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FACULTY OF SOCIAL SCIENCES
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MASTER'S THESIS

# A Virtual Mind Palace: Adapting the Method of Loci to Virtual Reality

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**Abstract**

This master's thesis investigates the design and development of an application in the medium of Virtual Reality (VR). The application, called the Mind Palace Application (MPA), is an adaptation of a popular mnemonic called the the Method of Loci (MOL). The application is designed to answer research questions regarding how different features of VR impact our memory of Virtual Environments (VEs) and who benefits from this technology.

The research design involves a controlled experiment on three groups of six informants. The three groups were to complete a memory task using three different approaches. The experiment group used the MPA in Immersive VR using a Head-Mounted Display (HMD), while a second group used the application in Desktop VR, i.e the application on a desktop computer. The third group used the MOL without any technological aid. The group that used no technological aid performed better than the VR groups.

The memory- and spatial ability of the informants were gathered prior to the experiment. The results suggests that informants with higher spatial ability obtains more benefit from using the MPA and the MOL. High spatial- and memory ability and successful interaction followed strong performance in the memory experiment.

The group that used no technological aid had informants with higher spatial- and memory abilities than the VR groups, and also had the most successful interaction. Therefore, these factors are believed to have had most impact on the results. Time lost in navigation with the VR interfaces is also discussed as a potential influencer.

Enjoyment, and features of Immersive VR such as presence and immersion correlates negatively with the memory of the VEs. Although the study indicates these negative correlations, it is questionable whether it is the features of Immersive VR causing these results, or if it is the poor spatial- and memory abilities of the group using the application in Immersive VR.

This thesis presents suggestions for further research to more thoroughly answer the research questions and to clear the ambiguity of the results. The main suggestion for future studies is to sort informants into groups based on spatial- and memory ability. This way each group would stand equal before the memory task.

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# List of Acronyms

| | |
|---|---|
| VR | Virtual Reality |
| VE | Virtual Environment |
| VRLE | Virtual Reality Learning Environment |
| HMD | Head-mounted display |
| MOL | Method of Loci |
| MPA | Mind Palace Application |
| 3D | Three-dimensional |
| IVR | Immersive Virtual Reality |
| DVR | Desktop Virtual Reality |
| NUI | Natural User Interface |
| ATW | Asynchronous Timewarp |
| HCI | Human Computer Interaction |
| RTD | Research Through Design |
| RQ | Research Question |
| API | Application Programming Interface |
| HTML | HyperText Markup Language |
| CSS | Cascading Style Sheets |
| JS | JavaScript |
| DOM | Document Object Model |
| URL | Uniform Resource Locator |
| ITQ | Immersive Tendencies Questionnaire |
| WebGL | Web Graphics Library |

# 1 Introduction

The Year 2016 has been called "The Year of Virtual Reality", as high quality immersive Virtual Reality (VR) hit the commercial market from many angles simultaneously (Cellan-Jones, 2016; Chris Morris, 2015). Oculus released their first commercial product, HTC released their Vive, and Sony released Playstation VR. When Google presented the Google Cardboard at the I/O conference in 2014 it was clear that affordable Immersive VR was just around the corner. In 2016, Google has now followed up with their Daydream View, joining Samsung's GEAR VR in delivering Immersive VR to smartphones. It is especially the products aimed towards smartphones that are making VR affordable for consumers. Owning a smartphone is very common, and it is estimated that there will be 6.1 billion smartphone users in 2020 (Lunden, 2015).

The success that started with the Google Cardboard is owed to a happy coincidence; the smartphone is full of sensors and covered with a big screen, which incidentally is a perfect fit for a head-mounted display (HMD). Combining a smartphone with a Google Cardboard or other similar lens-boxes makes an HMD that enables stereoscopic (3D) vision. These 'boxes' usually contain a slot for the phone, and one lens for each eye. The phone is placed behind the lenses, which captures the light emitting from the screen and delivers it to the eyes. The image on the screen is split in two, delivering one side of the screen to each eye to create an illusion of depth, i.e a stereoscopic image. In this way, the mini world on the mobile screen is captured and displayed to ones field of view. The gyroscope in the phone then lets the users navigate and orient themselves in the 3D environment by moving the head.

VR has become more accessible because we can use our already-owned smartphones to deliver Virtual Environments (VEs) in addition to the HMDs by Oculus and HTC, which uses PCs to power their graphics. Only seven years ago, Huang, Rauch, and Liaw (2010) mentioned how "traditional immersive VR systems are expensive, fragile, and not suitable for long term use" (p. 1171), and therefore they were "not accessible to many learners" (p. 1771). This is no longer the case, and it raises interesting questions regarding possibilities for use.

## 1.1 Motivation

As the market is flooding with HMDs priced down to 75 USD, it is safe to assume that the use of VR technologies will rise. This raises a question that is now more relevant than ever; what can and should this technology be used for? We should investigate its use not only for gaming and entertainment, but as an information system for learning, memory and data visualisation. How should we store and present information in this medium to design for optimal memory and learning? We should look into this domain because of the promising aspects of this new medium. The potential of VR lies in that it might be motivating for students to learn in an engaging way, and experience the information in a learning environment in new ways. These VEs could be filled with information we want to be able to recall. VR technology may allow the student to be placed in an environment designed for a specific learning purpose that is free from distraction. Technology and information flow through the web is already responsible for informing children and students, although the ways they learn are not necessarily designed for that purpose (e.g, Games, YouTube, Wikipedia, Television). With VR we have the possibility to design whole environments, such as exploration worlds and "serious games", where every aspect of a room or world is relevant to the content to be taught. This is the motivation for my choice of research area.

## 1.2 Objective

For this study, an application for the medium of VR will be created. The application design will be based on design elements and pedagogical approaches found in existing research. The purpose of the application is to test the possibilities of the medium to enhance memory recall, and try to isolate the influencing factors and features of the medium. This thesis will focus on identifying and testing the features in different kinds of VR that may enhance memory recall. The application created will be a technological adaptation of an ancient mnemonic called the Method of Loci (MOL). In Norway the MOL was popularised by Oddbjørn By, a Norwegian "Grand Master of Memory". In their co-authored book, By and Bjørshol (2011) explains the method as the 'Travel Route'. They explain how one provides visual illustrations for the items to be memorised, and places them in a well-known location:

> *"A travel route is a journey through a building or area. For instance, I can make a journey through the house where I grew up. I picture the entrance door. The area outside the door will be the first step of the journey. The next area will be the porch, the hall, the stairs, living room, kitchen, washing room, bathroom, office and bedroom. Then I have a travel route of 10 places"* (By & Bjørshol, 2011, p. 17)

To illustrate the concept further, they ask the reader to find a personal location they remember well, and to isolate certain steps in the journey. They go on to ask the reader to 'visualise' Vladimir Putin, a goose, mickey mouse etc. at different places in their newly created travel route. Finally, they explain: "These things were not arbitrary, the ones you memorised. They are associations to the the biggest countries by area in the world" (By & Bjørshol, 2011, p. 18). The MOL, as explained here, is often referred to as the 'Memory Palace' or 'Mind Palace technique'. In this way of abstracting information we can use simple visualisations to remind us of greater concepts. When recalling less complex information, associations are not used (e.g an apple). The expected reason for the efficiency of the method is that we remember visuals far better than text. This phenomenon is called the 'picture superiority effect', and is well documented (Defeyter, Russo, & McPartlin, 2009; McBride & Dosher, 2002). When connecting such visualisations to a place we already remember well, we now have a 'place to go to' when we need to remember, say, the 10 biggest countries by area in the world.

The application developed and used in this thesis, from now on referred to as the Mind Palace application (MPA), will be an adaptation of this method to a VE. The same principles will be present; one can place objects in different parts of the environment to act as a memory aid. The VR technology goes well with the MOL because it is a strong visual medium capable of delivering actual environments as a ground on which we can interact and perform the MOL. In this way we can test a whole new way of structuring and presenting information, in a format that may be more exciting for the user and by its nature promote memory recall.

## 1.3 Scope

This thesis focuses on the development of the MPA and the use of the application in a controlled experiment. The MPA will not be tested in an educational setting, nor designed towards that use. Its development will be targeted towards a research experiment in a controlled setting, and the application design will be grounded in desk research through a literature review. The MPA will be developed as a high fidelity prototype to fit this exact research project – not as a general product targeted at consumers. This means that the MPA for instance will not provide login functionality, branding, or a visual profile, etc., but instead act as a tool to carry out research on VR technology in relation to memory recall.

## 1.4 Organisation

This thesis is organised into 7 chapters. Chapter 2 presents the preliminary literature review, where previous research in the related fields are discussed. The research methodology is presented in chapter 3, and presents the research design and the development methods. Chapter 4 presents the design and development of the application. In chapter 5 the results from the experiments will be presented, and in chapter 6 these results will be analysed and discussed. Chapter 7 contains conclusion and future work.

# 2 Fields of research and Related Work

The research in this thesis is mainly situated within the fields of Human Computer Interaction, Technology-Enhanced Learning, and Psychology. In addition to reviewing VR as a technology, this chapter will outline previous work on how we interact with, and how we learn in VEs. VR is a technology that in itself has many different aspects and uses. Knowledge about this medium has been developed within very different fields, from informatics to psychology, thus the knowledge will be drawn from a variety of research disciplines. This method of combining knowledge from different fields as elements that lead to a design is known from Zimmerman, Forlizzi, and Evenson (2007). Following their model, "interaction design researchers integrate the *true* knowledge (the models and theories from the behavioral scientist) with the *how* knowledge (the technical opportunities demonstrated by engineers)" (Zimmerman et al., 2007, p. 497). Hanson and Shelton (2008) describes their approach to designing for VR somewhat similarly, in that they were "using a synthesis of literature and approaches from engineering, computer science and education" (p. 118). The common thread of this related work, however, is that it circulates around VR and its potential for experiences, interaction, memory recall, and learning in human beings. The aim of this chapter is to situate the thesis in the field(s). In the end of the chapter it will be emphasised what this literature review will imply for the design of the MPA.

This chapter first reviews VR technology and the requirements for creating an optimal VE. Second, it reviews how we interact with these VEs. Third, it reviews what features contribute to learning, and research on Virtual Reality Learning Environments (VRLEs). Then the psychology relevant for VRLEs will be reviewed, i.e memory and learning, spatial cognition and cognitive load. Finally, research on the MOL, which is at the core of the application's functionality is introduced.

## 2.1 Technology

Research on VR is strongly affected by the available technology. The fidelity of the 'VR experience' is strongly dependent on the quality of the technology enabling it. Therefore, in this section, we will first define the different kinds of VR. Further, the desirable features of VR technology and what it takes to achieve them will be reviewed.

### 2.1.1 Virtual Reality

VR has become a relatively broad term, as the technologies for achieving it has increased in complexity over the years. VR refers to everything from the first Sims ™ game running on an old computer, to a total encompassing VE with HMDs, 3D graphics, natural movement and tracked controllers. Generally, however, VR or a VE, may be defined as "an artificial environment which is experienced through sensory stimuli (as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment" (Webster, 2016). Thus VEs are *interactive*, which separate them from, say, a movie where the user is a bystander. The definition also mentions how this environment is 'experienced'. This is one of the elements of VR that is dependent on the technology, and the reason behind the term's ambiguity. The technology and the objectives of these VEs vary much in detail. They vary in how and what sensory stimuli introduce you to the environment, and to the environment to which you are introduced. Therefore there are many different ways VR can be categorised.

In this literature review the categorisations that will be presented are based on distinctions that have implications on the design of a VE and the features it will afford. Although many VR technologies often share the same features, different technologies may afford these at different fidelities. An example here may be the notion of presence or engagement, which the first Sims ™ game may give you to a certain extent, but an encompassing total environment may maximise.

### 2.1.2 Immersive VR versus Desktop VR

Generally, VR may be divided into two different groups, Immersive VR and Desktop VR. VR without stereoscopic vision, HMDs or wall projectoring are traditionally called 'Desktop VR', referring to the traditional desktop computer with a monitor, keyboard and mouse. The interaction is usually through keyboard and mouse, but gestures may also be used. In Immersive VR, however, the user is more immersed in the VE through, for instance HMDs, and normally rotates the head to navigate their viewpoint instead. The majority of the research over the last 20 years has been carried out on non-immersive VR applications, as the technology for immersive VR until recently has been expensive and of lower quality.

### 2.1.3 Magical VR versus Realistic VR

An example of a categorisation relevant for the design of VEs is brought forth by Mania and Chalmers (2001). They separate two approaches to VR into the categories of Realistic VR and Magical VR. Realistic VR is often used to simulate a task or environment, such as a driving simulator. This has implications on the design of the software. In Realistic VR, the means must be prioritised over the end if its training should be possible to transfer into the real world. That is, performing a heart transplant in a VR simulation should not be easier than it is in real life, as the value of the training is dependent on the degree to which the simulation corresponds with reality. This approach will affect the design of the application and the experience of the users. Magical VR is less inhibited by training requirements, which means that one may use any means to achieve the desired end result. This is possible in magical VR because the means are not the end themselves, which actually is the case for realistic VR. This distinction is natural to make, as it has an impact on the objective or purpose of a VR application and how to design for this, especially in terms of content abstraction and interaction.

### 2.1.4 Features

In the previous section, the medium of VR was defined. This section will present what the technology actually offers, and why it is relevant. VR is an attractive technology because of its flexibility. When one is simulating or creating realities, it is (almost) not far fetched to say that anything is possible. The great thing about VR is that it is a way to view software in the same way as we view reality. Software and information technology is flexible – thus any reality can be created. In short, most desirable features of VR as a technology revolve around the feature of immersion. From a technical point of view, immersion is the key feature to account for, to 'place' the user in the VE. This is what makes VR technology relevant, allowing us the ability to step inside our created worlds of content.

#### Immersion

Immersion is viewed as the prime feature of VR, and is for instance responsible for the hype VR has within the gaming world. Immersion is closely related to presence, and these terms are often used interchangeably. For this reason, they are in need of being properly defined (Mania & Chalmers, 2001). Presence is, in most cases within VR, described as the subjective feeling or sense of being there (Hanson & Shelton, 2008). In VR, presence is often an objective or goal in itself, where "higher levels of presence are deemed more successful" (Bailey, Bailenson, Won, Flora, & Armel, 2011, p. 1). Mania and Chalmers (2001) write that immersion, in relation to presence, should be defined by more technical terms. Immersion can be defined as the degree to which you are surrounded by your content in terms of your perceptions. What triggers our senses in VEs will either be the technology or the world around us, that is, VR technology may fully immerse your visual field, but may not immerse your hearing, thus you are only partially immersed.

In theory, if all our senses were controlled by the technology, we should be fully immersed. Thus, immersion does not just involve the visual and auditory senses. Haptic and force feedback (tactile) will also play an important part in the future of VR.

Less explored, but still relevant, is smell and taste replication – which can also help to immerse the user in the VE.

Lin, Duh, Parker, Abi-Rached, and Furness (2002) describes immersion as "the experience that one is wrapped in a surround, similar to being inside an elevator" (p. 2). But will we feel present just because we are immersed? A study by Dinh, Walker, Hodges, Chang Song, and Kobayashi (1999) found that immersion is a precursor for presence, stating that increasing sensory input will increase both presence and memory. It is therefore probable, but it is also possible to be physically present in an environment and still not have a subjective feeling of 'being there' if we are not engaged in the experience. We are in those cases immersed in the environment, but our attention or engagement is not directed outwards to the VE. Presence is thus dependent on the relationship between immersion and engagement. Lin et al. (2002) defines engagement towards VR as "the degree to which the subjects' attention is directed to the VE, similar to when one is engrossed in a novel or a movie" (p. 1). But how does one increase engagement? Lin et al. (2002) further writes that having an objective to perform in the VE may increase engagement, which in their case was a memory test. This could enhance presence because the task would direct the attention towards the VE (Lin et al., 2002).

This thesis adopts the distinction of these terms that describes presence as "the subjective sense of being in a place, and immersion as the objective and measureable properties of the system or environment that lead to a sense of presence" (Dalgarno & Lee, 2010, p. 3). Another compliant definition is that "immersion is a term for technologies that increase the perception of presence" (Tüzün & Özdinç, 2016, p. 230). To design for presence, one should then increase immersion and engagement. Examples of increasing immersion can be increasing the field of view (Lin et al., 2002). Hardiess, Mallot, and Meilinger (2015) also mention that stereoscopic simulation can increase immersion, and mentions HMDs among other technologies as a means to achieve this. It is more likely that one will feel present in the VE the more it looks and 'feels' like a real environment in which one could actually physically be present. Thus, in short, any technological sensory input that resembles and gives detail to the VE will, by definition, increase immersion.

### 2.1.5 Requirements

In the previous section we found that technological immersion must be settled to allow for the user to feel present in the environment. In this section requirements of the technology to deliver immersion will be presented, and later the details of these requirements will be explained. For details on how to achieve this we will have to look to the gaming industry as they are at the forefront of the technology. Valve corporation, an American game development company, has its own research team on VR. At Steam Dev Days, Abrash (2014) presented a list of requirements the system must fulfill to immerse the user. Table 2.1 presents a comparison of HMDs according to these requirements.

Table 2.1: Comparison of HMDs

| | **Oculus Rift** | **Samsung GEAR VR** | **HTC VIVE** | **Google Daydream View** |
|---|---|---|---|---|
| Field of View | 110° + | ≈101° | 110° | ≈90° |
| Resolution | 2160 x 1200 | 2560 x 1440 | 2160 x 1200 | 2560 * 1440 |
| Pixel Persistence / Screen | 2 ms (OLED) | Low Pixel Persistence Mode (Super AMOLED) | 2ms (OLED) | Unknnown (AMOLED QHD) |
| Refresh Rate | 90 Hz | 60 Hz | 90 Hz | ≈60 Hz |
| Optics | Aspheric fresnel-hybrid lenses | Aspheric lens | Aspheric fresnel-hybrid lenses | Aspheric lens |
| Optical Calibration | Yes | Yes | Yes | No |
| Tracking | Sub-millimeter. Rotational & Positional | Rotational only | Sub-millimeter. Rotational & positional. | Rotational only |
| Latency | <20 ms (AWT) | <20 ms (AWT) | <20 ms (AWT) | <20ms |
| Price HMD | 7890,- NOK + computer cost | 900,- NOK + phone cost | 9500,- NOK + computer cost | 750,- NOK + phone cost |
| Development difficulty | Medium / Hard | Easy | Medium / Hard | Easy |

The list by Abrash (2014) were presented as following:

- A wide field of view (80 degrees or better)
- Adequate resolution (1080p or better)
- Low pixel persistence (3 ms or less)
- A high enough refresh rate (Over 60 Hz, 95 Hz is enough but less may be adequate)
- Global display where all pixels are illuminated simultaneously (rolling display may work with eye tracking)
- Optics (at most two lenses per eye with trade-offs, ideal optics not practical using current technology)
- Optical calibration
- Rock-solid tracking – translation with millimeter accuracy or better, orientation with quarter degree accuracy or better, and volume of 1.5 meter or more on a side
- Low latency (20 ms motion to last photon, 25 ms may be good enough)

### 2.1.6 Technology Review

In the following section, the requirements introduced in section 2.1.5 of VR will be explained, and the different HMDs will be evaluated according to these.

#### Field of View

Field of View (FOV) in VR can be defined as the extent, or the degree, of the virtual world that is visible at any given moment. Lin et al. (2002) measured impact of FOV in relation to numerous factors, including memory. They found the performance of the users to be very similar at 100°, 140° and 180°. Humans have naturally close to 180° FOV, however, it is not common for HMDs to deliver a FOV in this range.

It should be mentioned, however, that Star VR has released an HMD delivering a FOV of 210°, meaning one would have to turn the eyes without turning the head to get a grasp of the whole FOV. StarVR was not considered in this review, as it is not yet available for purchase. Between the HMDs being compared here, Oculus Rift and HTC Vive score the highest, with over 110° FOV. Samsung's GEAR VR's FOV can be as high as 101° dependent on the phone used, which is 20° higher than the minimum demand proposed by Valve. The Daydream View also score over Valve's minimum with 90°.

#### Resolution

Resolution in VR refer to the amount of pixels making up the graphical display in the HMD. All of the reviewed HMDs had a resolution over the minimum requirements. The GEAR VR delivers a Super AMOLED display of 2560 * 1440, as compared to the minimum of 1920 * 1080. On this point the GEAR VR actually outperforms both the HTC Vive and the Oculus Rift, whereas the Daydream View comes in equal – depending on the phone that is being used. A more appropriate measure for this, however, is pixels per inch, as an inch occupies a considerate proportion of your FOV when magnified by the lenses. The Oculus Rift and HTC Vive lands at 461 PPI, whereas the GEAR VR lands at 571 PPI.

#### Pixel persistence

Pixel persistence has been one of the greatest challenges of VR. Pixel persistence refers to how long a period each pixel is visible for. The requirements put forth by Abrash (2014) demands 3ms or less pixel persistence. The first Oculus Development Kit 1, had a terrifying 16ms persistence, which is the natural default for a 60 Hz LCD screen. To get as low as 3ms it is necessary to 'cheat' the technology.

Rejhon (2013) explains that 1 ms of pixel persistence equals 1 pixel of motion blur during 1000 pixels/second. In theory this means that to achieve a low pixel persistence of 1ms, one would need a 1000 Hz screen to manage it. This is too ambitious today, which is why it usually is solved in another way. The problem of pixel persistence is mainly that you see each picture for too long of a time, and this can not yet be solved by increasing refresh rates. For a small period of time your brain will perceive an incorrect image relative to what your brain think you should see. Our brains are used to perceive continuously updated frames of reality. When it instead sees the same frame in the HMD, nausea appears.

