OMNI

Distributed Tangibles for balanced game-play including visually impaired people

Bachelor Thesis

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Abstract

OMNI is a game developed to allow visually impaired and non-visually impaired people to play a balanced game together. The game consists of five distributed tangibles, which are four cups and one hub. The cups of OMNI can vibrate. Users should react to these vibrations by flipping a vibrating cup. However, the tangibles all worked independently, making it difficult to play a game with OMNI. The goal of this research is to understand how a change in hardware influences OMNI with regards to durability, game experience and potential to implement a diversity of games on OMNI. Using multiple criteria in a weighted decision matrix, new hardware components for OMNI were selected. These components are a vibration motor, speaker, inertial measurement unit and nRF24L01. Afterwards, four different games were selected which were possible to implement with the selected hardware. For each of the four games, seven different player interaction patterns were conceptualized to show the diversity of games for OMNI. The four games have been implemented such that together the seven player interaction patterns were represented. The hardware is tested on performance and the games were evaluated with four players, who have played each game twice. Once with a blindfold on and once without a blindfold to test if the games are suitable for balanced gameplay. Moreover, an expert on the target group was interviewed to evaluate the four different games. The user tests showed that the users were positive about the game. Furthermore, both the expert and the players agreed that most of the games are suitable for visually impaired people. However, it is recommended to test the product with the target group to confirm this finding.

Acknowledement

First, I would like to thank my supervisors Dennis Reidsma and Robby van Delden for giving me the opportunity to continue working on OMNI for this Graduation Project. Moreover, their guidance, support and feedback has helped me greatly throughout this project. Second, I would like express my gratitude to Laurie Barents from Visio for her enthusiasm about the project and for allowing me to interview her and sharing her expertise on the target group. Third, I would like to thank my housemates for participating in the user tests and giving honest feedback on the game. Last, I would like to express my thanks to Bart Schepers for his support throughout the project.

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1 Introduction

"Think about Halli Galli, Whack-a-mole or Fruit Ninja. How do you play these games if you cannot see the cards, the mole or the fruits? What if you are visually impaired and want to play a reaction game with your family and friends? That is where OMNI comes in. OMNI is a high speed reaction game based on vibrations, a game without visual cues. A game for everyone."

OMNI (Figure 1) is a game which consists of four cups and a hub.[1] Each of the cups can vibrate using a vibration motor. A tilt switch can register when a cup is flipped or not. When a cup vibrates, the player should flip the cup. Using this mechanism, it is possible to do multiple games. For example: 'Memory', where a player has to find two cups which are vibrating with the same pattern. Another game could be 'Defuse the Bomb' where the player has to flip the cups as fast as possible. If one cup vibrates for longer than two seconds, the bomb will explode and the player has lost the game. As OMNI does not rely on sight, the game can be used to create balanced games between visually impaired and sighted people.

Figure 1: Image of OMNI the game.

OMNI is created during the sixth module of the bachelor Creative Technology based upon user research with visually impaired people. As there are little reaction games for this specific group, the aim of the project group was to develop a reaction game with visually impaired people in mind. During this module, a lo-fi prototype was made and tested.

In the seventh module of Creative Technology, a business plan for OMNI was made and new games concepts were created. In October 2019, the opportunity was given to go to Dutch Design Week with OMNI. In the weeks in advance of Dutch Design Week new cups were created and the hardware was adapted. With the new hardware it was possible to feel the vibrations in the cup and flip them, but playing a real game was not possible.

There are not many tangible games designed for visually impaired people. Examples are Blind Hero [1], which makes Guitar Hero available for visually impaired people, and a pointing games [2], which is designed to help visually impaired people understand pointing. Both of these games use haptic feedback to guide the visual impaired user. This research presented in this report will give examples on what other technologies can be used in the design of tangibles for visually impaired people.

The goal of the thesis is to adapt OMNI to allow for different games. To improve the hardware, communication between the cups should be included so that the cups can work coordinated. The influence of the adapted hardware on OMNI is researched in this report. Therefore, the goal of the thesis is to answer the following question: *How does a change in hardware affect the durability of OMNI and influence the game experience and the potential to use OMNI to design a diversity of games?*
To answer this question hardware components, player interaction patterns and game types were researched.

[1] https://www.youtube.com/watch?v=aCumtBbHgng&feature=youtu.be; *Accessed on 24-06-2020.*

The research starts with a context analysis in Chapter 2 on the target group, tangible games, game types, player interaction patterns and hardware components. Chapter 3 describes the methods and techniques used throughout Chapter 4, 5, 6 and 7 to come from an idea to an evaluated prototype. Chapter 4 describes the ideation phase, in which game ideas are generated and the hardware selection is made. In Chapter 5, specification of the prototype is done. The prototype is realised in Chapter 6 and evaluated in Chapter 7. Chapter 8 gives a conclusion of the research, which is followed by a discussion and recommendations in Chapter 9.

2 Context Analysis

The first step to the research is to gather information about the target group, game types, available tangibles and hardware components. The chapter starts with information about the target group. After this more information about game types and interaction patterns were researched to understand games. This part is extended with available tangible games, to get an overview of the state-of-the-art on tangible games. Next, different sensors, actuators and communication modules are discussed to gain more insight on hardware components. Last, previous prototype tests of OMNI are discussed.

2.1 The target group: visually impaired people

The research on the target group was done by interviewing an expert on the target group and looking at information on assisitive devices for visually impaired people.

OMNI is designed for visually impaired people. According to Visio[2], an institution which helps people with a visual impairment in the fields of rehabilitation, education and living, the Netherlands contains approximately 223.000 visually impaired people and 76.000 blind people[2]. The terms visually impaired and blind are used differently throughout the world [3]. For example, in the United States blind means having no or low vision, while in Europe blind means having no vision and visually impaired means low vision [3]. According to Visio[2], a person is considered visually impaired when the visual acuity is less than normal, there is a smaller visual field or if there is an exceptionally sensitivity to light. Being blind means that a person can see less than 5 percent or that the sight is limited to less than 10 degrees[2]. Therefore, it does not mean that a blind person sees nothing at all, as some blind people can still see the difference between light and dark. Throughout the research, the term 'visually impaired people' used. In this research, the term includes both visually impaired and blind people.

2.2 Expert interview

To understand the target group better, an interview was held with a therapist of Visio. This therapist is focused on rehabilitation with visually impaired people. The therapist teaches people with a visual impairment how to do every day activities, such as cooking, getting dressed, making coffee and playing games.

The first part of the interview focused on board games. It became clear that there are many board games that visually impaired people can play. Visio looks at how certain board games can be adapted so that a visually impaired person can play it. For example, in the game Ludo (Figure 2) it is possible to alter the pawns so that each color has a different shape. This way, it is possible to distinguish one color from another. Aside from board games, Visio has not looked into games involving technology or sound.

The next part of the interview focused on the use of technology by a visually impaired person. According to the therapist, there are many things that a visually impaired person can use, for example an iPhone. The iPhone can read everything on the screen out loud and when an app is designed with visually impaired people in mind, the iPhone will mention where a button is located and what this button is linked to. Furthermore, screen readers can be used to read computer screens, which makes phones and computer accessible for visually impaired people.

Considering OMNI is a game with 5 seperate elements, the question was asked how a blind person knows where a certain element is located on the table. The therapist mentioned that this is why board games are easy, since the person knows where he or she should feel to find the game. When a cup is moved, the visually impaired person will hear it but probably needs to feel again where the cup is. This means that it could be unfair when one of the players moves one of the cups of OMNI. Considering that many visually impaired people still use parts of their vision, the therapist advised to add contrasting colors to the cups, so that the visually impaired can use the contrasting colors to distinguish one cup from another.

With regards to game play, the therapist was very enthusiastic about OMNI. The therapist mentioned that it would be good to implement both a multiplayer and singleplayer games on OMNI since there are

[2] https://www.visio.org/nl-nl/slechtziend-of-blind; *Accessed on 09-04-2020.*

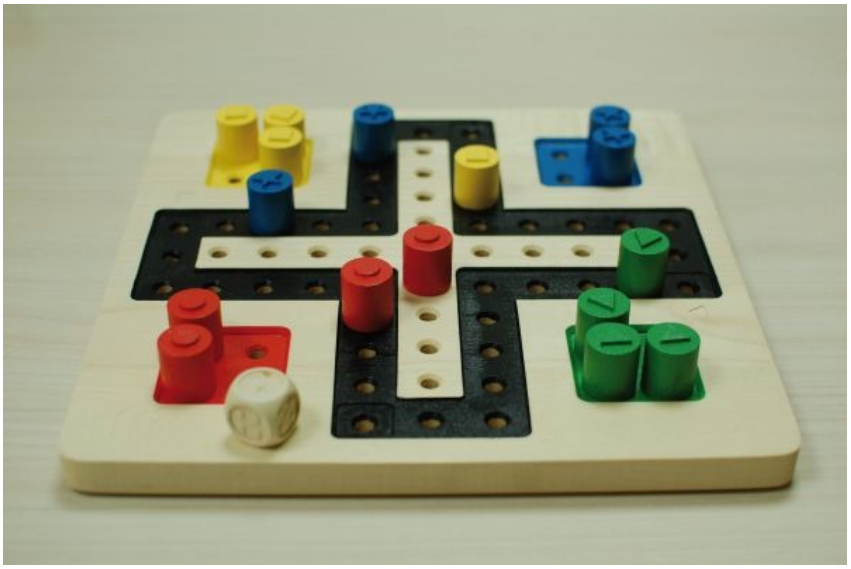


Figure 2: Example of the adapted version of Ludo for visually impaired people.[3]

visually impaired people who like playing games but have not many people in their environment to play the games with.

2.3 Assistive devices

After the interview, assistive devices were researched to see what technologies are available for visually impaired people. It was found that there is a wide variety of assitive devices. Next to the screen reader mentioned earlier, a Refreshable Braille Displays can help using computer screens [4]. Refreshable Braille Displays convert text on a screen to Braille. This device contains of 40 Braille cells. Each cell contains of 8 dots which can move up and down. This way, the Refreshable Braille Display can convert the text on the screen to Braille.

Next to assistive technologies to use computers and mobile phones, there are also many assistive devices which make daily tasks easier. One of those technologies is a liquid level indicator, which can be seen in Figure 3. This is a device with two little sticks that can be put into a glass. When a visually impaired person pours liquid into the glass, the device will make a sound or vibrate to indicate that the glass is full. Moreover, there are many assistive devices which say the measured value out loud, such as kitchen scales, measuring cups, thermometers and tape measures.[4] The downside of these devices is that they are often expensive due to the technology inside.

From the interview and the assistive devices, it became clear that the target group make use of technology, where output is often tactile or audio feedback. Moreover, the use of contrasting colors is helpful to see where a certain object is placed.

2.4 Games

The next step is to get to know more about games. In this part, game types are discussed, after which interaction patterns for games are described. Last, the current available tangible games are mentioned.

2.4.1 Tabletop game types

There are many different board games, so to classify these games Notebeart and Conrilly made a classification for board- and tabletop games [5]. The classification consist of 35 selection lists. One game can belong to a maximum of 6 different selection lists. This way, games similar to each other belong to the same selection lists. The 35 selection lists contain selection lists on game type, game mechanism,

[3] https://irishuys.nl/product/mens-erger-je-niet/; *Accessed on 10-06-2020.*
[4] http://worldwidevision.nl/; *Accessed on 09-04-2020.*

Figure 3: A liquid level indicator. The pins in the glass detect the liquid, after which the device starts to make a sound or vibrate.[5]

number of players, and playing time. For OMNI, the game mechanism of is determined by the cups, rather then by a board or dice, making these selection lists irrelevant. Moreover, as it is not known what games are implemented on OMNI, time based categories are left out. Lastly, number of players is not taken into account within the game types as these are described by different player interaction patterns, which is discussed in subsubsection 2.4.2. The selection lists based on game types relevant to OMNI are described below [5]:

- **Action games**; games in which sports and physicality are available. In these games, you are not comfortable in your chair.
- **Bluffing games**; games in which you can pretend and bluff.
- **Deduction games**; using logical thinking and combining information, the answer can be found.
- **Memory games**; games in which certain things should be memorized.
- **Skill games**; games in which a certain skill is needed to do the game.
- **Quiz games**; games in which players answer questions.
- **Word games**; games where one should recognize or form letters or words.
- **Number games**; games where number should be combined or put in the right order.

2.4.2 Player interaction patterns

Games can be played alone, against each other or in teams. Fullerton [6] created a list containing 7 different interaction patterns. These interaction patterns are described below and shown in Figure 4.

1. **Single player versus game**; in this structure, the player wants to beat the computer. Example of such a game is Pac-Man. These types of games often use puzzles or other structures to create a conflict.
2. **Multiple individuals versus game**; in these games, players play against a game, but no interaction between the players is necessary. Examples of such games are bingo and roulette.
3. **Player versus player**; two players which directly compete against each other. Examples of this is tennis or chess.

[5] http://worldwidevision.nl/; *Accessed on 09-04-2020.*

4. **Unilateral competition**; in a unilateral competition two or more players compete against one player. This is for example the case with tag, where one player is against the other players.
5. **Multilateral competition**; three or more players compete directly in a multilateral competition. An example of this is Monopoly.
6. **Cooperative play**; two or more players play against the game system. These types of games are often involved in children's games.
7. **Team competition**; two or more groups of players compete against each other.

2.4.3 Available games

As now the game types and interaction patterns are known, it is interesting to look at what game types and interaction patterns are used in tangible games. Considering there are not many tangible games for visually impaired people, digital non-table top games for visually impaired people and tangible games for sighted people are also included.

Digital non-tabletop games for visually impaired people
An example of digital non-table top games for visually impaired people are audio games. Such an audio game is A Blind Legend. This game uses binaural sound to direct a user to a certain location.[6] Urbanek and Güldenpfennig researched audio games [7]. In their research, Urbanek and Guldenpfennig asked people who often play audio games their opinion about the games. The authors found that certain qualities influenced the audio game experience. For example, it was found that many audio games feel the same, as the games use the same audio files and game elements. Moreover, the paper mentioned that the social aspect in audio games is important. The players enjoy playing with each other, but also with players who are not used to these types of games. This point is something which is also relevant to OMNI, as the goal is to create a balanced game which can be played with visual impaired and sighted people. In addition, one of the guidelines given in [7] is to consider the option that community members can create new additions for the game as well. For OMNI, this option could be taken into account, by making a platform where the community can program new games for the device.

Tangible games for visually impaired people
Considering the target group, the most interesting tangibles are the tangibles developed for visually impaired people. By researching what games are developed, it is possible to see what gaps OMNI can fill.

Oliveira, Cowan and Fang et al. [2] created a game for visually impaired people using a glove with haptic feedback. In this pointing game, there is a screen with digital targets which the visually impaired person should touch. To direct the hand of the visually impaired person to the right place, vibrations in the glove are used. The game consists of three rounds. In each round, the player should hit a certain amount of targets. A target is hit when the players hand is within close distance of the target. The amount of targets increases in each round. To enhance the game immersion, the soundtrack of Mission Impossible is used. Each round, the tempo of the music increases, since the players should move faster.

Yuan and Folmer [1] have adapted Guitar Hero to Blind Hero to make it accessible for visually impaired people. Guitar Hero[7] is a rhythm game, which lets players use a guitar-shaped controller with colored buttons to simulate playing rock music. The players should press the buttons at the right time. Using a screen, it is indicated when a certain button should be pressed. When it is correctly pressed, the players will hear the correct guitar riff for that part of the song. To turn Guitar Hero into Blind Hero, haptic feedback is used. By using a glove with vibration motors, it can be indicated using vibration which button should be pressed. Each finger represents one button.

Both of the above mentioned games are single player versus the game games and belong in the category of skill games, since the player should react on the targets or music in the song. Moreover, both

[6] http://www.ablindlegend.com/en/home-2/; *Accessed on 17-04-2020.*
[7] https://www.guitarhero.com/game/ghlive;*Accessed on 01-07-2020.*

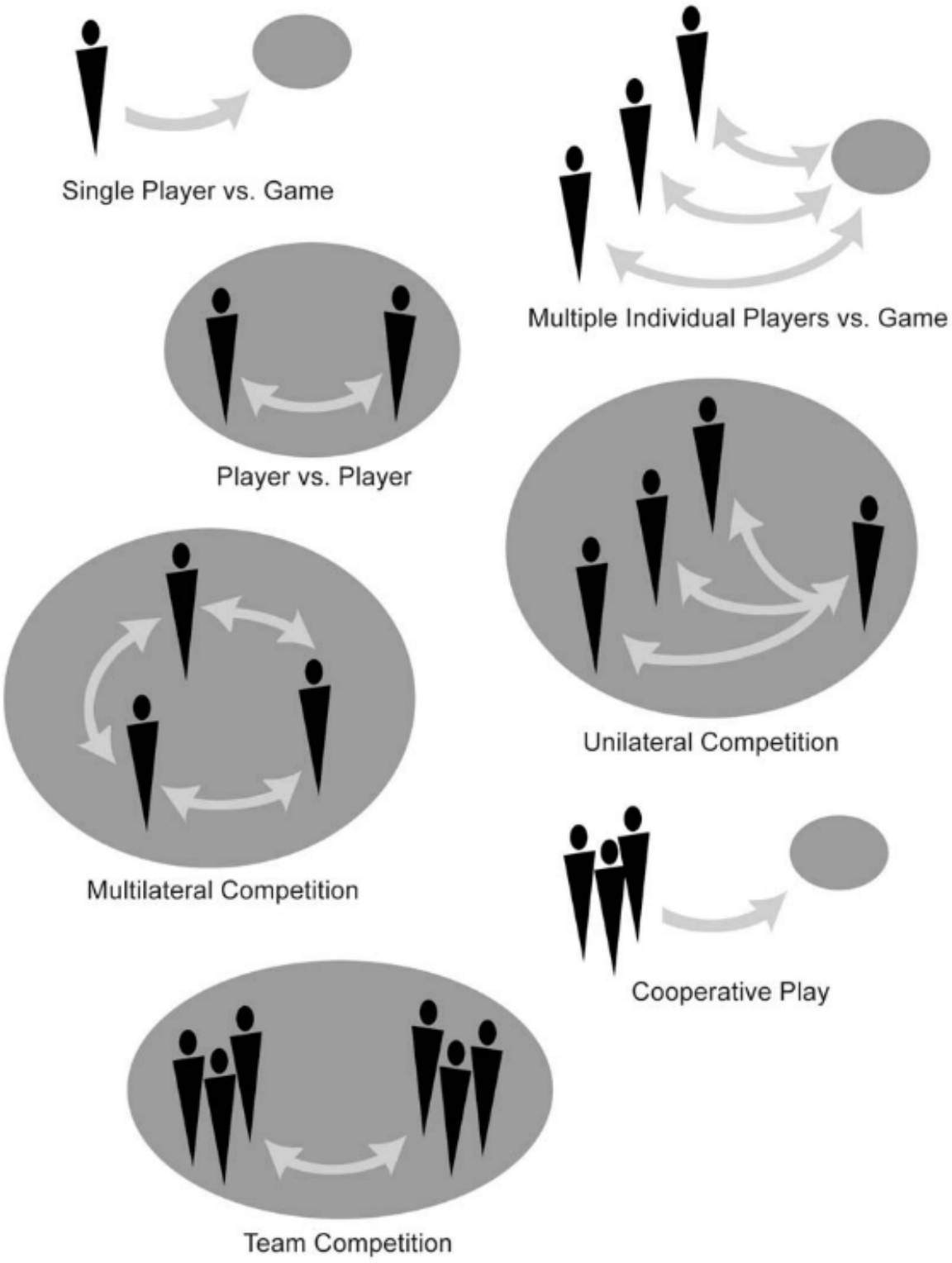


Figure 4: Player interaction patterns [6]

games make use of tactile feedback using vibration motors in a glove. Sound is used for feedback with Blind Guitar Hero, while it is used for game immersion in the pointing game.

Tangible games for sighted people
Since there are little tangibles developed for visually impaired people, an overview on tangibles for sighted people is given. This overview can be used to get insights in commonly used game types and player interaction patterns in tangible games.

Soute et al. [8] have developed a tangible game for children. The game is called "Save the Safe" and it is played in two teams of four players. One team play the guards of the safe, while the other teams are burglars. The burglars have 5 minutes to steal the key from the guards and open the safe. The game can be played in two modes. In one mode, the key is a ball. The safe can be opened by touching the safe with the ball. In this mode, all players know who has the key.
In virtual mode, the players wear a belt. The belt of the person with the key is vibrating. A key can be stolen from the player when another player is close by the key keeper for more than 3 seconds. After three seconds, the vibration will move from one player to the other. The safe can opened if a burglar with the key comes close to the safe, then the key will be transferred to the safe.

