mind, if you could basically make it any shape or size basically phone size, but how big or small would it have to be?
39. I don't know. Like yeah, phone service, but difficult. I wouldn't make it too thin, because then I think you have the problem that people can't really grab it and and it's it's unusual because I think phones are not that in usually. I would make a bit more. Umm, I don't know that you're gonna grab it. Into these more, but it has a few more corners stuff. Do you also need like that material?
40. So I mean basically I will probably 3 print the shell.

41. Yeah.
42. So my idea is that I have a shell I put in the components and then I just close it up and maybe with like a screw or something close it. So if you do have to take it apart, you can just take it apart. But then the issue is with the tracker, because it also has to be attached to it somehow. OK, so the initial idea I had was that I could maybe like make a clip where I can attach the tracker to and then clip it onto the phone.
43. Yeah.
44. But do you think there would be issues if the phone would be like a bit thicker, so like maybe double the size or triple maybe?
45. No, I don't think so. I think it would actually be better to have it a bit thicker than to have it thinner. hmm, because I don't. I'm just thinking, well, people are like if you don't hold your own phone, it's more difficult to grab because it used to your own phone. And then I'm like, people are potentially at some point in the Study there would be running or, I don't know, moving quickly. And then I think the danger of, like letting go of it is way higher than it would if you have, like, a super that's also maybe something about the weights.
46. Is there an optimal weight?
47. Yeah. I mean, it's very difficult to have the same weight as a normal phone, right? Because you have to put some some things in it and also you have to some sensor there, umm. Yeah, I mean it should be some words light and somewhat close to the phone, but I don't think
48. it's that bad if it's a bit heavier than than a normal phone.
49. No, because it gets used to it. I think I think most people like for the 1st 5 minutes, it's gonna be weird, but it's gotta be weird anyways because you're gonna be Real Life Environment. It's not, and I think then the phone is the least problem.
50. I mean, for my study that I'm doing, it's not that important that the phone feels real, something a little bit. I mean, I'm not gonna implement it anyways, but if I would if paying for my study, I would find it way more interesting to see how the phone looks in the VR environment. So how the graphic is because like for me I always find it weird when phones are used in games because they always look kind of weird thing and kind of like out of place.

10.2.3 Transcript second test participant b

1. What are your first impressions of setting up the device? Any steps that were difficult? Anything that wasn't clear?
2. But I didn't know if I had to put them the clip at the bottom or at the back of the device. Uh, But then once I had, it was OK. I mean, I think it's also depending on where where you put it, because it will put it somewhere else of something. Then it would have been fine.
3. Uh, and how was the tracking interfere itself?
4. I think it was good. I think it would work well one time I noticed the the the device and the rest and just like slips back and forth. I don't know what I did, but it was just like it went for, went to the left for for like a second and then came back just like glitched or something. Yeah, personally I don't think there are some things that I think it could be so either it has to be that it's not tracking correctly. So you send better in the tracking area or it's the PC because it is using a lot of processing power. Yeah. So then it starts. Stops using the processing power for the tracking and I think maybe if I start running it as a program instead of in the unity soon itself, then it might be better. But I don't fully know why it costs us that as well. Yeah. So I don't think it's the biggest problem because it's just for one time for like the split sake. Yeah, just it's so, yeah, I'm gonna perform that.
5. was there anything with the setup procedure that was specifically well?.
6. Well, yeah, we'll figure most of the things were pretty clear. You assume that I dont know anything was that I already knew something that was like from the from scratch. Basically I mean OK, I didn't know that they were called. But maybe describe them first.