OLED screens, which all of the compared HMDs deliver, are known for being superior when it comes to motion blur, because they have an instant pixel response of 0ms. This does not fix the problem of motion blur due to pixel persistence, however, because the success rate is not defined relative to their own millisecond update – but to how we perceive it with our eyes. It is not about how fast it changes, but for how long each image is displayed. Rejhon (2013) defines this problem as "sample and hold". Sample and hold means that a frame is continuously displayed until the next frame is ready (Rejhon, 2013).

That is the source of the problem, and can be solved with "low pixel persistence" modes. With low pixel persistence modes, the screen goes black before the next frame is ready to show, so that one either sees a black screen (which for such short periods of time our brains do not notice), or the correct frame. This is a necessary mode before computer screens can (sustainably) show images in many hundred frames per second. All of the above-mentioned devices have the possibility of enabling a low pixel persistence mode, which shows each frame for a shorter period of time, thus solving the demands of low pixel persistence. Daydream VR has not released information about this, but it is highly unlikely that they would dismiss a software solution for this challenge.

#### Refresh rate

Refresh rate in VR refers to the amount of times the graphical display can refresh the frame per second. HTC Vive and Oculus Rift are clear winners on refresh rate, while GEAR VR and Daydream hits the minimum requirement of 60 Hz. Asynchronous timewarp (ATW) is a technology that helps VR deliver smoother framerates. According to Antonov (2015), ATW "is a technique that generates intermediate frames in situations when the game can't maintain frame rate, helping to reduce judder" (para. 1). ATW does not impact the hardware, however, it is a software solution to help utilize the hardware better. ATW is used by Oculus Rift and GEAR VR.

#### Optics

The ability to calibrate the optics is afforded by the GEAR VR, Oculus Rift and HTC Vive, but not by Daydream View. Oculus Rift and HTC Vive has more premium optics compared to GEAR VR, but all of the reviewed HMDs match the minimum requirements.

#### Tracking

When it comes to tracking, the Oculus Rift and the HTC Vive are superior. They are the only HMDs compared that operate with positional tracking in addition to rotational tracking. The rotational tracking of the GEAR VR headset has a good response time and fulfills the minimum requirement due to the sensors from Oculus that are used in the HMD. Daydream View specifications are currently unclear.

#### Motion to photon latency

Motion to photon latency refers to the latency between the movement of a user rotation to the corresponding change in the graphical display. The reason why HMDs such as Google Cardboard, etc. are not considered in this technology review, is due to their motion to photon latency. The sensors in the phone alone are not precise enough when it comes to latency, and nausea is again a problem. Google Cardboard is today more a proof of concept for VR on smartphones than it is feasible for use over longer periods of time. All of the reviewed HMDs here, however, have a motion to photon photon latency of less than 20ms. Samsung cooperates with Oculus, and uses the same internal measurement unit in their GEAR VR headset as is used in the Oculus Rift. The HTC Vive and Daydream View have their own sensors capable of delivering low latency.

#### Summary

Having reviewed the relevant HMDs on the market today, most of them are fit for the task of immersion. The specifications for the Daydream View are a bit unclear, however, and the specifications are the lowest. Therefore, only Oculus Rift, HTC Vive or GEAR VR stand out as candidates for application development.

## 2.2 Human Computer Interaction

In the previous section, VR technology was reviewed. This section will look at how humans relate and interact with this technology. Immersive VR is a radically different visual technology, compared, for example, to a desktop computer. It is then natural to suppose that the ways we interact with VR technology also will be different. Interaction design choices are often forced by the nature of the technology itself. When one is fully immersed in a VE for instance, one would not even be able to view the traditional keyboard and mouse. Also, by the nature of orientation in a 360° environment, one needs to move the body to be able to view the environment in its entirety. The lack of practices and standards for interacting with VR was illuminated with the launch of Google Cardboard in 2014. When cheap VR suddenly was available for the masses, few of the applications in the Play store/App store had any form of interaction at all. There were simply no standards for it yet, at least for mobile devices. The same pattern can be seen in the literature, although some ways of interaction stand out as successful.

### 2.2.1 Natural Interaction

T. A. Mikropoulos and Natsis (2011) write that "although VR supports multisensory interaction channels, visual representations dominate" (p. 776). Few studies in their literature review made use of the interaction affordances of the VR medium to make interaction intuitive. T. Mikropoulos and Bellou (2006) designed a virtual science laboratory where 8 physics students interacted with the laboratory equipment through a data glove (see Figure 2.1).


Figure 2.1: Example of a data glove

Their findings describe intuitive interaction through natural manipulations in real time as a characteristic of VR that enables features contributing to learning outcomes, e.g presence and autonomy. Winn, Windschitl, Fruland, and Lee (2002) had students exposed to a simulation of water movement and salinity in the ocean. The students were divided into two groups, one group in Immersive VR and another group in Desktop VR. Within the simulation, the immersed students oriented themselves more easily than the group who used the desktop VR equivalent of the application. They wrote that for the immersed students, "looking around was as natural as it is in the real world", while for the other group, "it required an overt, unnatural manipulation" (p. 502). This lead to the Desktop VR group orienting themselves less than the IVR group.

Brondi et al. (2015) also compared the use of natural interaction with the more classic use of mouse and keyboard. The subjects who participated had been given the task of solving a collaborative puzzle game. They found that although the desktop VR group performed better in the game, the natural user interface (NUI) offered higher levels of engagement (Brondi et al., 2015). T. A. Mikropoulos and Natsis (2011) write in favor of the intuitiveness of natural interaction. They explain intuitive interaction as "a desirable characteristic for every educational environment" (p. 776), and further write that "VR is claimed to be the only technology up to now that supports intuitive interactivity..." (p. 776).

Interaction with VEs has been a challenge. Roupé, Bosch-Sijtsema, and Johansson (2014) identified the complexity of the navigation interfaces as one of the main reasons that VR has not yet had the impact that was predicted in previous research literature, and they propose that a NUI could be a way to solve this. For a NUI, the user should be able to "operate technology through intuitive actions using gestures, voice, touch, and the NUI becomes invisible in a way that the user does not have to put a lot of cognitive efforts into interaction" (Roupé et al., 2014, p. 1). Within Human Computer Interaction (HCI), using the human body as an interface has been a well-researched topic the last 20 years, using HMDs.

Several studies suggest that interfaces with body movement can enhance navigation performance and experience (Bruder, Steinicke, & Hinrichs, 2009; Moeslund, Hilton, & Krüger, 2006; Poppe, 2007).

Natural interaction seem to be the most promising approach to the interaction challenges of VR. It makes sense that we would prefer to behave as we do in our everyday lives, when the VR simulations let us "play ourselves". In Oculus Rift and HTC Vive, one can now use hand controllers that are viewable through the HMD. In the future, with this same technology, it would be possible to 'map' every body part, bit by bit transferring oneself into the VE. When this is done, one need not wonder how to jump, dodge or shoot in a game; every action would be performed the same way in real life as in VR. This is the core of intuitive interaction, and could help reduce cognitive load as one does not go through an interface in the same way. One would not need to learn the NUI, one would already know how to use it. This may remind of the vision of "Tangle Bits" put forth by Ishii and Ulmer (1997), where the surrounding world is the interface instead of a GUI on a computer screen. They describe their vision as "an attempt to bridge the gap between cyberspace and the physical environment by making digital information (bits) tangible" (Ishii & Ulmer, 1997). Though their vision was not concerned with VR, but rather *actual* tangible interaction, VR is relatively similarly trying to make information pass as "physical artefacts", although they are virtual. By interacting with VEs one interacts with the digital information.

## 2.3 Virtual Reality Learning Environments

### 2.3.1 Learning Features

So far, this chapter has reviewed VR in terms of technology and interaction. This section discusses how VR technology can be used to enhance memory and learning. The primary hope for VR in terms of learning is perhaps that it may be a more exciting way to experience learning content. Hanson and Shelton (2008) wrote that "educators want to take advantage of the immersive qualities that today's technology can provide with the intent to engage students in learning activities" (p. 118). There are several features of VR that may create opportunities for learning, and these can be used in the design of VRLEs.

T. A. Mikropoulos and Natsis (2011) reviewed ten years of literature on educational VEs, from the period 1999 – 2009. In general, almost all the studies they reviewed were positive in regards to learning outcomes. They present seven features of VR that contribute to learning; "first order experiences mainly coming from free navigation and first-person point of view, natural semantics, size, transduction, reification, autonomy and presence" (T. A. Mikropoulos & Natsis, 2011, p. 777).

It is interesting to note how many of these revolve around the learner or user. The users should 'play themselves' in the VRLE to get a first order experience, and navigate from a first person point of view. The user should be free to control the medium and navigate it as he or she wants, thus the feature of autonomy. An example of why this benefits learning is put forth in a study on orientation in VEs by Tüzün and Özdinç (2016), who also identified autonomy as one of the strong features of VRLEs. In their study, they had two groups of freshmen students being introduced to the campus. The students in the first group were walking with a guide, and the other group of students did their orientation virtually. They found that the virtually immersed students recalled spatial route detail better than the authentic group. The key feature of why they learned more spatial knowledge was that they could control their own pace while walking around (Tüzün & Özdinç, 2016). Other research illuminates the same principle, such as bus travellers learning less spatial knowledge than car drivers, because they are more passive towards their environment (Appleyard, 1970).

The features that mentioned by T. A. Mikropoulos and Natsis (2011) that do *not* revolve around autonomy and the learner centered approach, were reification, size, and transduction. Reification can be defined as 'bringing something into being', and refers to the flexibility of software to adapt to different situations. Size also refers to this same kind of flexibility. In VR, one can see the same building in a scale relative to oneself 1:1, or make it small so one can view it as if from a far. Thus, size can be adjusted to be real – or simply practical. Transduction is closely related to this, as it can help us 'perceive' things we would not normally be able to perceive. T. A. Mikropoulos and Natsis (2011) write that "a VE as a transducer extends the user's capability to feel data that would normally be beyond the range of their senses or experiences" (p. 770).

### 2.3.2 Presence

Presence was also on the list of features by T. A. Mikropoulos and Natsis (2011). They write how "the sense of presence shows the need for educational environments where the students prefer to behave like they do in the real world and 'be' inside the learning environment" (T. A. Mikropoulos & Natsis, 2011, p. 774). According to Tüzün and Özdinç (2016) also, presence should be a design element to ensure that the experience is engaging. Lin et al. (2002) report results that suggest subjects may have recalled the VE better when they had a stronger sense of presence. According to Hanson and Shelton (2008), presence is one of the quality indicators of a well-designed VE for education. They write that "well-designed artificial environments meet three criteria: they permit students to experience high levels of presence, they are interactive and they are autonomous" (p. 119).

### 2.3.3 Pedagogy

When designing a VRLE, Huang et al. (2010) advices that "researchers and educators need to deploy a sound theoretical framework and supporting instructional principles to facilitate building novel VRLEs" (p. 1172). Sánchez, Barreiro, and Maojo (2000) describes a weakness with VR as a learning tool as "that there are hardly any theories or models upon which to found and justify the application development" (p. 345). In their paper they propose a model for this:

> "The central component of the model is the metaphorical projection, which provides the guidelines for the entire virtual world design. The goal of metaphorical design is to create a semantic space . All its elements are configured symbolically to make sense of an artificial environment that students can visualise and experience with their senses. The virtual environment thus becomes the physical representation of the knowledge to be taught. Students must perceive, assimilate and make sense of the stimuli from this environment. It is a question of interpreting or reading and not just sensing or experiencing the environment. This is the characteristic, which, in our opinion, distinguishes virtual reality as an educational technology: the possibility of creating symbolic spaces capable of embodying knowledge" (Sánchez et al., 2000, p. 360)

The visual medium of VR could be used to create a semantic space, where the meaning lies in the 'physical' representation of objects. Another pedagogigal approach to VR is presented by Cheung et al. (2008). They present what they call a virtual interactive student-oriented learning environment (VISOLE). They explain VISOLE as a "game-based constructivist pedagogical approach that encompasses the creation of an online interactive world modeled upon a set of interdisciplinary domains in which students participate as citizens to take part cooperatively and competitively in shaping the development of the virtual world as a means to construct their knowledge and skill" (Cheung et al., 2008, p. 17). Here we see constructivist and experientalistic elements, that learning comes through interaction and being exposed to the environment where the knowledge resides. Hanson and Shelton (2008) comments on what designers need to make this possible in VEs, writing that "an interface that allows for the manipulation of 3D objects in virtual space offers the student control over what they saw and when they saw it, thus offering them a certain level of autonomy and virtual feeling of reality" (p. 119). The element of constructivism that occurs when the VE is altered through interaction may be beneficial for learning and memory.

## 2.4 Psychology

So far this literature review has discussed VR technology, interaction with VR and VR in the context of learning. This section will review how the human mind reacts to VR technology. The field of Cognitive Psychology is relevant to understanding how the human mind responds while being exposed to VEs. Often described as mental activity, cognition "describes the acquisition, storage, transformation and use of knowledge"(Watlin, 2009, p. 2). This section will review research on spatial cognition, different types of memory, learning and cognitive load. In addition to this, this section will review mnemonics and research on the MOL.

### 2.4.1 Memory and Learning

Memory and learning are two terms that are closely intertwined, and should be explained. Memory can be defined as "the process of maintaining information over time" (Watlin, 2009, p. 489). A normal further division of memory, is into working memory (also known as short-term memory), and long term memory. Working memory contains "only the small amount of information that a person is actively using", (p. 493) or "the brief, immediate memory for material that is currently being processed" (Watlin, 2009, p. 495). Long term memory, on the other hand, can be defined as "the large-capacity memory that contain one's memory for experiences and information that have accumulated over a lifetime" (Watlin, 2009, p. 488). Learning stand in close relation to memory, and can be defined as the insertion of knowledge into the long term memory, or as "the process by which changes in behavior arise as a result of experiences interacting with the world (Gluck, Mercado, & Myers, 2016, p. G-6). The relationship between memory and learning will then be that the memory is the record of the experiences that are acquired through the process of learning (Gluck et al., 2016).

Often the confusion between memory and learning may in reality refer to the confusion between 'memorising' versus 'understanding' a set of data. An example to this may be that if one has simply memorised the name of some influential historical persons (data), one might be able to namedrop them on a test, if one also recognises the question, as it was the only context in which the answer was learned. One would not, however, necessarily be able to relate this data to other kinds of information (knowledge), e.g the implications these persons had on their time. One can say that memorisation is remembering out-of-context, or for the sole sake of recalling, while understanding is viewing the information in the correct context, relative to other information in ones memory. While understanding reflects, draws red lines and sees patterns, memorisation is just data.

The concepts of learning and memory are very closely intertwined; if one can not recall the knowledge one has learned, it is of no use. A big part of the MOL is to repeat the travel route – navigating in the environment to ensure that the knowledge is transferred to the long term memory. When asked when a person should use the MOL, By and Bjørshol (2011) explain that it should be used in those situations where one would like to have a note, for instance at an exam. Although one may know much about Stalingrad it is no good if one can not recall it during the exam, thus all it takes is an association to Stalingrad to bring forth all the information one already knows. The memorised keyword then acts as a reference to the learned knowledge.

The MOL is a way to 'store' information in a new thematised context. An analogy can be made to cooking. One may have all the ingredients in the house, but by finding, weighing them and organising them first, one may stand stronger and be more efficient in the cooking process. The ingredients have then been isolated from their original location and stored in a context and relation that is specific to the task to be performed. Although the items themselves are not 'learned' as concepts, learning is still relevant because we learn the 'travel route' or the relation each of these items have to each other. The MOL allows restructuring of learned information, and this new structure must be learned. This is why it is interesting to look at research on learning and pedagogy in the context of a memorisation technique. There is of course also good reason to believe that features of VEs that enhance learning will also enhance memory, as these two are so closely intertwined.

### 2.4.2 Constructivism

T. A. Mikropoulos and Natsis (2011) write how the underlying pedagogical approach in VEs often leans towards constructivism. Constructivism in the context of VEs can be defined as presenting users with content to be experienced and interacted with so that users can construct their own knowledge, that is knowledge in relation to themselves and their ideas. Watlin (2009) defines the constructivist approach in memory as "the perspective that people construct knowledge by integrating what they know, so that their understanding of an event or topic is coherent and make sense" (p. 485). Hanson and Shelton (2008) recommended the use of VR in education because it supports experiential learning. Experiental learning is constructivist, as the learning builds understanding through a process of interaction and reflection. Referring to John Dewey, a writer who influenced constructivism, Hanson and Shelton (2008) wrote:

"[John Dewey] advocated that while not all experience is education, all education should be experiential. Because VR supports experiential learning, we recommend the use of VR technologies across a variety of disciplines and embrace its design and development despite the struggles" (Hanson & Shelton, 2008, p.129)

Research previously cited in this chapter often revolves around autonomy, learner-centered approaches and egocentric representations where the user should play themselves. These approaches are very compatible with natural interaction, and the experiential and constructivist pedagogy that VR applications often build on.

### 2.4.3 Spatial Cognition

As previously mentioned, the key feature that makes VR unique as a medium, is the immersion it affords. In VR, to a varying degree, we adhere to the environment as we do in real life. We are surrounded by the VE in terms of our senses, feel present in it, and need to navigate in it. It is therefore relevant to look at research on spatial cognition – especially in relation to memory. Spatial cognition is a broad area on how people construct cognitive maps, how they recall the world they navigate, and how they store objects in a spatial array (Watlin, 2009). How we navigate and remember places is relevant for this thesis, as the core concept of the MOL is to navigate in an environment to remember its content, through the construction of a cognitive map.

Parsons, Courtney, Dawson, Rizzo, and Arizmendi (2013) explain that navigation in VR can be suggested as equal or representative of real world functioning. This means that we navigate and also remember in relatively the same way in VR as we do in real life. Hardiess et al. (2015) conclude in their paper that "virtual reality can be fruitfully used within spatial cognition research" (p. 136). Tüzün and Özdinç (2016) write that studies of spatial learning in VR and real life deliver similar results. But how do people navigate in VEs? Stankiewicz and Kalia (2007) did some research where the participants were given the task to navigate through a virtual maze. They found that the subjects relied much more on the landmarks that were specific in their appearance. Tüzün and Özdinç (2016) describe the benefits landmarks provide as that they are unique and static and thus good reference points, and play a part in how we create the knowledge of routes.

Other interesting research shows that we do not only derive spatial knowledge, for instance knowledge of a town, from being exposed to it physically. Frankenstein, Mohler, Bülthoff, and Meilinger (2011) showed local inhabitants a view of their town in VR. In remembering the different places and locations, they performed much better when they were facing north. As humans do not have an inner compass, this shows that spatial orientation and memory is also derived from maps. These different views are often described as 'egocentric' and 'allocentric' views. While an egocentric view views other objects as spatially relative to oneself, in an allocentric view the locations of items are defined relative to eachother, as in a map.

Bae et al. (2012) found that egocentric representation delivered better results in terms of presence and realism compared to allocentric representation. First order experiences with egocentric views should therefore be prioritised over allocentric views. These do not, however, need to be mutually exclusive. It is possible to combine these, just as we combine several sources when learning navigational knowledge.

Figure 2.2: Screenshot from WoW, showing allocentric view

Both of these reference frames are used when a user perceives the environment, orients and navigates, and remembers the environment (Roupé et al., 2014). In computer games it is normal with navigation both in terms of first person view, and third person view for reference to the environment in a grander scale. In this case, the third person view, or allocentric representation, would be map in the corner of the field of view as a dot showing your location on it. An example of this can be viewed in Figure 2.2, from the game World of Warcraft.

#### Gender differences in terms of spatial abilities

Regarding spatial abilities, there is a slight difference between the genders. Males typically perform better than females on tests of spatial abilities (Barnfield, 1999). This may cause a difference in the effectiveness of VR technology and the MOL between the genders. When reviewing spatial abilities especially relevant for the MOL, however, females may perform better than males. Eals and Silverman (1994) found that females surpass males on some tasks, in particular recall of object location, which is at the core of the MOL when adapted to VR. Research by Feng et al. (2007) suggest that differences between genders can be eliminated after navigation in action games on a computer. This may also be the case for VR navigation.

### 2.4.4 Cognitive Load

Cognitive load refers to the amount of mental activity used in the working memory. T. A. Mikropoulos and Natsis (2011) report that Immersive VR apps may take up too much cognitive load. This is dangerous, as there may be no more cognitive load left to focus on the content to be learned. Out of the 53 papers T. A. Mikropoulos and Natsis (2011) reviewed, only 16 used immersive educational VEs. Although cognitive load was a concern, those who delivered immersive VR systems had positive results on learning and attitude for the users. Cognitive load should be a concern when designing a VR applications for learning or memory as VR can deliver cognitively demanding experiences. An example of this as a potential pitfall is illustrated in a literature review by Selverian and Hwang (2003). They presented 17 research studies on presence and learning, which reported that although there were presence, most had failed to connect this to the learning objectives and achievement. From this we see that presence is not necessarily a positive feature in itself, it can also be used poorly. Learning will not *necessarily* increase with presence, unless it is directed towards the learning objectives. As with communication in general, noise should be removed from the medium.