Next to 'Save the Safe' Soute has also developed another device for outdoor play. This device is Picoo[8] (Figure 5). Using the Picoo game console, different games can be played. According to their websites, there are four games on Picoo. These are:

- *Zombierun*, where one player starts as a Zombie. When he comes close to another player, this player changes into a zombie and can contaminate other players.
- *Lightning Bolt*, where one player has a the lighting bolt, which will be transferred to someone else when the players move close enough to the player with the lighting bolt. The player who has the lighting bolt when the game ends after two minutes, wins the game.
- *Spyhunt*, similar to Lightning Bolt, one player gets a buzz. The game is played in two teams. One player should steal the buzz from another play by moving close the the person with the buzz. The team who has the buzz at the end of the game, wins.
- *Whack-a-Mole*, cards, 'moles', will be hidden. These cards can be scanned by the consoles to show that the card has been found. If one of the players cannot find a card, the player is out of the game.

Figure 5: The device Picoo, developed by Soute and Tetteroo.[8]

Picoo is a good example on how one device can create games using multiple player interaction patterns. "Zombierun", is an unilateral competition, which turns in a team competition as more players are turned into Zombies. "Whack-a-Mole" is a multilateral competition, where players compete against each other to win. "Lightning Bolt" and "Spyhunt" show how games can be adapted to create similar games with

[8] https://www.picoo.com; *Accessed on 09-04-2020.*

two player interaction patterns.

Another interesting product is My Storyball[9]. My Storyball contains a motion sensor and smart audio to enable immersive gameplay. Using different skins over the ball, different games and quests can be played. Using Bluetooth, it can be connected with an app to load new content onto the ball. The Storyball uses the single player versus the game interaction pattern, since the game makes quests which should be performed.

Kuang, Druga and Zhang created a skill and action game called BallBit Adventure [9]. This is an interactive racing game. Each player controls a robotic ball called a "Ballbit". The goal of the game is to work together to get through different stages. A Ballbit can wear a magnetic casing which can attach to other modules to progress through different obstacles and stages. For examples, in one stage the Ballbits need to collect a key which is needed to open a safe. The Ballbits should roll through a stage made out of acrylic sheets. The Ballbit Adventure game is a good example on how cooperative play can be used in tangible games.

Another commercial skill game is "Tik Tak Boem" by Goliath Games[10]. In a multilateral competition, players draw a card with a syllable on it. With this syllable they should make a word. When they have mentioned a word, they throw a plastic 'bomb' to the next player, see Figure 6a. This player should say a word with the syllable and throws the bomb to the next one and so forth. The player who has the bomb in his hand when it goes off loses the game.

(a) Tik tak boem (b) Bop it! (c) Simon

Figure 6: Different types of tabletop tangible games which are on the market.

Hasbro has created the game "Bop it!"[11], which can be seen in Figure 6b. This is a game where the device tells what should be done. For example, when the device says "Twist it", the device should be twisted. This game is also great for visually impaired people, since it works solely using audio instructions.

Another game designed by Hasbro is "Simon"[12](Figure 6c). Simon is a game which consists out of four buttons which can light up. These buttons will light up in a pattern, which the player should repeat. Each button also makes a different sound, meaning that one can also remember the sounds. This is a great example of a pattern game. Considering OMNI has four cups, it would be possible to make a game like Simon with OMNI. In this game, a cup would vibrate and make a sound to indicate the pattern.

Both "Bop it!" and "Simon" are games which are played as single player versus the game, where the goal is to reach a high score. In "Simon" this score can be gained by memorizing the pattern as "Simon" is a memory game. "Bop it!" is a skill game, where a good reaction on the right command is needed for a good score.

[9] https://www.mystoryball.com/; *Accessed on 09-04-2020.*
[10] https://www.goliathgames.nl/product/tik-tak-boem/; *Accessed on 08-04-2020.*
[11] https://shop.hasbro.com/en-us/product/bop-it-electronic-game:308B6AC0-BBE7-4211-AFFD-EF0E953E5080; *Accessed on 08-04-2020.*
[12] https://shop.hasbro.com/en-us/product/simon-game:6B0A06E3-5056-9047-F532-6A891FAEBA15; *Accessed on 08-04-2020.*

Table 1: Available tangibles games categorized per game type and player interaction pattern.

Game type	Action Game	Memory game	Skill game
Player interaction type			
Single player vs game	My Storyball [13]	Simon [14]	The pointing game [2] Blind Hero [1] Bop-it [15]
Multiple individuals vs the game			
Player vs player			
Unilateral Competition	Lightning bolt[16] Zombierun[16]		
Multilateral Competition			Whack-a-Mole[16] Tik tak Boem[17]
Cooperative play			Ballbit Adventure [9]
Team competition	Save the Safe [10] Zombierun[16] Spyhunt[15]		

To give a clear overview of the available games and their player interaction and game types, Table 1 was created to show the player interaction pattern and game type for each available tangible game. The table shows that skill and action games occur often in tangible games. Moreover, each of the interaction pattern except multiple individuals versus the game and player versus player occur in the above mentioned games. With the exception of Picoo, each game only uses one player interaction and one game type. OMNI could fill a gap by creating a tabletop device on which different game types with different interaction patterns can be played which can be played by sighted and visually impaired people alike.

2.5 Technologies

To explore the hardware solutions for OMNI, different technologies are discussed in this section. The section starts off with a literature research on communication technologies. Afterwards, sensors and actuators are researched to get information about hardware components which could be implemented in the prototype.

2.5.1 Communication modules

The information for this has been researched for Academic Writing. It has been adapted to fit into the Graduation Project

During previous test with OMNI (subsection 2.6), it has been found that the cups should work dependant on each other. When the cups are connected, it is possible for the cups to react on each other. For example, one cup can start 2 seconds after another cup is flipped. Moreover, it is easier to generate new patterns for certain games. For the cups to work dependently on each other, they should be wireless connected. However, implementation of wireless systems cost money and time, thus it is important to make a well-funded decision on which system to implement. This decision can only be made in an appropriate way with more information about the requirements of OMNI and the properties of communication systems. This is why four different communication systems are researched. The four systems compared are Bluetooth Low Energy, Zigbee, nRF24L01 and Wi-Fi. These four systems have been selected based on wireless communication systems commonly used in other tangibles. Moreover, these four systems are often used in home appliances, which is why these seemed suitable for OMNI.

Requirements for wireless communication in OMNI
To select a communication system, it should be known what requirements are needed to choose a sys-

[14] https://www.mystoryball.com/; *Accessed on 26-02-2020*
[15] https://shop.hasbro.com/en-us/product/bop-it-electronic-game:308B6AC0-BBE7-4211-AFFD-EF0E953E5080; *Accessed on 08-04-2020.*
[16] www.picoo.com; *Accessed on 29-06-2020.*
[17] https://www.goliathgames.nl/product/tik-tak-boem/; *Accessed on 08-04-2020.*

tem. In this part, the general requirements for a wireless communication are discussed, afterwards the requirements for OMNI are discussed.

When selecting a wireless communication system, there seven are main requirements. According to Horyachyy [11], these requirements are: low costs, low power consumption, good security, good operating range, interoperability and sufficient network performance. However, Chakkor et al. [12] and Fornazier et al. [13] list similar requirements but leave out interoperability. Moreover, the authors add network topology to the list of requirements. Horyachyy [11] mentions network topology when talking about range, while Chakkor et al. [12] and Fornazier et al. [13] see it as a seperate requirement. This can be explained since the network topology does not influence the range in which a certain system can communicate. This means that the 7 main requirements are: low costs, low power consumption, good security, good operating range, good interoperability, good network performance and good network topology.

Despite the fact that the seven requirements are important for most devices with wirelesss communication, not all seven requirements are important for OMNI. Interoperability is less important for OMNI than the other requirements. To begin with, Horyacchy [11] defines interoperability as "different devices from different manufactureres may be connected" [11, p. 21]. Since the four cups of OMNI should only be connected to each other and not to other devices, interoperability is not important. Consequently, there are 6 requirements for the wireless communication system in OMNI left, which are low costs, low power consumption, good operating range, good security, sufficient network performance and network topology.

Review of the communication technologies
As the requirement for the system are known, the communication can be reviewed based on the requirements. The first requirement is the cost of the communication system. A reduction in costs will cause more costumers to buy the product. This means that when OMNI is produced, the costs should stay low. Horyachyy [11] and Fornazier et al. [13] state that Wi-Fi, Bluetooth, Radio Frequency and Zigbee are all low cost. This means that all four communication systems are suitable to be used in OMNI.

The second requirement is the operating range of the communication system. The requirement for OMNI is that the operating range is at least 2 meters since OMNI is a tabletop game. Table 2 shows the different operating ranges of the communication systems. The table shows that the ranges of Zigbee and Wi-Fi differ in different researches. All authors agree that both Zigbee and Wi-fi reach at least 100 meters. Since OMNI requires an operating range of 2 meters, this means that all four systems could be used for OMNI. However, when multiple sets of OMNI are used in the same room, interference could occur when the devices are close to each other. This means that an operating range of above 10 meters could cause more interference. This makes the range of Bluetooth most suitable.

Table 2: Table of the range of the Zigbee, Bluetooth Low Energy and Wi-Fi.

Sources	Horyachyy [11]	Lee et al.[14]	Mendes et al.[15]	Cardova et al. [16]	Baker [17]
Bluetooth Low Energy	10 m	-	10 m	10 m	10 m
Wi-Fi	Indoor: 700 m Outdoor: 1000 m	100+ m to 10 km	100m	-	10-100 m
Zigbee	10-100 m	70-100 m	10 - 100m	10-100 m	10-300 m
Radio Frequency 2.4 GH	250 m	-	-	-	-

The third requirement is power consumption. It is undesired to have to change the batteries of the game each day, which is why low battery consumption is important for OMNI. Baker and Hafeez et al. [17] [18] mention that Zigbee has a lower power consumption than Bluetooth Classic. This is explained since Bluetooth Classic devices are "constantly alert" [17, p.24]. Zigbee sleeps most of the time [17]. The reason for this is that Zigbee has been designed for low power consumption while Bluetooth Classic has not. However, this is why Bluetooth Low Energy was developed. This is a version of Bluetooth which uses low power consumption [19]. Radio Frequency 2.4 GH is mentioned by Horyachyy as being ultra low power [11]. Horyachhy and Hafeez et al. [18] state that WiFi has a higher power consumption than to the other systems. Since it is desirable for the game to not run out of battery, the communication system with the least power consumption is most desirable. This means that considering the power

consumption, Zigbee, nRF24L01 and Bluetooth Low Energy are most favourable for OMNI. Wi-Fi is least favourable due to high power consumption. The high power consumption of Wi-Fi is explained by the network performance of Wi-Fi.

The fourth requirement is the network performance. Network performance is partly defined by the data rate of the system. The data rate is the amount of data per second which can be send from one device to another. The requirement for OMNI is that sensor data can be send from one cup from another. According to Lee et al. [14] and Chakkor et al. [12] the maximum data rate of Zigbee is 0.25 Mbit/s, while the one of Bluetooth Low Energy is 0.72 Mbit/s and Wi-Fi 54 Mbit/s. The data rates of nRF24L01 can be set to 0.25 Mbit/s, 1Mbit/s or 2Mbits/s [11]. The advantage of a high data rate is that it is possible to send more data at the same time. With the data rate of Wi-Fi, it is possible to send videos, while with low data rates it is only possible to send audio or sensor data. Considering OMNI will send sensor data through, a high data rate is not needed. In short, OMNI does not desire a high data rate. This means that Bluetooth Low Energy, Zigbee and nRF24L01 have a more suitable data rate for OMNI than Wi-Fi.

Despite having the correct data rates, the data will not reach the correct cup if the required topology is not available. A topology is the way nodes in a network are connected. The three most important topologies for OMNI are a point-to-point network, a star network and a mesh network. In a point-to-point topology, two devices are connected with each other [17]. A star topology is a network in which all nodes are connected to one central control point, forming a 'star' [17] [20]. In a mesh topology, all devices can communicate with each other [17]. Using a mesh topology, it is possible to create large and complex networks. OMNI will operate using a mesh topology or star topology, depending on the game. Since a point-to-point topology only works for two devices, this topology is not suitable for OMNI. According to Horyachyy [11] and Baker [17], Bluetooth Low Energy is able to make point-to-point and star-topologies but unable to make a mesh network [19]. Wi-Fi, nRF24L01 and Zigbee are able to create a point-to-point-, star- and mesh topology [16][17][21]. In short, OMNI will function using a star or mesh topology thus Zigbee, nRF24L01 and Wi-Fi are suitable for OMNI. Consequently, Bluetooth Low Energy is not suitable, as it cannot create a mesh network.

The last factor to discuss is the security of the three devices. The requirement for OMNI is that the game has good security, since it is unwanted that the players get recorded or eavesdropped while playing. The least secure option is nRF24L01. The module does not use any encryption, meaning that the encryption should be implemented in the Arduino sketch to have some security. All other systems use some sort of encryption. Horyachyy [11] mentioned that Zigbee the security models have some "critical issues" [11, p. 34]. Contrasting to this, Hafeez et al. state that Zigbee has a "highly secured connection" [18, p. 667]. Cardova [16] also mentioned that possible to attack Zigbee using inexpensive tools. So it is not clear to say whether Zigbee is secure or not. Bluetooth Low Energy uses the same safety protocol as Bluetooth Classic. Contrary to Zigbee, the security of Bluetooth does not depend on the system, but on the user. When two Bluetooth devices, the user should enter a PIN code or password to give permission to pair the devices [11]. The security of Bluetooth depends largely on the strength of these passwords and pins [11]. The security of Wi-Fi is considered to be "sufficient protection for most low-security applications" [14][p. 8]. Hence the most secure system is Wi-Fi. Bluetooth is secure, but this also depends on the password or PIN. nRF24L01 is the least secure option for OMNI, considering it does not use encryption. When selecting Zigbee or nRF24L01, extra security should be added in the code of Arduino.

Conclusion

The aim of this part of the context analysis is to find which wireless communication system is best to connect the four cups of OMNI. To find the best communication system, the following system properties have been looked at: costs, range, power consumption, network performance, network topology and security. It was found that the costs of Wi-Fi, Zigbee, nRF24L01 and Bluetooth Low Energy are all low. Moreover, the range of all systems cover the network desired for OMNI, which is 2 meters. However, Bluetooth has a maximum range of 10 meters, which is advantageous when multiple games are played in the same room. The shorter range will decrease the possibility for interference. With regards to the power consumption, Zigbee, Bluetooth Low Energy and nRF24L01 are the best choice, since these battery last longest. Wi-Fi has the shortest battery life and is therefore least suitable for OMNI. The high power consumption is in line with the data rates of the systems. Wi-Fi has the highest data rates and thus asks for the most power. However, for OMNI, a high data rate is not needed, which is why nRF24L01, Zigbee or Bluetooth Low energy are more suitable. Furthermore, OMNI will be configured in a mesh or

star topology, which makes Bluetooth Low Energy unsuitable, as Bluetooth Low Energy cannot operate in a mesh topology. In similar fashion, Zigbee, nRF24L01 and Wi-Fi are suitable, since these systems are able to operate in a star and mesh topology. Lastly, the security of Wi-Fi and Bluetooth Low Energy is good, while Zigbee has some critical issues and nRF4L01 has no security at all. To conclude the paper, the best choice for OMNI would be either Wi-Fi, Zigbee or nRF24L01, as the correct network topology cannot be made with Bluetooth Low Energy. The advantage of Wi-Fi is that it good security, but Zigbee and nRF24L01 have a longer battery life. Therefore, to choose the best option for OMNI a decision should be made about what is more important, security or battery life.

2.5.2 Sensors

To iniate interaction in OMNI different sensors and actuators are researched. Of each sensor and actuator, it is described what kind of interaction can be provoked using this technology can be used for OMNI.

Switch A switch is one of the simplest methods to get input from a user. A switch works using a button. When the button is pressed, the button makes contact with an electric circuit. This closes the circuit, meaning that current starts to flow through the circuit. When the button is released, the connection is lost and the circuit is open, which stops the flow of current.
A type of switch is the **tilt switch**. A tilt switch can detect if something is upright or upside down. The switch is in one state when the switch is facing down and in the other state when the switch is facing up. In OMNI the tilt switch can detect when a cup is flipped. The button could be used in the following way: when a player flips a cup, the player presses the player's button to indicate which player should earn a point for the flipped cup.

Optical sensor Optical sensors can be used to measure displacement and distance. The sensor consists of three basic parts; a light source, a light sensor and a transmitting medium. The sensors are constructed in such a way that a change in distance between the sensor and transmitter will be measured or the sensor will have the transmitter and receiver next to each other. In this last configuration, the transmitted light will reflect on the measured object and be received by the sensor. The reflected light will have a lower intensity than the light send out. Since the intensity of the transmitted light is known, the distance of the object can be calculated. [22]
For OMNI as a tabletop game, the optical sensor could be used to detect what the distance between the cups is so that the cups stay on the same place. Moreover, when using multiple optical sensors it could be possible to sense when a cup is held and how a cup is held, based on which sensors detect light and which do not.

Capacitive sensor A capacitor can be used to sense in multiple ways. A capacitor consists of two plates. The capacitance of a capacitor depends on multiple variables, for example the space between the two plates, the plate area and the dielectic between the two plates. The internal parameters of a capacitor (area, plate distance and dielectic material) can be changed, which makes it possible to measure displacement, rotation or pressure. External capacitance can be used to detect human touch. In a parallel capacitor circuit, a person can add a capacitance to a known capacitor. Another option is to interface the capacitive sensor such that one plate of the capacitor is connected to the Arduino. The other half is formed by a person. This way, it is possible to measure the position of hands or fingers. The advantage of capacitive sensing is it is possible to measure the presence of a human without the human touching the device. [23]
In OMNI, the capacative sensing can be used to register when a player is touching or is going to touch the cup. When using multiple capacitive sensors, it is possible to detect how the cup is held.

Touch sensor A touch sensor can detect human touch. Touch sensors are more sensitive than buttons and are able to respond on different types of touch, for example tapping or swiping. The touch sensor works using capacitive sensing as described in the previous paragraph. In OMNI, the touch sensor could be used similarly as the switch.

Fingerprint sensor For Arduino, there is a fingerprint sensor module available. This module is an optical sensor. It takes an image of the finger on the scanner, which it analyzes to see if the fingerprint matches an earlier accepted fingerprint. The module can store up to 1000 fingerprints in its memory.

[18] For OMNI, the fingerprint scanner could be used to select a certain game, where each finger can represent one game.

Light sensor A light sensor is a sensor which detects light. The sensor converts light energy into an electrical signal. A common light sensor is the light dependent resistor (LDR). This resistor changes resistance when light is shine upon the resistor. When there is no light, the resistance is very high. When light reaches the LDR, the resistance decreases.[19]
In OMNI, a light sensor can be used to detect when someone has put their hand around the cup. It could also be used to see what side is up, when both the bottom and top have a LDR.

QR-scanner Arduino has some QR-scanner modules. A QR-code is a "Quick Response" code. The code can be used to send data. For example, by scanning a code you can go to a certain website.[20]
For OMNI, the QR-scanner and code can be used to select different games. It could also be used to play memory with cards with QR-codes on them, where next to textile feedback on the cards also audio feedback could be given using the cups.

RFID tags RFID technology is used in a wide range of activities, from playful behaviour in toys to pay transactions using the RFID tags (see Figure 7). When a passive RFID tag is in range of a powered reader, it will communicate a small amount of data to indicate presence and identity. RFID works wirelessly and can be embedded into anything. RFID tags do not require physical openings for network or power connection. RFID has some properties which should be considered when designing using RFID tags. One of those properties is that RFID tags work two-sided due to the RFID fields. This means that objects with two distinct sides work good, such as a coin or card. [24] In Picoo [21], the controllers contain RFID readers. Cards which can be used in games contain RFID tags. Using this, hide and seek can be played where the card are hidden have to be found by the players. For OMNI, it might be possible to give each player a ring with a RFID tag. By adding a RFID reader in the cups, it can be sensed which player has flipped a certain cup. This way it is possible to track scores when doing a multiplayer game.