10.2.4 Transcript second test participant a

1. Then my first question is, what are your overall impression of the the steps and that's the way you had to do things, anything that sticks out, anything that too difficult, too easy?
2. Umm, nothing too easy, I'd say. I think it was. So everything went well when I did it, so I don't know what would happen if it goes wrong. Umm. Yeah, I think the most tricky thing at the start would be the setup of the trackers. If the room is not workable you need to have at least two outlets or a connection extension or something. Umm, so I'd probably bring one along. And probably bring like a connection extension or something. Yeah, but maybe a good thing to also put on the list that you might need. Yeah, because if you are in a room with like one outlets on one wall, then you need to have them. And that sometimes happens where the outlets in in some of the experimentation rooms that are just right next to the door. And then there's a long extension cable running towards the PC and everything set up there, and then all the spots are occupied there.
3. Yeah.
4. Then you really need to figure out what you what you need. So yeah, extension cord would be one thing. And then it was good that in the instructions that said there should be sort of head hide or above even, but they don't have to be, but they should face each other and ideally they look down and no. So in this situation we have one that's yeah, about head height and the other one that's not that I, I mean, I'm not sure if it worked. But they see each other, I think. So basically this is now the the range that it's tracking, and if you're holding the Fox tracker within that area, which is basically the area where you will hold your hand when you're yeah doing it, then it's fine. If the tracker work to be higher, like on their shoulder, then it might be a bit more difficult than they would actually both have to be had high. So then I I'd say that would be a nice thing to put in the explanation. I mean it's it's sort of obvious, but then again, sometimes the obvious needs to be stated.
5. How everything worked so I had the idea of maybe making a sort of video or let's go for for specific steps that I think might be more difficult. Do you think that's helpful or would you skip over that?
6. I think I think it's helpful. You know, when you when you play a board game? Sometimes, umm, when you have the instructions and your body thinks that perfectly reasonable and do you think I don't understand? And then you have to watch your video of somebody actually doing it. And they're like, ah, OK, that's what they mean. So I think just having a second sort of channel of information would be helpful. OK, similar to what I said when I said Ohh. You know, it would be nice to see a sort of example setup that's prototypical so that that know what I'm building towards, but it's tender to when I'm building a shelf, then I know that's gonna be shelf. So I know, alright, this board is probably gonna be here. So yeah, I think I think it would be helpful.
7. OK, uh, are there any challenges that might come to mind when with the steps you perform anything that maybe too difficult like you already mentioned the the positions, but it's something else.
8. Yeah, the positions, the outlets and. Maybe in some regards to the the the wire having to be attached or. Don't sink to the touching the wire would be a problem. It just means that you need to bring wire. UM. I would. I guess the biggest problem would be if it if the software for whatever reason doesn't recognize one or more of the, you know pieces. Hmm. Setups seems, at least for now. Umm. Seems to me like it's it's easy enough. Umm yeah, I guess I would. As I said, I would have sort of, you know, prototypical movement checklist for the participants to do before the experiment so that we're sure that the usual range of motion is definitely trapped. Mm-hmm. And they don't lose connection halfway through, and then you have to do the whole experiment again.
9. Like for example you you like the pictures during the device trackers that that made were missing in uh.
10. Yeah, I like pictures. Pictures that great. Also, the sort of you know sanity check, things like Look at the trackers. If there was B&C, if there's a green light, great. OK, love checklists. If there is an A showing in one of them, no good.

11. Anything else you would like to mention?
12. I guess what if I lose connection? How? How to troubleshoot or something? Umm, I guess that's more of a of a living document situation where if there is a problem, you write down how you fix it and then future people can look at the fix. OK, so I'm not sure if you can anticipate all the users' problems. They can start with a troubleshoot document already with like common problems.