Tüzün and Özdinç (2016) reviewed several papers and found that minimising distracting elements in the environment would increase immersion, heighten the participation and increasing conceptual and spatial learning. Roupé et al. (2014) suggested that since the human mind have limited visual working memory capacity it is important to not overload it with navigation tasks. They also found that the users who used their body for navigation found it easier relative to the mouse and keyboard approach, and that it demanded less cognitive effort (Roupé et al., 2014).

Lee and Wong (2014) addresses cognitive load theory and the different kinds of cognitive load that is relevant for designing VRLEs. They write how "the process of learning requires working memory to be actively engaged in comprehension of instruction material to encode to-be-learned information for appropriate schema construction to be stored in long-term memory" (Lee & Wong, 2014, p. 51). That is, there needs to be more resources available than to just simply experience the content – there must be capacity to sort and process the information as well. They further review some papers and conclude that learning is inhibited when the total cognitive load in a learning task is greater than the capacity of the working memory. In their paper, they mention three types of cognitive load: intrinsic; extraneous; and, germane. Of these four, germane load is the one identified as relevant for learning. Of germane load they write that it is "the load that is necessary for learning and it results from the way information is presented and the circumstances in which it is presented" (Lee & Wong, 2014, p. 51). They further advise to prioritise activities and representations that maximise germane load while other kinds should be minimised such that the total cognitive load does not exceed the memory resources of the user.

### 2.4.5 The Method of Loci

So far VR, memory and learning, spatial cognition and cognitive load has been discussed. This section will look deeper into the mechanics of the MOL. The MOL is a mnemonic. A mnemonic can be defined as a mental strategy to improve memory (Watlin, 2009).

The MOL in particular, is defined by Watlin (2009) as "a memory strategy in which items to be learned are associated with a series of physical locations, arranged in a specific sequence" (p. 489). Further, she describes that during recalling of the items, one review the locations in order to retrieve the memory items. As explained in the introduction, the method consists of visualising objects at certain locations. The visualised objects often act as associations to the content that is to be recalled if the content is complex, but otherwise the memory items are just visualised themselves. In constructing such a mental model of memory items, one is designing a cognitive map.

A cognitive map can be defined as a mental representation of an external environment (Watlin, 2009). This environment is filled with mental images, that is, mental representation of stimuli when the stimuli is not physically present (Watlin, 2009). When creating such a Mind Palace with the MOL, one creates a cognitive map with mental imagery. Baddeley (1992) describe a component in his working memory model that processes both these kinds of information, the spatial (cognitive map) and the visual (imagery). He describes this as the "visuospatial sketchpad", on where we write visually and spatially to our memory, as is done using the MOL. Though explained earlier, a more detailed guideline for executing the MOL is described here:

1. Find an environment or a building to act as your location, like your workplace or home.
2. Isolate a number of steps or spots within this location, corresponding to the number of items you need to remember.
3. Visualise these items, or associations to them, at their given place in the location (e.g the logo of Google Chrome to remind you of the element Chromium).
4. Repeat the travel route 'in your mind' to reinforce the memorisation.

Such associative images need a certain sense of creativity, like imagining Putin to remind you of Russia. Even better, the images should be rather "exceptionally designed" (p. 30) and "emotionally evocative" (Long, 2016, p. 30) to promote memory. By visualising images, we can exploit the 'picture superiority effect' to aid in memory recall.

#### Research on the MOL

In the previous section, the mechanics of the MOL was described. In this section actual research will be reviewed. The MOL is very subjective in nature, as the associations the users make are relative to their own mind – and content of thoughts are inobservable. Legge, Madan, Ng, and Caplan (2012) reports that "research on the MOL is challenging due to the MOL's reliance on individualistic and internal proceses (i. e imagining oneself through a personally familiar environment)" (p. 381). They further comment on this, explaining that researchers "could not control the spatial properties and features of the environments participants used" (Legge et al., 2012, p. 389). This makes research on the MOL challenging. When it comes to effectiveness, however, there has been done much research. For instance, the MOL was shown to be more effective for generating secure and memorable passwords relative to a text-based mnemonic (Nelson & Vu, 2010). De Beni and Cornoldi (1985) researched the MOL in memorisation of concrete words. They found that "the overall performance of the loci mnemonic group was far better", compared to the group who did not know loci mnemonics (p. 11). Hu and Ericsson (2012) quote a study from Susukita (1933), stating that the "professional memorist, Ishihara used a pre-memorized set of 400 specific locations to memorize lists of around 2400 digits" (p. 238). From this it is clear the MOL is an effective mnemonic.

But has there been done any research on the MOL with VEs? Legge et al. (2012) conducted comparisons between three different ways of trying to remember information. One group used the traditional MOL, by using a familiar place as the location, like their house. Another group was supposed to use a VE that they were subjected to for only five minutes prior to the study. After these five minutes, they were not allowed to view the environment anymore. The third group acted as a control group, and was not instructed in the MOL. Note that the group who used the VE did not use an application to connect their visualisations to the environment, they were exposed to the environment on the screen, and then used the conventional MOL on their newly created impression of the location. They found that their virtual protocol substantially improved memory recall relative to the control group (Legge et al., 2012). Relative to the conventional use of the MOL, the "virtual protocol for the MOL was not significantly different from the conventional MOL strategy" (Legge et al., 2012, p. 385). These results took into account both the recalling of items and their order, that is lenient-scoring and strict-scoring. This shows that it is not important, at least for short-term memory, to use a location one remembers very well.

### 2.4.6 Other Mnemonics

The MOL is far from the only effective mnemonic. This section will review other mnemonics that are based around organisation. These mnemonics present different ways of organising the memory items to increase memory recall.

#### Chunking

A popular method is called "chunking", and is an organisational strategy where one combines several small units into larger units (Watlin, 2009). In this way, one may for instance remember one item instead of four, where that items attributes or properties would be the other three items. Another popular mnemonic is the first-letter technique, where one takes the first letter of the words one want to remember, and compose a word out of it (Watlin, 2009). Yet another popular method is the narrative technique, where one makes up stories that links the different words together, in a fashion quite similar to a chunking technique.

## 2.5 Summary and Relevance

This chapter reviewed VR technology and how it relates to humans in terms of interaction, learning and psychology. This literature review will act as a foundation on which the MPA will be designed. Designing the MPA is a good example of designing a 'Magical VR' application. A goal is first asserted; to recreate the mental processes of the MOL in an immersive VE. In developing a magical VR app, any means that are favorable to achieving that goal may thus be applied. Through this literature review it is clear how compatible an adaptation of the MOL could become with the strongest features and pedagogy elements associated with VR. In terms of experiental learning, the users knowledge can be constructed through interaction with the VE. As for the features relevant for learning, the users could 'play themselves' from a first person point of view to get a first order experience. The design could allow the users to be *autonomous*, to be their own guide, free to move where they want in the environment.

Adapting the MOL to the MPA should involve designing for the user to be able to embody the world with metaphorical knowledge, as Sánchez et al. (2000) stated. This can be incorporated by allowing the users to place images as associations to knowledge in the VE. In this way, by using the words of Hachaj and Baraniewicz (2015), the MPA will be a "...virtual world capable of embodying the knowledge to be taught" (p. 397).

From the research on spatial cognition, there are several relevant factors to consider for the design of the MPA. How users navigate in VEs and how they remember these locations, are especially important when designing for memory of the environment. It is relevant down to the essence of the MPA's concept; if you remember the place you have 'been', you will remember the content you were supposed to memorise. Use of landmarks as reference points, and the use of both allocentric and egocentric views should be incorporated in the design to boost navigation.

The research on cognitive load suggests to be careful and selective with content in the VEs, to not overfill the environment. This is to avoid distraction from the content to be recalled or learned. Data also supporting this design choice, is the findings suggesting that presence is only a good feature if connected to the things to be memorised. Thus, the MPA should not have unnecessary distracting elements that may take the focus away from the memorisation task.

During this literature review, the technology which the MPA should be delivered through was also reviewed. When deciding what hardware to use, the comparative review from the literature was used, in combination with some criteria posed by the project, namely cost and development difficulty. Because of the limited timeframe of this research project, much depended on the development difficulty, and the cost was a natural limitation due to the scope of this project. Both GEAR VR and Daydream View have mobile browsers as they are phones, which enables the use of web technologies for VR development. Web languages are relatively easy to use, which is an advantage.

Samsung GEAR VR was within the range of both cost and development difficulty, and passed all the minimum requirements. Google's Daydream View was even cheaper than the GEAR VR, however, due to Daydream View's later release date, its worse FOV and other unknowns, GEAR VR was chosen.

The reason why Samsung GEAR VR was chosen over Oculus Rift and HTC Vive was mainly because of the importance of rapid prototyping and cost. Although Samsung GEAR VR is above the minimum requirements, it must be mentioned that both Oculus Rift and HTC Vive is superior in terms of technology that makes way for immersion. If the goal of development was a more final product it is clear that these HMDs would have been a better choice to truly test the features of VR. Both Oculus Rift and HTC Vive afford much more sophisticated means of interaction, through positional tracking and tracked controllers. As these HMDs use powerful computers to render the graphics instead of a smartphone, the graphical quality is also better.

# 3 Research methodology

In this chapter, the research- and development methods for this thesis will be discussed. First, the goal of the research will be stated by defining the research questions. Further, the research methods for answering these questions will be presented. The first research method that will be explained is the Research Through Design model, as it is the overarching method concerning this thesis as a whole. Further, the desk research and the methods of development will be presented. Finally the experiment design is presented before the chapter is summarised.

## 3.1 Research Questions

The research questions are the following:

- **RQ1:** How can the MOL be adapted and developed to a VR app?
- **RQ2:** How do features of Immersive VR impact the memory of VEs?
- **RQ3:** Which group of people benefit from visualisations in the medium of VR?

## 3.2 Research Through Design

The research in this thesis follows the Research Through Design model (RTD) by Zimmerman et al. (2007). The RTD model was presented as a way for HCI design researchers to deliver good research. It comprises four stages that act as criteria for what is good HCI research, and how it should be presented. This method is relevant to how the research is organised and presented as a whole, and thus encompasses the whole research project. The research is organised after this model to ensure and document that the presentation of this research is done well. In presenting the RTD model, we will go through the 4 stages presented by Zimmerman et al. (2007):

1. **Process**
   To ensure quality documentation in research, the research process in general will be well documented. This is so that the process can be reproduced by other researchers. This is fulfilled by documenting the technologies used, the development processes and explaining the software solutions.

2. **Invention**
   The artefact or product must "constitute a significant invention" (Zimmerman et al., 2007, p. 499). The MPA follows these criteria and fits well the description of a "novel integration of various subject matters to address a specific situation" (Zimmerman et al., 2007, p. 499). This is shown in the literature review, where knowledge from different fields are taken as input to the design of the application. According to Zimmerman et al. (2007), novelty need not be in the individual elements of an artefact, but may be "in the integration of many technical research contributions from a variety of disciplines into a single working system" (Zimmerman et al., 2007, p. 498).

   This is what gives novelty to the MPA; there is available research on VR and the MOL, but what is known about the MOL in VR? This is how the RTD model "focuses more on the whole instead of the parts" (Zimmerman et al., 2007, p. 497). In this thesis, the RTD model is applied as a means to ensure that the application can help answer the research questions, by being an "embodiment of theory and technical opportunities" (Zimmerman et al., 2007, p. 498).

3. **Relevance**
   According to Zimmerman et al. (2007), RTD is about producing an artefact or product that should take the world from the current state to a preferred state. To fulfill the requirement of 'Relevance', researchers should define this preferred state that they want to achieve, and argue "why the community should considered this state to be preferred" (p. 500). In the case of the MPA, the preferred state the invention should bring, would be more knowledge about the MOL, better memory applications for students, better knowledge of the pedagogical features of VEs and who benefit from these. It would also give us data on how different kinds of VR works in terms of their impact on memory.

4. **Extensibility**
   The stage of extensibility is quite similar to the stage of process. It addresses documentation, so that the commmunity can use the knowledge created by the research. Extensibility is concerned with the research paper's ability to affect and extend its knowledge to other projects. This stage will be ensured with thorough documentation on development, technologies and software used.

## 3.3 Desk Research

Desk research in the form of a literature search was carried out to present a review of relevant fields of research. This included research on VR technology, interaction with VR, use of VR for the sake of learning, and cognitive psychology. In addition to this, research on mnemonics, and in particular the MOL, was reviewed. The results of this literature review was presented in chapter 2. The following websites were used to query for relevant papers: ScienceDirect, Google Scholar, Nordicom, Springer, and ACM Digital Library. The papers were gathered by first evaluating the relevance of the paper title towards this thesis. Then, the abstracts of the gathered papers were read, and based on this, a list of relevant papers were selected for reading. The search queries are here presented as a list under the topic for which it is relevant:

**Learning**

1. Virtual Reality + Learning
2. Virtual Reality Learning Environments
3. Virtual Reality + Classroom
4. Virtual Reality + Education

**Interaction**

1. Virtual Reality + Interaction
2. Virtual Reality + Human Computer Interaction
3. Virtual Reality + HCI
4. Stereoscopic + Interaction
5. Head-mounted Display + Interaction
6. Google Cardboard + Interaction
7. HTC Vive + Interaction
8. Oculus Rift + Interaction
9. Samsung GEAR VR + Interaction

**Technology**

1. Virtual Reality
2. Immersive Virtual Reality
3. Desktop Virtual Reality
4. Google Cardboard
5. Head-mounted Display
6. Virtual Reality + Field of View

7. Virtual Reality + Stereoscopic
8. Virtual Reality + Android
9. Virtual Reality + iPhone
10. Virtual Reality + Smartphone
11. Virtual Reality + Oculus Rift
12. Virtual Reality + HTC Vive
13. Virtual Reality + Samsung GEAR VR
14. Virtual Environments

**Psychology**

1. Cognition
2. Spatial memory
3. Spatial learning
4. Virtual Reality + Method of Loci
5. Method of Loci

In addition to these search queries, papers were found by investigating the sources of the selected papers, and by searching after related terms discovered in the papers.

## 3.4 Technology Development

To best answer the research questions, the traditional waterfall method was chosen for the software development. This method was chosen as the scale and scope of the project is small and its requirements relatively clear. As the MPA is the MOL adapted to the medium of VR, a clear vision of the functionality the application had to deliver existed from the start. The requirements are clear as they are gathered from the mechanics of the MOL, and based on research from the literature review. If this were to be a product for a commercial market, however, an iterative development method might have been more suited to address the problems, as its requirements would have to be adapted to a market or to a certain group of people. This is not the case, however, as this application should be specialised to answer the research questions. In the next section this development method will be presented.

### 3.4.1 Waterfall

The Waterfall model was first formally presented by Royce (1987). Although the model originally was intended for "managing large software systems", as the title of his paper suggests, it is today mostly recommended for smaller software projects. Royce (1987) reviews the method quite critically because of the risk involved with testing late in the process. The method is radically different from the "fail fast" philosophy of agile software development methods. Royce (1987) commented on these risks in the paper introducing it, writing that "I believe in this concept, but the implementation described above is risky and invites failure" (p. 329). For this reason, it is usually only recommended for smaller projects where the requirements are known to a higher degree. The method varies somewhat in the number of stages. Common for all versions of the waterfall model is that one stage does not overlap another, that is, each stage should be completed before the next one begins.

Below the process of the five stages that will be followed in developing the MPA will be described. Further, it will be discussed why the waterfall model is a good choice to go along with the RTD model. The development process of the MPA will be outlined in chapter 4, according to the stages of the waterfall model.

- System and Software Requirements
  During this stage the requirements for the application is set. In this stage one is working to figure out what the system should do, and what needs to be implemented to deliver this.
- Program design
  During this stage the pieces of required functionality is placed into some sort of architectural scheme. This is the stage after system requirements and before coding, where one decides how "the design" should afford all of the system requirements.
- Coding
  During this stage the list of requirements of the program design is developed to the actual product.
- Testing
  During this stage the software is tested to ensure its functionality.
- Operations
  The stage of operations is usually where the product is delivered to the customer, and when maintenance of software and bug fixing occurs. In our case, this stage will be when the experiment is conducted.

### 3.4.2 Compatibility of Methods

The waterfall model and the RTD model presented in the research methodology does not have any contradictive elements, although HCI research often use iterative development methods. The first step of RTD for example, is a good match for the waterfall model. One of the great benefits of the waterfall model is that it delivers good documentation, due to its very refined and singular processes. The second stage of RTD, "invention", demands a thorough situating of the work in the literature review to show that the product is a novel invention and contributes to the field(s). This will be addressed in the first stage of the waterfall model, as the design and system requirements will be based on the literature review. The two remaining stages of the RTD model, relevance and extensibility, are not closely tied to any sole stage in the waterfall development model. These will be prioritised in the writing of the thesis in general. In short, one could say that the waterfall model is an appropriate way of creating the design in the RTD model.

## 3.5 Experiment Design

In this section, the design of the experiment and the instruments used in the experiment will be explained. The experiment comprises six stages: 1) a pre-test consisting of a spatial ability test, a memory test, and a pre-questionnaire; 2) training to ensure the user knows how to use the MPA and the MOL; 3) the memory experiment; 4) recall test of the memory experiment; 5) a post-questionnaire regarding their experience and 6) a short interview. These tests and questionnaires will be further explained in section 3.5.2. In addition to these six stages, the informants will be called one week after the initial experiment, to see how many of the memory items they are able to recall. The informants will not be made aware of the memory test occurring one week after the initial test. This decision was taken to prevent any sort of memorising in the mean time. This carries the risk that some of the informants will not want to come back or be unavailable, however, this risk is evaluated as low. Before any of these six stages, the informants will have to sign an informed consent form, viewable in appendix A. The informants will be observed during the process and there will be taken notes of potential relevant factors. An overview of these stages can be found in Figure 3.1.

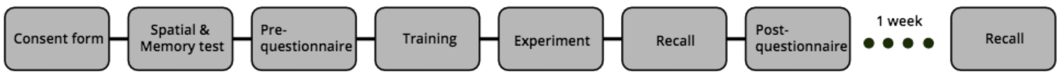



Figure 3.1: Experiment stages

### 3.5.1 Experiment Groups

The purpose of the experiment is to answer two of the three research questions, namely RQ2 and RQ3. That means, 1) to determine how features of Immersive VR impact the memory of VEs, and 2) who benefit from visualisations in VR as a memory aid. RQ1 is answered through the development of the MPA, as it concerns how the MOL should be adapted and developed to the medium of VR. To answer RQ2 and RQ3, an experiment is designed to test the informant's ability to recall a list of items using the VR application. To control these results, however, it is necessary to also include a control group. The informants in the control group are not to use any technological aids, however, they will still use the MOL. In this way, both groups will use the same mnemonic, only the technology would separate them.

To answer RQ2, of how features of Immersive VR impact the memory of VEs, another control group is also necessary. By only testing the experiment group and the control group, it will not be possible to know whether it is the immersiveness of the VR technology or simply the visual representation that are responsible for the results. Therefore, another control group will be included that will use the application in Desktop VR. Thus, there are three groups who will take part in the research experiment:

- The first group will use the Mind Palace application in Immersive Virtual Reality. This group will be called IVR.
- The second group will use the Mind Palace application in desktop VR. This group will be called DVR.
- The third group, a control group, will use the MOL as instructed normally, without any technical aids. This group will be called 0VR.

By having these three groups it is possible to better document and isolate from where the potential effects on memory comes. We can thus relate our results from the IVR group towards the DVR group to see the effects that the immersiveness and other VR factors brings. By comparing the DVR to the 0VR, which effects visual representation and desktop navigation of the MOL will have on memory will be clear. If only the IVR group would be compared to the 0VR group, it would not be possible to separate visual immersion as a factor different from general visual stimuli. The results of the 0VR group simply illustrates the effects traditional MOL in isolation provides us.

What will be tested then, in increasing complexity, will be 1) a pure MOL-instructed group (0VR), 2) a MOL-instructed group using the Desktop-version of the MPA (DVR) and 3) a MOL-instructed group using the Immersive VR version of the MPA (IVR). Table 3.1 illustrates these groups and what separates them.

Table 3.1: Different experiment groups

| Experiment group IVR | Control group DVR | Control group DVR |
|---|---|---|
| MPA in Immersive VR. | MPA in Desktop VR. | MOL w/o technological aids. |

### 3.5.2 Instruments

The previous section discussed the experiment design and mentioned several questionnaires and tests as part of the experiment stages. In this section, the reasoning behind the inclusion of these instruments will be presented. The use of cognitive tasks and self-report measures as instruments apply in order to answer RQ3, that is, who benefit in terms of memory from visualisations in an immersive environment.

#### Spatial ability test

Prior to the activity, the informants take a spatial ability test. The spatial ability test will be gathered from JobTestPrep.com, and comprises five different tasks that are to be completed in four minutes. Upon completion one receives a score of 1 - 5, 1 being the lowest spatial ability score. This is account for individual differences that may be of importance for the results. As the MOL and the medium of VR has a 'spatial dimension', how humans reason spatially may impact the results of the experiment. Spatial visualisation and reasoning ability is an important factor that has an impact on how humans process 3D visualisations (Huk, 2006; Lee & Wong, 2014). A study by Lee and Wong (2014) found that low spatial ability learners were more positively affected by VR than high spatial ability learners in a learning task. This is supported by the "ability-as-compensator" hypothesis (Mayer & Sims, 1994). This hypothesis states that low spatial ability learners benefit more from 3D models because they have difficulty reconstructing visualisations on their own. According to this hypothesis, high spatial ability learners would not gain that much benefit as they can create these visualisations on their own and is in no need of assistance.