Figure 7: Collection of objects containing an RFID tag. [24]

[18] https://www.hackster.io/nickthegreek82/arduino-fingerprint-sensor-tutorial-103bb4; *Accessed on 30-04-2020*
[19] http://wiki.edwindertien.nl/doku.php?id=education:physicalcomputing:03_making_sense; *Accessed on 30-04-2020*
[20] https://circuitdigest.com/microcontroller-projects/arduino-qr-code-generator; *Accessed on 30-04-2020.*
[21] www.picoo.com; *Accessed on 10-04-2020*

Bluetooth Beacons Bluetooth beacons are similar to RFID tags, but require energy to work. The advantage of Beacons over RFID tags is that a Bluetooth Beacon can be scanned using a mobile phone and send small data packets, like an URL or temperature. Furthermore, Bluetooth beacons have a larger range (4m up to 23m indoors [25]) than RFID tags and Beacons can be used for localization [26].
For OMNI, the beacons could be used similar to the RFID tags.

IMU sensor An Inertial Measurement Unit (IMU) is a 9-axis sensor that measures orientation, velocity and gravitational forces by combining an accelerometer, gyroscope and magnetometer into one. An IMU can detect rotational movements over three axes, pitch, roll and yaw. These axes can be seen in Figure 8. The accelerometer can detect the rate of change in velocity in an object and measure information about pitch and roll. The gyroscope can measure the change in rotation over the three axis. The magnetometer serves for a gravitational force on the IMU. IMU's are used in fitness trackers for motion trackers and orientation or in Segways for stabilization of the vehicle.[22] The main disadvantage of IMU's is that drift occurs in the sensor.
In OMNI, the IMU can be used to register when a cup is flipped. Moreover, it can sense how a certain cup is flipped. Using this, OMNI gets the option to make games where players should get the cup into a certain position as fast as possible.

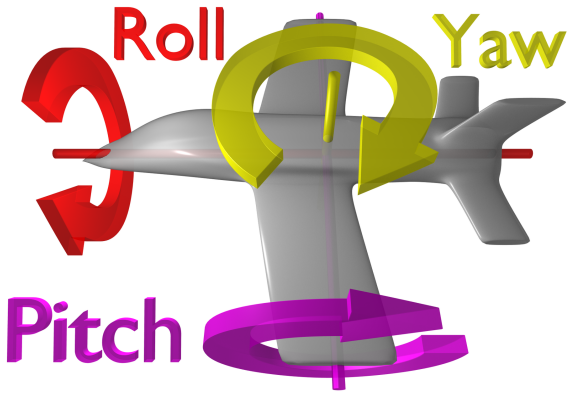


Figure 8: The three axis which an IMU can measure.[23]

Pressure sensor A pressure sensor can measure the pressure put onto the sensor. The sensors acts as a transducer. It generates an electrical signal based on the pressure put onto the sensor.
For OMNI, such a sensor can be used to sense if a cup has been flipped by adding a sensor to the top and the bottom of the cup.

Microphone A microphone can be used to detect sound and the volume of sound. When a user talks, the air will move back and forth due to vibration of the air. These vibration will cause a sound wave. When the sound wave hits the microphone, a membrane in the microphone will vibrate. This changes the magnetic field inside the microphone, which will cause a small electric current to flow from the microphone. This current can be measured to see if sound is present. With louder sounds, the vibrations will have a larger amplitude. This makes the membrane vibrations larger and thus the electrical currents will also be larger. This way, it is possible to measure sound. [27]
In OMNI, this can be used to have speech input when selecting a certain game. Moreover, it could also be used to detect sound or sense when a person is blowing or screaming into the microphone.

[22] https://www.seeedstudio.com/blog/2020/01/17/what-is-imu-sensor-overview-with-arduino-usage-guide/; *Accessed on 02-04-2020.*
[23] https://commons.wikimedia.org/wiki/File:Flight_dynamics_with_text.png; *Accessed on 10-04-2020.*

2.5.3 Actuators

LEDs Light-Emitting Diodes (LEDs) are diodes which emit light when a current passes the diode. The LEDs are able to be indicating or illuminating. In Picoo [24] the LEDs are used to indicate on which team a player is and when a new game start. Using LEDs as an indication will not be suitable for OMNI, as it is designed for visually impaired people.

Vibration motor A vibration motor is a motor which vibrates when power is given to the motor. The vibration motor can be used to give an indication or feedback. In the tangibles designed for visually impaired people, the vibration motors are used as an indication. In the example of Blind Hero [28] the vibration motors indicated to the user which finger should be pressed. In the study of Oliveira et al. [2] the vibration motors were used to direct the user with his hand to a certain spot. In Picoo [13] the vibration in one game is used as an item, where children should take over the 'buzz' from each other. In other games in Picoo, it is used as feedback when something has gone correctly. In OMNI, the vibration motor can be used to indicate that the cup should be flipped.

Speaker A speaker or piezo buzzer can be used to generate sound. Sound can be used in different ways in gameplay, for example to give audio instructions or to give feedback. Furthermore, a background sound can enhance the game, making the game more exciting or more peaceful depending on the music, as is done in the study of Oliviera et al. [2]. In Picoo[16], the audio is used as feedback to indicate that a certain action has been performed correctly. However, in Simon[25], the sound is used to give an indication about which button should be pressed. In OMNI, audio instructions about the games can be given using the speakers. Moreover, the speaker could be used to give feedback on whether or not a cup has been flipped correctly.

Electromagnet An electromagnet is a type of magnet which only has an electric field when there is an electric current. The magnets usually consist of wire wound around a coil. Depending on the way the current flows, it is possible to change the electrical field. Electromagnets are used in motors to make the motor rotate and in loudspeakers to make the membrane vibrate to make a sound.
In OMNI, the magnet could be used to keep the cups on the same place after the cups have been flipped. By activating the magnet when the cup is turned and a permanent magnetic board, it is possible to move the cups to the desired position.

Motor As mentioned above, an electromagnet is used to make a motor rotate. Using a motor, it would be possible to push certain elements up or down, using gears to convert rotational movement into linear movement. This would make it possible to change the shape of the OMNI cups. Moreover, the motor can be used to create Braille cells. The disadvantage for using a motor for a Braille cell is that 6 pins need to move up or down to make one letter, meaning that at least 6 motors are needed.

2.6 Earlier Prototype tests

Due to COVID-19, it was not possible to do physical prototype testing during the context analysis phase. Luckily, during module 6 of the Bachelor Creative Technology some prototype testing has been done. Moreover, during Dutch Design Week many people have seen and tested the product.

During module 6 of the bachlor Creative Technology, a lo-fi prototype of OMNI was tested. This prototype can be seen in Figure 9. The prototype consisted of small wooden cups on a board. The cups contained vibration motors which could be turned on or off from a computer. During this research, three variations of the game were tested. These variations were:

1. One cup vibrating at the same time or multiple cups vibrating at the same time.
2. Different strengths in vibration to see what works best.
3. Test a multiplayer and single player game to see what works best.

From this research the following results were found:

[24] https://www.picoo.com; *Accessed on 09-04-2020.*
[25] https://shop.hasbro.com/en-us/product/simon-game-for-kids-ages-8-and-up:11B65A99-E662-4178-9C36-4E2B63B52093; *Accessed on 08-04-2020.*

- The cups were placed on a wooden board. When the cups vibrated, they made a sound on the wooden board. Moreover, the wooden board vibrated along with the cup, which made other cups vibrate as well.
- During the game, it was not clear what the goal of the game was and when a player had won the game
- The game was both as a single player game and a multiplayer game engaging. Important is that both games should have a competitive element.
- The game did not have feedback when a correct cup was turned, which made it unclear if someone found the correct cup.

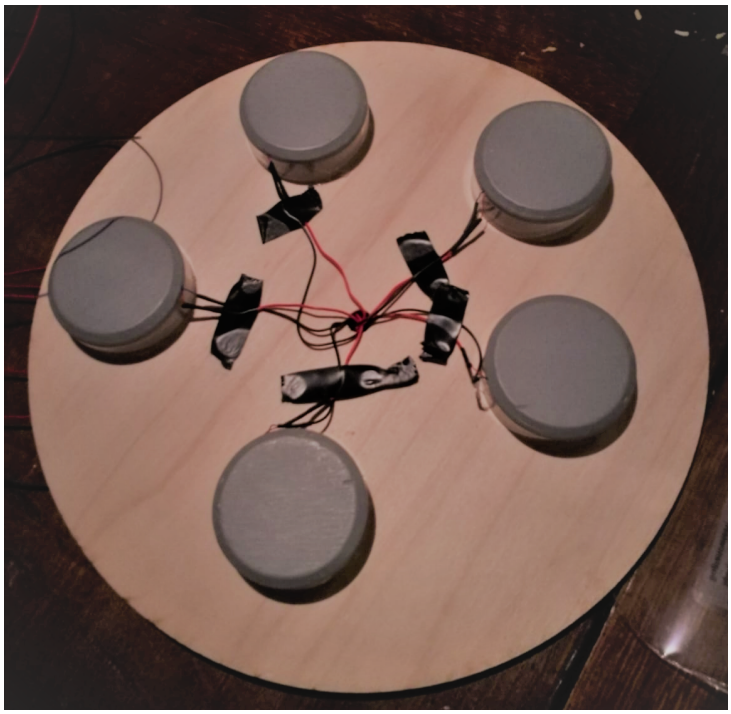


Figure 9: The first prototype of OMNI.

The results were taken into account after which a hi-fi prototype has been made in module 7. As this module was about writing a business plan, testing of the new hi-fi prototype was unfortunately not done. However, this hi-fi prototype is exhibited on Dutch Design Week, where more than 100 people have tested the product. The version taken to Dutch Design Week can be seen in Figure 10. During Dutch Design Week, the cups could not communicate with each other. They were programmed in such a way that each cup would vibrate on a random time interval. The cup would continue vibrating until the cup was flipped, after which the vibrations stopped. After a random time interval, it would start to vibrate again. A buzzer was added to the cups to provide feedback.

During Dutch Design Week, the testing was informal, as visitors could touch and play with the product. By observing these players, possible improvements for the product were found. For example, the game missed a clear goal. When players flipped a couple of cups they would be like: 'What now?'. To prevent this, a clear goal and a beginning and ending of the game can enhance the game experience. It would also be good to make clear who has won a certain game, to enhance a competitive element. Moreover, as the cups worked independently, it happened that 4 cups were vibrating at the same time. When they were flipped, it took a couple of seconds before another cup would start to vibrate, which made the game less engaging, as the players would feel the cups but nothing happened. Lastly, many positive feedback was given on the game and many ideas about new games were offered for example, follow the pattern, memory, hide and seek or ideas were one would use the cups as input for a quiz where each cup is an answer.

Figure 10: OMNI on Dutch Design Week.

With all information gathered on the target group, games, available tangibles and hardware, the ideation for new hardware combinations can be done. But before going to the ideation phase, the next chapter will explain the methods and techniques used throughout the following chapters of this report.

3 Methods & Techniques

This chapter explains the methods and techniques used throughout the research. During the research the creative technology design process is used, which is described in the first section of the chapter. Section 2 and 3 describe the morphological analysis and weighted decision matrix used in the ideation phase. Section 4 describes the MoSCoW method. The other sections describe methods used in the evaluation phase; the hardware performance test, the user test and the expert evaluation.

3.1 Design Process for Creative Technology

The Creative Technology design process consists of four different phases. These phases are the ideation phase, the specification phase, the realisation phase and the evaluation phase [29].

During the ideation phase, the goal is to come up with new ideas or new technologies for a design problem [29]. The ideation phase consists of two phases. During the diverging phase, the goal is to think of many ideas for the problem and to push past obvious ideas to generate new ideas [30]. The inspiration for these new ideas can come in many ways. For example through brainstorming, looking at related work and existing solutions, and by doing interviews. Next to these methods, a morphological analysis was used to generate new ideas. When many ideas are gathered, the convergent phase starts. In this convergent phase, requirements and user needs can be used to reduce the amount of ideas. In this project, converging is done using a weighted decision matrix.

When the ideation phase is finished, the specification phase starts. In this phase, the idea generated in the previous phase is refined to get a more specific idea. The specification is needed to go to the realisation phase. [29]

During the realisation phase, the idea generated and specified in the previous two phases is realised. In this phase, functional testing can be done. [29]

However, functional testing can also be done in the evaluation phase. In the evaluation phase, the project realised is evaluated based on requirements identified in the ideation phase. This can be done through user testing. After the evaluations, the designer can reflect on the idea to see what could be improved on the product.

3.2 Morphological Analysis

As mentioned above, a morphological analysis was used during the ideation phase. A morphological analysis is a method for identifying and investigating the total set of possible solutions to a problem. The problem is separated into different parameters. For each parameter, multiple values are assigned. By combining different values for each parameter, new ideas can occur. This can be done very systematically, where each combination is explored [31].
The morphological analysis was performed in the following way; different cards were made with all available sensors and actuators on it. Each round of 3 minutes, two actuator cards and one sensor card were drawn. These cards can be seen in Figure 11. For each combination that was drawn, game ideas for OMNI were thought of. It was chosen to select two actuators as one actuator can iniate interaction, while the other can provide feedback. The sensors senses the interaction between the cup and the player. This idea generation was done for 15 rounds.

3.3 Weighted decision matrix

To select hardware components for OMNI, a weighted decision matrix is used. In a weighted decision matrix, each component gets a score based on criteria. The score of a component for a criteria is based on how well the hardware components matches the criteria. For the decision matrix a score of 5 means that a component matches the criteria well, while a score of 1 means that the component does not match the criteria.

3.4 MoSCoW method

To prioritize the requirements created in the specification phase, the MoSCoW method is used. With the MoSCow method, the requirements are sorted in 4 different priority groups. These groups are:

- **Must have**; these requirements must be implemented in the product. Without these requirements, the project has failed.[32]
- **Should have**; "features that are nice to implement if at all possible."[32, p. 518]
- **Could have**; features that could be nice to have, but are "less advantageous than the 'Should haves'." [32, p. 518]
- **Won't have**; these requirements are not implemented in the current project. These could be added to the project in a later stage. [32]

3.5 Hardware performance test

During the evaluation phase, the performance of the selected hardware is tested. The procedure for the performance test can be found in subsection 7.1.

3.6 User Testing

In the evaluation phase, the product was tested with users. The prototype is tested in two ways. First, the game experience of the users is tested. Second, the players will be asked about the different game types and game player interactions patterns.

3.6.1 Participants

Due to COVID-19, it was not possible to test with the target group. To limit contact with new people, the game is tested with housemates. The participants do not have a visual impairment and are between the age of 20 and 24. Four participants were available to test the game with. The participants are referred to below as players.

3.6.2 Procedure

Each player played seven short games. The games played are selected during the specification phase and can be seen in subsection 5.2. Each of the games has a different interaction pattern. All the seven games were played twice to see if the games are suitable for the target group. This allowed all players to play the game with and without a blindfold on. Each player played one game alone, one game against another player and five games together with three other players. After all the games were played, the participants were asked to fill out a questionnaire. After this questionnaire a short interview was held.

3.6.3 Questionnaire

After the players had played all games, the players are asked to fill out a questionnaire. The goal of the questionnaire is to find out how the players experienced the game. The questionnaire used is the Game Experience Questionnaire, developed by IJsselsteijn et al. [33]. The questionnaire consists of three parts; the core questionnaire, the social presence module and the post-game questionnaire. Two of the three modules are used in this research; the core module and the social presence module. Using the core questionnaire, it is possible to asses game experience based on immersion, flow, competence, positive and negative affect, tension and challenge. One of the statements in the questionnaire is removed: "I was interested in the game's story" as the game does not have a story. The social presence module investigates empathy, negative feelings and behaviour involvement between different players. With the two questionnaires, the game experience of the players can be investigated. The questionnaires can be seen in Appendix C. [33]

3.6.4 Interviews

After the questionnaires were filled out, each player was interviewed individually. This interview is done to get more insight in the perception of the players towards the games and player interaction patterns. To explain the players about the interaction patterns, Figure 4 was used to explain the different patterns. The questions of the interview are written in Appendix C.

3.7 Analysis User Test

As the number of participant in the study is low, it is chosen to show all data, rather than computing the average scores of each category. Therefore, to analyse the results the questions were grouped in the categories and a graph was showing the answers to each question in the category. Based on these graphs, the game is evaluated. Next to the graphs, the average score for each category for each player is calculated. This is done by scoring each of the answers where 'Not at All' is scored as 0 and 'Extremely' is scored as 4. When a score is close to 0, a player does not feel a certain feeling during the game, while if the score is close to 4, this feeling is very present. In Appendix C, which item belong to which category is shown in the scoring guides.

3.8 Expert Evaluation

Next to user testing and the performance test, the game was also be explained to the therapist of Visio. This is done using Skype, where Simon was be shown and the other were explained. After the games were explained, the expert was asked about her opinion on the games, whether the games are suitable and fair for the target group and what could be improved.

4 Ideation

The ideation chapter describes the generation of new ideas for games on OMNI using a morphological analysis. These ideas are used to select suitable hardware components for OMNI using a weighted decision matrix. In the last section, the communication device is selected.

4.1 Idea Generation

Different ideas were generated with a morphological analysis, as discussed in **??**. The sensors and actuators which were in the card deck can be found in Table 3. An image of the cards can be found in Figure 11. All ideas generated during the morphological analysis can be found in Appendix A. The ideas generated during this phase are used for selecting hardware components and some of the games were realised on the prototype in the later phase.

Table 3: Sensors and actuators used during the morphological analysis.

Actuator	**Sensor**
Vibration motor	Button
Stepper/DC motor	Tilt Switch
Speaker	Optical Sensor
Electromagnet	Touch sensor
Pump	IMU
	Microphone
	Fingerprint sensor
	Light sensor
	QR-scanner
	Pressure sensor

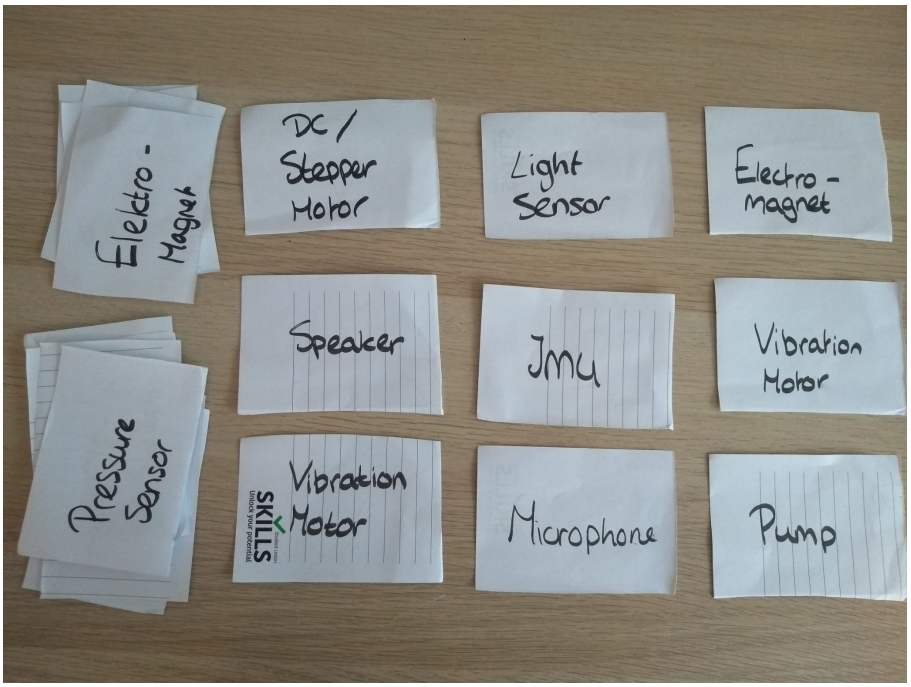


Figure 11: Example of the cards used to generate ideas for OMNI. On the left, there are two piles. The upper pile contains cards with sensors, while the lower pile contains actuators. The left column shows actuators, middle column sensors and the right column actuators.

4.1.1 Selection criteria

To select hardware components, six criteria were used. The criteria are based on the target group, the available games with a certain hardware type and properties of the hardware components. Moreover, as the casing of the prototype was realized during an earlier project, this was taken into account when creating the criteria.

1. **The hardware should not introduce an unfair advantage or disadvantage for the target group.**
   As the game is designed for visually impaired and non-visually impaired people to play a balanced game together, the hardware should not give one of the groups an advantage. Such an advantage could occur when objects move across the table, since visually impaired people cannot see this, while sighted people can see this. This was also mentioned during the interview with Visio (subsection 2.1). The other way around, Braille is easier for visually impaired people compared to sighted people as visually impaired people are more used to Braille than sighted people.