10.2.5 Transcript third test participant a

1. The ramping is basically more better in that sense because the moment you're closer, you know you're going the right direction.
2. Yeah.
3. So when it works, it works better because basically when you move here, you instantly went the right path except for when you were here and you had to go there.
4. Yeah, you started walking in, in circles moving forward. So that that's, I guess, the compromise of the two so far, uh. It depends a bit like maybe an option is to combine the two systems. The you I I don't really know how you would do that though, but I guess you could.
5. But it seems like the the ramping up is nice for when you're right.
6. Yeah.
7. Because then you're really know. You're right. But it's bad at telling you when you're wrong. Yeah, because the differences in vibration or beeping or whatever.
8. yeah, they change all the time.
9. Like the red would have been very helpful from the first, so just it's basically the same, just it starts beeping faster the moment you get close to something. But when you're walking away, it starts beeping red. But it's bad at telling you when you're wrong.
10. So that that I have, because I think that the red and green was a very nice thing actually, maybe red and green can be confusing for colourblind people. Also, maybe checkpoint placement is something that needs to be refined, but this is also an issue that we face in the other project.
11. Yeah.
12. Well, we now thought about placing checkpoints not at the intersection, but slightly to towards the direction where you should be going.
13. Ah yeah, I just placed it around the corner, right?
14. I mean that that could work, but then yeah, no, that actually makes sense. I'm thinking of maybe if you're like here then checkpoint would be here and then the next would be here, yes. So maybe people would start like when you're moving this direction. It would also show green still yes, when you're working with distance and then here it would only show red so that you would be back to work as well. So I don't know if that's harder or easier to distinguish than right there there in this situation it's. Or I guess in real life that little test off space would be an office or a story through.So you would kind of know from complex umm, it's not supposed to go in there of course, but in in this very nondescript environment which is very confusing. I like to do this and this would just be that end, yeah.
15. Yeah, the that basically all of this is just to show what the device can do. But then of course, all the the other things behind it, it's not really something that I think I will go very deep into course I can do suggestions of what the device can do differently to help with these social problems.
16. But yeah, definitely, but this is. What one thing I felt that I especially in the very first two rounds that are played. The sense of liberation is almost. Not at all. Or maybe I was focusing them too much on the red and green. But then I guess for that the vibration will not that important. Maybe it could also be because they were so consistent that I ended up zoning them out. Because when it's ramping, you notice when they're at peaks and you

notice the lack of them when they're not there, but for the red and green. Basically, you always feel vibration when you're going the right way. You feel stronger, and if you're going the wrong way, they're lighter. But they're always there.

17. Yes.
18. So you were saying basically the light system of going right and wrong and the the. Liberation and and sounds like was there a preference for sound?
19. So one where you notice it more. I guess also in the second one and the ramping, yeah, because there wasn't strange in sound umm and I'm not sure if I braces or sound they change the the there was a difference in sounds when you're going the right on the wrong way. Wasn't to me, it wasn't super noticeable. It could just be me, yeah. But I really felt like once you said, oh, it's the red and green and something to it, because at first I was confused. I didn't really notice that it was really umm, but once I have this information I was focusing on the color yeah.
20. Yeah, I mean that is very interesting though. But basically like where was the focus done before looking at the red and green?
21. I tried to focus on all of the all everything at once. Yeah, yeah, I think I was. There were changing in sounds and they said something about sounds and I tried to like tire sounds. Yeah, certain events, but there was nothing like because I need to checkpoint and maybe. Yeah, but I wasn't sure why. What that people's for, which makes sense that it didn't know and and then I do, I couldn't distinguish the sounds between going this way or that way. But maybe at that point I was also not. I didn't know whether that I was going to write or the wrong way, because I've been that I didn't distinguish between sounds because I was going the wrong way in both things. So then of course, it would be no difference and and the preparations. I thought that there were there was stronger and ramping. Condition then the very first one. The first time were very overwhelming.
22. Which is kind of weird because the strongest vibration in the ramping is the same as the regular vibrational going the right direction, right?
23. Yeah. Didn't feel like that.
24. At least the that's how I coded it.
25. Believe you that this is what the code says and the 100% believe that this is what the device does.
26. I mean. The device could be psychological effect of and probably is like all of and moving towards like feeling the difference basically.
27. Yeah.
28. And there is no didn't have a reference point.
29. Yeah.
30. So when it's vibrating strong you you don't, uh, you you have no bottom limit.
31. Yeah, but that is there when with the remedy. I thought, OK, it's just that the device, yeah.
32. That is also very interesting.
33. OK, so this this could be an interesting discussion point where you think about to the the vibrations between going right and wrong. Should there be different in strength? Or should there be different in pattern?
34. Yeah, but it's once long ones and should then the the difference in strength maybe be even bigger. Yeah, maybe because now it's basically I think I I don't know exactly, but I think it's halfway strength for going the wrong way and fully strengthening going the right way. Didn't feel big difference and I was so zoned in on this red and green. Yeah, I was holding the phone like this.Like, I mean, OK, in the transcription you don't know, but I had it in my hand in front of myself. But what I really did like is it's looked like a phone.
35. Umm were there any issues with the tracking?
36. They were once or twice where I put it, the phone down to my side. Where I saw it disappear. And that could be because I was blocking one of the cameras. Yes, my body are the the thing of two base stations should be that when one loses tracking the other one should still see it. Uh, but then again, nothing is perfect. So there are times when it loses tracking and I was running around quite a bit. Umm, there's only one thing to check is the cable. Hmm, that needs to be super long or overhead. And then I started, you know, turning

the other way round to unwind myself. Umm yeah, but that's fine. Yeah, but this I guess something to keep in mind that there should be overhead. I was worried that the phone or the box would be too big. The you know, I was worried that you felt clumpy in my head.