Mayer and Sims (1994) also present the "ability-as-enhancer"-hypothesis, stating that high spatial ability learners should benefit from the VR-based application as they would use less cognitive efforts in the environment, thus freeing mental power for mental model construction. By this hypothesis, low spatial ability learners would not benefit from the VE, as this would cause them to be cognitively overloaded. An example of a study supporting this hypothesis was carried out by Huk (2006). He explains that "students with low spatial ability became cognitively overloaded by the presence of 3D models, while high spatial ability students benefited from them as their total cognitive load remained within working memory limits" (p. 392).

By measuring the spatial ability of the informants, the results of the experiment could help to see whether spatial ability has an impact on the results, and perhaps who will benefit from a virtual adaptation of the MOL, be it those with higher or lower spatial abilities.

#### Memory ability test

When the spatial ability test is completed, the memory ability of the informants is tested prior to the experiment. This is to account for potential differences in general memory capacity between the informants. This information is important to have for the analysing of results, and makes it easier to identify the factors causing either high or low recollection of items from the experiment. The memory test that will be used is gathered from PsychologistWorld.com. The informants are to look at 12 words for 60 seconds, and will be asked to recall as many of these words as they can. A score is given from 0 to 12, 12 being the best memory score. This memory score can be compared to Miller's Magic Number, stating that 7 + or - 2 is the normal capacity for short term memory that humans have (Miller, 1956) Any score between 5 and 9 would then be normal. In the comparisons in the analysis these scores will not, however, be classified into poor, normal or superior, but simply with a 12-point scale, where each remembered item is worth one point.

#### Pre-Questionnaire

When the informants have completed the memory test, some other potentially influencing factors will have to be accounted for. The informants of the IVR group will fill out a questionnaire, answering questions about back problems, vision, balance disorders or high susceptibility to motion sickness, as these factors may impact the results (Lin et al., 2002). The IVR and DVR group will be asked about their age, gender, and whether they have any previous experience with gaming or mnemonics. The IVR group will also be asked if they have any VR experience from beforehand. All these factors are relevant as they may impact how they perform in the memory experiment. The questionnaires also contain a selection of questions from the Immersive Tendencies Questionnaire presented by Witmer and Singer (1998). These questions measure how the informant usually relates to movies, games, daydreams etc. in terms of immersion. This may be relevant to how they perceive and get involved in VEs. The 0VR group will fill out a smaller questionnaire, querying their age, gender, and whether they have any previous knowledge of mnemonics, as the VR-related questions are not of relevance for this group.

#### Post-questionnaire

When the experiment is complete, the informants will be presented with a questionnaire that queries them about their experience using the method and/or the technological aid. Some of these questions are gathered from the Presence Questionnaire by Witmer and Singer (1998), revised by the UQO Cyberpsychology Lab (2004). The reason why this questionnaire will not be used in its entirety, is due to its well founded criticism by Slater (1999). For instance, a question in the questionnaire asks whether the informant is able to control the events in the VE. If he/she is, this is supposed to be a sign of presence

– that is, the subjective feeling of 'being there'. This, however, presumes that a user is able to control events in his or her own life, and supposes that any resemblance between the VE and real life would induce presence. In this way, the presence questionnaire asks after factors *believed* to induce presence, it does not ask if the user feel present. In the end it becomes a self-fulfilling prophecy – the factors believed to cause presence become the definition of presence itself.

In theory, this could result in a factor supposed to increase the feeling of presence for some person, would be the proof of presence for some whom it did not bring a feeling of presence. The questionnaire does, however, have good questions, some of which were extracted for inclusion. When reviewed, these questions will not be be used to calculate a presence score, but their answers will be reviewed and compared between the different informants.

#### Interview

After the post-questionnaire the informants will partake in a short, informal conversation to identify possible factors that had been overseen, such as mistakes in applying the method, software errors etc. In this interview they will also be asked to describe their experience using the applications or the MOL in their own words. The informants will be asked the following questions:

- How did you find the experience in general?
- Was there something you did not like about the experience?
- Was there something about the experience you particularly enjoyed?
- Did you feel stressed during the experiment?
- Did you use any mnemonics in addition to the application [or method of Loci]?
- Did you feel that the application [or method] assisted you in recalling the items?
- Do you have anything to add that you think may be of importance?

### 3.5.3 Training

After the pretesting consisting of the spatial ability test, memory test and the questionnaire, all the informants will be taught the concepts of the MOL. The IVR and DVR group will also be given a brief explanation on how to use the software, and test the interaction. In this way, the IVR and DVR group will be exposed to the environment before the memory experiment. This is to try to make up for some of the natural advantage of the 0VR group, who use an environment they are familiar with as their location. In addition to the training in navigation, the 0VR and DVR group will be given an overview of the architectural "blueprints", that is, an allocentric illustration of the VE.

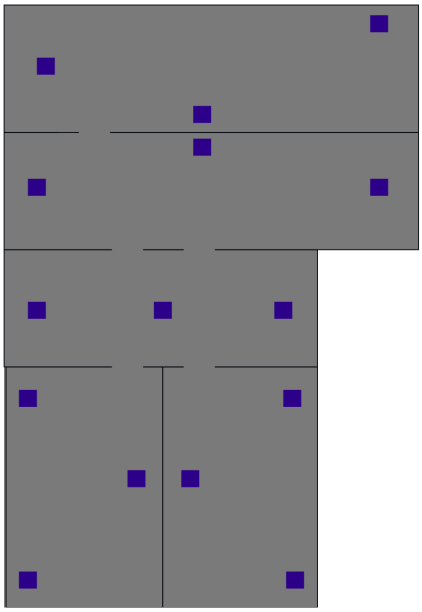


Figure 3.2: Allocentric illustration of the MPA's VE

This overview can be viewed in Figure 3.2. The blue squares represent where the image placeholders are located, that is, where the memory items should be placed.

In this phase, where the IVR and DVR groups explore the VE of the MPA, the 0VR group will choose a location they know well, and isolate 15 places within that location for the placement of items. It will be made sure that neither of these groups will "contaminate" their Mind Palace with this training, so that their Mind Palace (virtual or in the mind) is ready for the experiment. That is, none of the informants will 'fill' their Mind Palaces with information while practicing the MOL, as this could impact the results. When it comes to teaching the principles of the MOL before the experiment, it is important to verify the informants knowledge of the method (Legge et al., 2012). The training may thus vary somewhat in length and conversation to ensure that each candidate has the correct impression of the method. This is important because if someone misunderstood the mechanics, they could perform worse (or better), and there would be an unknown factor. Between the training and experiment, the IVR group will wait long enough for any potential simulator sickness symptoms to go back to normal levels.

### 3.5.4 The Memory Experiment

In the previous section, the training for the memory experiment by the use of the MOL and the MPA was discussed. In this section, the memory experiment itself will be discussed. The task in the memory experiment is to try to memorise 15 items during the course of 5 minutes. This number of items was decided after a pilot study, discussed in section 3.6. The list of items that are presented here, were gathered from different memory tests online. The list were reviewed to try to identify possible semantical connections between items that would make it easy for the informants to recall the list.

1. Chair
2. Ice Cream
3. Scissors
4. Plant
5. Dog
6. Clock
7. PC
8. Spaghetti
9. Umbrella
10. Football
11. Lightbulb
12. Pen
13. Glasses
14. Police officer
15. Fork

Though some time is thought to be lost in interaction and navigation in the VE of the IVR and DVR group, every group is given the same amount of time. This is the only way to compare the methods – to give each group equal time. For the IVR and DVR group, the memory items would only be presented to the informants as they placed them in the MPA. That is, they would never view the words themselves – only the images that are revealed as they interact with the MPA. For the 0VR group, the items to remember will be presented through a unordered list, given to them on a sheet of paper. The 0VR group will have access to this list of 15 items during the whole memorising phase, while the IVR and DVR group will only access the items when they view them in the MPA. This may impact the results – that the last items are not known known until the last couple of minutes, as they are placed last. If the VR groups were to have a list, it would have to be a steady list on the screen following their every move, and this would probably impact the immersion. To have something static locked to the field of view when moving in a VE would feel weird, as everything normally changes when we move our heads in 'real life'.

#### Recall

When the experiment is complete, the informants are asked to recall the objects they were to memorise. All the groups are asked first to list the items on a sheet of paper, and if they prefer, in the order that they placed them. They are not informed that order should be an element being memorised in itself, however, it will be interesting to see for how many this will become a natural bi-effect of the method, and if this will vary between the different approaches to the memory task.

## 3.6 Pilot Study

Before the experiments themselves, a pilot study was conducted with five informants. This was to find out how much time to set aside for the research experiment, and to ensure the functionality of the software. In addition to this, it was necessary to find out how much time an informant should have available in the VE. This pilot study was only done on one group, and this group tried the experiment as planned for the IVR group. This was because the experiment of the IVR group was believed to use the most time. Thus, by testing the most complex group in relation to time, we were able to know that the other groups would not use more time than that, as they share every stage of the experiment – the only difference being that the questionnaires will be shorter for the DVR and 0VR group. The informants in the pilot study were given 12 items to remember and 5 minutes to perform the MOL. The results of this pilot study that led to the decision of increasing the memory items in the memory experiment to 15 are discussed further in chapter 5.

## 3.7 Summary

In this chapter the research- and development methods for the thesis was presented. The next three chapters describes the development of the technology, the results of the experiment and provides an analysis and discussion of the results.

# 4 Development

In this chapter, the course of development of the MPA will be outlined. The course of development of the MPA followed the Waterfall model for software development. This chapter, presenting the development of the MPA, will be organised after the different stages of this method, that is 1) system and software requirements, 2) program design, 3) coding and 4) testing. The final stage, operations, which is the experiment, will be presented in the next chapter.

## 4.1 System and software requirements

In this section, the requirements which the software must fulfill will be defined, that is, what the software should be able to do when the development is finished. A general description of the system requirements is drawn first and foremost from two sources: 1) the adaptation of the MOL and 2) the identified features of VR that contribute to learning found in the literature review. First the reasoning behind the requirements gathered from the mechanics of the MOL will be described, before those gathered from the literature. After these have been briefly discussed, what they imply and actually mean from a development perspective will be described.

During the development, each of these requirements will be organised with Trello, an application that divides them in different sections. They will be organised into three categories: as 'backlog', 'in progress' and 'done'. When the development is in the beginning of the coding stage, every user story will be in the backlog, and the coding stage of the development is over when every user story has been placed in the 'done' category in Trello.

### 4.1.1 Requirements from The Method of Loci

In this section, what the MOL implies in terms of requirements for development of the MPA will be described. As the MOL is the mechanics the application first and moremost should pursue, it will of its own nature deliver requirements for the development. To adapt the processes of the MOL, a Mind Palace is needed, that is, a three dimensional VE. It has to be possible to navigate and orient oneself in this environment. It must also be possible to instantiate objects, that is images, to any given association one might have.

It should be possible to place these objects at a given location within the Mind Palace. If the software can afford this, it will have covered the mechanics of the method.

### 4.1.2 Requirements from the Literature Review

In this section, what basis the literature review gives us for defining requirements for development of the MPA will be described. To best utilise the isolated features of VEs that contribute to learning, we need to coordinate these with the baseline of the MOL. The VE should be autonomous, that is, that the user should be in control. This will already be fulfilled by the ability from the MOL requirement stating that the user should be able navigate the room and instantiate objects of association using the Mind Palace as a metaphorical projection of meaning in real life. In addition to this, it should be easy to orient oneself in the user environment.

From the literature, we see that landmarks should be made to act as reference points. The user should also be able to navigate from an egocentric view, as this increases the feeling of immersion and similarity to reality. Also, the user should be able to view his location from an allocentric view. Similar to landmarks, this will give the user different reference points. What this implies from a technological perspective will be described under section 4.1.3.

Other design principles from the literature review are less explicit, and are therefore not written as requirements. These, however, will also affect the nature of the design. Examples of this are that the user interface needs to be simple, that elements in the MPA should not be distracting to reduce cognitive load, etc. The user attention should also be directed towards the learning content, to maximise the positive impact of presence. These are not easy to implement as "features", but rather something that should be considered in the implementation of every feature – that no feature works against this principle, but in the degree it is possible, for it.

### 4.1.3 List of Requirements

Based on the descriptions from the MOL and the literature, these requirements have been defined:

- Three-dimensional Virtual Environment:
  At the core of the application functionality, the MPA needs to deliver a 3D VE. A 3D VE can be defined as an environment where the user can perceive stereoscopic vision, and view the environment in all of the 360°. As the MOL is dependent upon having different "stops" in the travel route, the VE needs to be large enough, and contain different, distinct "sub-places" within the environment. That is, it needs to resemble a room with different features that are distinct from one another so

that the user can establish a contrast between them, as opposed to an endless open three-dimensional emptiness.

- Navigating and orienting
  The user should to be able to navigate in the VE. That is, the camera viewpoint of the user in the 3D VE needs to be able to change its location. The user needs to be able to 'walk' or transport himself in the direction he or she is seeing.
- Instantiation of objects
  The user should be able to instantiate images, to any association, and place these objects at any given location in the MPA.
- Saving
  Each individually created Mind Palace must be stored for documentation purposes for the research, to ensure the informants success in interaction with the MPA. It must be possible to view the entirety of the Mind Palace in the research analysis. This requirement is included due to the needs of the research, not the MOL or the literature review.
- Natural interaction and orientation
  The user should be able to use natural interaction to interact with the VE.
- Allocentric view
  The user should be presented with an allocentric view of the structure of the rooms in the Mind Palace.
- Egocentric view
  The user should be able to navigate from an egocentric view, viewing objects as he or she would view them in real life.
- Landmarks for reference points
  The Mind Palace should be filled with landmarks, i.e. objects as reference points, to aid in spatial navigation.
- Desktop VR version
  Another final requirement, posed by research needs, and not the literature or the MOL, is that the MPA should also be able to be used on a PC for the DVR group.

## 4.2 Program design

In the previous section, the requirements that the software must fulfill was outlined. This section will present how the software architecture should be designed to facilitate for the implementation of these requirements. This section will describe how these different components can be stitched together to one application, and will describe the frameworks and the build of the application.

Figure 4.1: Samsung GEAR VR HMD

Each requirement will be presented anew while it is described how this should be implemented in the actual design by code and functionality.

- Requirement 1: Three-dimensional Virtual Environment.
  The first requirement of a 3D VE is the core of the application. The hardware chosen for the application is the Samsung Galaxy S7 with its GEAR VR HMD. The GEAR VR HMD in isolation and in combination with the Samsung S7 Phone can be viewed in Figures 4.1, 4.2, 4.3, 4.4, and 4.5:

  One of the main reasons that the GEAR VR was chosen, was the opportunity for use of web languages such as JavaScript(JS), HTML and CSS. These languages will run in a browser on the Samsung Galaxy S7. For this to be possible, a browser supporting a VR API had to be found so the GEAR VR HMD could be used.

  The most supported VR standard for the web today is WebVR. WebVR is an experimental JS API that provides access to HMDs such as Oculus Rift, HTC Vive, Samsung Gear VR and Google Cardboard (WebVR.info, 2017). WebVR is thus an API that lets us use the sensors of the GEAR VR HMD. When development started, only one browser for mobile had enabled WebVR support: the Samsung Gear VR Browser. It was decided to use the WebVR API utilize the GEAR VR HMD.

  Now that hardware and a browser supporting WebVR was in place, a framework to create the graphics was needed. One of the most popular graphics library today on the web is WebGL (Web Graphics Library), a JS API for rendering 2D and 3D graphics within web browsers. After some research, a web framework that uses WebGL and WebVR in combination was found: A-frame. By using A-frame technology, more could be done with less code. Thus, the technical solution for creating a three-dimensional VE included the Samsung GEAR VR hardware, the Samsung Gear VR Browser, and the A-frame framework. Figure 4.6 and 4.7 shows a VE created with A-frame on the Samsung S7 without an HMD.

Figure 4.2: GEAR VR Touchpad and buttons

Figure 4.3: GEAR VR lenses and proximity sensor

Figure 4.4: GEAR VR phone attachment

Figure 4.5: GEAR VR with phone attached

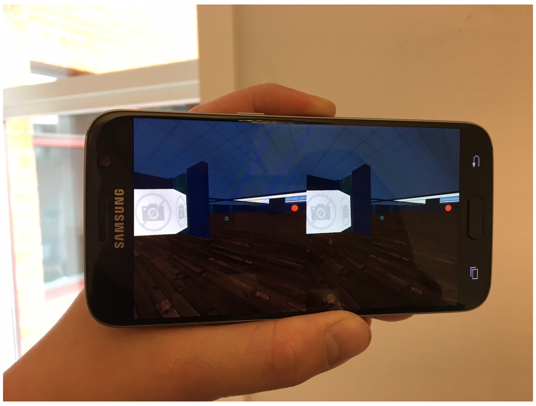



Figure 4.6: WebVR Stereoscopic image 1


Figure 4.7: WebVR Stereoscopic image 2

These figures illustrate how the stereoscopic image is created. The image is duplicated, and the view differ slightly in the two images. By looking at the circle in the cube at Figure 4.6, one will see that the circle is complete in the left image, but not in the right image, showing the slight difference enabling the stereoscopic effect.

A-frame's "Hello World" example ("Hello WebVR", Figure 4.8) shows a navigatable 360° VE with three different shapes, consisting of only 17 lines of written HTML code. Of course, the framework itself consists of millions of lines of JS code that makes it easy to use few lines of code to create VEs. By using this technology, it is possible to set up an environment, create walls, roofs, etc. and to furnish and create the VE into more of a location than an abstract space. It is also possible

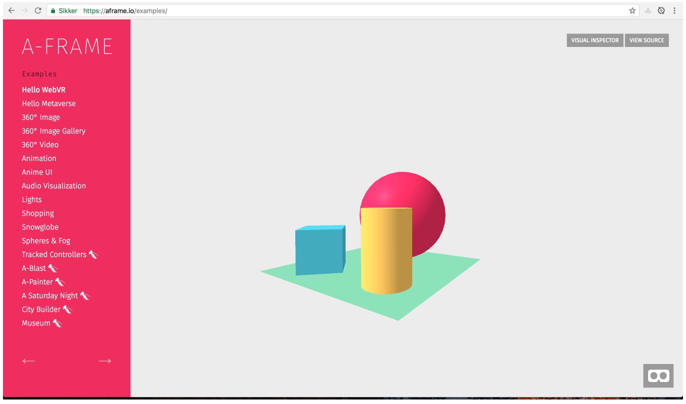



Figure 4.8: Hello WebVR

to create limitations to how far one could transport the camera viewpoint, etc. In this way, a three-dimensional VE for GEAR VR could be created.

Two issues arose concerning the projection of the 3D VE on the Samsung GEAR VR. The pixel persistence mode discussed in section 2.1.5 on the Samsung was not initially triggered by the A-frame framework. It could be manually turned on, however, by enabling developer mode on the Samsung. Another challenge occured while attempting to test the VR software with the HMD. When connecting the phone to the HMD, the Oculus software would launch – and all navigating, typing of URL's, etc. would have to be done in VR. To avoid this, one could either root the phone and do some changes, or download an application that would enable you to turn this feature on or off at will.

- Requirement 2: Navigating and orienting
  When the 3D VE had been created, the second requirement puts forth the need to move about in the environment. A-frame supported navigating on the PC by pressing the W-A-S-D keys, but did not initially respond to the touchpad on the GEAR VR HMD. By modifying the framework code, it was possible to isolate the functions responsible for moving forward and execute these at will. The walking function was thus isolated and ready to be executed through different ways of interaction, which will be explained more thoroughly in requirement 5, which concerns natural interaction. Orientation in 360° was already solved by A-frame. One would move the head to change the orientation in the environment in IVR, and use the mouse in DVR.

- Requirement 3: Instantiating of objects
  The third requirement demanded that the user should be able to create objects capable of visualising any association the user might have. As web technologies are being used, this would mean inserting an HTML element into the DOM (Document Object Model). This would first and foremost demand a form of user input in the


Figure 4.9: A-box HTML element

form of a keyword of what were to be visualised. How this keyword is entered will be discussed under requirement 5 of natural interaction. The easiest solution to find a visualisation to any given association, was deemed to be an image search. Microsoft Bing was chosen over Google as their API was easier to use. When the keyword had been entered by the user, an image corresponding to said keyword would be returned using the search API. This image would then have to be included in an HTML element which was inserted into the VE/DOM, with the location of the user in the VE. For this 2-Dimensional picture, the easiest way to ensure that it would be viewable from every part of the VE, is to create a cube – where each of the six sides included the picture.

In A-frame, this could be solved with the HTML element called "a-box". This element takes attributes to define it, such as position, rotation, width, height, depth, and finally src. The parameter "src" would refer to the URL of the image to be filled. The result is a box as found in figure 4.9, where the keyword was "undefined".

To fulfill the requirement of placing objects, the object had to be created with JS. The written script created an a-box element, gave it an URL returned by the search API, the location of the camera viewpoint(user), a certain width, height, depth and rotation, and inserted this into the DOM, thus visible in the VE. The JS code responsible for creating the A-box element is divided into two figures, and can be viewed in Figure 4.10 and 4.11. An example of the corresponding HTML code of two a-boxes that were created by the script, is viewable in figure 4.12. This generated HTML code was retrieved by a JS Query in the developer tools of Google Chrome.