2. **The costs to implement the hardware in the prototype should be low.**
   As the prototype is in the development phase, many changes will be made to the prototype. When the costs of the prototype is high, these changes can become expensive.

3. **The hardware components should be easy to implement.**
   Easy to implement hardware makes it easier to create the prototype. This criteria is scored on the amount of wires which should be connected. When extra elements, such as transistors or resistors are needed, the score gets lower, since this increases the implementation difficulty.

4. **The hardware components should allow for different user actions.**
   When a hardware component gives for multiple user actions, more games can be played using this component. For example, with a tilt switch, the user can flip the cup. With an IMU, the user can flip the cup, rotate the cup and tilt the cup. This means that there are more actions using an IMU compared to an tilt switch.

5. **The hardware components should not decrease the durability of the product.**
   Currently, OMNI consists of five plastic cups. The cups do not have holes or gaps in them, meaning that the cups are strong. The hardware components should not decrease the durability of the product. This could, for example, happen with a button. Considering a hole needs to be drilled in the cup to push the button out, the product durability decreases. Moreover, as the technology is on the cup, it is more likely to break when the cup falls than when the electronics are inside the cup. This criteria is rated on where the holes are positioned. The top and bottom will be more fragile, considering the flipping motion of the game, therefore, hardware with holes on the side will score higher than when holes are on the top of bottom.

6. **The hardware components should allow for a variety of games.**
   The variety of games are based on the games described in Appendix A. Based on the number of times a hardware components is mentioned in Appendix A, a score is given for this criteria.

With the above mentioned criteria, the hardware components have been scored. How the scores are assigned for each criteria can be seen in Table 4. The decision matrix is shown in Table 5. The scoring and argument for each scoring can be found in Appendix B.

Table 4: Definition of how scores are assigned for each criteria.

(a) The hardware should not introduce an unfair advantage or disadvantage to the target group.

Score	Definition
5	No unfair advantages (no visually aspects or Braille)
4	
3	Some unfair advantages (use of buttons etc.)
2	
1	Many unfair advantages (moving elements and visual cues or things where Braille should be read).

(b) The hardware components should allow for a variety of games.

Score	Definition
5	More than 20 games
4	15 - 20 games
3	10 - 14 games
2	5 - 9 games
1	less than 5 games

(c) The hardware component should allow for different user actions. (E.g. flipping and rotating)

Score	Definition
5	5 or more user actions
4	4 user actions
3	3 user actions
2	2 user actions
1	1 user action

(d) The hardware component should not decrease the durability of the product.

Score	Definition
5	No extra holes or gaps in the cups.
4	One extra hole on the side.
3	Only holes in the sides of the cup.
2	One opening in the top.
1	Multiple openings in the top and bottom.

(e) The hardware components should be low in costs.

Score	Definition
5	less than €2.50
4	€2.50 - €4.99
3	€5 - €7.49
2	€7.50 - 9.99
1	€10 or more

(f) The hardware should be easy to implement.

Score	Definition
5	2 wires (power + ground)
4	3 wires (power + ground + data)
3	more wires, but no extra components
2	1 extra component
1	multiple extra components

Table 5: Decision Matrix of the different type of hardware for OMNI.

	Unfair advantage	Variety of games	User interactions	Durability	Low costs	Implementation	**Total score**
Weight	**5**	**4**	**4**	**3**	**2**	**1**	
Vibration motor	5	4	1	5	5	5	75
Motor	1	3	1	1	5	1	35
Speaker	5	4	1	4	5	5	72
Electromagnet	2	1	2	2	4	2	38
Pump	5	1	1	2	3	1	46
Button	3	1	1	3	5	2	44
Tilt Switch	5	4	2	5	5	2	76
Optical Sensor	3	1	1	3	1	4	38
Touch Sensor	3	1	1	3	1	4	48
IMU	5	5	4	5	2	3	83
Microphone	5	2	2	4	5	1	64
Fingerprint sensor	3	1	1	3	4	3	43
Light sensor	4	1	1	1	5	2	43
QR-Scanner	2	1	1	3	1	3	32
Pressure Sensor	3	2	2	1	4	2	44
RFID tags	5	2	2	5	3	3	65

Table 6: The ranking after scoring the hardware in the decision matrix.

Ranking	Hardware	Score
1	IMU	83
2	Tilt Switch	76
3	Vibration motor	75
4	Speaker	72
5	RFID	65
6	Microphone	64
7	Touch sensor	48
8	Pump	46
9	Button	44
9	Pressure sensor	44
11	Fingerprint sensor	43
11	Light Sensor	43
13	Optical sensor	38
14	Electromagnet	38
15	Motor	35
16	QR-scanner	32

Based on the scores given using the decision matrix, the hardware was ranked. The ranked electronics can be seen in Table 6. As can be seen from the table, the highest scoring hardware is the IMU, which is followed by the tilt switch. Considering the IMU can do all things the tilt switch can do, only one of those two sensors will be implemented in the prototype. On the third place is the vibration motor, followed by the speaker. The top three scoring components were chosen. Therefore, the hardware consists of an IMU, vibration motor and speaker.

4.2 Communication Module

Next to the hardware components, a communication unit should also be implemented in the prototype to make the cups dependent on each other. In subsubsection 2.5.1 four different communication modules have been discussed. To select a 6 criteria were used: communication module low costs, low power consumption, good operating range, good security, sufficient network performance and network topology. After the analysis, three suitable options were found. These are Wi-Fi, Zigbee and nRF24L01. The advantage of Wi-Fi is that it has better security but a shorter battery life than the other two modules. Since the vibration motor requires a lot of power to function, it is desired that other components are low power. Therefore, Wi-Fi is not suitable for OMNI. This means that Zigbee and nRF24L01 are left. The final selection was made based on costs. A Zigbee module is 26 euros per node, while a nRF24L01 is 3 euros. Based on this difference, it is chosen to use the nRF24L01 communication module for the prototype.

As all hardware components are decided upon, more specification was done to get a specific idea before starting the realisation phase.

5 Specification

During the ideation phase, is was decided that an IMU, vibration motor, speaker and nRFL24L01 are implemented into the new prototype. To go from the hardware components to a working prototype, the requirements for the product and the games to implement should be specified. Using information gathered during Dutch Design Week and with the interview with Visio requirements for the game are set up. The requirement are prioritized using the MoSCoW method to define which requirements are most important and which are least important. Moreover, a selection is made on which games to implement and new variations of the selected games are created using different player interaction patterns.

5.1 Requirements

Each requirement is put into one of the four MoSCoW groups. For each requirement, a rationale is given to explain why a certain requirement is important.

5.1.1 Must have's

- **The operating range of the communication device must by at least 2 meters.**
  The cups should be able to communicate when they are on a table. This is likely to be less than 2 meters apart.
- **The system must operate in a star network.**
  To send all data to the right cups, a star network is required.
- **The cups must provide haptic feedback or audio feedback**
  Considering the target group for the game is visually impaired people, the feedback of the product should not be based on sight.
- **No vision must be needed to set-up and play the game.**
  As the game is designed for visually impaired people, it should be possible to start the game without needing vision.
- **The game must be balanced when a visually impaired person plays against a sighted person.**
  Since OMNI is a game designed for visually impaired people to play together with non-visually impaired person, one of the groups should not have an advantage when playing the game.

5.1.2 Should have's

- **The cups should have different textures.**
  With different textures, the visually impaired people can distinguish the different cups from each other.
- **Each game should have a clear goal.**
  From the lo-fi prototype testing, it was found that a clear goal for OMNI missed. Therefore, this should be implemented in the game.
- **The game should contain different types of games.**
  To create a diversity of games, different types of games should be implemented. The different game types are described in subsection 2.4.
- **The games of OMNI should have different player interaction patterns.**
  As described in subsection 2.4, there are seven different player interaction patterns. By implementing multiple player interaction patterns, the player gets new opportunities to interact with the game.
- **OMNI should consist of at least four different games.**
  To increase diversity in games, multiple games are desired. As OMNI consists of four different cups and one hub, each of the cups could be use to select a game. Four is the minimum as with four games, each cup can be used to select at least one game.

- **The batteries should be replaceable.**
  Considering the system takes quite a lot of energy, the batteries should be replaceable by the players.
- **When a game is selected, a clear signal should be given to indicate what game is selected.**
  Considering the visually impaired target group, it should be clear what game is selected.

5.1.3 Could have's

- **The battery in the cups could last longer than 8 hours.**
  To avoid the game running out of power quickly, the batteries should last at least a whole day of playing, so 8 hours or longer.
- **The prototype could last minimum 2 years.**
  As the product could be used during the next semester and later during demo days or to pitch the product, the prototype could last for a minimum of 2 years.
- **Different components could be replaceable.**
  To increase durability of the product, broken parts could be replaceable.
- **Each game could be played multiple times without people knowing the answer.**
  For games like Simon, it is important that each time the game starts a different pattern is chosen to keep the game fun.
- **The system could survive a fall from 1 meter to the floor.**
  As the cups will be flipped in a rush, there is a possibility of the cups falling on the floor. To ensure durability, the cups could survive this fall.

5.1.4 Won't have's

- **The box to store the product in won't be adapted to the new games.**
  A box has been made for Dutch Design Week for OMNI. This box was very expensive. Moreover, the focus of the thesis is the hardware of the product, not the looks of the product.
- **The cups won't have contrasting colours.**
  The therapist at Visio mentioned that contrasting colours are useful for visually impaired people to distinguish the different cups. Considering the situation around COVID-19, it is more difficult to 3D print new cups at the universities facilities. It is also chosen to not paint the cups, as it is not known how the paint will react to the 3D printed structure. Therefore, it is chosen not to give the cup contrasting colors.
- **The product won't have a user manual.**
  Since the focus of the thesis is on hardware, it is chosen to not make a manual for the game.

5.2 Specification of Games

Based on the requirements, the game should consist out of different game types and at least four games should be implemented. To decide which game is implemented on the prototype, the available game with the communication unit, speaker, vibration motor and IMU were selected from the set of games in Appendix A. The selected games are sorted into the game categories discussed in subsection 2.4. Unfortunately, during the ideation phase no bluffing and number games were thought of. Therefore, these game types are not represented in the table. The table with the sorted games can be seen in Table 7.

As it is not realistic to implement all games within the Graduation Project, games should be selected to implement on the prototype. The games are chosen based on the following criteria:

- OMNI should contain games from multiple different game types.
- The games should be easy to implement.
- The game should be easily adapted to implement multiple player interaction patterns for the games.

- The games should show the functionality of all hardware components.
- No extra materials next to OMNI should be needed to play the game.

Table 7: Games based on game-type which could be implemented on OMNI. *italic* means that the game was also possible with the old prototype. * means that more variations are possible with the new prototype. The **bold** game names are the selected games to implement on the prototype.

	Action	**Deduction**	**Memory**	**Skill**	**Quiz**	**Word**
Games	Be Fast! **Defuse the bomb** *Hide and seek* ***Musical Chairs*** OMNI-it Party and Co.	Mastermind	*Memory* ***Simon****	Find the bomb Flipping! *Follow the Buzz** **Open the Safe** *Same sound** Stay in rhythm	OMNI Quiz 2.0	Word generation

Based on the criteria, the following games were chosen to be implemented on OMNI during the realisation phase.

Simon The first game to implement on the device is Simon. Simon is a memory game where a player should remember and repeat a pattern [26]. Each round, the pattern becomes a little harder. For OMNI, it means that the cups will vibrate in a pattern, for example, first cup one, then cup three etc. The player should replicate this pattern by flipping the cups in the right order. Simon can be played as a single player versus the game or multiple individuals versus the game interaction patterns without having to make many adaptions to the game. Moreover, since Simon is a known game, there are examples on how to code Simon on an Arduino, making it easier to implement the game.

Defuse the bomb The second game to implement is Defuse the Bomb, which is an action game. In Defuse the Bomb, the cups vibrate one after another for a couple of seconds. The player should flip the cup to defuse the bomb. If a player flips the cup too late, the player will lose the game. The goal is to flip as many cups as possible before letting one bomb explode. Similar to Simon, this game makes use of the vibration motor, communication unit and IMU.

Open the Safe The third game to implement is Open the Safe. In Open the Safe, the players should rotate the cup to a certain position. Using vibrations, the cup indicates whether the player is moving towards or away from the correct position. It is chosen to implement Open the Safe as it uses the IMU in a different way compared to the other two games. In the other games, the IMU is used to detect a flip, which can also be done with a tilt switch. When using the IMU in Open the Safe, the added value of the IMU compared to a tilt switch is shown. Another advantage is that this game, just like Simon, is easily adapted to a multiplayer game.

Musical Chairs The last game to implement is Musical Chairs. This game makes mainly use of the speaker, while the other games use the vibration motor the most. Moreover, this game is selected as the game is easy to implement as communication between the devices is not necessary.

Unfortunately, not all game types are implemented on the prototype. First of all, Mastermind is not selected, since for Mastermind, one should see the earlier tried patterns and the results of the patterns to be able to get the right pattern. This is difficult for OMNI with the selected hardware. The Quiz is not chosen since these require quiz-cards with questions next to the OMNI device. As it is not desired to have extra materials, this game is not selected. Lastly, the word game has not been selected since it is difficult to use an Arduino and the piezzo buzzer to output sounds such as words or letters.

[26] https://shop.hasbro.com/en-us/product/simon-game:6B0A06E3-5056-9047-F532-6A891FAEBA15; *Accessed on 11-06-2020.*

5.3 Player interaction patterns

With the four different games selected, concepts for each of the player interaction patterns for each games are created. The variety of games and player interaction patterns shows the flexibility and potential of OMNI as a game device.

5.3.1 Simon

- **Single Player vs. Game**
  The player should try to beat the high score, by remembering the pattern generated by the game for as long as possible.
- **Multiple individuals vs. game**
  Each player repeats the pattern generated by the game. When a player does not know the pattern anymore, this player is out. The game continues until one player is left.
- **Player vs. Player**
  One player starts with a pattern. The other player copies the pattern. In the next turn, the first player adds one cup to the pattern. This continues until one of the players does not know the pattern anymore. This player loses the game.
- **Unilateral Competition**
  One player creates a pattern. The other players each have one cup. Working together, the other players should flip their cups to recreate this pattern. After each round, the pattern makers adds one cup to the existing pattern. If the pattern maker does not know the pattern anymore, the pattern maker loses. If the players make a mistake while recreating the pattern, the pattern maker wins.
- **Multilateral competition**
  The first player makes a pattern, the second player repeats the pattern of the first player and adds one cup to the pattern after which the third player repeats the pattern and adds one to the pattern etc. The last player standing wins.
- **Cooperative play**
  Each player gets one cup. The game signals a pattern, which the players should recreate together.
- **Team Competition**
  Similar to player vs. player, but multiple people can be in a team, working together to remember the pattern for as long as possible.

5.3.2 Defuse the bomb

Just as Simon, there are also different interaction patterns for Defuse the bomb.

- **Single player vs. Game**
  One cup starts to vibrate, the player should flip the vibrating cup. The cups will vibrate with smaller time intervals, meaning that the player should flip faster. When a cup vibrates for more than x seconds before it is flipped, the player has lost the game. Goal of the game is to beat the previous high score.
- **Multiple individuals against the game**
  When the cups vibrate, they make a sound. This sound indicates to which player this bomb belongs. This player should flip the cup to defuse the bomb. If a player flips a cup which does not belong to the player, he helps another player. If someone is too late with flipping a cup making the sound of the player, the player is out. The last player standing wins the game.
- **Player vs. player**
  One player activates bombs by flipping non-vibrating cups. The other player should defuse the bombs by flipping vibrating cups. If one cups vibrates for more than x seconds, the bomb activator player wins. If after 3 minutes no bomb has exploded, the playing defuser the bombs wins the game.

- **Unilateral competition** Similar to player versus player, but one player is activating bombs and multiple players are defusing the bombs.
- **Multilateral Competition**
  Players play against each other as in player versus player. However, when a defuser loses, another player can try to defuse the bombs. The player who wins against most other players wins the game.
- **Cooperative play**
  Similar to single player versus the game, but the players work together to flip the cups as fast as possible to beat the previous high score.
- **Team competition**
  The team competition is similar to player versus player, but instead of one player defusing or activating, this is done in a team so multiple people are activating and defusing bombs.

5.3.3 Open the Safe

In open the safe, the players should rotate a cup to the right position to open the safe. For this game, all seven player interaction patterns can be created.

- **Single player vs. game**
  The player should rotate each of the 4 cups to the right rotation. When the cup is at the correct rotation, the cup will stop vibrating. If all cups are at the right rotation, a sound signal indicates the game has won.
- **Multiple players vs. the game**
  Each player gets one cup. The game sends rotations to which the cups should rotated to. First person to rotate the cup to the right rotation wins the game. By sound and vibration, it is indicated when the cup is rotated correctly.
- **Player vs. Player**
  Each player gets two cups which should be rotated to the right orientation. This should be done three times. The fastest player wins.
- **Unilateral Competition**
  One player enters the code, by rotating the cup three times. To enter a number, the player should keep the cup still for 2 seconds. The three players should try to crack the code. If a player does this within x seconds, the players win, else the single player wins.
- **Multilateral Competition**
  Each player gets one cup. This cup should be rotated to the correct orientation 3 times. Fastest player wins.
- **Cooperative play**
  The players should work together to get the cups to the right orientation as fast as possible. If the 4 cups are in the correct orientation, a sound signal is given. The 4 cups should be turned to the right orientation 3 times to win.
- **Team competition**
  Players play in a team against the other players. There are two variations. In the first variation, two players play together, where one players feels the vibrations of the other and the other way around. This means that good communication is necessary to crack the code. In this game, the fastest team to have correctly rotated the cups wins.
  In the other variation one player can only start rotating its cup when the other player in the team has rotated the cup to the right orientation. Fastest team wins.

5.3.4 Musical Chairs

- **Single player vs. Game**
  When the music stops, the player should grab the cup. The game records the time taken to grab the cup. The goal is to react as fast as possible on the stopping music.

- **Multiple players vs. Game**
  Similar to singe player vs. game, but this time there are multiple cups. The cup that is grabbed fastest will vibrate to indicate the win to the player.

- **Player vs. player**
  There is one cup in the middle of the table. The hub plays a song, when the song stops, the players should grab a cup as fast as they can. The player who gets the cup wins the game.

- **Unilateral Competition**
  One player controls the music. When flipping the hub, the music will stop. When the music stops, the players should grab a cup. The person who does not get a cup is out. The last player standing wins.

- **Multilateral competition**
  The same as player vs. player but with more cups. There are four cups, meaning that the game can be played with a maximum of five people.

- **Cooperative play**
  Players should work together to grab all cups as fast as possible after the music has stopped. To win the game, the cups should be grabbed within x seconds.

- **Team competition**
  There are multiple teams, each round a player from the team is selected to grab the cup. If a player does not get a cup, the player is out, meaning that the team consists of less people. If all player of one team are out, the team has lost the game. The last team standing wins the game.

If all these interaction patterns are implemented on the prototype, the prototype contains 28 different games. As this is not realistic within the assignment, a choice was made on which games to implement on OMNI and which games not. This choice was made based on the following criteria:

- Each different player interaction pattern should be implemented on the prototype.

- Each game should be implemented.

Next to these two criteria, if a game is originally based off another game, such as Simon and Musical Chairs, this game is implemented on OMNI in the same game pattern as the original game is. This is chosen since these games are considered enjoyable in these game patterns. To see if the games are enjoyable on OMNI, the same interaction patterns are used. This means that Simon is played in a single player vs. the game pattern and Musical Chairs as a multilateral competition.

The following games and interaction patterns have been chosen.

- **Single player vs. game**: Simon

- **Multiple individuals vs. game**: Open the Safe

- **Player vs. player**: Defuse the bomb

- **Unilateral Competition**: Defuse the Bomb

- **Multilateral competition**: Musical Chairs

- **Cooperative play**: Simon

- **Team competition**: Musical Chairs

It has been chosen to do Simon as a single player vs. the game and cooperative play, as they both can be done with the same configuration, where the game generates a pattern which should be copied by the player/players. This makes the game easy to implement. Moreover, since Simon is originally a single player game, players might already understand the concept of the game. Defuse the Bomb is done as a player versus player and unilateral competition. This is chosen since these can both be implemented making one version of the game. In this version, one cup will vibrate if the cup is flipped and stops vibrating if the cup is flipped again. Musical Chairs is chosen as a team competition and multilateral competition. Since Musical Chairs is normally a multilateral competition, it is chosen to choose this game

as a multilateral competition, since players are likely to know the game. This game is easy to implement as a team competition, as this is almost similar to the multilateral game. This leaves Open the Safe and multiple individuals vs. the game. In this game, each player gets a cup and has to try to open the safe.