37. Cool. That's good too. That that's actually great discussion point.
38. I was really worried that it feels super clunky because it is big. Yeah, but once I had it and then you probably scaled the representation and the made something a bit more normal looking or it tells. Yeah, then it looks less big though.
39. This will I did intentionally make it a bit more thick. So, but then slightly slimmer. So it still looks like a real phone, just with a very big battery.
40. Yeah, but yeah, that at least the skill is also quite similar, just slightly and in this way, like I knew how big this thing is before you put it over my head. But if this A that could be an experiment, I honestly I like the they're putting it into people's hands when they are already in the because then they don't have this preconceived notion of how big the device is.
41. Yeah, that actually makes sense.
42. It's feel like you were actually holding the phone as well in fear. Yep, cause it isn't tracking the phone as it's tracking the tracker, so the phone is actually offset off the tracker, so I have to do some creative health putting of the phone. So, but as long as it feels realistic, that's good.
43. That sounds good. Well said the the weight was that good enough?
44. I didn't know, but that's good. I thought it was perfectly fine, but I couldn't see myself doing this for 20 minutes or so. Probably easy, I think.
45. Now you you when I think it went about 10 to 15 minutes.
46. Ohh then I I can't see myself maybe even holding it for 30 minutes.
47. How heavy is this? Like 200 grams, then grams.
48. Uh 360, actually, everything together.

10.2.6 transcript third test participant b

1. What was your overall experience of using the device in this environment?
2. I think it was way more helpful than the last time, so the last time I used it I was a bit more confused about the signals and this time I think It was pretty clear. I mean, the first time at the very beginning I was bit confused because it was kind of overwhelming having the three stimuli simultaneously. But yeah, especially the the red and green light was was really helpful.
3. OK. So, but that was basically using the the whole impulse system. There you have the red and green light. Yeah, that was not present during like the the second system. did you notice that at all? Or were you focused on the other signals using that?
4. So I think in the first run I didn't really focus on the other two signals. So the listening and the vibration, because I think that well the, the red and green was enough. So I didn't really care about the others. And then the second one I am it way more attention to the noise, I think compared to the vibration and the green light, I mean it was kind of a combination of all three of them. But I think the most prominent was the noise, and the most helpful because you couldn't really, I think it's harder to distinguish like the frequency and the noise and the flashing of the green light.
5. Is there a way to bring the vibrations up to the others?
6. I think it's difficult because you really focus on the other two stimuli because it's way easier, especially with you can just look at it and you see where you go. I think that you kind of get used to the vibration and don't really notice the subtle differences anymore. Yeah, sometime. I don't know how you could. I don't make it stronger, but I don't know if you can like you make it infinitely stronger. I don't know if that really makes it different difference. Or decrease the our signals, but also it's probably not that good.
7. In in which system did you notice it more?