- Requirement 4:
  The fourth requirement stated that once this Mind Palace is created, and objects instantiated, this specific instance of the VE should be stored.

```
//Function responsible for getting the position of the user.
function getPosition() {
    var position = document.querySelector('#camera').getAttribute('position');
    return position;
}

function placeObject(positions) {
    var params = {
        "q": document.getElementById("param").innerHTML, // sets searchQuery to searchParam
        "count": "1",
        "offset": "0",
        "mkt": "en-us",
        "safeSearch": "Moderate",
    };
    $.ajax({
        url: "https://api.cognitive.microsoft.com/bing/v5.0/images/search?" + $.param(params),
        beforeSend: function(xhrObj) {
            xhrObj.setRequestHeader("Ocp-Apim-Subscription-Key", "7136e1a7f59e48a2a627f8b1a4a3615b")
        },
        type: "GET",
        data: "{body}",
    }).done(function(data) { //Anonymous function called when image has been found.
        //A-box attributes being set.
        var rotation = "0 45 0";
        var width = "3.5";
        var height = "3.5";
        var depth = "3.5";
        var myBox = document.createElement("a-box"); //a-box-element is created
        var variable = getPosition(); // Position of user stored in variable
        var variable3 = variable.x + " " + variable.y + " " + variable.z;
        myBox.setAttribute("src", data.value[0].thumbnailUrl); //a-box-element is given URL as src
        myBox.setAttribute("position", positions); // position set
        myBox.setAttribute("rotation", rotation); // rotation set
        myBox.setAttribute("width", width); // width set
        myBox.setAttribute("height", height); // height set
        myBox.setAttribute("depth", depth); // debth set
```

Figure 4.10: JavaScript code 1

```
        var myContainer = document.getElementById("objects"); //get container for placement
        myContainer.appendChild(myBox); // Box appended

        //Gets the list of the keywords to place
        var x = get_query_string_parameters();

        //Turns list into array.
        var elements5 = Object.keys(x).map(function(k) {
            return x[k]
        });
        globalVariable++; //Index goes up, as one cube/image is now placed.
        if (elements5[globalVariable] != undefined) { //If the list is not empty, update param
            document.getElementById("param").innerHTML = elements5[globalVariable];
            save();
        } else {
            document.getElementById("joakim").remove(); //Remove param if noone left.
        }
    }).fail(function() {
        alert("error");
    });
}
```

Figure 4.11: JavaScript-code 2

```
> document.getElementById("objects");
< ▼<a-entity id="objects" position rotation
  scale visible>
      <a-box id="14.828358871528451 1.6
      5.373352973226371" src="https://
      tse4.mm.bing.net/th?
      id=OIP.20BmjaMN39mZcqq42n7PqgEsDE&pid=Api"
      material position rotation width="3.5"
      geometry height="3.5" depth="3.5" scale
      visible></a-box>
      <a-box id="12.435601019666645 1.6
      -0.8600828196949938" src="https://
      tse4.mm.bing.net/th?
      id=OIP.20BmjaMN39mZcqq42n7PqgEsDE&pid=Api"
      material position rotation width="3.5"
      geometry height="3.5" depth="3.5" scale
      visible></a-box>
      " "
    </a-entity>
```

Figure 4.12: JavaScript-code 3

When an informant creates a Mind Palace he is manipulating the DOM of the web application, creating a unique version of it. This session then exists as HTML code, but will dissapear as soon as the application is reloaded, unless there is a way to save the content of the MPA. During development it was decided to store the session by saving the parent element of the a-boxes, that is, the element that contained all the features of the individual VE. This was stored in the localStorage of the PC with a save-button, where one entered the number of the informant. When using the MPA in VR, however, it was decided to store these in the cloud instead, using Google's Firebase solution. Before entering each Mind Palace, the informant number is specified in a menu so that the individual Mind Palace would be stored in the cloud connected to the informant number – ready for inspection during analysis. Figure 4.13 shows the interface for the researcher to launch the MPA, with buttons to specify which informant number the Mind Palace should be saved under. Figure 4.14 shows the Firebase interface that contains the HTML codes of the 12 informants. Figure 4.15 shows how the pure HTML code is stored, according to the number of the informant.

- Requirement 5:
  The literature recommends that the user be able to interact through natural interaction. This was partially solved by the orientation in the 360° environment by moving ones head. When it came to navigation, the GEAR VR's lack of positional tracking was limiting. When it came to user input, however, speech recognition could be implemented, so that the user could "talk objects into existence". By using the Web Speech Recognition API by Google, the words the user would say were recorded, stored in a variable, and assigned different inputs to different JS functions. An example of this would be "Place Cat", where the first word of the string would be a function, and the second word act as a parameter to that function. After some work with the Web Speech API, it was possible to store the input of the microphone in a variable, and by analysing it, execute different functions.

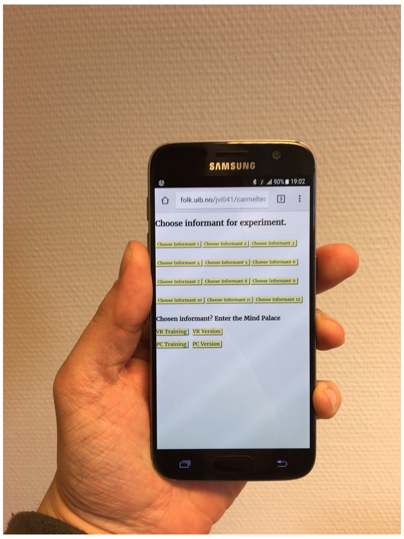



Figure 4.13: Interface to launch the MPA

In addition to using this for input on instantiating of objects, this was also used for walking. A user would say "Go" and "Stop", and this would execute the walking functionality as were mentioned isolated in requirement 2. Thus, a user could now navigate and move about in the 3D VE, and instantiate objects to any association he or she might have by issuing voice commands.

- Requirement 6: Allocentric view.
  Creating an allocentric view, that is a map in bird-perspective of the VE, proved to be challenging in terms of time and development. Instead, as an attempt to replace this, a blueprint of the MPA architecture will be printed and shown to the informants before the experiment.

- Requirement 7: Egocentric view
  The requirement of egocentric view was already solved by the use of A-frame. The camera viewpoint and layout of the whole ordeal is made in such a way that the camera viewpoint acts as your eyes in the environment. By changing the height of the camera somewhat, and the speed of the movement, the egocentric view and navigation of the MPA was optimised.

- Requirement 7: Landmarks
  The requirement of landmarks, or objects as reference points, were rather loosely integrated in the general designing of the VE. The main design involved the idea of having five different rooms/areas with objects in them to act as reference points. These objects should be relatively 'normal', so that the user would not perceive the objects as being significant, but rather that they were used to create a certain atmosphere, a certain *kind* of room. As it is normal in the MOL to use one's apartment or house, the MPA aimed to replicate this.


Figure 4.14: Firebase: overview of MPA storage

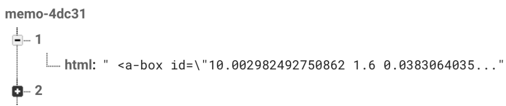



Figure 4.15: Firebase: HTML code storage

The VE consisted of an office / library, a living room, a kitchen, an outside area and a garage. The office (Figure 4.16), is illustrated by a desk with a computer and a bookshelf.

The living room (Figure 4.17) consisted of a sofa and a TV, while the kitchen (Figure 4.18) had a dining table and a bar.

The outside area did not have a roof, but instead a sky, and some plants, viewable in figure 4.19.

The garage had a car in it (Figure 4.20). As for landmark use, the doors were quite wide and numerous, so that it would be possible to spot the different rooms while in another room. This was an attempt to visualise the reference points at all times.

- Requirement 9: Desktop VR Version
  By using A-frame, there was not really any extra work in optimising the application for the desktop. Interaction with the DVR application, however, unlike the VR group, would not use any speech to control the events, but rather mouse and keyboard for interaction, clicking to place a box, and specifying the keyword through the keyboard.

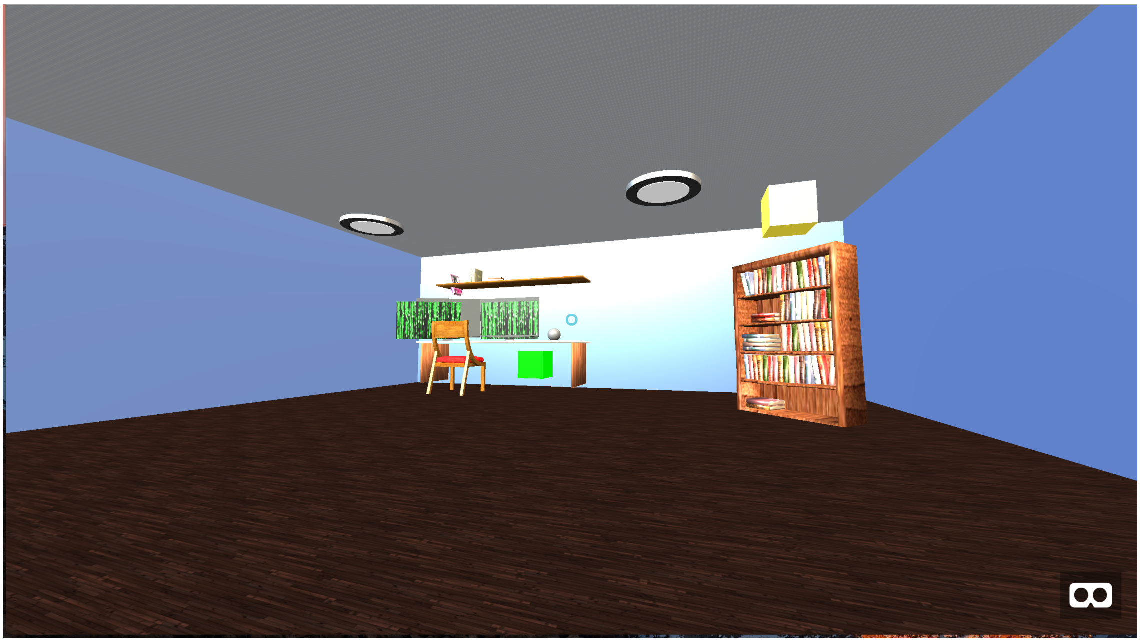


Figure 4.16: MPA: Office

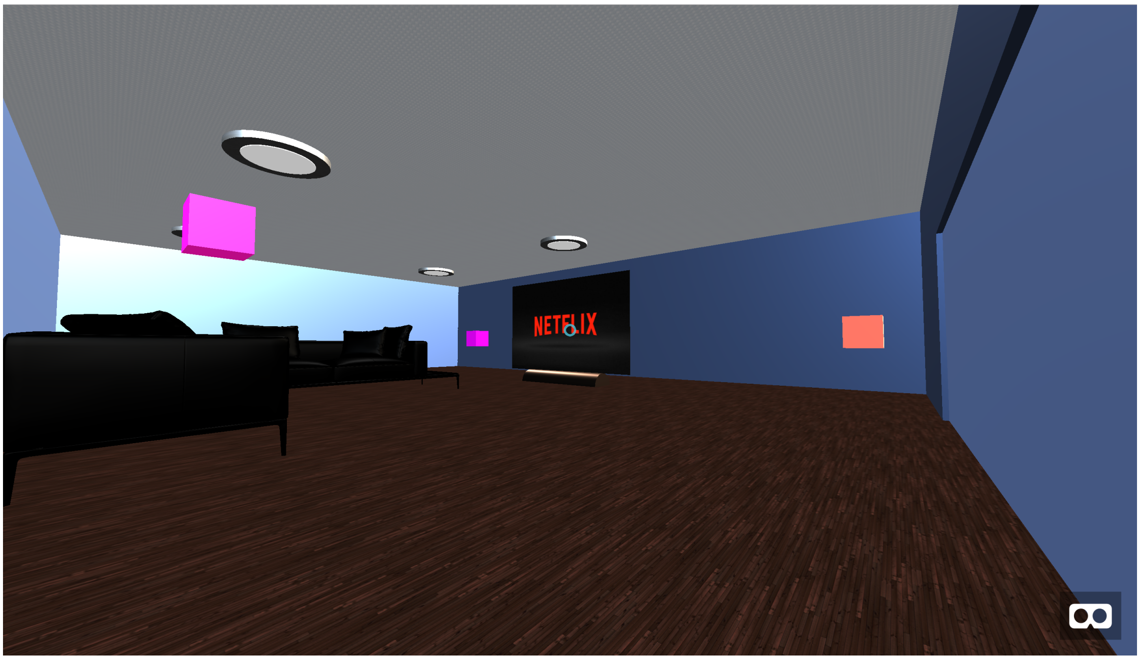



Figure 4.17: MPA: Living room

Figure 4.18: MPA: Kitchen

Figure 4.19: MPA: Outside area


Figure 4.20: MPA: Garage

## 4.3 Coding

In the previous section the application design was discussed. This section concerns the process of implementation and development of this design. In this section, the development process and any issues concerning it will be presented. All the development was done by one developer in the course of approximately four months. During most of the development, the code was written and previewed in Google Chrome on a desktop PC. When each feature was considered complete in the Chrome browser, it was tested in VR in the Samsung Internet Browser. During this stage there would often be another stage of debugging to optimise it for VR. This proved to be challenging as it was hard to isolate what went wrong when in VR. Traditionally, one uses the developer tools in the browser to distinguish which event or JS-line that is not firing. This is not available on the Samsung phone, however, as the whole device is busy creating the VE. It is possible to use Wi-Fi debugging for this, but this did not succeed, therefore, for some time in the development process, there were lots of "shots in the dark". Apart from this, the development went smoothly. A-frame is a neat framework that enables web developers to create applications in VR with normal, straight forward JS DOM manipulation. JS can be used to create, remove and transform the VE at user input, which is all that is necessary in order to create a dynamic VE.

## 4.4 Testing

When all of the requirements were developed, it was time to test the application. During the testing several issues in need of a solution arose. These issues will be addressed throughout this section. The testing was done by five information science master students, and the developer.

#### Web Speech API

Although the Web Speech function of the MPA worked in terms of executing functions and storing parameters – this feature brought other issues to light. During the development of the Web Speech Interface, the functionality was tested on desktop computers and on the Samsung phone in non-VR mode. Although it worked well, a great disadvantage was uncovered. When immersed in the VE, one no longer had access to a physical list of the elements which one is to place. One would have to go in and out of the VE every other word, and this was found to be an annoying element. This way of interacting would then only work well if one remembered all the memory items, and if one remembered all the memory items, one would not have to use the application. It was decided, therefore, that the user should input the keywords before entering VR – and in such case, as it won't add anything to the immersion any longer, it would be easier to do it by entering text.


Figure 4.21: Interface 1

Also during testing, the web speech API occasionally, though quite seldom, got the wrong word, which was an annoying aspect. Therefore, this approach was abandoned in favor of non-natural interaction. Instead, a graphical user interface was implemented, see Figure 4.21, where the user entered the names of the things to be visualised beforehand by text.

### Altering the MOL-instructions

During the testing and discussing of the research experiment, a mnemonics expert was consulted for advice. He was consulted regarding teaching and informing informants about the MOL. This was to ensure that the application would be a correct representation of the method, and to receive input from him on how to best optimise the theory of the MOL with the software. He suggested to 'alter' the planned instruction of MOL slightly to fit our experiment better. Originally, it was planned that the informants should create individual associations to the items to remember. One would for instance, if using the MPA, write the keyword "Putin" to remind you of Russia, etc. In this test, however, as everyone would be new to the art of associations, the expert suggested to eliminate this part of the method. Through discussion we predicted that the ability to come up with good associations within a given time limit would differ amongst 18 informants who were just informed about the method. A way to do this would be to give the informants objects to remember that could be visualised easily themselves, instead of more complex memory items. Our expert explained that when he went shopping –

he never visualised associations to the things he went to buy, but rather visualised the things themselves. By changing this element of the instruction to the informants, every informant would stand more equal.

This research design change altered the role of user input in the application. As everyone would visualise the things themselves, there would be no need for them to enter the keywords into the application – as everyone would have the same keyword. Entering the keywords would also, in this case, give each informant less time with the visualisations in the VE. Therefore, the list of keywords was hardcoded in the application instead of relying on user input. Thus, it was changed first from being entered by speech, to being entered by text, to not being entered by the user at all.

#### Altering placement

Another way of altering the MOL to make it easier on beginners, was the placement of items. The concern in this case was that the users may have too much freedom of choice, and that this could result in the MOL being performed in a poor manner. There is a fine line between not "using the space well enough", and crowding too many memory items in a room. After the discussion with the expert, it was decided to further minimise the decision making and cognitive load of the informants, but in this way also reduce their freedom to a certain extent. Instead of the users being free to place a box wherever they wanted in the MPA, the design of the room was altered so that there were places reserved for "box-placing". This was a means to reduce time, cognitive load and to be certain that each informant would place their boxes somewhere "natural" and according to the method. It would be harder to compare the results if some informants had placed all of their memory items in one room, while others had spread them out.

To symbolise where a user could place the items, the room was designed with colored boxes, hovering in the room, representing where items could be placed (see figure 4.22) When the user looked at this box for 5 seconds – an image would appear on it. So in this stage, it was changed from having the user place a box wherever he or she wanted, to giving them a placeholder to indicate where they should be placed. The MPA was designed with three and three items together in each room, in five different rooms, making up the total of fifteen items.

#### Walking change

During the testing of the MPA, the main source of frustration came from walking initiated by a voice command. Although it worked fairly well, there was a delay of about 1+ second from when the command was uttered to when the effects took place, creating some confusion when everything started to suddenly move; this was especially annoying when stopping, as one might miscalculate and end up too close to a wall. After some research into different applications on the GEAR VR, the main way of navigating seemed

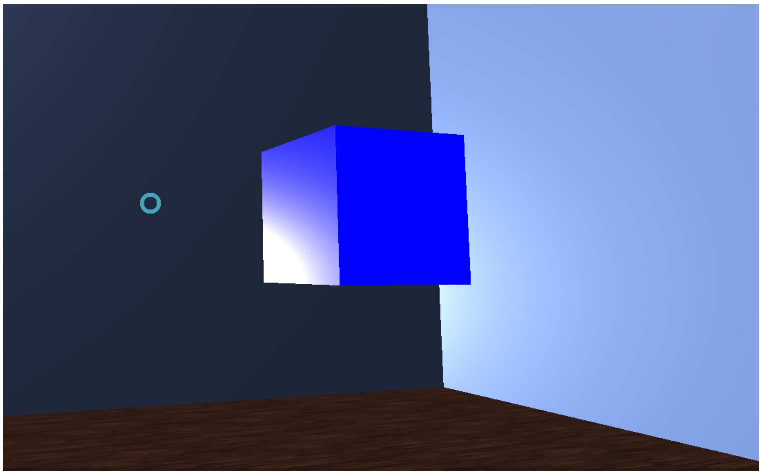


Figure 4.22: MPA: Object placeholder

to be to hold in the touchpad when one went forward. This was implemented, and it seemed to give the user more control. Thus, speech controlled was abandoned in favor of touchbased walking.

#### Browser change

During testing of the MPA, there were some who experienced motion sickness due to low framerates. When testing and comparing this to native applications in the Oculus app on the Samsung S7, the MPA was rather dissapointing. Although the Samsung Internet Browser supported WebVR and input from the GEAR VR headset, it seemed as if the more sensitive gyroscope in the GEAR VR headset were not used. The rotational tracking was comparable to that of Google Cardboard. In trying to address this problem, some changes were made to optimise the application for Google Chrome – which had recently received WebVR support. Google Chrome unfortunately did not support the sensors in the GEAR VR headset either.

Finally, there came news of a browser called "Carmel Developer Preview", a browser created by Oculus themselves. After testing some demos on this browser, it was determined that the browser were able to use the sensors in the GEAR VR headset. As this would reduce nausea and overall framerates, comfort etc., it became the top priority to make this work. The browser is still very experimental, and does not even have the possibility to enter an URL. Websites could be launched from other browsers, however, if one entered "ovrweb://" before the normal URL. Originally, the MPA would not work in the browser, only displaying a black screen. Eventually after some changes, it worked – but the touchpad had to be replaced as it no longer worked as it did in the previous browsers. This was only altered slightly, however; instead of pressing the touchpad down, the user had to slide it upwards instead.