This way, the two earlier mentioned criteria are reached. As the games and player interaction pattern of each game are decided upon, the games can be implemented on the prototype.

6 Realisation

With the specification of the product finished, the hardware can be implemented into the prototype. The goal is to realise the earlier mentioned four different games in the seven different interaction patterns, so that the games can be evaluated in the next phase.

6.1 Casing

For this research, the 3D printed cups of the previous Dutch Design Week prototype are used. Considering the COVID-19, 3D printing was more difficult, which is why it was chosen to not 3D print new cups. The earlier printed hub was too small to fit the electronics in. However, as there are two sets of cups, it is chosen to combine one top and one bottom of two different cups in the other set. This way, the hub is the same size as the cups, but feels and looks different. This means that the hardware can fit in and the hub is still distinguishable from the other cups. The Dutch Design week hub and the new hub can be seen in Figure 12.

Figure 12: From left to right: Hardware, Dutch Design Week hub and the new hub

6.2 Components

As discussed during the ideation phase, the prototype consists of an IMU, speaker, vibration motor and a nRF24L01. These components will be powered using a 9V battery. As a microcontroller, the Arduino Nano will be used.

6.2.1 Arduino Nano

The game is controlled by an Arduino Nano. The choice for Arduino was made as this is used often throughout the Creative Technology program. Therefore, there is prior knowledge on using Arduino, making it easier to use an Arduino compared to other microcontrollers. As the cups are small, an Arduino Nano is selected, as larger Arduino's do not fit into the cup. The Arduino Nano makes used of the ATmega328 chip.[27]and is powered by a 9V battery. The 9V battery is connected to the Arduino using a battery cap. The power wire is connected to Vin, while the ground wire is connected to the ground on the Arduino.

6.2.2 IMU

To detect the flipping motion and the rotational motion for Open the Safe an inertial measurement unit is used. This IMU is the MPU9250/6500. The MPU9250/6500 consists of an accelerometer, gyroscope and a magnetometer. When implementing, the IMU should be placed correctly, considering it measures the x, y and z-axis. Therefore, if the board is placed tilted, the IMU will give wrong measurements. The IMU is powered by the Arduino using 5V. The board itself uses 3.3V, but the voltage regulator on the board limits the voltage to 3.3 volt. The IMU is not connected to the 3.3V output of the Arduino, since this is used for the nRF24L01. Next to the power and ground cable, the SCL and SDA of the IMU

[27] https://store.arduino.cc/arduino-nano; *Accessed on 27-05-2020.*

should be connected to the SLC and SDA pins of the Arduino (A4 and A5 respectively). The SCL and SDA pins are used by the Arduino to communicate with the IMU using I2C.[28]

6.2.3 nRF24L01

To send data from one Arduino to another the nRF24L01 is used. This device can both send and receive information. The transceiver operates in the 2.4 GHz frequency band. Its data transfer rates can be set to 250 kbs, 1Mbps and 2Mbps. The nRF24L01 is connected to the Arduino with 7 wires. Two of those are the power (3.3V) and the ground wire. Next to that, the CE, CSN, SICK, MOSI and MISO pins of the nRF24L01 must be connected. The CE pin is used to select whether the nRF24L01 will transmit or receive data. The CSN pin is used to listen to the Arduino. The SCK, MOSI and MISO pins are used to communicate with the Arduino using SPI.[29]

6.2.4 Vibration motor and piezzo buzzer

The vibration motor and piezzo buzzer should both be attached to a pin which is able to do Pulse Width Modulation (PWM). PWM pins are able to switch on and off at 500Hz to simulate voltages between 0 to 5 volt. Using the PWM pins, it is possible to regulate the tone of the piezzo buzzer and the vibration strength of the vibration motor. The buzzer is connected to D6, while the vibration motor is connected to pin D5. [30]

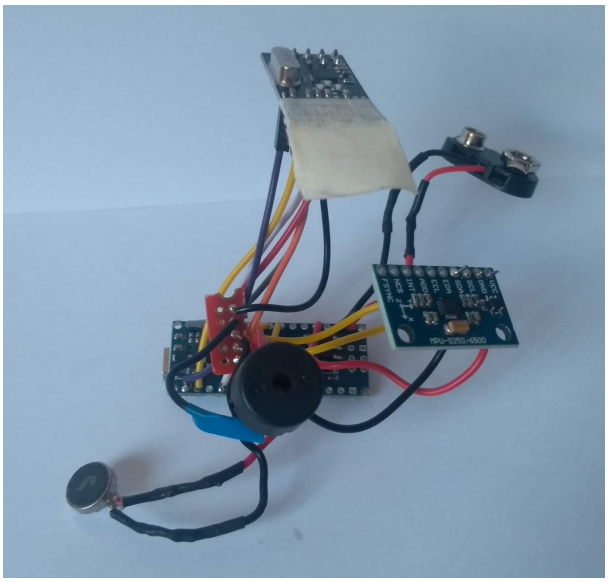


Figure 13: All hardware soldered together

6.3 All hardware together

All hardware was soldered together using lead free solder. For the first soldered set, the wires were too long and the hardware did not fit into the cup. Therefore, it was chosen to use shorter wires for all components. The downside of shorter wires is that it is more difficult to manoeuvre the IMU to the correct position and to tape the vibration motor to the cup. This meant that the wires could break when moving the IMU or vibration motor. One of the soldered hardware sets can be seen in Figure 13. Moreover, the vibration motor has very thin wires, which caused the wires to break. To solve this problem, heat shrink was put around the vibration motor wires to strengthen the wire. Due to the breaking wires, the vibration motors had to be re-soldered many times. For node 2, the re-soldering damaged pin D5 of the Arduino board. Therefore, the vibration motor of node 2 is connected to D3. When connected to D3, the vibration motor works as expected.

[28] https://www.arduino.cc/en/Reference/Wire; *Accessed on 10-06-2020.*
[29] https://lastminuteengineers.com/nrf24l01-arduino-wireless-communication/; *Accessed on 10-06-2020.*
[30] https://www.arduino.cc/en/Tutorial/PWM; *Accessed on 10-06-2020.*

For the IMU it proved hard to do the calibration correctly and to get the yaw, pitch and roll from the data. Therefore, the flip is detected using measurement of the magnetometer on the z-axis, as this worked very well for the three games which do not use the other axes of the IMU. For 'Open the Safe' it has been decided to rotation over the roll axis instead of the yaw axis as it was difficult to get correct readings of yaw, while roll was easier and more accurate.

6.4 Arduino Code

When all the hardware has been soldered together, it was time to code the Arduino sets to make it possible to play all the games. For the prototype testing, all games were written in seperate files. This was done as the memory of the Arduino is too small to contain the four different games. The Arduino code can be requested by the author or supervisors.

7 Evaluation

To see if the ideas and implementation of the product have the expected result, the product is evaluated. This evaluation is done in three parts. In the first part, the sensor is tested based on performance. In the second part, the product is evaluated in a user test. In the third part, the new product is discussed with an expert on the target group to see if the games fit the target group.

7.1 Procedure for the hardware performance tests

The procedure for the performance tests for each of the hardware components is described below.

7.1.1 IMU performance test

The IMU is used to detect a flip in three of the four games. Therefore, it was tested how accurate the IMU detects the flips of the cups. Each cup is flipped 100 times. The cup counts the amount of flips using a flipCounter variable. However, as the hardware cannot be connected to the Serial Monitor while in the cup, the node sends the amount of detected flips to the hub using the nRF24L01 module. The hub is connected to the Serial Monitor and prints the amount of detected cups by the node. To get accurate results, this experiment was repeated thrice.

7.1.2 Vibration motor and Speaker

The vibration motor and speaker are tested using the same test. The cups are turned on for 40 minutes, running a code which turns the vibration motor and speaker on for one second and then off for one second. As this is done for 40 minutes, the vibration motor and buzzer are turned on and off over a 1000 times.

7.1.3 nRF24L01

The performance of the nRF24L01 is tested by sending 10.000 packets from the hub to the four nodes and from the four nodes to the hub. One cup at a time is connected to a computer to read out the Serial Monitor. The cup prints the incoming data to the Serial Monitor. After the 10.000 packets are send, the amount of printed packets in the Serial Monitor are counted to see what number of packets reached the cup. This is repeated for all cups to see if all nRF24L01 modules are working correctly.

7.2 Results of the Performance tests

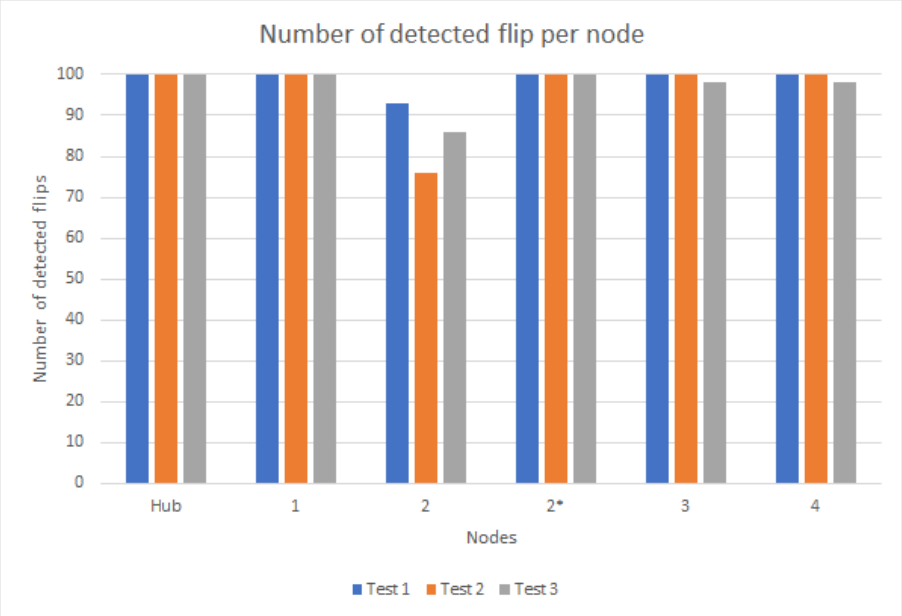
7.2.1 IMU performance test

The results of the IMU performance can be seen in Figure 14. As can be seen from the graph, node 2 detected less flips than the other cups. This was caused by an incorrect calibration of the IMU. After the test was over, the IMU of the node was calibrated again by changing the values which are used to detect the flip. With this changed, all flips of the cup were detected. As can also be seen in the graph, almost all flips were detected. With the correct calibration, 1496 out of the 1500 flips were detected, meaning that 99.73 percent of the flips were detected by the cups.

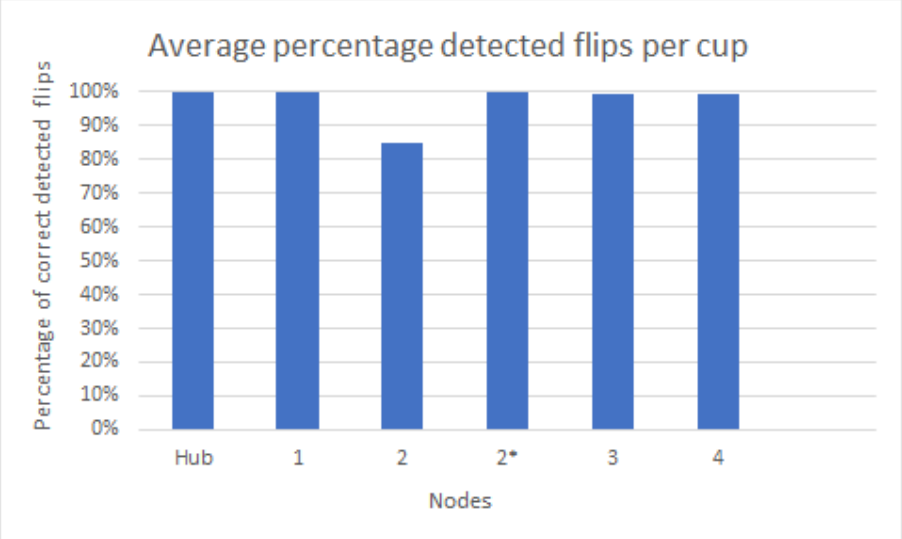
7.2.2 nRF24L01

The second test focused on the nRF24L01. This test is done to see if the communication modules are working as expected. This was tested by sending 10.000 packets from the hub to each node and from the nodes to the hub. To check how many packets reached the nodes and hub, the packets were printed to the Serial Monitor. The percentage of missed packages by each node can be seen in Figure 15.

Figure 15a shows the number of missed packets received by the nodes, while Figure 15b shows the number of missed packets received by the hub. As can be seen from the graphs, when the hub send to the nodes, nodes 1, 2 and 3 did not receive all packets, while node 4 does receive all packets. The hub received all packets from nodes 1 and 3, but missed some packets from nodes 2 and 4. The percentage of missed packages are low as the largest percentage of missed packages is 0.05 percent, measured when node 4 send packages to the hub.



(a) Detected amount of flips per cup for the three tests. 2* is node 2 after calibration.

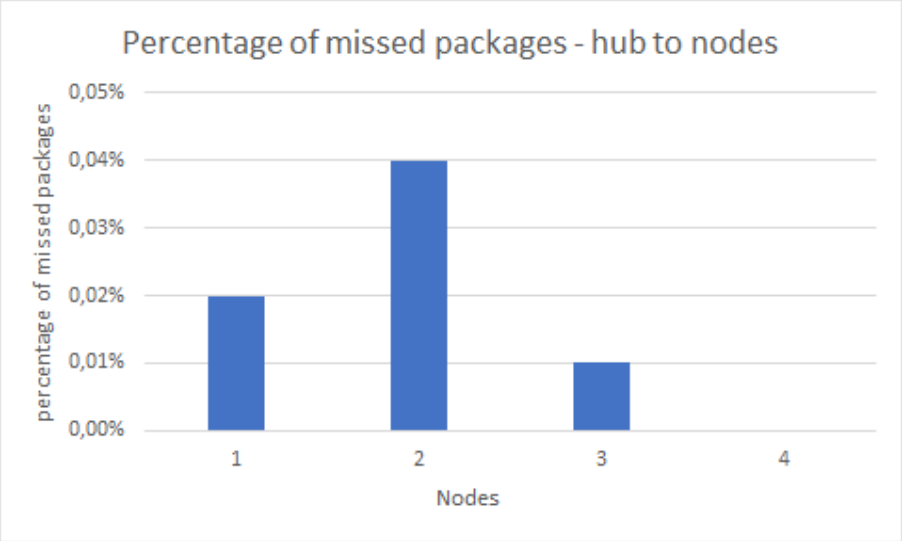


(b) Average percentage of detected flips from the three tests. 2* is node 2 after calibration.

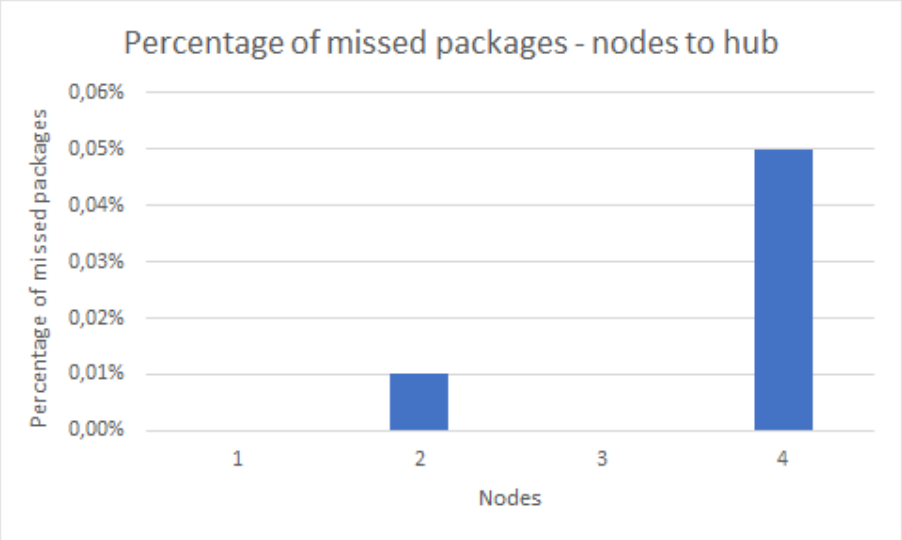
Figure 14: Results of the IMU performance test.

7.2.3 Speaker and Vibration motor

The vibration motor and speaker have been turned on for 40 minute. The hub and node 1 started working immediately and continued working until the system was turned off after 40 minutes. For node 2, the vibration motor did not work. It was found that the pin D5 was not working. This is probably caused by the soldering and desoldering of the vibration motor, as this had been done a couple of times due to breaking wires. The problem was solved by connecting the motor to D3, after which the vibration motor worked as expected and passed the 40 minute test. Node 3 started working as expected, but stopped vibrating after 4 minutes and 45 seconds due to the vibration motor wire breaking. The vibration motor was soldered to the Arduino again. With this cable re-soldered, the node worked as expected. Node 4 also did not work from the start, since one of the wires of the vibration motors was broken. As this was broken such that it could not be re-soldered, the vibration motor was replaced by another vibration motor. With the new motor, the cup worked as expected.
Throughout the experiment, the buzzer did not prove to be a problem as the buzzer always worked. The vibration motor wires are weak. The heat shrink attached to the vibration motor provided some extra



(a) Percentage of missed packages send from the hub to the nodes.



(b) Percentage of missed packages send from the nodes to the hub.

Figure 15: Results of the IMU performance test.

strength, but some of the wires still broke. A solution could be to use a different vibration motor or to use vibration motor module, on which the wires are secured on the module.

7.2.4 Conclusion performance test

Based on the performance test, the vibration motor proved to be the weakest component as the wires tend to break. The IMU and nRF24L01 both work very well as only few flips and packets are missed.

7.3 User tests

To see if users are positive about the four different games, user tests were conducted. The procedure for the user test is described in section 3. Unfortunately, during the user test it was found that not all games worked as expected. For example, in Simon not all packets reached the right nodes, or the packets reached the nodes but the node would not start vibrating. For testing, this was solved by telling the participants which cups should have vibrated when one of the cups did not vibrate. When a packet was not send from the node to the hub, the participant was asked to flip the cup again.
When testing Open the Safe, the game did not work. The players have played the game, but the vibration did not get stronger which means that it was impossible for the players to rotate the cup to the right

position.
In Defuse the Bomb, the time at which a bomb exploded was too short, which made the game impossible to win for the defusing team. This also caused the game to be over quickly.
Musical Chairs worked as expected.

7.3.1 Game Experience Questionnaire

After the players had played the games, the players were asked to fill out the game experience questionnaire. The core-questionnaire consists of 32 questions and the social-presence module consists of 17 questions. These questions can be grouped based on category. As the questionnaire is filled in by only four persons, it is not possible to calculate Cronbach's alpha, which is a measure for internal consistency between the questions in one category. According to Samuels [34], a "reliability analysis should not be attempted for sample sizes smaller than 30" [34, p. 3], as it allows for unreliable results. However, the questionnaire has been performed in other researches with a larger sample size. An example is the research of Law, Brühlmann and Dekker [35], where the questionnaire was completed by 633 participants. They found the Cronbach's alpha of larger than 0.8 for Immersion, Flow, Competence, Tension and Positive affect. The Cronsbach's alpha for negative affect was 0.68 and for Challenge 0.57 was found. This means that for the first 5 groups, the consistence between the questions is good, while for the Negative Affect and Challenge, this is questionable and poor. [36] found that the Cronsbach's alpha for all categories is larger than 0.7 in a research with a sample size of 380. This indicates that the internal consistency between the questions is acceptable. Considering the internal consistency of most categories are seen as acceptable, the questions are grouped in these categories. However, as the sample size is small, it is chosen to show what a participant has answered for a certain question. The results of the questionnaire per category can be seen in Figure 16. Moreover, the average score per categories per person is shown in Table 8 together with the standard deviation of these mean scores.

Table 8: Mean scores for each of the 7 categories per user.