8. In the second look And the first one that I really didn't notice it at all. I don't see why do you think that this. I think because in the first light was way more prominent, so the other ones I didn't need to focus on. And then the second one, the live was less permanent. So I had to rely a bit more on the other two now because kind of a mixture of
9. so, uh, then about the device that you were holding, did it like in VR that like look like a phone, feel like a phone? Was it realistic enough?
10. Ohh, I'd say that in VR it looked like a. I mean it kind of like a phone. Yeah, it didn't feel that much like a phone because probably also because I wasn't holding it like a phone I was holding like this. Like you would hold a phone. Maybe you can tell people to do that?
11. Umm, that would be an idea.
12. Maybe then, if may feel a bit more immersive. But yeah, it wasn't. Like in a way or something. It was. It was nice.
13. Was it too heavy or good enough?
14. No, that actually what I wanted to say is that it's really light. So it's really good. Yeah, I expected it to be way heavier when.
15. OK. So it's good. Uh, I'm something else that that the others already experienced was the where the cables. Did they get in the way much?
16. I think once when I had to like basically do a U turn. Yeah, more or less than it was kind of in the way on the head. And it was like, scared to just stumble across it. Yeah, I mean, I wasn't walking, but you kind of feel like you were working.. But yeah, I think that's more VR thing.
17. Then how did you notice the the waypoints when you reached them?
18. I think yeah, after a while I noticed that there's like a beep. When you arrive at them, I didn't really get that for the first one or two check points, but then like the don't know. Yeah, kind of. It's about something. Yeah, I think it was the same for the second.
19. Yeah, right.
20. And and you also notice it because somebody all the stimuli were gone.
21. Yeah. So you would so for the second one, that's indeed. From what I've seen is that people notice it more. Yeah, because it it becomes big, big, big. And then the moment you hit it, it's basically, you know, decreases by a lot.
22. I do want to say for the second system it felt really satisfying to reach the checkpoint as, you reach the checkpoint I was like yes!

10.2.7 transcript third test participant c

1. I then the first question, what's your overall? Like things that that stick out about device overall impressions?
2. Umm. So especially about the device over impression is that I feel the the vibration output or just feeling wise could be stronger because sometimes at the moment you felt. I could most get most of the information out of the audio itself, and it would have been in a way also been fine. Umm, it was nice to have it as a as a complementary feedback. Essentially, umm, so you didn't have to look at it in order to feel like what's happening. But I do think that I was using the vibration more as a backup information and those focusing quite a bit on the audio part of it.
3. Did it look like a phone feel like a phone?
4. No. So it felt like a device that is a prototype for one. It wasn’t uncomfortable to hold, but it felt like so a good approximation for it. I it required a bit of a a suspension of disbelief, tweeted the phone. That said, I usually use iPhone 12 mini. OK, so this is probably as far away from the size it could be. But in terms of handling it, it didn't feel weird. But it felt like a big brick instead of a phone.
5. OK. and about the the tracking VR where there were some hiccups from what I saw, but were they like common enough to it's just send you out of VR that you notice that it's like too bad or?
6. So I find it difficult to answer because there were a couple of hiccups. Umm, I'm personally working not so often with VR, but often enough that it I don't really pay attention, so it's a

much to it anymore and when it happens because it happens quite frequently. So for me personally it was not super distracting, but I'm not super easily distracted by smaller parts, so I focused more on the intention of what the experience tested about rather than, uh, beginning parts. I will say that I think the first time around was the most confusing because it's more like figuring out what is meant to be the the good signal. But yeah, bad signal and funny enough, like obviously it's very clear that green is good and red is bad. But somehow I think the tone itself gave me at first the opposite impressions of it as to signals that I only once you confirm to me that the green one is a good one did I trust that. The tone for me suggested the opposite direction of it.