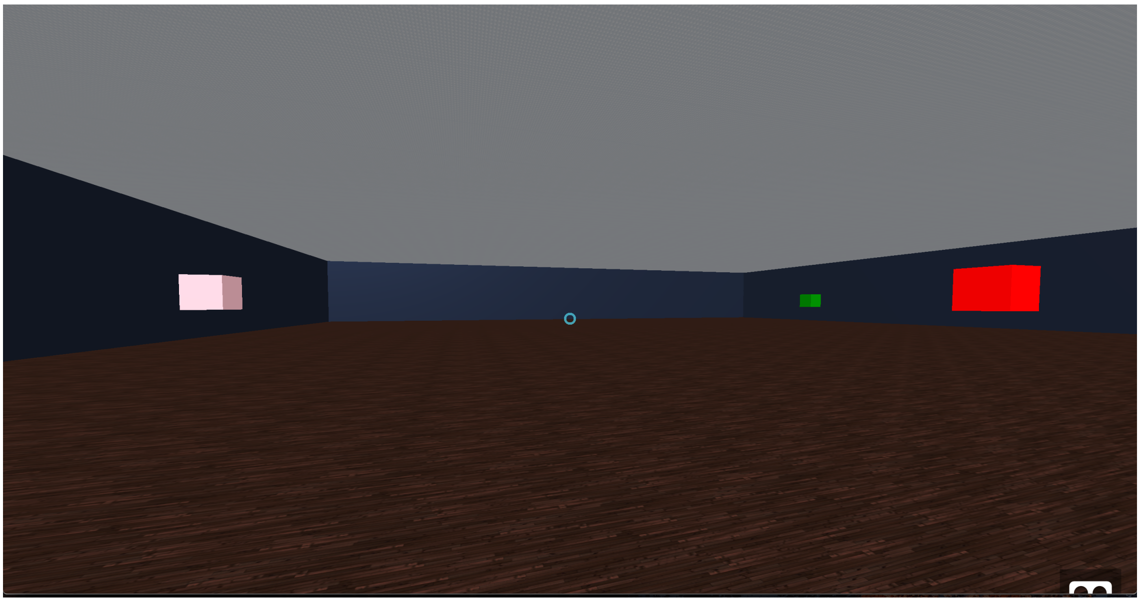


Figure 4.23: MPA: Unfurnished room 1

By this time software sorting movement for GEAR VR could be found at GitHub, and so there was no need to create a new solution as was previously necessary.

#### Performance issues

After furnishing the Mind Palace Application with 3D models, the refresh rate of the application unfortunately dropped. This was discovered quite late in the process, and there was no longer time to look for 3D models that were less forgiving in terms of performance. Because of this, the rooms turned out quite clean and were not very distinguishable from each other. The rooms as they appeared when the furniture was removed, is viewable in Figure 4.23, 4.24, 4.25, 4.26 and 4.27.

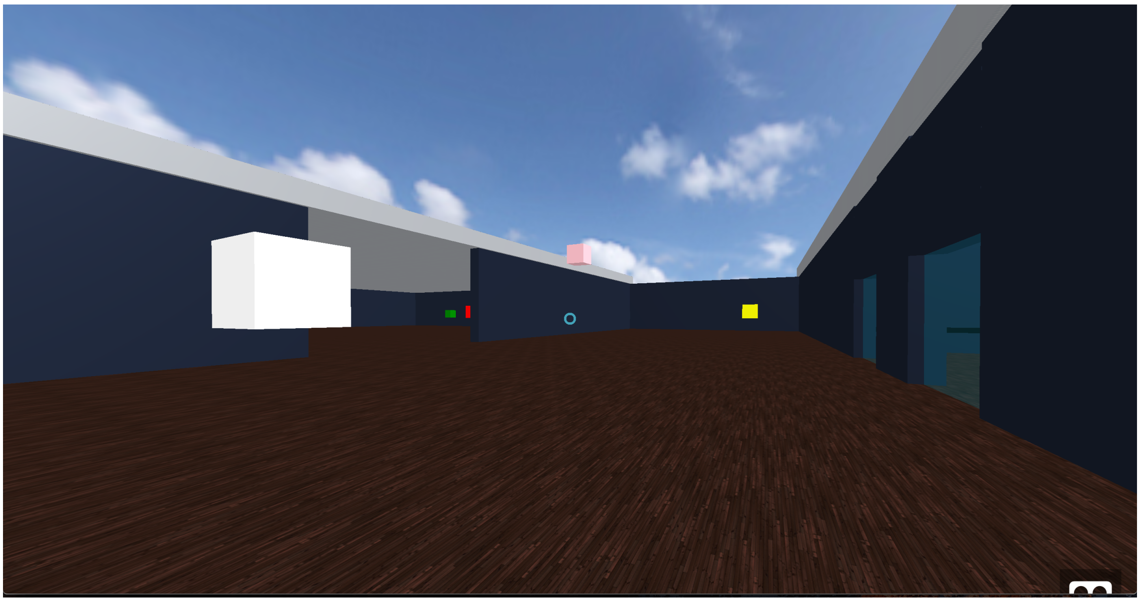


Figure 4.24: MPA: Unfurnished room 2

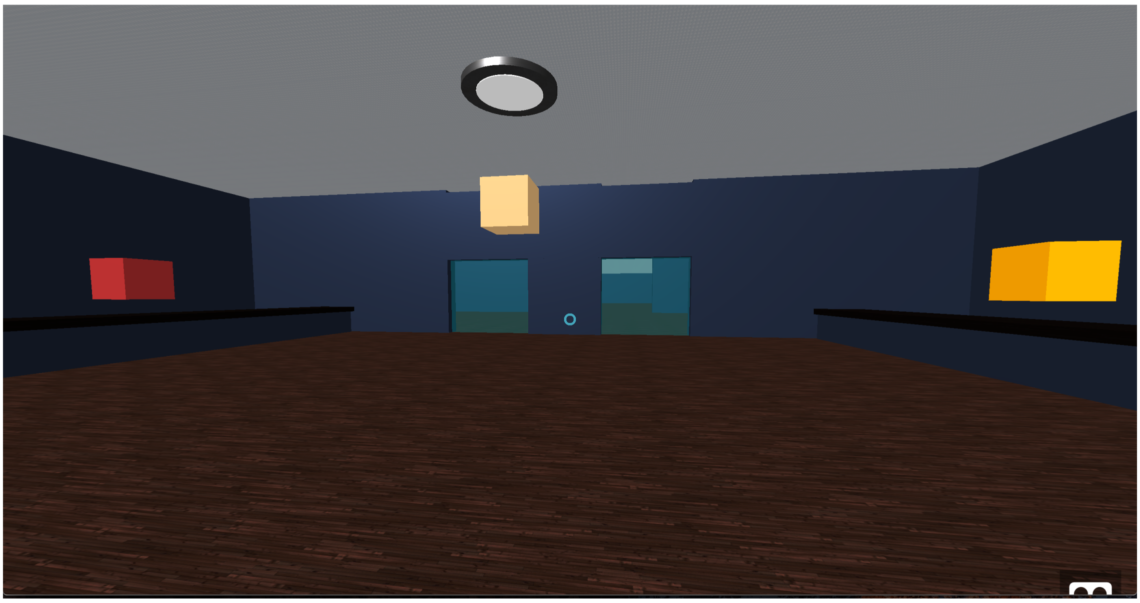


Figure 4.25: MPA: Unfurnished room 3

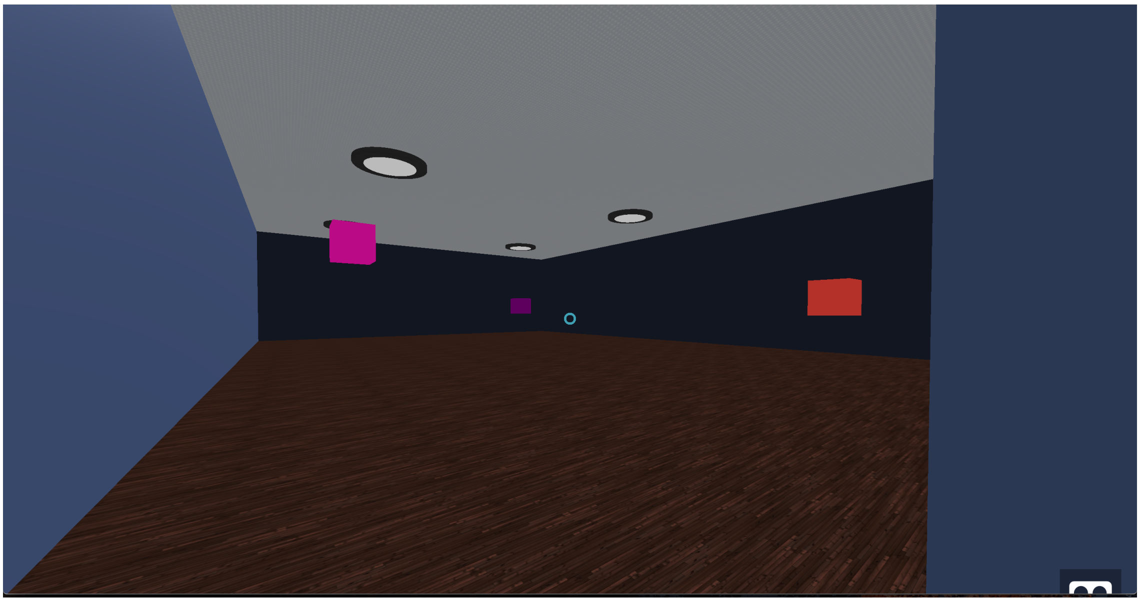


Figure 4.26: MPA: Unfurnished room 4

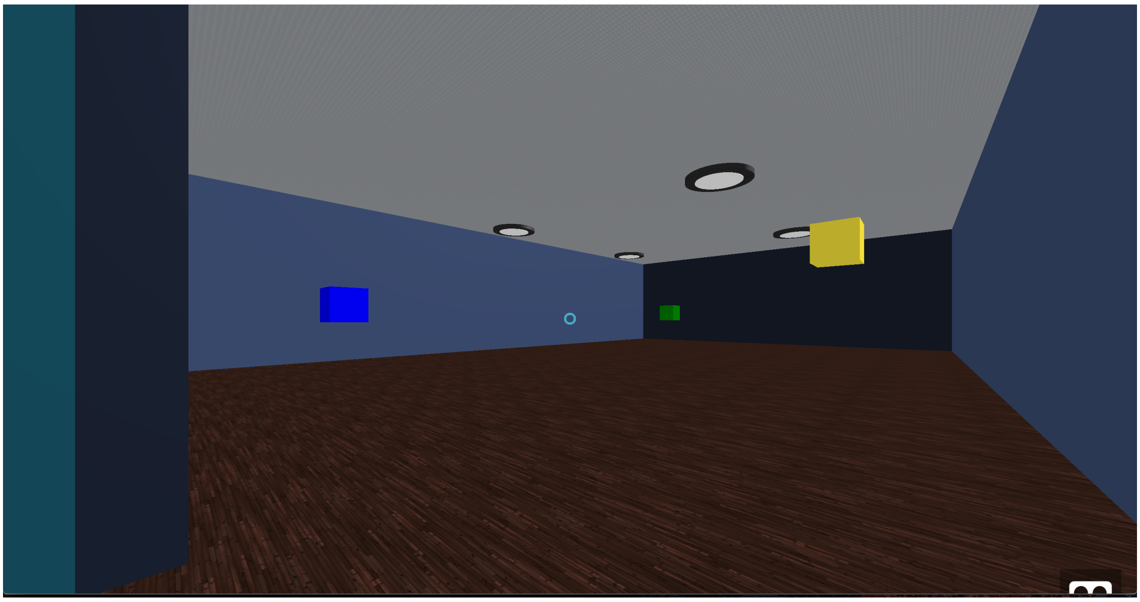


Figure 4.27: MPA: Unfurnished room 5

# 5 Results

In this chapter the data gathered in the research experiment will be discussed. First the results from the pilot study will be presented, as these results impacted the design of the main experiment. Second, the results from the experiment will be presented in the order of the IVR group first, the DVR group second and finally the 0VR group. When each group has been presented, comparisons across groups will be presented. Within each group, we will start by presenting the answers on the pre-questionnaires, then the experiment results, and finally their answers on the post-questionnaires and the interview. A total of 18 informants participated in the experiment. Over three days, six participants were involved each day. The students were recruited from a variety of fields, e.g antropology, media studies, pedagogy, information science, marine biology, etc. Information science had most representatives, with 6 out of 18 informants. Each experiment took approximately 35 minutes to complete.

## 5.1 Pilot study

A pilot study was conducted with five informants, who were Information Science students at the University. With a max cap of 12 memory items, the informants remembered from 8 to 11 items. It was therefore decided to raise the number of memory items to remember to 15 as an attempt to keep the roof high enough.

## 5.2 Immersive VR Group

In this section, the results from the IVR group will be presented. This section is divided into four subsections: 1) Pre-questionnaire, 2) Experiment, 3) Post-questionnaire and 4) Interview. The results from pre-questionnaire, experiment and post-questionnaire are sorted after spatial ability, and gathered in table 5.1. Questions regarding motion sickness, balance disorders and back problems are gathered in table 5.2. The codes and abbreviations in Table 5.1 are explained in the subsection in which they are presented and referred to.

Table 5.1: IVR Comparison

| Info no. | Spatial ability | Gender | Age | Vision | Memo. pretest | Memo. exp. | Memo. 1 week | MOL | ITQ | VG habits | Additional mnemonic | VR exp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | M | 25 | N | 9 | 15 | 10 | No | 1 | Seldom | Yes | Yes |
| 5 | 3 | F | 25 | C | 11 | 15 | 12 | No | 7 | Seldom | Yes | Yes |
| 2 | 1 | F | 23 | C | 11 | 15 | 15 | Yes | 10 | Seldom | Yes | No |
| 4 | 1 | M | 33 | G | 11 | 12 | 5 | Yes | 9 | Every week | No | Yes |
| 3 | 1 | M | 27 | RG | 7 | 11 | 11 | Yes | 9 | Every week | No | Yes |
| 6 | 1 | F | 25 | N | 10 | 11 | 11 | No | 10 | Seldom | No | Yes |

### 5.2.1 Pre-questionnaire

The pre-questionnaire include results on the memory test and the spatial ability test, and personal information such as age and gender of the informants. It also covered whether they had eye sight problems, back problems, physical balance, high susceptibility to motion sickness, video game experience, VR experience and mnemonic experience. The pre-questionnaire questions extracted from the Immersive Tendencies Questionnaire are also presented.

#### Spatial ability results

The results from the spatial ability test, see table 5.1, where the maximum possible score was 5, ranged from 1-4. The median was 1, while the average score was 1.83.

#### IVR Memory Pretest results

The results from the memory ability test, see column "Memo. pretest." in table 5.1, where the maximum possible score was 12, ranged from 7 - 11. The median was 10.5, while the average score was 9.8.

#### Age and Gender

The informants in the IVR group ranged in age from 23 to 33. The average age was 26.3 years. There were equal amounts of male and female informants.

#### Vision problems

The informant's vision status, see table 5.1, are coded after "N": for normal, "C": for contact lenses, "G" for glasses, and "RG" for reading glasses. None of the informants reported any uncorrected vision problems. Two informants used contact lenses, while

Table 5.2: IVR comparison

| Informant number | Balance problems | High susceptibility to motion sickness | Back problems |
|---|---|---|---|
| 1 | No | No | No |
| 2 | No | Yes | No |
| 3 | No | Yes | Yes |
| 4 | No | No | Yes |
| 5 | No | No | No |
| 6 | No | No | No |

one informant used glasses, and another informant used reading glasses when reading over longer periods of time. In the case of the informant who used glasses, it was tested whether her vision worked well uncorrected, as the HMD is very close to the eyes. This turned out to not be a problem. The informant using reading glasses guaranteed this would not impact his focus for such a short duration.

#### Balance, back problems  motion sickness

None of the informants reported any issues concerning physical balance. Two of the informants specified that they had a high susceptibility to motion sickness, and two informants informed that they had back problems. Data on these questions are viewable in table 5.2.

#### Video game and VR experience

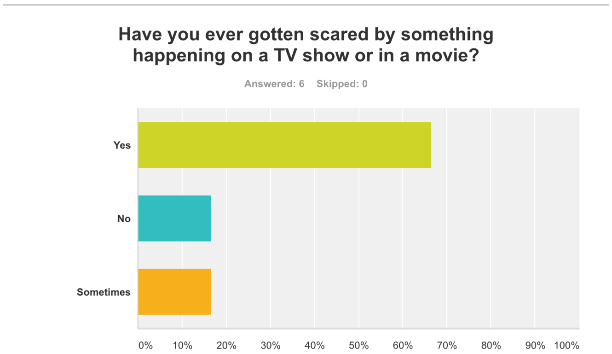
Video game and VR experience are also viewable in table 5.1 under the columns “VG habits” and “VR exp.”. Five of the six informants in the IVR group had previously used VR HMDs. When asked how often they played videogames, two informants answered that they played every week, while four informants stated that they seldom played.

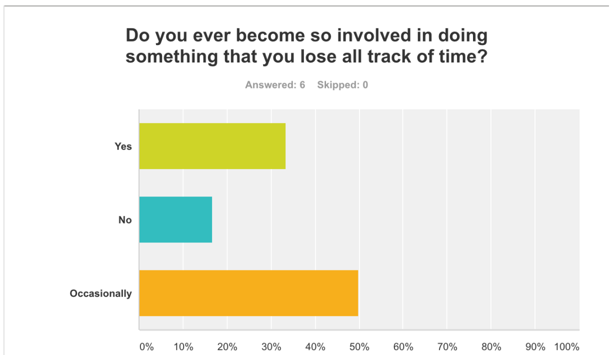
#### Mnemonic experience

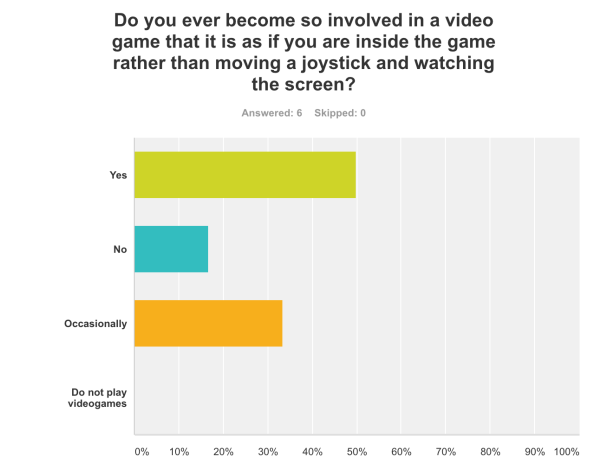
Previous experience with the MOL is viewable in table 5.1, under the column “MOL”. When asked whether they had any experience with mnemonic strategies or memory techniques, three informants answered no. The other three answered yes, and were therefore asked to specify which ones they knew of. All of these informants referred to the MOL. Thus, fifty percent of the informants in the IVR group knew about the MOL prior to the experiment.

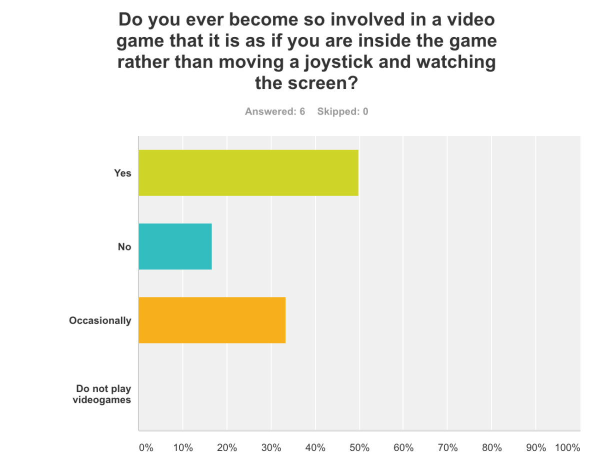
**Immersive tendencies**

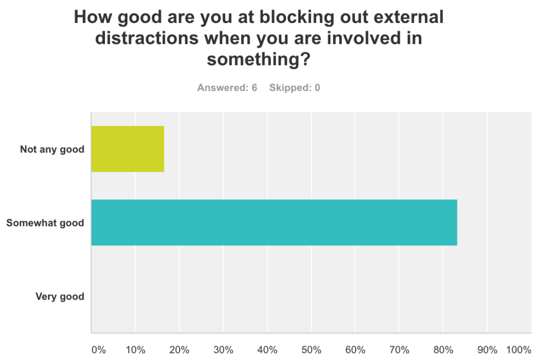
In this section, the informants answers on the six questions extracted from the Immersive Tendencies Questionnaire are shown. These questions and answers are illustrated graphically with SurveyMonkey, the software used to collect the questionnaire. Each informant is given a “score” meant to indicate their level of immersive tendencies. This score is based on numerating the different alternatives on the different questions to 0, 1 and 2, and adding the total. This score is viewable in table 5.1, under column “ITQ”. The maximum possible score in terms of immersive tendencies is twelve, as each question maximally can give two points of immersion. The average within the IVR group was 7.6 out of 12 points of immersion.

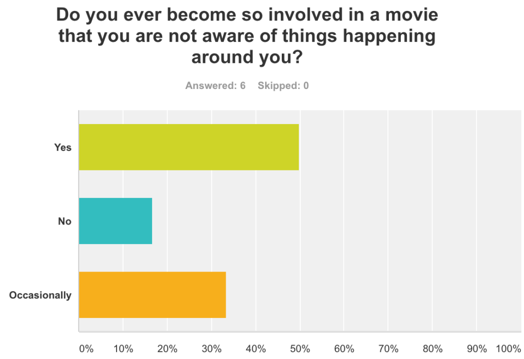




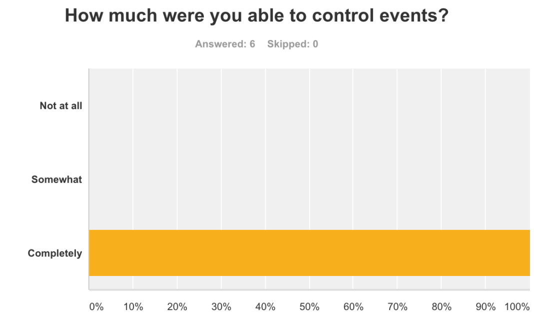



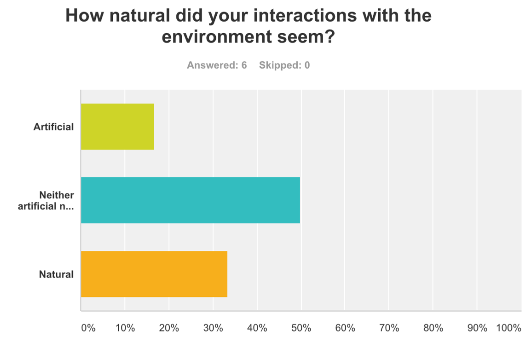

### 5.2.2 Memory Experiment

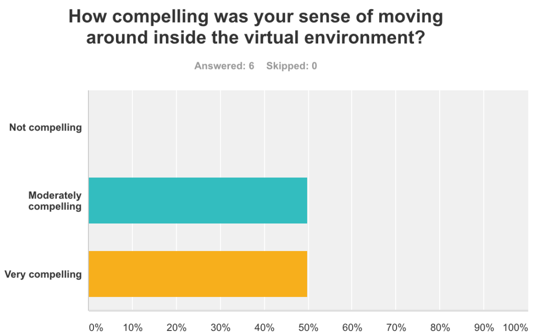
In this section, the results from the experiment for the IVR group will be presented, that is, their score on the memory experiment using the MPA. On average, the informants in the IVR group remembered 13.1 out of 15 items. When asked again about the results, the week after, the informants remembered on average 10.6 items. Both results are illustrated in table 5.1 under the columns "Memo exp." and "Memo 1 week".