Categories	Mean score for the players (SD)			
	1	**2**	**3**	**4**
Competence	2.6 (0.5)	2.0 (1.6)	3.0 (0.0)	3.2 (0.4)
Sensory and Imaginative Immersion	1.6 (1.1)	2.6 (1.7)	3.0 (0.0)	2.6 (0.8)
Flow	3.8 (0.4)	0.8 (1.1)	2.8 (1.1)	3.0 (0.7)
Tension/Annoyance	1.3 (0.6)	2.3 (1.2)	1.7 (1.2)	0.3 (0.6)
Challenge	1.6 (0.9)	1.6 (1.1)	3.0 (0.0)	1.6 (1.1)
Negative affect	1.0 (1.4)	2.8 (1.9)	1.0 (0.8)	0.0 (0.0)
Positive affect	3.0 (0.7)	2.6 (1.1)	3.2 (0.4)	3.2 (0.4)

Competence The first category tested on is competence. The results of competence are shown in Figure 16a. As can be seen from the graph, most of the players felt skillful and the players all felt fairly competent and thought they were good at the games. The players felt that they were fast at reaching the targets game, but one player did not feel successful. Moreover, as can be seen from Table 8, competence scores a 2 or higher for all players, showing that the players feel competence while playing.

Sensory and Imaginative Immersion Figure 16b shows the results of the questionnaire based on immersion. As can be seen from the graph, there are mixed opinions with regards to immersion. For example, two of the participants did not felt imaginative, while two other players felt fairly and extremely imaginative. Moreover, two players felt that they could fairly explore things, while another person felt that this was only slightly the case. Most players saw the game as a rich experience. Table 8 shows that one player had a low feeling of immersion, with a score of 1.6. The other players felt more immersion, scoring 2.6 or 3.0. Therefore, it can be concluded that immersion is higher for some players than for others.

Flow Similar to immersion, Figure 16c also shows mixed opinion. Table 8 shows that one player does not feel flow at all, scoring a 0.8, while another experienced flow very strong, scoring an 3.8. The player experiencing little flow can be seen back in the graphs in the questions: "I forgot everything around

me", "I was deeply concentrated in the game" and "I lost connection to the outside world". It can be concluded that the experience of flow depends per person for this game.

Tension/Annoyance As shown in Figure 16d, most players were slightly annoyed, irritable and frustrated. As shown in Table 8, tension is experienced different by the players, as this ranges between 0.3 and 2.3. Therefore, it can be concluded that some tension is experienced while playing the game.

Challenge Figure 16e shows that the players did not think that the game was hard, but the players felt challenged. The time pressure was felt, but three out of four players did not felt pressured. The players felt that they had to put moderately effort into it. Table 8 shows the thee of the four players players felt a low feeling of challenge. This can be explained since the players did not think that the game was hard, nor felt pressure. To conclude, the graph shows that the game proved a slight challenge for the players, but the players did not think that the game was hard.

Negative affect Figure 16f shows the questions with regards to negative affect. As can be seen, none of the players were given a bad mood by the game. Two out of the four players thought about other things while playing the game. One player felt bored during the game, while the other three players did not feel bored. Table 8 also shows that one person felt more negative feelings than the other players, as this person scored 2.8 on negative affect, while the others scored 1.0 or 0.0. To conclude, most people experienced little negative affects while playing the game.

Positive affect As Figure 16g shows, all players had a positive view on the game. The players thought it was fun and enjoyed the game. One player did not feel happy because of the game, but the others all did. Most of the players also felt fairly content. This is also seen back in Table 8 as the scores for positive affect are 2.6 or higher.

Conclusion core-questionnaire
The graphs and table show that the players felt competence while playing the game. Immersion and flow were scored mixed depending on the users, as some players scored high on immersion and flow, while others scored low. The game proved to be a challenge for the players, but the players did not feel pressured. Lastly, some players experienced negative feelings during the game, but overall the players enjoyed the game and felt good while playing the game.

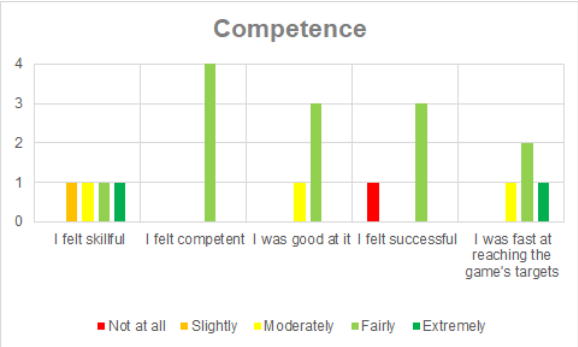
7.3.2 Social Presence Module

Next to the core questionnaire, the players were also asked to fill out the social presence module to research the social interaction between the players during the game. The result of this questionnaire can found in Figure 17. The average scores of the players for each category can be found in Table 9.

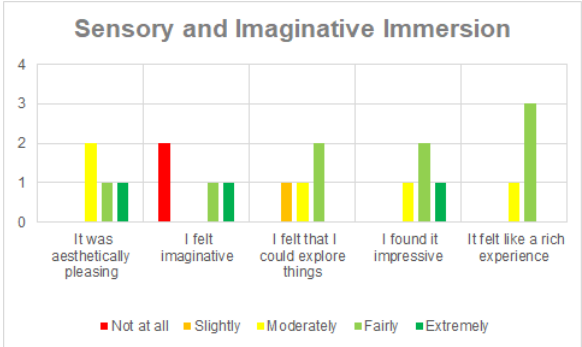
Table 9: Average scores of the players for the Social Presence module

Categories	Mean score for the players (SD)			
	1	**2**	**3**	**4**
Empathy	1.3 (1.6)	1.5 (1.2)	2.2 (0.8)	2.2 (1.2)
Negative feelings	1.2 (1.3)	1.8 (1.8)	2.0 (0.7)	1.6 (1.3)
Behavioural involvement	1.8 (0.8)	2.5 (1.0)	2.3 (0.5)	3.2 (0.8)

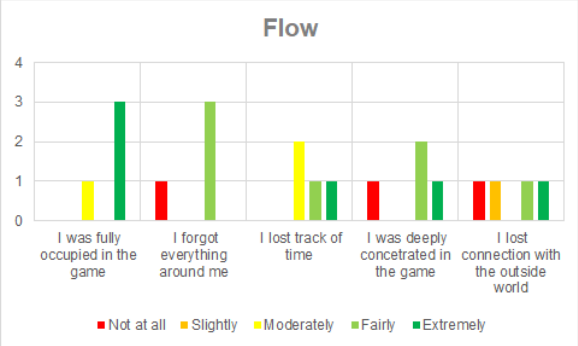
Psychological Involvement - Empathy The first category based on empathy can be seen in Figure 17a. The graph shows that the players slightly empathized with the players, though two players felt fairly connected to the other players. The happiness of the players did moderately affect other players, which can also be seen the other way around. One player was not influenced by the happiness of others and did not think his happiness influenced others. As can be seen in Table 9, the scores for empathy range between 1.3 and 2.2, meaning that no strong empathy is felt. Overall, there is not a strong empathy feeling between the players, but the players did found it enjoyable to be with the others.



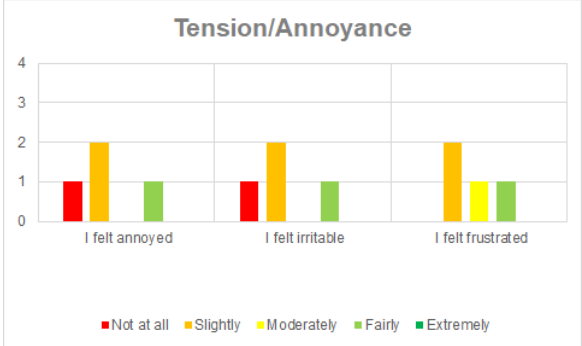
(a) Competence



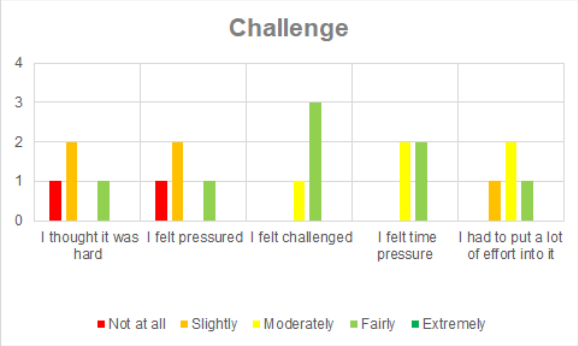
(b) Immersion



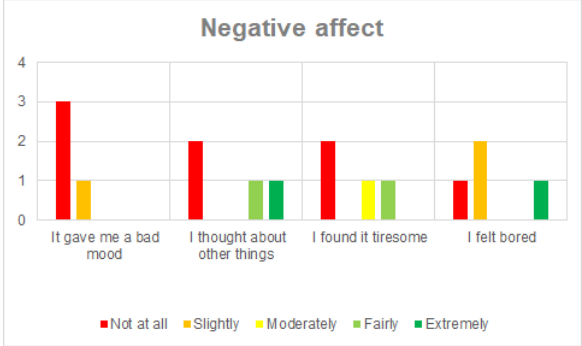
(c) Flow



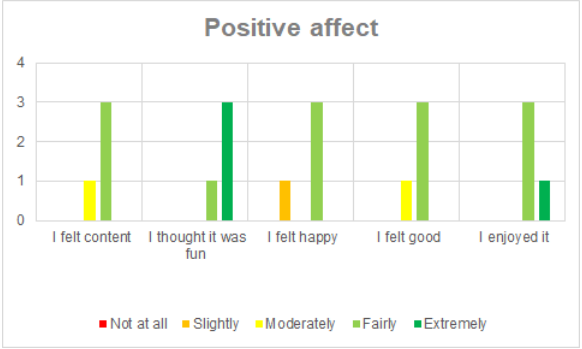
(d) Tension/Annoyance



(e) Challenge

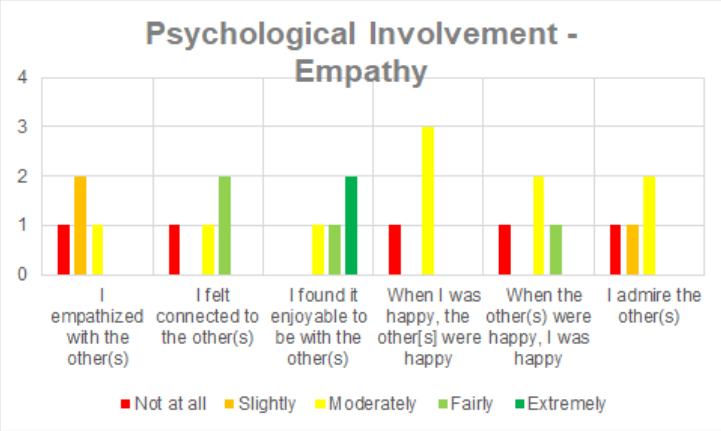


(f) Negative Affect

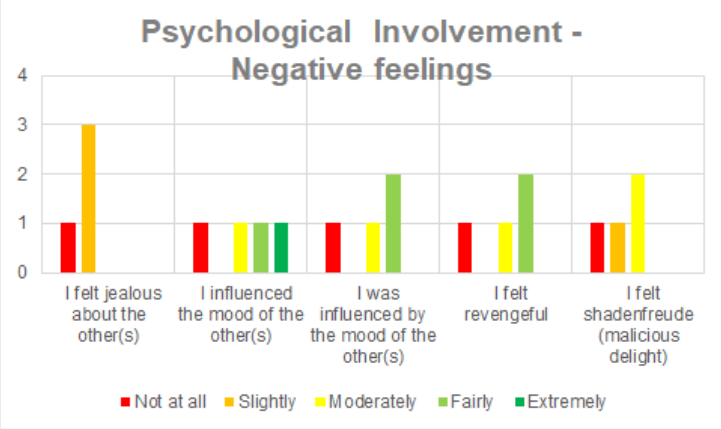


(g) Positive Affect

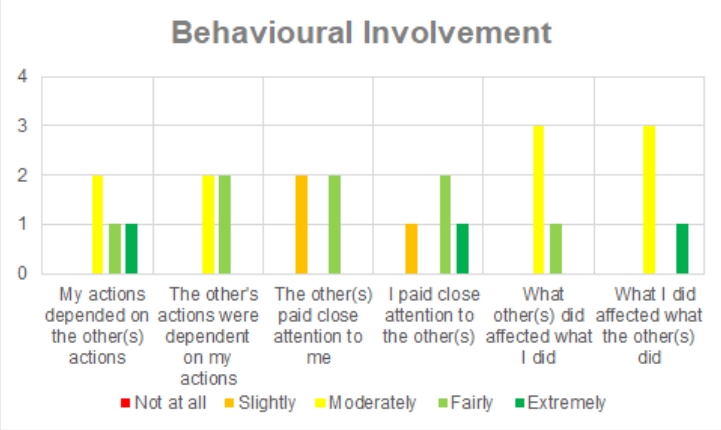
Figure 16: Results of the core module of the Game Experience Questionnaire with n=4 respondents. The questions are grouped by their 7 components. The x-axis shows the questions and the y-axis shows the numbers of players.



(a) Psychological involvement - Empathy



(b) Psychological involvement - Negative Feelings



(c) Behavioural Involvement

Figure 17: Results of the social presence module of the Game Experience Questionnaire with n=4 respondents. The questions are grouped by 3 categories. The x-axis shows the questions and the y-axis shows number of players.

Psychological Involvement - Negative feelings As Figure 16f shows, the players were not jealous of the other player, nor felt a lot of shadenfreude. Some players were influenced by the mood of others and had the feeling that their mood influenced the other players. Two players felt fairly revengeful, while another player felt not at all revengeful. Table 9 shows that the scores for the negative feelings range from 1.2 to 2.0, meaning that some negative feelings are felt.

Behavioural involvement As can be seen from Figure 17c, the players felt as if their actions depended on actions of other players and the other way around. Two players felt that other players paid fairly close attention to them, while two other players found this only slightly. Moreover, the players felt that what others did affected what the player did moderately and the other way around. This is also seen in Table 9, as the scores for behavioural involvement show that the players felt that others influenced their behaviour.

Conclusion Social Presence Module
To conclude, some negative feelings were experienced during the game, though these feelings were not strong. Moreover, the players did not have a lot of empathy for the other players, but the players were influenced by the behaviour of the other players.

7.3.3 Post-game interview

After the participant had filled out the survey, a small interview was held to get the opinion of the players on the different games, the player interaction patterns and to see how the players felt when blindfolded. The transcripts of the interviews can be found in Appendix C.2.2.

All players mentioned that they liked Simon. One of the reasons given is that "it was nice to have to remember the sequence" (Participant 2). Participant 1 really enjoyed the cooperation mode, as it added a 'fun new dynamic to the game'. However, one participant enjoyed the Simon cooperation game least as the participant experienced this game mode as boring, since the player had to wait on the other players. Overall, Simon is one of the games that the players enjoyed most. With Simon, one player felt that being blindfolded helped the person to feel the cups better. The others experienced that Simon did not feel unfair when wearing a blindfold.

The second game played is Defuse the Bomb. The general comment on Defuse the Bomb is that it was impossible to win if you were the defuser, since the bombs exploded too fast. Moreover, this game was not seen as fair when the activating team was blindfolded, as the other person can see which bombs get activated. However, generally the players enjoyed the game. One player mentioned that the game is more challenging to the other games.

The next game was Open The Safe. Unfortunately, this game did not work during the testing, but the concept was explained and the players have felt shortly what the idea of the game was. The players mentioned that it was a pity that it did not work, but that they like the idea. Moreover, the participants mentioned that this game was fair when playing blindfolded against non-blindfolded people.

Last, Musical Chairs was played. One of the player mentioned enjoying the game since you had to react very fast. Three out of the four players mentioned that the game is not fair with a blindfold on. Two reasons where given: with a blindfold on, it is not possible to check if the other person sticks to the rules and it is easier to grab the cup when you can see where the cup is standing. To improve the game, a player suggested placing all the cups on the table and letting the cups vibrate which can be taken. This way, seeing where the cups are is less of an advantage.

Most of the player interaction patterns were recognized by the players with the exception of multiple individuals against the game. The participants thought that Open the Safe was a multilateral competition. This might be caused since no clear explanation about the player interaction patterns was given, but only an image displaying the different player interaction patterns was shown.

With regards to which player interaction pattern fits OMNI best, the players mentioned different player interaction patterns. Cooperative play is mentioned twice, together with multiple player vs. the game and a multilateral competition. Single player vs. the game is mentioned once. The reason for cooperative play is that the players think that this interaction pattern is most fair when playing with visually impaired people. Multiple players vs. the game and single player vs. the game was mentioned by a player as in these games one plays against the game rather than against others. The player finds that the games work best if you are focusing on your own instead of focusing on other players.

The least suitable player interaction pattern for OMNI is a team competition according to two play-

ers. One player thought that too little cups are available for a team competition, while the other player thought that the Musical Chairs team competition was more a player vs. player competition. A multi-lateral competition is also mentioned, since one participant thinks that this allows for more advantage for sighted people.

The players mentioned that all games felt different due to their different concepts. One player phrased this as "each game has its own dynamic", due to the player interaction patterns. Another player felt that the game was different as "different cognitive functions were used", as in Simon the players need to remember a pattern, while Musical Chairs is about reacting fast. Another player described that the games were different as some vibrations were iniated by the computer, while other vibrations were caused by other players.

The last question asked the players what could be improved for OMNI. The following improvements were given:

- Change Musical Chairs such that the player has to grab the vibrating cup, instead of the only cups on the table.
- In Defuse the Bomb give the bomb more time to explode, so that the game is possible to win for the defuser.
- Create a cup-holder for Simon, so that it is easier to find the cups back after you've flipped one of the cups.
- Add better sound feedback to indicate clearly if something is correct or wrong.

Conclusion Interviews
Overall, the players enjoyed the different games. All the games felt different to the players, due to the different player interaction patterns and actions in the game. With regards to fairness, the players felt that most of the games were doable when being blindfolded except for Defuse the bomb. However, the players mentioned that Defuse the Bomb en Musical Chairs were not fair when blindfolded.

7.4 Expert evaluation

To see if these games are suitable for the target group, an expert review is done with a therapist at Visio. During this interview, Simon was shown to the expert and the other three games were explained, so that the therapist got to know the game concepts for each of the games.

The therapist mentioned that the games are fun, especially the interaction. She expects that all four games can be played by visually impaired people. Furthermore, she thinks that the 'Musical Chairs' is a good alternative for reaction games which are not suitable for visually impaired people and she explained that it is good that the visually impaired people can participate without having a disadvantage, which is especially the case with Open the Safe.

This is important, as there are visually impaired people who do not want other people to adapt to them. They just want to participate in a game, without having to adapt the whole game. Therefore, for games which are not completely fair, the therapist suggested adding blindfolds to the box. This way, the game is designed to be worn with a blindfold, which causes the focus to be less on making a game fair for the visually impaired person.

Although the expert thinks that the games are suitable for the target group, she does think that some games are unfair due to difference in hand-eye coordination between a sighted and visually impaired person. This is especially the case in Simon, as it easier for a person to grab a cup in the middle of the table if you can see where the cup is. This is why Open the Safe is more fair than Simon, as the player is already holding the cup. For Defuse the Bomb and Musical Chairs, this can cause a problem. Moreover, the spatial orientation of a visually impaired person differs per person according to the therapist. This means that for one person it can be much easier to remember where the cups are compared to another person. This might also be possible to solve by placing the cups in a container, as the position of the cups is fixed this way.

Next to OMNI as a game, the idea occurred that OMNI could be used to practise spatial orientation or to learn how to use different senses. Spatial orienttion could be practised by placing the cups on different places in a room and hearing where this sound comes from. Senses can be trained with OMNI using the different colors and different textures of the cups together with different sounds and vibration patterns. Moreover, OMNI could also be used for education, where a quiz can be done with the different cups as answers.

Conclusion Interview
The therapist was enthousiastic about the games, but was not sure if all games are fair for the players. To make the games more fair, the therapist suggested to add blindfolds to the game. This could also decrease the advantage which is created by a better hand-eye coodination for sighted people. Finally, it can be explored how OMNI can be used in a therapeutic or educational context.

7.5 Conclusion evaluation

To conclude the evaluation, it can be stated that the games are successful. During the expert interview, it became clear that the games are suitable for the visual impaired target group, but to improve the game some adaptions can be made, like adding a blindfold to the game box. During the user test, the players found that Simon and Open the Safe were experienced as fair when the players were blindfolded. Defuse the Bomb en Musical Chairs were in the advantage of sighted people. Despite not all games being fair, the questionnaire and interview showed that the players were overall positive about the game.

8 Conclusion

The aim of the research was to answer the research question: "How does a change in hardware affect the durability of OMNI and influence the game experience and the potential to use OMNI to design a diversity of games?". To answer this question, first new hardware was selected, after which this hardware was used to implement new games onto the OMNI device. These new games were tested to see if the games are successful.