7. Which is also important right now, which brings me to the weight of the device which you see like are there issues with that? Would it be too heavy like compared to an iPhone? I mean, it's probably a lot heavier.
8. I didn't. I think for me, for mostly it was the shape rather than the weight. I didn't have any problem weight, so I think if anything it would be the size that I would have felt the weight. Yes, my phone is lighter, but for some reason maybe also to affect that thing has the back of the hand a bit so it's comfortable enough to grab. I can't see them during the experiment itself felt any kind of annoyance about that part.
9. Umm, like right now moving. It's just with the thumbstick and turning. You have to do yourself. Would you see that being an issue later? Or, umm, like with an option to rotate using the controller.
10. Yes, I don't think it's ideal. I feel I it is a bit more nauseating for me personally to control via joystick like to make myself move by the movement. Umm, I think this is fine for the duration of what the experiment was about and, but it does not make me feel like it's easy to remember that I'm controlling something rather than uh, being in a situation. So I mean, that's where something like teleport or natural movement, obviously. Would feel different right now, that part felt like I'm in a simulation of something, and it's about where I'm where my character goes rather than where I go.
11. Would like with teleporting, would that not bring you more into the VR world when it comes to like escaping a building?
12. I mean, it might be that might be depending for each person. And that might be a personal preference, but I kind of interpreted I contextualized a bit more like an eye blink. Almost, because you usually have this as a movement option and so I think neither of the two are great, but one is closer to how I would feel comfortable with you doing it. Obviously would would be amazing if it's an actual Omni thread.
13. Uh, then, for the logic behind the the two system basically. First, the hot and cold system. You said it wasn't like very logical. Which one was correct when you first tried it. Would that also has to do with standing still?
14. Maybe as well. Yeah. So it definitely helped to have the information that it only is information that is that I can trust when moving, which I think comma for me feels very logical because I feel like especially in a situation where I don't know where to go makes sense to me to stand to reorient them, not move while we reorient it. So it's more like then once you know that it's a working with that information rather than it feels natural to as part of. That said, I do feel like that the second version, so the constant information gets as you get closer necessarily is better. I found the first one more intuitive. I just wish it would work while standing.
15. So basically, would you then expect it like pointing in the right direction?
16. I guess so, yeah, OK, so the the that also me using the the phone is kind of like a directionality of where we need to go is this good is this bad. That would be kind of I think would would feel the most natural to me. OK, that is not while moving, but this is kind of the direction giver. I think as the second part more like a compass. Almost. So when it's pointing in the right direction then it's like showing green yeah, and when it's moving pointing in the wrong direction, that would feel more intuitive to me because also that's the way how I use when I use the phone for navigation purposes. This kind of is the angle where I get to know what I would see, even if it doesn't have AR, it's just it orients the map towards then it's kind of feels very natural to use this as the angle point of what pointed towards me. That's what I kind of expected in the first moment. You get your eye will readjust. So here's the

thing, then it for the for the last one. I didn't feel it necessary anymore because it was the point. So I could just kind of dangle it and I just use the information. Umm so I don't know. It depends a little bit of how the situation would feel like of if I have something to hold already. Umm, I could use it as information point. Yeah, but I can also imagine if it would be a phone that it won't hold, but I have in my pocket for example. Then it's not possible and therefore then and on different system would be better.

17. Yeah, so, so indeed the second option is more for holding it in your pocket. Yeah, to have like some sort of direction of where you need to go.
18. And obviously, because they're feels like it can't tell what direction and facing or somehow it thinks is more OK. Where's this when I'm holding it somehow I expected to do more by the fact that I'm giving you the direction and it doesn't seem to give
19. and a location as well.
20. Yeah exactly. I didn't have the feeling that I'm not sure if it's true that the first of the two experiments were was shorter as an actual amount of space that I had to. You know, to leave umm, so I'm alternative. Not 100% sure to what extent I'm feeling that the first one was preferable just because it happened to all the be faster. Umm, I'm not 100% sure, but I don't think so. I think feel back about it. I just was a bit more comfortable with it once I got the information. How it is supposed to work. So I don't think that the future impact looking up, but it was kind of something I got a notice. There's quite a bit that was quite much faster. Yeah, but I also have the feeling with the with the second one that even though it was clear, I felt like I had to do more testing out of directions and didn't feel as snappy you because you kind of have to wait for this feedback of is it more or is yeah, more, more, more. So it's a little bit more having to wait for the feedback of it.
21. Yeah. So that that's also indeed with the whole code. It's the moment you're doing something wrong. You instant get that feedback and when it's ramping you like you don't notice the distance when you take one or two steps sectors,
22. so it takes me more time. Wait, before I have understood what's happening, but other than that I don't think something specific else comes to mind.
23. Then something related to the testing the does the risk strap like bother in any way or is it like no the reception problem at all?
24. I think the one thing that I wish cables going up, yes we preferable because about two situations where it was kind of getting tangled. briefly, it was OK. Umm, but it's just one of the things like I would be nice if it's if I can be certain then how I step does not actually create a danger.
25. Yeah. So right now I did not really have any way of doing that. So like this is I got it, I got it doesn't that would be the.
26. Yeah, we felt like, OK, I have to be a bit careful here. Yeah, that would have been preferable, but otherwise it was good.