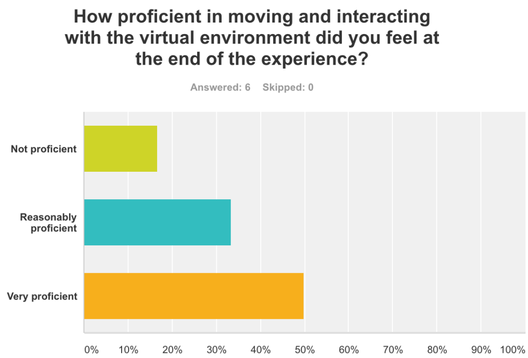
### 5.2.3 Post-questionnaire

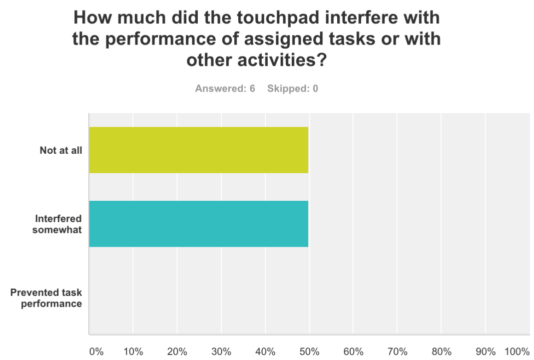
In this section, the informants answers on the post-questionnaire will be presented. These are mainly the questions extracted from the Presence Questionnaire by Witmer and Singer (1998), but also some other questions regarding their experience of the use of VR. These other questions regarded use of allocentric view in remembering of memory items, questions about irritability, nausea and enjoyment, and whether they felt present in the VE. These are presented as visual screenshots from SurveyMonkeys graphical representation.

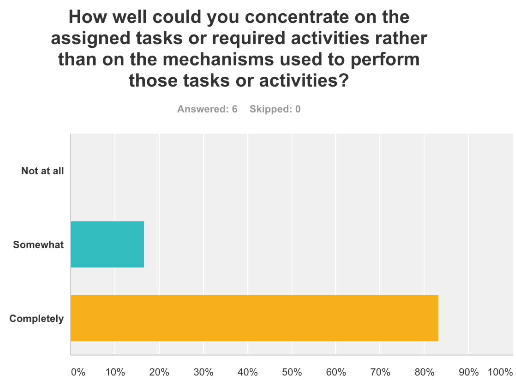

How much were you able to control events?
Answered: 6 Skipped: 0
Not at all
Somewhat
Completely
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

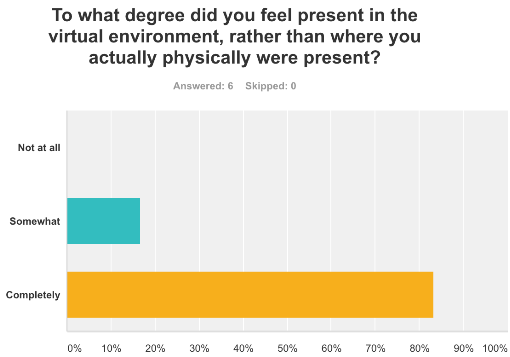

How natural did your interactions with the environment seem?
Answered: 6 Skipped: 0
Artificial
Neither artificial n...
Natural
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

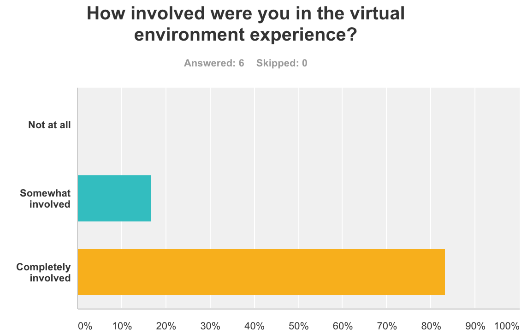

How compelling was your sense of moving around inside the virtual environment?
Answered: 6 Skipped: 0
Not compelling
Moderately compelling
Very compelling
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

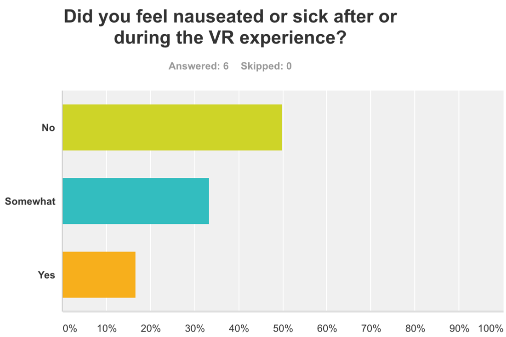

How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?
Answered: 6 Skipped: 0
Not proficient
Reasonably proficient
Very proficient
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

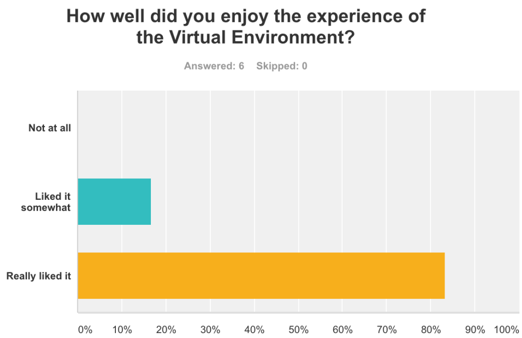

How much did the touchpad interfere with the performance of assigned tasks or with other activities?
Answered: 6 Skipped: 0
Not at all
Interfered somewhat
Prevented task performance
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

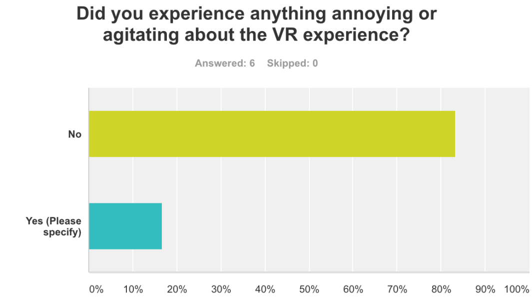

How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?
Answered: 6 Skipped: 0
Not at all
Somewhat
Completely
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

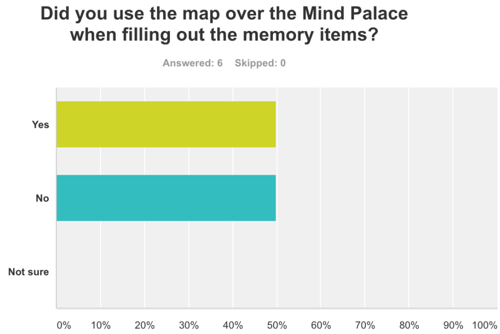

To what degree did you feel present in the virtual environment, rather than where you actually physically were present?
Answered: 6 Skipped: 0
Not at all
Somewhat
Completely
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

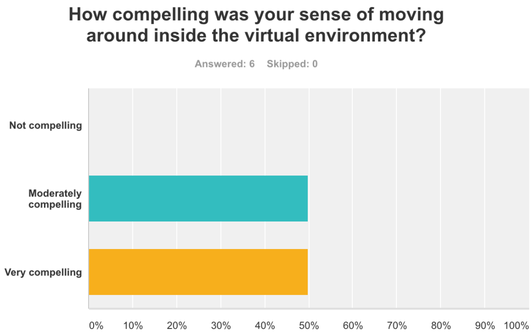

How involved were you in the virtual environment experience?
Answered: 6 Skipped: 0
Not at all
Somewhat involved
Completely involved
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%


Did you feel nauseated or sick after or during the VR experience?
Answered: 6 Skipped: 0
No
Somewhat
Yes
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%


How well did you enjoy the experience of the Virtual Environment?
Answered: 6 Skipped: 0
Not at all
Liked it somewhat
Really liked it
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%




### Comments in questionnaire

On the question "Did you experience anything annoying or agitating about the VR experience", informants who answered yes were given the opportunity to leave comments. The only informant who answered yes commented that he felt the movement through the room was unnatural.

### 5.2.4 Interview

After the informants had answered the post-questionnaire, an interview comprising seven questions followed. The interviews lasted approximately five minutes for each informant. This section will introduce these interviews, and a selection of the answers the different informants gave. Each question will be stated before the informants answers are presented. The interviews were recorded, transcribed, and read through before organised into this section.


Figure 5.1: Wordcloud on the VR experience

#### The experience

**Q1: How did you find the experience of the Virtual Environment, in general?**
Informant 1 informed that it was very exciting. He had always wanted to explore VR, but had never had any chance before. Informant 2 said it felt natural. To explain her experience, she said: "When I took of my glasses, it felt like "Wow, am I here?"". She described herself as engrossed in the VE. Informant 3 and 4 were a little less enthusiastic, explaining the experience as "alright". Informant 5 described the experience as "fun and exciting", explaining that she also really enjoyed memory tests. Informant 6 described that she found being in VEs very fun, no matter what it was, and that it was exciting. A wordcloud based on the adjectives used to describe the VR experience can be seen in Figure 5.1.

#### Annoying elements

Themes: *Simulator sickness, lack of detail, artificial movement*
**Q2: Was there something you did not like about the experience?**
Informant 1 informed that he became somewhat nauseated, and ascribed this to the combination of concentrating hard and being in VR at the same time. Informant 2 also complained of some simulator sickness, however, this only happened during the VR training. After commenting on this, she was told to try to avoid going forward whilst changing direction of movement, that is, moving the head. She followed this advice, and did not experience any simulator sickness during the memory experiment.

Informant 3 complained that the rooms were very similar and of same colors, and thought that if they were more detailed it might be easier to connect memory items to the rooms. He also mentioned that the moving did not feel very natural, and as there were no natural acceleration, he felt like a drone flying slowly through the space. Informant 5 experienced some trouble with the focus in the VR headset, but stated that she forgot this during the experience. It did not seem to impact her performance or view of the memory items, and she commented that it was easy to spot the different boxes of images because of their size. Informant 6 complained that it took some time before she knew that she could place boxes from a distance, and that she had needlessly used too much time navigating close to the boxes. Informant 6 also specified that she thought it might help if the rooms were somewhat more furnished.

#### Positive elements

Themes: *Natural spaciousness, memorable images, immersion*
**Q3: Was there anything about the experience you particularly enjoyed?**
Informant 1 explained: "I found the spaciousness to be natural. I forgot where I really was, and fully and wholly thought about where I should move within the virtual room". Informant 2 and 5 specified that they liked the outside area, where they could view the sky. Informant 3 recalled that he specifically enjoyed one of the memory items, the image of a dog. He commented that it was a funny image, and therefore more memorable than the others. He compared this to a rather boring stock image of a lightbulb, which had the opposite effect. Informant 4 was positively surprised about the quality delivered by this specific VR technology, that the GEAR VR "actually weren't too bad". Informant 5 specified that she liked how the rooms were clean and relatively unfurnished. At first, she became worried she might not be able to distinguish between them, but when they were filled with memory objects she was glad that this was the case, as she thought it might have been too much details in the room otherwise. Informant 6 was positively surprised that although the graphical environment was "obviously artificial", she still felt very immersed.

#### Stress

**Q4: Did you feel stressed during the experiment?**
Informant 1, 3, 4 and 5 answered they did not feel stressed. Informant 2 became a little stressed because of the time limit, because almost 4 out of 5 minutes had passed, and she had not placed all the items yet. Informant 6 also became a bit stressed in terms of time when the experience almost was at an end. This was the same informant who had used more time in walking up to objects unnecessarily.

#### Additional mnemonics

**Q5: Did you use any mnemonics "on top" of the application?**
Informant 1 mentioned that he always placed the right box in the room first, and went from right to left. He also mentioned that towards the end he felt the need to create a story, because he did not get much time to look at the last objects he had placed.

Because of this he created a story where he needed [glasses] to witness the [policeman], where both glasses and policeman were the objects to remember. He also found it natural to couple three and three items, as there were three items in each room. Informant 2 and 5 also created stories, but for every item in the room. For instance informant 2 informed that she made a story where she sat in a [chair], and ate [ice cream], and used a [scissor] to cut the ice cream cone off, because she didn't like it. She created similar stories for all the different memory objects.

Informant 3 and 4 did not create any such stories. Informant 3, however, noticed that in one of the rooms three of the objects had the same capital letter, making it easier to remember. Informant 6 told that the only relevance she saw between the items was that some things had the same colour, the scissors, the spaghetti and the umbrella – and used this as a way to remember them. Apart from this, she did not create any stories or anything similar.

#### Memory effect

**Q6: Do you believe the application assisted you in recalling the items?**
Informants 1, 2, 3, 5 and 6 agreed that the application helped them remember the items. Informant 4, however, who were familiar with the MOL from beforehand, did not find using the application helpful. He explained: "This was much because the room was unknown to me. It became another element I had to remember, in addition to remembering the items themselves". He was then further queried if he thought he would do better by just performing the MOL without the application, and he was certain that would be the case.

#### Other

**Q7: Do you have anything to add that you think may be of importance?**
Informant 1 specified how it worked really well for him, and that he just as easily could repeat those fifteen things at the end of the interview. None of the other informants had anything to add.

## 5.3 Desktop VR Group

In this section, the results from the DVR group will be presented. Like the previous group, this section is divided into four subsections: 1) Pre-questionnaire, 2) Experiment, 3) Post-questionnaire and 4) Interview. The results from pre-questionnaire, experiment and post-questionnaire are sorted after spatial ability, and gathered in table 5.3

Table 5.3: DVR Comparison

| Info no. | Spatial ability | Gender | Age | Vision | Memo. pretest | Memo. exp. | Memo. 1 week | MOL | ITQ | VG habits | Additional mnemonic |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 5 | M | 23 | RG | 11 | 15 | 13 | Yes | 10 | Every week | Yes |
| 9 | 4 | F | 21 | N | 8 | 15 | 13 | No | 3 | Never | Yes |
| 11 | 3 | F | 25 | N | 11 | 14 | 10 | No | 6 | Never | No |
| 7 | 3 | M | 21 | G | 10 | 15 | 13 | Yes | 9 | Every day | Yes |
| 8 | 3 | M | 24 | N | 12 | 15 | 13 | Yes | 4 | Never | Yes |
| 12 | 2 | F | 26 | G | 9 | 12 | 10 | No | 10 | Seldom | Yes |

### 5.3.1 Pre-questionnaire

First, their scores on the pre-questionnaire will be presented. This involves just the same data as the IVR group, except some questions that only were relevant for the IVR group have been removed. The questions removed were those concerning balance, back problems, simulator sickness and whether they had tried VR headets before.

#### Spatial ability results

The results from the spatial ability test, where the maximum score was 5, ranged within the group from 2 to 5. The median was 3, while the average score was 3.3. The different scores can be seen in table 5.3.

#### DVR Memory pretest results

The results from the memory pre-test, where the maximum score was 12, ranged within the group from 8 to 12. The median was 10.5, while the average score was 10.1. The different scores can be seen in table 5.3.

#### Age and Gender

The informants age ranged within the group from 21 to 26. The average age was 23.3 years. There were equal numbers of male and female informants. The different values can be seen in table 5.3.

#### Vision problems

None of the informants reported any uncorrected vision problems. Two informants used glasses, while one informant used reading glasses when sitting in front of a screen for several hours. The glasses did not pose any problems, as these informants did not have to wear an HMD like the IVR group, and could keep their glasses on. Which informants used glasses can be seen in table5.3.

### Video game experience

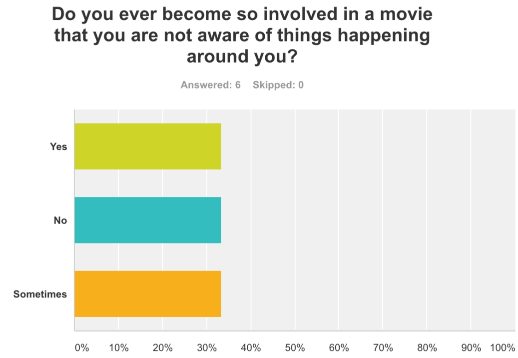
Three of the informants informed that they never played computer games. One informant filled out that he played every day, another played every week, and the last informant seldom played any video games. These answers are viewable in table 5.3.

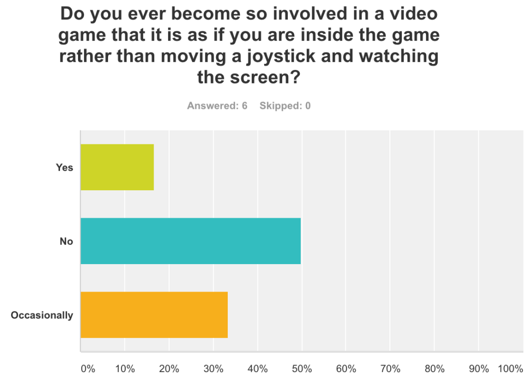
### Mnemonic experience

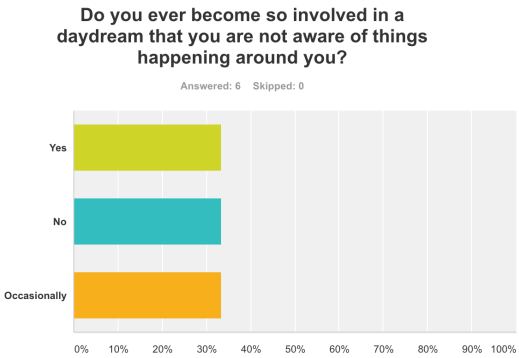
When asked if they had any experience with mnemonic strategies or memory techniques, three of the informants answered yes, and the other three answered no. One informant specified that he had learned about the MOL in a psychology class, and knew how to use it. The two other informants also referred to the MOL in some or other way, but none of them were 'heavy users' of the method. These answers are viewable in table 5.3.

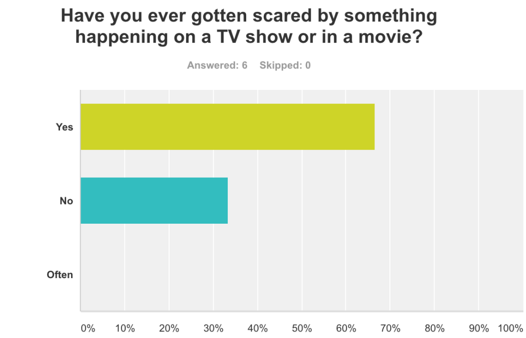
### Immersive tendencies

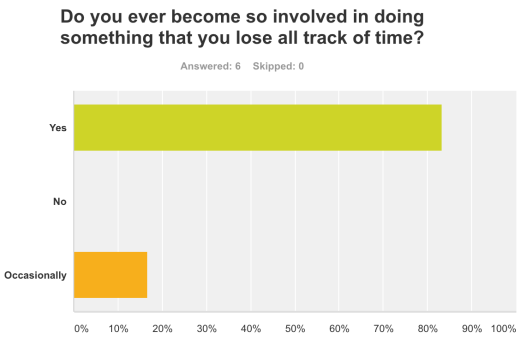
In this section, the informants answers on the six questions extracted from the Immersive Tendencies Questionnaire are presented. As in the previous section, there will also be a table representing their Immersive Tendencies score, generated from these answers. The average score of the group was 7, while the highest possible score was 12. The scores are viewable in table 5.3. The answers on the questions are viewable in the illustrations from SurveyMonkey:

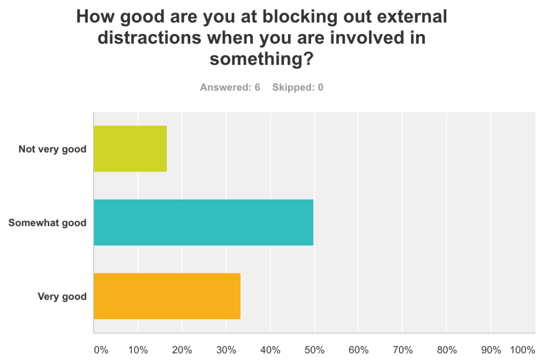


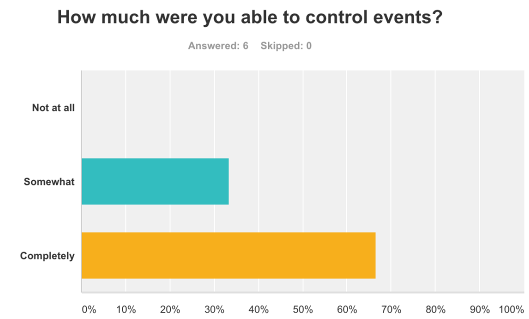



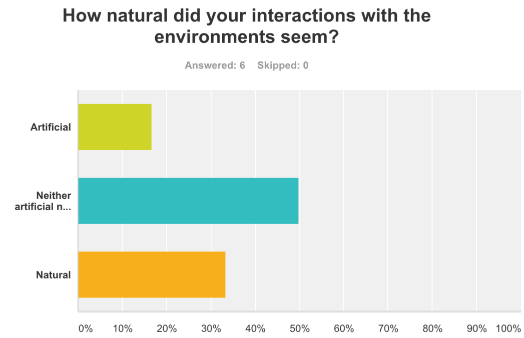

### 5.3.2 Memory Experiment

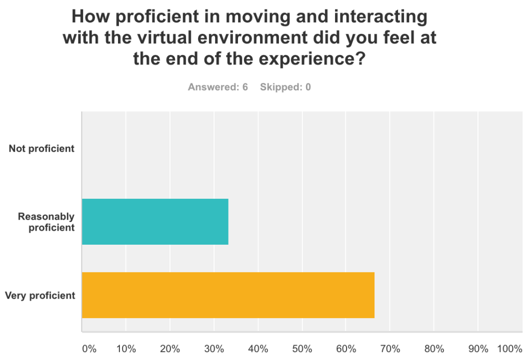
In this section, the results from the memory experiment for the DVR group will be presented, that is, their score on the memory experiment using the DVR MPA. On average, the informants in the DVR group remembered 14.3 items. When asked again about the results a week after, the informants remembered on average 12 items. Both results can be viewed in table 5.3.