The new hardware was selected using two methods. First, different sensors and actuators were researched during the context analysis phase. This information was used to generate new ideas during the ideation phase and to make a selection on which hardware components to implement in the device. The hardware was selected based on costs, difficulty of implementation, user actions, available games, the target group and durability. Using these selection criteria, it was chosen to implement a vibration motor, speaker, nRF24L01 and inertial measurement unit.

With these new hardware components selected, new games could be implemented on the device. To make a selection for these games, game types and player interaction patterns have been researched. This information was used to make a selection of games which represented different game types and player interaction patterns. Four games were selected, which were Simon, Open the Safe, Defuse the Bomb and Musical Chairs. For the four games, all player interaction patterns have been conceptualized and for each game one or two player interaction patterns were implemented, so that it was possible to test four different games and seven different player interaction patterns.

During the evaluation phase, the hardware components have been separately tested. These tests show that most components work well. However, the vibration motor proved to be the weakest part of the hardware, as the wires of the vibration motor broke multiple times.
To test the game experience of the players, the players filled out a Game Experience Questionnaire. This questionnaire showed that the players were generally positive about the games, but that the opinions with regard to feelings of flow and tension differed. It was also found that the feelings of social presence in the game was low for empathy and negative feelings. However, the questionnaire showed that the behaviour of players influenced the other players.
During the user tests, the players agreed that Simon and Open the Safe were fair when a blindfolded player played against a non-blindfolded player. The other games showed a bias toward sighted players. The expert from Visio expects that all games are suitable for the target group, but does not know if all games are fair. In case a game is not fair, she suggested to add a blindfold to the box, so that the blindfold becomes part of the game. During the user tests, the players recognized most player interaction patterns and experienced that all games were different.

In conclusion, this research shows that when selecting the right hardware a diversity of games can be integrated on the prototype. With the help of game types and player interaction patterns, four complete different games using seven player interaction patterns were integrated into the prototype, showing a wide diversity of games in OMNI.

9 Discussion and Recommendations

Certain aspects of this research provide room for discussion. For example, assumptions about the target group, criteria for the hardware selection and elements of the user tests. After the discussion, some recommendations for the prototype and further research are given.

9.1 Target group

Throughout the development of the game, there has been no contact with the target group. A therapist working with visually impaired people has been consulted, but this is not the same as consulting a person who is visually impaired. This means that some assumptions are made of the target group without consulting the target group. Moreover, due to COVID-19 it was not possible to test the game with visually impaired people. Therefore, it is not known if the game fits the needs of the target group. It is recommended to test this game with the target group. During these tests, it is useful to research the balanced game play between sighted and visually impaired people for each of the games, since it appeared during this research that not all games are fair.

9.2 Hardware selection

In subsubsection 2.5.1 it is mentioned that Bluetooth is not suitable to use for OMNI as it does not allow a mesh network. However, none of the games realised in the realisation phase make use of a mesh topology, as they all use a star topology. This means that Bluetooth would also be suitable to use. Moreover, in this research an Arduino Nano has been used, while an ESP32 might also be suitable. However, the Arduino was selected since it was previous used for OMNI and other options have not been explored. When doing a similar project, the possibility to use another microcomputer could be explored.

During the ideation phase, one of the criteria to select hardware components is: "The hardware components should allow for a variety of games." This criteria was scored based on ideas generated with a hardware component during the morphological analysis. However, when generating these ideas, a bias can occur to certain hardware components, meaning that more ideas are generated with these components or the components are added to more games. So using this criteria, the bias is taken along with the selection of hardware components.

Moreover, the hardware components are scored on user actions but not on which user actions. This means that two components with exactly the same user actions will score the same, while both components might not be needed as they both allow for the same actions. When this distinction was made, other hardware might have been selected.

9.3 Game selection

During the ideation phase, the game types were not taken into accound when generating game ideas for OMNI as the idea generation was done using a morphological analysis. Therefore, in the specification phase, there weren't game ideas for all different game types. However, it would be possible to create number games or bluffing games on OMNI. One number game could be that each cup vibrates a x amount of times, the player should put the cups from the least vibrations to the most vibrations. A bluffing game could be that players play in a cooperative mode. However, one player tries to secretly sabotage the game. In Simon this could for example result in a player that "accidentally" flips a cup too early. The other players should try to find who is the sabotaging the game.

If throughout the ideation phase, the available game types were more clear and for each of the game types different ideas for OMNI were tried to thought of, it could be that different games would have been selected during the ideation phase.

9.4 Hardware performance test

During the evaluation phase, a hardware performance test was performed to test the performance of the individual hardware components. In these test, it was found that the IMU most flips, this means that in Simon or Defuse the bomb when a cup is flipped, this is likely detected by the IMU. However, when the flip is not detected, the pattern at Simon could be detected incorrectly. In Defuse the bomb the

cup won't start or stop vibrating, making it clear that the IMU did not detect the flip. The speaker worked as expected, meaning that feedback is given correctly throughout the games and that Musical Chairs can be played as expected. The breaking vibration motors has a large influence on the game as it makes it impossible to play Simon, Defuse the Bomb and Open the Safe as these all work with the vibration motor. For Simon, the new pattern cannot be shown when the vibration works. In Defuse the bomb, it is not clear which bombs are activated when the vibration motors do not work and for Open the Safe it is very hard to find the right orientation without the vibration motor. A solution for the breaking vibration motors could be to use a vibration motor module, where the vibration motor and wires are attached to the module. Another option would be to use another vibration motor as shown in Figure 18b. The nRF24L01 did not send all packages, which can decrease the player experience of the games. For example in Simon if the last cup of the pattern is not shown, the pattern cannot be copied correctly meaning that the player will fail. This will decrease player experience. A solution for this problem would be to keep sending the packets, until a confirmation that the packet has been received is given. This way, it is ensured that all packets are received.

During the hardware performance test, the battery life of the nodes have not been tested. It is recommended to test how long the battery lasts to see if the power consumption is acceptable.

9.5 User tests

The players filled out the game experience questionnaire after playing seven games. This means that it is not measured what the players think of each game. It is chosen to do one questionnaire instead of seven, as the players might not fill in the survey as serious if they have to do it seven times. However, this means that the questionnaire only gives an overview of the game-experience of multiple games, rather than the game experience of one game. This could explain the mixed opinions of the players. Moreover, since the questionnaire is only completed by four persons, it is difficult to use the results for good conclusions as the opinion of one person affects the data significantly. Therefore, it is recommended to rephrase the questions of the questionnaire or ask the participants to fill out multiple questionnaires.

Next to the survey, the interview could also be biased through the relationship of the author with the participants of the user test. As the users were housemates, it is possible that the users were more positive about the games to not hurt the feelings of the author and to be good housemates. Moreover, in the interview it is harder to be negative about the game compared to the questionnaire. This could explain why the results of the game experience questionnaire and the interview are not similar on all points.

Next to the above mentioned recommendations, some recommendations for further research were found.

9.6 Recommendations for further research

First of all, as stated earlier, the game should be tested with the target group to test if the games are suitable for the target group and to see if the games are balanced.

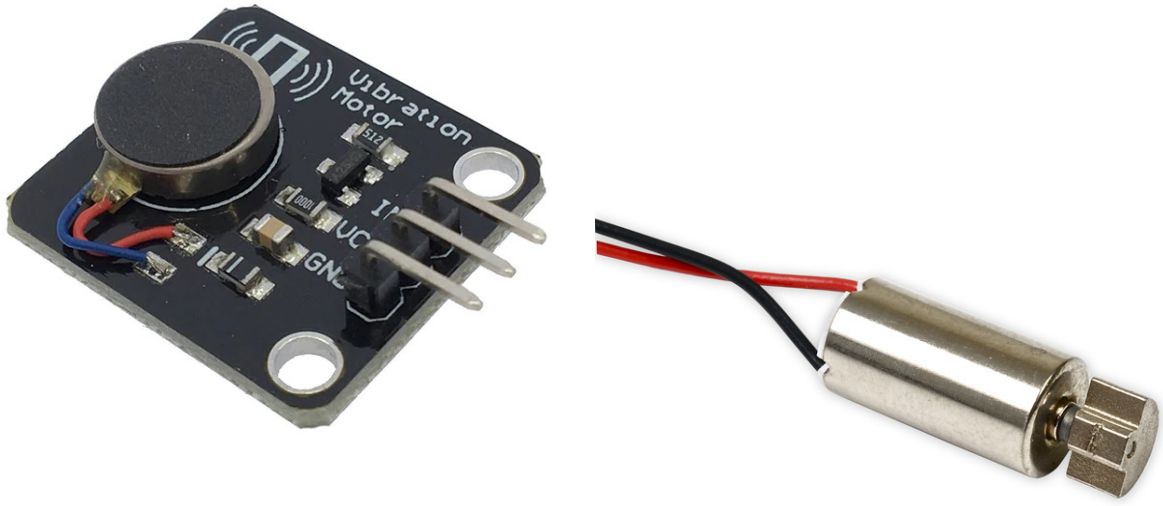
Second, during the interview with the therapist of OMNI, it occured that OMNI could also be used to help training senses and spatial orientation. With contrasting colors, the speaker and the different textures, it is possible to allow for a multi sensory experience which can be used to train the senses. Moreover, the cups can also be placed in a small space to train spatial orientation, where one play should reach to one cup after another. Lastly, OMNI could also be used educational, where an (online) quiz could be done where the cups of OMNI are the input. All these possibility could be explored together with the user group in a further research.

Third, interesting for further research is to test all different player interaction patterns of the different games. With this research, it is possible to show the number of games possible with OMNI and to test these. Moreover, with all player interaction patterns implemented of one game, it is possible to test how the players experience the player interaction pattern and if the player interaction patterns feel different to the players.

9.7 Recommendations for the prototype

Lastly, throughout the project some limitations of the prototype were found. The following points are recommended to adapt in a next prototype:

- **Give the cups contrasting colors.**
  The therapist at Visio mentioned during the first interview (subsection 2.1) that some visually impaired people can still see something. Therefore, contrasting colors can help to distinguish one cup from the other.
- **Make a bigger hub.**
  The hardware does not fit into the hub, since the hub is smaller than the cups. To overcome this, a new hub should be printed which is approximately the same size as the cups.
- **Create small holes in the cups so the audio can be heard better.**
  The plastic cups do not let through a lot of sound, meaning that the audio feedback can barely be heard. To solve this problem, small holes in the casing close to the buzzer are recommended.
- **Use better/different vibration motors.**
  The vibration motors which are used throughout the project had very thin wires which kept breaking. Heat shrink proved to help, but not enough to have a durable product. An alternative would be to use coin vibration motor secured to a module or to use different vibration motor. The different alternatives can be found in Figure 18
- **Attach an on/off button to the cups**
  Unfortunately, there is no on/off button attached to the cup. This could be easily done by soldering a switch between the GND of the battery cap and the GND of the Arduino. More testing should be done to find where the switch should be positioned on the cup, so that players do not turn off a cup during a game.
- **Create a board where the cups can stand in.**
  This makes it easier to know where each of the cups are located. This might decrease the hand-eye coordination advantage of a sighted player.
- **Apply speech output in the cups.**
  When speech output can be used, audio instructions on the games can be given. Moreover, the high scores of Simon and Defuse the Bomb can be told out loud.



(a) Vibration motor module (b) Other type of vibration motor

Figure 18: Possible replacements for the vibration motor.

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Appendix A: Games for OMNI

Be Fast! Each player has a cup in front of him/her. All cups start vibrating at the same time. The fastest player to flip the cup, wins the game. The cup of the winner will vibrate to indicate the winner.
Technology: vibration motor, tilt switch, communication unit

Be Fast! 2.0 The 4 cups are in the middle of the table. One of the cups starts vibrating. Goal is to be the first player to grab the vibrating cup.
Technology: vibration motor, communication unit

Diffuse the bomb When a cup vibrates, the player should flip the cup. The cups start vibrating faster after each other. At a certain point, two cups can start to vibrate at the same time. The goal is to flip as many cups, thus to flip the cups as fast as possible.
Technology: vibration motor, tilt switch, communication unit

Find the bomb All cups vibrate, but one cup vibrates stronger than the others. Find this cup. Each round, the difference between vibration strength decreases, meaning that the game gets harder. The strongest vibrating cup should be flipped to indicate that it has been found.
Technology: vibration motor, tilt switch, communication unit

Flipping! Flip as many cups as you can within 30 seconds. Multiplayer version: each player gets a cup. Flip this cup as many times as possible within 30 seconds. The winner is indicated using a vibration motor.
Technology: tilt switch, vibration motor

Follow the buzz A buzz will move from one cup to another. The players should follow the buzz and flip the cup where the buzz has stopped. The player that flips the correct cup wins the game.
Technology: vibration motor, tilt switch, communication unit

Hide and seek[31] One player hides the cup. When a cup is hidden, the person flips the cup to indicate that the cup is hidden. If all cups are hidden, the hub will count down, after which the other players can search for the cups. When a cup has been found, the player flip the cup. to make the game easier, the cups can make a sound to indicate where the cups are.
Technology: tilt switch, speakers and communication unit

Mastermind[32] The first player flips the cup in a certain order. The second player should find the order in which the cups have been flipped by the first player. After each time, the hub indicates with a sound if there were any cups in the pattern and if some cups were flipped in the right order.
Technology: tilt switch, speaker

Memory[33] The hub vibrate in a certain pattern. The players should find the cup that vibrates identical to the hub. When they have found that cup, they should flip the cup to indicate that the cup has been found.
Technology: vibration motor, tilt switch, communication unit

Memory 2.0 If a cup is flipped, the cup makes a sound. Each player flips two cups. Cups with identical sounds should be found. The player who finds most memories wins.
Technology: speaker, tilt switch, communication unit

Musical Chairs[34] There are the amount of players minus one cups on the table. So with four players, there are three cups on the table. The hub of OMNI starts playing a song. When the song stops with playing, the players should grab a cup as fast as possible. The player who does not have a cup is out.

[31] Game based on Hide 'n' Hunt, a minigame in Wii party. https://www.nintendo.nl/Games/Wii/Wii-Party-283938.html;*Accessed on 14-06-2020.*

[32] Game based on the Mastermind tabletop game. https://www.intertoys.nl/shop/nl/intertoys/spellen-puzzels/breinbrekers/mastermind-000; *Accessed on 14-06-2020.*

[33] Game based on the memory tabletop game. https://www.ravensburger.org/uk/discover/memory/index.html; *Accessed on 14-06-2020.*

[34] Based on the party game, Musical Chairs https://en.wikipedia.org/wiki/Musical_chairs; *Accessed on 14-06-2020.*

This continues until one player is left, who has won the game!
Technology: speaker

Musical Chairs 2.0 Cups are in the middle of the table. The cups start vibrating one by one. When a cup vibrates, one player can take the cup. This continues until everyone except one has a cup. This person is out. The last person in the game wins.
Technology: vibration motor

OMNI Quiz 2.0 One player asks a question to the other players. In this game, each cup is an answer (A, B, C, D). The players should take the cup of the right answer. The first person taking the cup of the right answer, gets a point. Player with the most points wins the game.
Technology: tilt switch, communication unit
OMNI-it![35] Similar to Bop-it. The speaker inside the OMNI hub gives instructions what should happen to the cups of OMNI. For example: Slap it, Flip it, shake it, turn it around, move it on its side, roll it etc. This can be played with multiple players. The cup of the winning player starts to vibrate after the game to indicate the win.
Technology: speaker, IMU, button

Open the Safe (individual)[36] Rotate the cups to open the safe. When the cup is rotate, a buzz will indicate whether the player is moving in the right direction. When the cup is in the right rotation, the vibration will stop. All 4 cups should stop vibrating to open the safe. The aim of the goal is to get the 4 cups in the right rotation as fast as possible.
Technology: vibration motor, IMU, communication unit

Open the Safe (multiplayer) Each player gets one cup. The cup should be rotated three times to the right angle. When the cup is rotated to the right angle, a feedback signal will be given, after which the cup starts vibrating again. The first player to get the cup three times to the right rotation wins.
Technology: vibration motor, IMU, speaker, communication unit

Party and Co.[37] All cups of OMNI have a different function. One cup is an arrow. It is put to its side and rotated to see what player gets the turn. Another cup will indicate what this player should do. For example: sing a song, draw something, imitate someone etc. While the player sings a song, teammates should guess which song is sung. The third cup acts as a stopwatch to keep track of time. This game can be played in two games. Scores will be kept track using cups. Each team has one cup. Flip the cup of one team to indicate that the team earned a point.
Technology: IMU, speaker, commmunication unit

Same sound All cups have five sounds. By flipping the cup, one can move through the sounds. Aim of the goal is to put the four cups to the same sound as fast as possible. The player which sets all cups to the same sounds fastest wins.
Technology: tilt switch, speaker, communication unit

Simon[38] The cups vibrate/make a sound in a pattern, the player should copy this pattern by flipping the cups in the right order. Each round, the pattern extends with one cup.
Technology: vibration motor, speaker, tilt switch, communication unit

Simon Multiplayer One player starts with thinking of a pattern, the next player copy the pattern and adds one new cup. The third player copies the pattern of the second player and adds one cup etc. The player which can copy the pattern the longest wins.
Technology: vibration motor, speaker, tilt switch, communication unit

[35] Based on the "Bop-it!" game https://shop.hasbro.com/en-us/product/bop-it-game:BAF3E554-5056-9047-F594-13DBF24F605E; *Accessed on 14-06-2020.*
[36] Based on the game "Twist Ending" in Mario Party 9 https://www.nintendo.nl/Games/Wii/Mario-Party-9-281870.html; *Accessed on 14-06-2020.*
[37] Based on the party game "Party and Co." https://www.intertoys.nl/shop/nl/intertoys/jumbo-party-en-co-original; *Accessed on 14-06-2020.*
[38] Based on the game "Simon" https://shop.hasbro.com/en-us/product/simon-game:6B0A06E3-5056-9047-F532-6A891FAEBA15; *Accessed on 14-06-2020.*

Stay in rhythm The hub beeps in a certain rhythm. The players should flip their cups in the same rhythm as the cup is beeping. The player who can keep the best rhythm wins.
vibration motor, tilt switch, communication unit

Word Generation; Each cup is one letter. The players should change the cups in different orders to form words. This is done in a team. The team who generates most words, wins the game.
Technology: speaker

Balletje-balletje[39] Put a small blanket on top of the OMNI cups. One of the cups starts to vibrate, to let the players know where the vibration is. After the cup has stopped vibrating, one player moves the cups. The other players tell which cup had the vibration by removing the blanket from the cup. A light sensor will detect which cup has been chosen. When this cup contained the vibration at the beginning, a sound will indicate it is correct. If it is a wrong, the correct cup will start vibrating.
Technology: light sensor, vibration motor, speaker, communication unit

Bumper OMNI The cups will be placed on their sides. Using a smartphone, the cups of OMNI can be controlled. The cups are placed on a square, goal of the game is to push other cups out of the square. When a player comes close to your cup, your phone will make a sound, indicating the position of the other cups.
Technology: motor, smartphone

Catch the cup the cups move over the table using a motor. One cup starts to vibrate and the players should flip the vibrating cup. The one who flips most vibrating cup wins the game.
Technology: stepper motor, vibration motor, communication unit

Commando Pingelen The cups make a tone, depending on the tone the cup should be flipped in a certain ways. For example: flip clockwise, flip counterclockwise. False beeps are given which should be ignored.
Technology: IMU, speaker, communication unit

Correct order Put the cups in the right order. Each cup makes an animal sound. The player should put the cups from small animal to large animal. Using RFID tags in the side of the cups, it can be detected if the cups are placed in the correct order.
Technology: RFID tags, RFID readers, speaker

Find the treasure Next to the hub and cups, a new element is added, a treasure chest. This chest is closed using an electromagnet. By flipping the cups in the right order, the treasure chest open. Each time, a wrong cup is flipped, the player should start over with the pattern. When the complete pattern is correct, the treasure chest opens. Using a sound, feedback is given on whether the correct or wrong cup is flipped.
Technology: speaker, tilt switch, electromagnet, communication unit

Find the vibrating cup Feel all cups and flip the vibrating cup. The player who flips most cups correct wins the game.
Technology: vibration motor, tilt switch, communication unit, way to detect who flipped the cup

OMNI Music Generator Each cup can make different sounds. By flipping the cup, different sounds can be selected and cups can be turned on or off. This way, a soundtrack can be generated.
Technology: speaker, tilt switch

OMNI Quiz The players play a quiz against each other. The cups are placed on their sides. Each player has one cup. Each time a question is answered correctly, the player pushes the side of its cup. The cup will roll a X centimeter forwards. First person to reach the finish wins.
Technology: motor

OMNI Puzzlebox All cups of OMNI contain different puzzle of different levels. One can come to

[39] Based on the Shell-game https://en.wikipedia.org/wiki/Shell_game; *Accessed on 14-06-2020.*

another level by hitting OMNI in the right places, placing cups on top of each other or by turning the cups to the right orientation. Sounds will indicate when something goes correct or not and when a new level is reached.
Technology: IMU, button, motor, communication unit

OMNI Race The cups should be placed on their sides. When clapping or screaming into the microphone of the cup, the cup moves forward. The first cup to reach the finish wins the game.
Technology: motor, microphone

OMNI Weight The top of OMNI consists of a pressure sensor. Each player should find a certain object of a certain weight to place on top of OMNI. A tone indicates whether the object is too heavy or too light. The first player to have the correct weight on top of OMNI wins the game. *Technology: pressure sensor, speaker, communication unit*

Pop the balloon The cup contains a microphone in which the players should blow. When the players blow into a cup, the top of the cup comes off and a balloon comes out. The first person to pop the balloon wins the game.
Technology: microphone, pump

Puzzle OMNI Using an electromagnet, the cups of OMNI are made magnetic. Magnetical puzzle pieces can be attached to OMNI to solve a puzzle around OMNI. When the puzzle is finished, the electromagnet is turned off and the puzzle pieces will fall off the cup.
Technology: Electromagnet

RFID puzzles The game has 20 different animal-shaped RFID tags. Each cup loops 5 different animal sounds. The player should scan the correct animal to the cup which makes this animal sounds. Goal is to do this as fast as possible.
Technology: RFID tags, RFID reader, speaker

RFID tag memory There are multiple RFID tags on the table. When an RFID tag is held on top of a cup, the cup will make a sound. The players should find two RFID tags with the same sound. The one collecting most pairs wins the game.
Technology: RFID tag, RFID reader, speaker

Rotate to the right position; The four cups are standing in a row. One should rotate the cup to the right position. The cups will stop vibrating when they are placed at the right rotation. Using RFID tags, the rotation of the cups are measured.
Technology: RFID tags, RFID readers, vibration motor

SCREAM! Each player gets a cup with a microphone in it. Aim of the goal is to scream as loud as you can. Player who screens the loudest, wins the game. This indicated by a vibration.
Technology: microphone, vibration motor, communication unit

SCREAM 2.0 Similar to SCREAM!. However, now if a player screams into a cup, the top moves off the cup and something rises out of OMNI. First player to see the full figure wins.
Technology: microphone, stepper motor, communication unit

Sing-Along By placing and RFID tag on top of the OMNI cups with RFID readers in them, OMNI will play a song. Different RFID tags will give different songs.
Technology: RFID tag, RFID reader, speaker

Sing-Star[40] The hub of OMNI plays a song. The players should sing along into their cups, containing a microphone. When the top of the cup moves up, the player should sing at a higher pitch. When the cup lowers, the player should lower its pitch. The best singer wins.
Technology: motor, speaker, microphone, communication unit

[40] Based on the game Sing-Star https://www.playstation.com/nl-nl/games/singstar-celebration-ps4/; *Accessed on 14-06-2020.*

Spikes Using a vibration motor, spikes can come out of the cup. When the spikes are out, a player may not flip the cup. When the spikes are in, the player should flip the cup as fast as possible. Aim of the game is to flip as many cups as possible.
Technology: motor, tilt switch, communication unit

Spinning cups Using a stepper motor, each cup rotates. However, one cup rotates faster than the others. Each cup has four buttons, one for every player. The players should press their own button on the fastest rotating cup to indicate that they have found the fastest spinning cup.
Technology: motor, IMU, buttons and a communication unit

Squeeze Each player gets a cup with a pressure sensor along the sides of the cup. All of the players should squeeze into their cup. The player that squeezest hardest in their cup, wins the game.
Technology: pressure sensor, communication unit

Whack-a-mole[41] The top of the cup can move upwards using a motor. When the top moves up, the player should hit the top of the cup to 'whack' the mole.
Technology: motor, pressure sensor, communication unit

Whack-a-mole 2.0 Similar to Whack-a-mole as described above, however, in this version, the cups move around over the table, making it harder to whack the moles.
Technology: motor, pressure sensor, communication unit

[41] Based on Whack-a-Mole. https://www.bol.com/nl/p/hitting-fun-whack-a-mole-sla-mol-malle-mollen/9200000052040959/; *Accessed on 14-06-2020*

Appendix B. Assignment of scores

Table 10: Unfair advantages created by the hardware component.

Hardware	**Visual aspects**	**Score**
Vibration motor	None	5
DC motor	Advantage for the sighted person, who sees the cup moving.	1
Speaker	None	5
Electromagnet	Advantage for the sighted person, who sees the cup moving.	2
Pump	None	5
Button	Advantage for the sighted person, who sees the position of the button	3
Tilt Switch	None	5
Optical Sensor	Advantage as sighted person can see the distance of sensed object to the cup	3
Touch sensor	Advantage for the sighted person as he sees the position of the touch sensor.	3
IMU	None	5
Microphone	None	5
Light sensor	Advantage for sighted person as he can see the light.	4
Fingerprint sensor	Advantage for the sighted person as he can see the position of the sensor.	3
QR-scanner	Advantage for the sighted person, who can see the position of the QR-scanner.	2
RFID-set	None	5
Pressure sensor	Advantage for the sighed person, who can see the position of the sensor.	3

Table 11: Number of games for which the hardware components is needed.

Hardware	**Games**	**Score**
Vibration motor	17	4
DC motor	10	3
Speaker	19	4
Electromagnet	2	1
Pump	1	1
Button	3	1
Tilt Switch	17	4
Optical Sensor	0	1
Touch sensor	3 (touch sensor can be used instead of button)	1
IMU	23 (IMU games + tilt sensor games)	5
Microphone	5	2
Light sensor	2	1
Fingerprint sensor	0	1
QR-scanner	0	1
RFID-set	5	2
Pressure sensor	7 (4 + games with button)	2

Table 12: Possible user actions which can be done with a technology.

Hardware	**User actions**	**Score**
Vibration motor	Feel vibration	1
DC motor	See the cup move	1
Speaker	Listen to the sound	1
Electromagnet	Move the cup connect things using magnet	2
Pump	Feel air blow	1
Button	Press button	1
Tilt Switch	Flip cup, shake cup	2
Optical Sensor	Measure distance to cup	1
Touch sensor	Touch the sensor Swipe sensor Pinch sensor	3
IMU	Flip the cup Shake the cup Rotate the cup. Roll the cup	4
Microphone	Blow in microphone Scream in microphone	2
Light sensor	Shine light on light sensor	1
Fingerprint sensor	Scan fingerprint	1
QR-scanner	Show QR-code	1
RFID-set	Read RFID tag Measure rotation of other cups	2
Pressure sensor	Touch sensor Squeeze sensor	2

Table 13: Influence on durability with regards to the sensor.

Hardware	**Durability**	**Score**
Vibration motor	Inside the cup	5
DC motor	Some openings on the bottom/-side to move.	1
Speaker	Inside the cup (maybe small holes to let sound through)	4
Electromagnet	Opening at top or bottom	2
Pump	Opening at top or bottom	2
Button	Openings at the side	3
Tilt Switch	Inside the cup	5
Optical Sensor	Opening at the side of the cup	3
Touch sensor	Opening at the top and bottom	1
IMU	Inside the cup	5
Microphone	Some openings to let sound through	4
Light sensor	Opening at top and bottom to detect flip	1
Fingerprint sensor	Opening at the side.	3
QR-scanner	Opening at the side	3
RFID-set	Inside the cup	5
Pressure sensor	Opening at the top and bottom	1

Table 14: Scores based on the costs. Prices are taken from Bens Electronics. *Price is taken from Adafruit, since Bens Electronics does not sell those.

Hardware	**Cost**	**Score**
Vibration motor	0.95	5
DC motor	1.75	5
Speaker	1.49	5
Electromagnet	4.95	4
Pump	5.95	3
Button	0.15	5
Tilt Switch	0.39	5
Optical Sensor	10.95	1
Touch sensor	1.49	5
IMU*	9.95	2
Microphone	0.89	5
Light sensor	0.28	5
Fingerprint sensor	4.95	4
QR-scanner	39.95	1
RFID-set	6.95	3
Pressure sensor	3.95	4

Table 15: The electronics needed to implement a certain hardware component.

Hardware	**Wires need to implement**	**Score**
Vibration motor	power + ground cable	5
DC motor	transistor, diode, resistor	1
Speaker	power + ground cable	5
Electromagnet	transistor	2
Pump	needs extra components	1
Button	3 wires + resistor	2
Tilt Switch	3 wires + resistor	2
Optical Sensor	3 wires	4
Touch sensor	3 wires	4
IMU	multiple wires	3
Microphone	transistor, resistor	1
Light sensor	3 wires + resistor	2
Fingerprint sensor	multiple wires	3
QR-scanner	multiple wires	3
RFID-set	multiple wires	3
Pressure sensor	3 wires + resistor	2

Appendix C. Usertests

C1. Game Experience Questionnaire

C1.1 The core questionnaire

Please indicate how you felt while playing the game for each of the items, on the following scale:

0 - not at all
1 - slightly
2 - moderately
3 - fairly
4 - extremely

1. I felt content
2. I felt skilful
3. I was interested in the game's story
4. I thought it was fun
5. I was fully occupied with the game
6. I felt happy
7. It gave me a bad mood
8. I thought about other things
9. I found it tiresome
10. I felt competent
11. I thought it was hard
12. It was aesthetically pleasing
13. I forgot everything around me
14. I felt good
15. I was good at it
16. I felt bored
17. I felt successful
18. I felt imaginative
19. I felt that I could explore things
20. I enjoyed it
21. I was fast at reaching the game's targets
22. I felt annoyed
23. I felt pressured
24. I felt irritable
25. I lost track of time
26. I felt challenged
27. I found it impressive

28. I was deeply concentrated in the game
29. I felt frustrated
30. It felt like a rich experience
31. I lost connection with the outside world
32. I felt time pressure
33. I had to put a lot of effort into it

Scoring guide

Competence: Items 2, 9, 14, 16, and 20.
Sensory and Imaginative Immersion: Items 11, 17, 18, 26, and 29.
Flow: Items 4, 12, 24, 27, and 30.
Tension/Annoyance: Items 21, 23, and 28.
Challenge: Items 10, 22, 25, 31, and 32.
Negative affect: Items 6, 7, 8, and 15.
Positive affect: Items 1, 3, 5, 13, and 19.

C1.2 The social presence module

Please indicate how you felt while playing the game for each of the items, on the following scale:

0 - not at all
1 - slightly
2 - moderately
3 - fairly
4 - extremely

1. I empathized with the other(s)
2. My actions depended on the other(s) actions
3. The other's actions were dependent on my actions
4. I felt connected to the other(s)
5. The other(s) paid close attention to me
6. I paid close attention to the other(s)
7. I felt jealous about the other(s)
8. I found it enjoyable to be with the other(s)
9. When I was happy, the other(s) was(were) happy
10. When the other(s) was(were) happy, I was happy
11. I influenced the mood of the other(s)
12. I was influenced by the other(s) moods
13. I admired the other(s)
14. What the other(s) did affected what I did
15. What I did affected what the other(s) did
16. I felt revengeful
17. I felt schadenfreude (malicious delight)

Scoring Guide

Psychological Involvement – Empathy: Items 1, 4, 8, 9, 10, and 13.
Psychological Involvement – Negative Feelings: Items 7, 11, 12, 16, and 17.
Behavioural Involvement: Items 2, 3, 5, 6, 14, and 15.

C2. The post-game interview

C2.1 Questions

1. What did you think of Simon?
2. What did you think of Defuse the Bomb?
3. What did you think of Open the Safe?
4. What did you think of Musical Chairs?
5. What game did you enjoy most? Why?
6. What game did you enjoy least? Why?
7. What different interaction patterns did you notice while playing?
8. What interaction patterns do you think fits OMNI best?
9. What interaction pattern fits OMNI least?
10. Do you feel that the games were different? Why?
11. How did you feel about the games being blindfolded?
12. Were the games fair when you were blindfolded?
13. What would you change/improve for the game?

C2.2 Transcript of the interviews

Participant 1

What did you think of Simon?
I like the cooperation version, was really fun. It changed the game, but it does make it easier, since you only have to remember which number you are in the sequence, however it does add a fun new dynamic of the game.

What did you think of Defuse the Bomb?
Quite impossible to win as the defuser and it more fun if you are blindfolded. Since then you are not just copying the person. But you really have to feel which cup is vibrating.

What did you think of Open the Safe?
That is the game with the most potential when it fully works. But I just could not figure out around which axis I should turn. The idea is quite original, I like the idea.

What did you think of Musical Chairs?
Maybe an addition where all cups are on the table and one cup does not vibrate, instead of having music. (Or only one cup vibrates when there are two people left), then sight is not an advantage. This might be a better way.

What game did you enjoy most? Why?
Especially when doing it individually, I liked Simon. It is similar to how we know it, but now you can feel the pattern instead of seeing it. I also think Open the Safe has a lot of potential.

What game did you enjoy least? Why?
I enjoyed the Defuse the Bomb the least. It gets chaotic really fast, though this can be the intention. Moreover, it felt impossible to win as the defuser. If it was easier to win as a defuser, the game would be more enjoyable. When you are blindfolded the gaame was more fun, since you had to feel which one was flipped over, instead of seeing it.

What different interaction patterns did you notice while playing?
single player vs. game, multiple player vs. the game (might say it is the Simon the game but can also be the coop version), player vs player, unilateral competition, team competition, multilateral competition. I missed multiple player vs. the game.

What interaction patterns do you think fits OMNI best?
I really liked the cooperation part here. The competition game where biased to people with sight. And with the cooperation games, this bias is there less as you are working together. Even if its only a slight difference.

What interaction pattern fits OMNI least?
In this case the team competition. The Musical Chairs with the team competition turned into a player vs. player, so the team competition was present but not really.

Do you feel that the games were different? Why?
With the Simon says, the coop mode felt different to the other games. The other dynamic of having to communicate with each other was interesting. With Defuse the Bomb it felt the same as player vs player and the unilateral competition were similar, except the latter was more chaotic. Musical Chairs felt the same. Open the Safe was only done in one mode.

How did you feel about the games being blindfolded?
When playing Simon, I felt as if the blindfold helped me. I think that I could feel the vibration better, as I was not able to look at the cups. With Musical Chairs, being able to see was a great advantage as you can see where the cup is.

Were the games fair when you were blindfolded?
None were impossible when you were blindfolded, except being defuser in Defuse the Bomb. Other than

that, being blindfolded did not make a large different. There was maybe a slight bias in some games, but it was all doable.

What would you change/improve for the game?
What I already mentioned for Musical Chairs. Make one of them not vibrate. For the bomb defuser, give more time before a bomb explodes, this way the game is better possible for the defuser.

Participant 2

What did you think of Simon?
Nice game, it was nice to have remember the sequence.

What did you think of Defuse the Bomb?
Nice, you can make it more difficult or easier. It allows for nice variation in the game.

What did you think of Open the Safe?
It is nice that there is also something individual in the game.

What did you think of Musical Chairs?
Not my strong game. I do not know. It is hard when you are blindfolded, as you cannot check if everyone sticks to the rules.

What game did you enjoy most? Why?
I think Simon, because it worked well and there was a nice cooperation element to it.

What game did you enjoy least? Why?
The Musical Chairs game.

What different interaction patterns did you notice while playing?
Single player vs the game, multilateral competition, player versus player, cooperative game and the team competition.

What interaction patterns do you think fits OMNI best?
I think multiple player vs. the game, a multilateral competition or single player vs. the game works best because I think it works better when you are focusing on yourself instead of on the others.

What interaction pattern fits OMNI least?
I think the team competition. This is a little difficult, since there are not many cups.

Do you feel that the games were different? Why?
The games were different. Some were iniated by the computer, so they started shaking themselves, while others were iniated by the players.

How did you feel about the games being blindfolded?
There were still fun, but the games were more challenging. The games were still doable.

Were the games fair when you were blindfolded?
If you are defusing the bomb when the other person is also blindfolded, it is fair but otherwise it is not fair anymore. Simon you can easily do with or without blindfold. Open the Safe is also good to do when blindfolded. Musical Chairs can be done with a blindfold on.

What would you change/improve for the game?
Maybe I would put the cup in the holder in the cup for Simon, so that you can find the cups easily, since if you flipped them and you remove your fingers, you do not know where the cups are positioned and if you are feeling the first cup or the second cup.

Participant 3

What did you think of Simon?
I really liked the game. I like that you need to remember the pattern. I thought it was going well. It was one of the games I liked the most.

What did you think of Defuse the Bomb?
I like this one as well, but it was harder than the other games. Especially with four cups, if the person changes the position of the cups, it is really hard to remember which cup is flipped. Sometimes I activated a bomb while I had to defuse them. I liked defusing with multiple people.

What did you think of Open the Safe?
It did not work, I like the idea.

What did you think of Musical Chairs?
I really liked that one because you have to react very fast. And it is a competition, I like that aspect.

What game did you enjoy most? Why?
Simon and Musical Chairs. For Musical Chairs I like the competition aspect. During the game, you are on the edge of your seat. And for Simon I really liked that you had to remember a pattern.

What game did you enjoy least? Why?
Open the Safe, because it did not work. I was expecting something and then it did not happen.

What different interaction patterns did you notice while playing? I noticed the following patterns: cooperative play, multilateral competition, player vs. player.

What interaction patterns do you think fits OMNI best?
Multilateral competition since most of the time it is one player for himself against other players, but I also like a team competition.

What interaction pattern fits OMNI least?
Multiple individual players versus the game. I did not recognize a game that was multiple players versus that game.

Do you feel that the games were different? Why?
They felt similar in a way that they were all with cups and they were vibrating. The games were really different, especially the last one with the music. Different cognitive functions were used. First you had to remember everything, later you had to be fast etc.

How did you feel about the games being blindfolded?
I think that most games were harder blindfolded.

Were the games fair when you were blindfolded?
Yes, except for Musical Chairs, since you did not know where the cups were on the table, when you were trying to grab it. That is also why I pushed a cup off the table.

What would you change/improve for the game?
Make sure that every game works, maybe with Musical Chairs, have a sound that does not have as much pauses, so that it is clearer when it stops, but this increases tension as well.

Participant 4

What did you think of Simon?
The game was fun, it was nice to do. It remembered me of the same game that you can play online. It really let me think of that games in other formats. The only drawback is that you sometimes had to assist.

What did you think of Defuse the Bomb?
The game was fun. It is a nice concept, a nice idea. Also more unique than Simon.

What did you think of Open the Safe?
Was also nice, if the game worked. The idea is nice to do since you are then in a race. Unfortunately, the hardware had some issues.

What did you think of Musical Chairs?
That was cool, but you really have an advantage when you have sight, so that is unfair.

What game did you enjoy most? Why?
Defuse the bomb, because it is unique in comparison to the other games. The other games you can easily do without OMNI, but Defuse the Bomb is a more unique game for OMNI. For Simon, you could also do this game online for example.

What game did you enjoy least? Why?
The Simon cooperation game. In single player, you are constantly working, while in the group form, you are bored half of the time. There should be a preference to select a cup from another player, so a cup does not have to be flipped three times in a row. This way, more people actively join the game.

What different interaction patterns did you notice while playing?
Single player vs. game, player vs. player, cooperative play, multilateral competition and team competition.

What interaction patterns do you think fits OMNI best?
Cooperative play and multiple individuals vs the game. These game interaction patterns are most fair for the visually impaired people, I think. These concepts do not have an advantage to visually impaired people.

What interaction pattern fits OMNI least?
Multilateral competition, this concept has the highest chance to give an advantage to sighted people.

Do you feel that the games were different? Why?
The games were different, they all had an unique concept. All of the games had their unique player interaction pattern. This made them unique and you had to do something different. Every game has its own dynamic.

How did you feel about the games being blindfolded?
Most of the games were fair when blindfolded. I did not really felt a disadvantage by not being able to see.

Were the games fair when you were blindfolded?
Yes, except for the Musical Chairs game.

What would you change/improve for the game?
Better hardware, so that it all works smoothly and flawlessly. Add some clear sounds when something is done correctly or incorrectly or when a bomb goes off. Better, clearer audio cues.