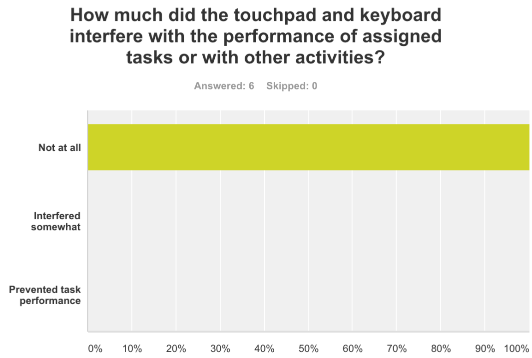
### 5.3.3 Post-questionnaire

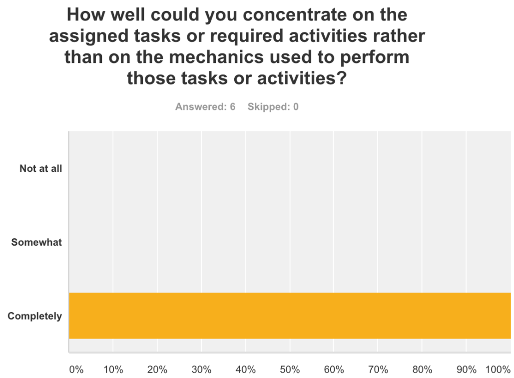
In this section, the informants answers on the post-questionnaire will be presented. Just as for the IVR group, this is mainly questions extracted from the Presence Questionnaire by Witmer and Singer (1998), but also questions regarding their experience of the application. Some questions are not included in this questionnaire, as they are only relevant for Immersive VR. An instance of this can be the question "How compelling was your sense of moving around inside the virtual environment?". The questions from the post-questionnaire are viewable in the illustrations from SurveyMonkey:

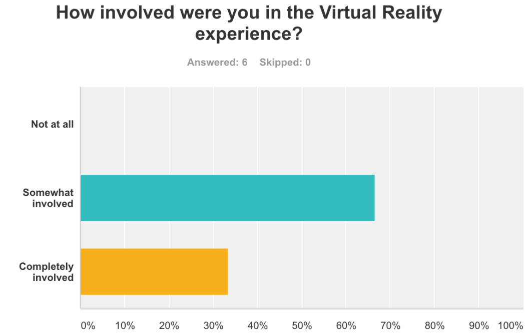


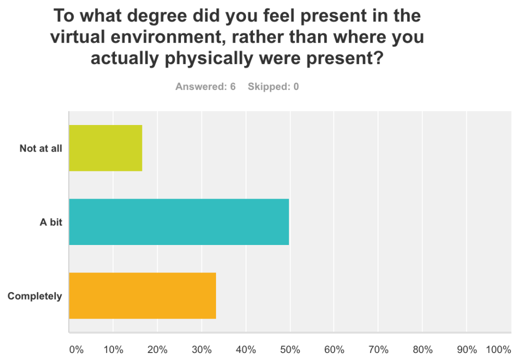



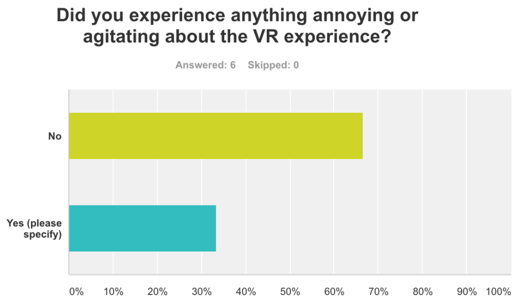










### Comments in the questionnaire

On the question “Did you experience anything annoying or agitating about the VR experience”, informants who answered yes were given the opportunity to leave comments. There were two informants who answered yes in the DVR group. One of them found it annoying that he could not run, jump or crouch in the DVR MPA. Another informant noticed a bug that prevented him from accessing a room towards the end of the session.


Figure 5.2: Wordcloud on the Desktop VR experience

### 5.3.4 Interview

This section presents the informants answers to the seven questions in the interview after the post-questionnaire. The DVR group were asked the same questions as the IVR group, and the answers will be presented in the same way.

#### The experience

**Q1: How did you find the experience of the Virtual Environment, in general?**
Informant 7 and 9 and 11 described the experience as "OK". Informant 8 described it as being "alright and understandable", while informant 10 described the experience as "smooth". Informant 12 explained that it felt like a game. A wordcloud generated from the adjectives used to describe the experience can be seen in Figure 5.2.

#### Annoying elements

**Q2: Was there something you did not like about the experience?**
Informant 8 experienced a bug towards the end of the experiment, which was an annoying element. This was the same informant who commented on a bug in the questionnaire. If it had occurred earlier, he said it might have had an impact on his results. Informant 10 and 12 would have preferred 3D models in favor of the cubes, and specified this during this question.

#### Positive elements

Themes: *Easy, dinstiguishable*
**Q3: Was there anything about the experience you particularly enjoyed?**

Informant 8 described it as easy to remember the different things in the rooms *although* they were very generic and similar. He said it still was possible to distinguish the rooms from each other, and were positively surprised by this. Informant 9 enjoyed having the allocentric overview of the application, and used this thoroughly during the experiment as a reference point, and to "check" whether she could recall the items. Informant 11 was positively surprised by how much easier it was to remember, compared to using just words, stating that it was "insane". Informant 12 was also surprised by how easy it was to imagine the objects visually afterwards.

#### Stress

**Q4: Did you feel stressed during the experiment?**
None of the informants reported stress during the experiment.

#### Additional mnemonics

**Q5: Did you use any mnemonics "on top" of the application?**
Informant 7 created associations between two items in each room, and remembered the last one as the "odd one out". For instance, in a room where policeman, glasses and fork were present, he pictured the policeman wearing the glasses, and used the fact that fork did *not* fit in the picture as a means to actually remember it. In each room, he claimed to find an item that was the "odd one out". Informant 8 also made a story around the different images, such as "the [glasses] were an old grandmother who couldn't see that the [policeman] were holding a [fork] in his hand". Informant 9 tried to remember the capital letters of each memory item, and made stories for some of the rooms. Informant 9 also said that grouping them in threes helped a lot. Informant 10 used a narrative technique on top of the MOL. For instance, he made a story where he kicked the [ball] so the [lightbulb] shattered, etc. Informant 11 did not use any additional mnemonics in combination with this method. Informant 12 combined words, such as "Policeglasses", and "Ice cream-scissors", and visualised these mentally as well.

#### Memory effect

**Q6: Do you believe the application assisted you in recalling the items?**
All of the informants believed that the MPA helped them recall the memory items. Informant 7 meant that the application definitely helped in remembering items, because it connected them to the locations which he later could revisit. Informant 8 also stated that it "absolutely" helped in remembering the items.

Table 5.4: 0VR Comparison

| Info no. | Spatial ability | Gender | Age | Memo. pretest | Memo. exp. | Memo. 1 week | MOL | Additional mnemonic |
|---|---|---|---|---|---|---|---|---|
| 13 | 5 | M | 31 | 12 | 15 | 14 | No | No |
| 16 | 5 | M | 25 | 12 | 15 | 15 | No | Yes |
| 14 | 5 | F | 24 | 11 | 15 | 14 | No | No |
| 15 | 3 | F | 23 | 10 | 15 | 14 | Yes | Yes |
| 17 | 3 | F | 27 | 9 | 15 | 13 | No | Yes |
| 18 | 2 | M | 23 | 9 | 15 | 13 | No | No |

#### Other

**Q7: Do you have anything to add that you think may be of importance?** Informant 10 stated that it was much more relaxing having it "like this" [meaning the MPA], than creating the route for oneself. He said that when he created his own route in the MOL, he often forgot where he went and placed items, and therefore he enjoyed having something more concrete as a reference, like an explicit correct answer.

## 5.4 0VR group

In this section, the results from the 0VR group will be presented. As for the previous groups, this section is divided into four subsections: 1) Pre-questionnaire, 2) Experiment, 3) Post-questionnaire and 4) Interview.

### 5.4.1 Pre-questionnaire

First, we will present their scores on the pre-questionnaire. This questionnaire is the shortest, as some of the questions from the previous questionnaires are irrelevant for a group that did not use technological aids. For instance, no questions from the Immersive Tendencies Questionnaire were included here.

#### Spatial ability results

The results from the spatial ability test, where the maximum score was 5, ranged within the group from 2 - 5. The median was 4, while the average score was 3.8. The different scores can be seen in table 5.4.

#### Memory pretest

The results from the memory pretest, where the maximum score was 12, ranged within the group from 9 - 12. The median was 10.5, while the average score was 11. The different scores can be seen in table 5.4.

#### Age and Gender

The informants age ranged within the group from 23 to 31. The average age was 25.5 years old. There were equal numbers of male and female informants. The different values can be seen in table 5.4.

#### Mnemonic experience

When asked if they had any experience with mnemonic strategies or memory techniques, two informants answered yes. One of these informants knew the MOL, while one explained "creating sentences based on the words I am supposed to use", most likely referring to a narrative technique.

### 5.4.2 Memory Experiment

In this section, the results from the memory experiment of the 0VR group will be presented, that is, their score on the memory experiment using the MOL in isolation. On average, the informants in the 0VR group remembered 15 items. That means that all the informants were able to recall all of the memory items. When asked again about the results one week after, the informants remembered on average 13.8 items. Both results can be viewed in table 5.4.

### 5.4.3 Post-questionnaire

In this section, the informant's answer on the post-questionnaire will be presented. Out of the three groups, this post-questionnaire is the shortest, containing only two questions concerning their use of the MOL. The first question asked how well they felt they managed to perform the method. To this question, all six informants answered they managed to perform the method "completely". The second question concerned how involved they were in their own visualisations. To this question, all the informants also answered that they were "completely" involved.


Figure 5.3: Wordcloud on the 0VR experience

### 5.4.4 Interview

#### The experience

**Q1: How did you find the experience of using this mnemonic, in general?**
Informant 13 felt it was "pretty smooth". He had placed a few things in his apartment in what he called bizarre ways, like an umbrella in the refrigerator and spaghetti in the bathroom. For the other items, he placed them where he would naturally have had those items in his house, turning it into his own items. The glasses were his wife's, the dog became a toy dog belonging to his son, etc. Informant 15, familiar with the method, said she liked it very much, although she does not use it very often. Informant 16 described the experience as "very fun", and said the story he created became very funny and absurd. A wordcloud generated with the adjectives used to describe the experience can be viewed in Figure 5.3.

#### Annoying elements

**Q2: Was there something you did not like about the experience?**
None of the informants found anything they did not like about the experience of using the MOL.

#### Positive elements

**Q3: Was there anything about the experience you particularly enjoyed?**
Informant 14 said she was surprised by the benefit the MOL could provide when remembering things in a specific order. Informant 16 said he was surprised by how fun it was to perform the method, and how well it worked. Informant 17 and 18 also were positively surprised by how well it worked.

#### Stress

**Q4: Did you feel stressed during the experiment?**
None of the informants in the 0VR group felt any stress during the experiment.

#### Additional mnemonics

**Q5: Did you use any mnemonics in addition to the MOL?**
Informant 13, as explained, integrated the things in the house to his own items. Informant 14 and 18 did not use any additional mnemonics in combination. Informant 15 created stories within the Mind Palace in addition to the placement of the items, such as "I looked at the [clock], figured out I had to hurry to cook [spaghetti], but I messed up and the [plant] started burning, so a [policeman] with [glasses] and a [dog] came...", etc. Informant 16 and 17 also created stories. For instance, informant 17 visualised her dad with an [umbrella] and a [football] in the bedroom.

#### Memory effect

**Q6: Do you believe the MOL assisted you in recalling the items?**
All of the informants in the 0VR group felt the MOL helped them remember the memory items.

#### Other

**Q7: Do you have anything to add that you think may be of importance?**
None of the informants in the 0VR group had anything to add.

## 5.5 Overview of Group Results

A table representing values from all groups is viewable in table 5.5. The table is ranged after informant number. Some rows are blackened for the DVR and IVR group, and these represent the questions these group were not asked in their questionnaires.

Table 5.5: Comparisons between groups

| Info no. | Spatial ability | Gender | Age | Vision | Memo. pretest | Memo. exp. | Memo. 1 week | MOL | ITQ | VG habits | Additional mnemonic | VR exp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | M | 25 | N | 9 | 15 | 10 | No | 1 | Seldom | Yes | Yes |
| 2 | 1 | F | 23 | C | 11 | 15 | 15 | Yes | 10 | Seldom | Yes | No |
| 3 | 1 | M | 27 | RG | 7 | 11 | 11 | Yes | 9 | Every week | No | Yes |
| 4 | 1 | M | 33 | G | 11 | 12 | 5 | Yes | 9 | Every week | No | Yes |
| 5 | 3 | F | 25 | C | 11 | 15 | 12 | No | 7 | Seldom | Yes | Yes |
| 6 | 1 | F | 25 | N | 10 | 11 | 11 | No | 10 | Seldom | No | Yes |
| 7 | 3 | M | 21 | G | 10 | 15 | 13 | Yes | 9 | Every day | Yes | |
| 8 | 3 | M | 24 | N | 12 | 15 | 13 | Yes | 4 | Never | Yes | |
| 9 | 4 | F | 21 | N | 8 | 15 | 13 | No | 3 | Never | Yes | |
| 10 | 5 | M | 23 | RG | 11 | 15 | 13 | Yes | 10 | Every week | Yes | |
| 11 | 3 | F | 25 | N | 11 | 14 | 10 | No | 6 | Every day | No | |
| 12 | 2 | F | 26 | G | 9 | 12 | 10 | No | 10 | Seldom | Yes | |
| 13 | 5 | M | 31 | | 12 | 15 | 14 | No | | | No | |
| 14 | 5 | F | 24 | | 11 | 15 | 14 | No | | | Yes | |
| 15 | 3 | F | 23 | | 10 | 15 | 14 | No | | | No | |
| 16 | 5 | M | 25 | | 12 | 15 | 15 | Yes | | | Yes | |
| 17 | 3 | F | 27 | | 9 | 15 | 13 | No | | | Yes | |
| 18 | 2 | M | 23 | | 9 | 15 | 13 | No | | | No | |

# 6 Analysis and Discussion

In this chapter, the results will be compared and variables of significance analysed. The informant's score on the memory experiment will be analysed together with potentially influencing factors to try to explain the results. The analysis will present as following: First, a comparison of the group's scores according to recall in the memory experiment. Second, the correlations between the informants memory recall scores and several factors will be reviewed, including 1) memory ability, 2) spatial ability, 3) immersive tendencies, 4) presence, 5) enjoyment, 6) interaction, 7) age, and 8) previous experience with the MOL, VR and videogames. The analysis will review results both within and across from groups.

Before the analysis of the results started, each of the twelve Mind Palaces generated by the informants in the experiment were checked for potential errors in execution. No errors were found, so the informants in the Immersive VR Group (IVR) and Desktop VR group (DVR) were able to perform the task as intended. The Mind Palaces of the group without any technological aid (0VR) could naturally not be checked as they did not use software.

## 6.1 Group Comparison of Memory Experiment

The most overarching factor for comparing the results is the group to which the informants belonged. In this section, the different group's performance in the memory experiment will be compared. The 0VR group outperformed both the IVR and DVR group in recalling memory items in the memory experiment. More specifically, the IVR group recalled on average 13.1 items, the DVR group remembered 14.3 items, and the 0VR group remembered 15 items. Similar results were found one week after the exposure to various experimental conditions. After one week, the IVR group remembered on average 10.6 items, while the DVR group remembered 12 items, and the 0VR group remembered 13.8 items. The results suggest that the MOL does not benefit in terms of effectiveness when combined or adapted to technological aids. There are, however, many factors that could have affected these results and these will be discussed further in this chapter.

## 6.2 Group Comparison of Memory Ability

Before the memory experiment, memory abilities were measured. This section will review the relationship between the memory abilities of the different groups and their scores in the memory experiment. This data can enlighten two interesting aspects: 1) which group had the best memory ability beforehand, and 2) whether their memory abilities affected the score using the MPA or the MOL.

The 0VR group had the highest average score with 11 items on the memory ability test prior to the experiment. The DVR group had the next highest average score on the memory pre-test with 10.1, and the IVR group had the lowest average score on the memory pre-test, with 9.8. Thus, just as with the memory experiment scores, the IVR group scores highest, DVR next highest and IVR lowest. This may help to explain the results from the memory experiment, as the IVR group who scored the lowest had informants with lower memory abilities, and the 0VR group who scored the highest had informants with stronger memory abilities. This may suggest that the 0VR group performed best in the memory experiment because of their high memory abilities. To investigate further whether this was the case, which group benefited the most from using the MOL or MPA will be reviewed in the next section.

### 6.2.1 Group Comparison of Obtained Benefit

To understand what group obtained most benefit from the MOL, the memory experiment scores must be reviewed relative to their memory abilities. To obtain data for comparison here, the score from the memory pretest is subtracted from the score from the memory experiment. In this way a measure on how much the MPA/MOL helped is generated. The IVR group had average increase of 3.3 items, the DVR group had an average increase of 4.2 items, and the 0VR group had an average increase of 4.5 items. These results follow the ranking of the memory experiment, showing the 0VR group as superior, DVR group as second best and IVR as the inferior group.

Thus, although the 0VR were the strongest memorists, it is clear that the approach of the 0VR group still offers an advantage in increased items of recall. The high scores of the 0VR group can thus not necessarily be explained only by the high memory ability of the 0VR group. It seems that the 0VR group still offers the most benefit, though an explanation may also be that the MOL works better on good memorists. These principles are the same for the other groups: the increase is lower in the IVR and DVR groups. Either, these results can not be explained only by the low memory ability of the groups, or the results suggest that the higher memory ability one has, the more one benefits from the MPA/MOL.

## 6.3 Spatial Ability

In this section, the relationship between the different group's average score on the spatial ability test and the memory experiment score will be reviewed. Differences between gender will also be reviewed, and it will be presented how the spatial ability results relate to the ability-as-compensator and ability-as-enhancer hypotheses. Finally this section will review the use of allocentric views in terms of spatial ability, and which informants who specified the recalled words in order.

As with memory ability, the 0VR group scored the highest with 3.8 points in spatial ability on average. The DVR group came in second with 3.3 points, while the IVR group had an average of 1.83 points. Within this group, we see that high spatial ability and high memory scores go together. To see if this is a recurrent theme, spatial ability will be compared to memory experiment scores across from groups as well. Those who had a spatial ability score of 1, remembered on average 12.25 items. Those who had a spatial ability score of 2, remembered on average 13.5 items. Those who had a spatial ability score of 3, remembered on average 14.8 items. Those who had a spatial ability score of 4 or 5 all remembered 15 items. These results suggest that the higher spatial ability one has the more functioning the MOL and the MPA is. As the 0VR group had both the highest spatial- and memory abilities, this may explain why they had the highest scores in the memory experiment.

### 6.3.1 Gender

Gender was taken into consideration because the literature suggests that there are gender differences regarding spatial abilities (Barnfield, 1999; Eals & Silverman, 1994). Therefore the effectiveness of VR technology and the MOL may also differ between the genders. In the total of all groups, males on average remembered 14.2 items while females remembered on average 14.1 items. Within the VR groups, males remembered 13.8 items while females remembered 13.6 items. Gender then, does not seem to impact the results. On the spatial ability tests, males scored on average 3.2 while females scored on average 2.7. Although males performed somewhat better than females in terms of spatial ability, and there are clear and consistent links between spatial ability and higher memory items, the gap is not far between males and females in memory scores. This may be explained by the study by Eals and Silverman (1994) stating that although females generally score lower on spatial ability tests, they score higher than men on tests on retrieving object locations which is relevant for the MOL.

### 6.3.2 Hypotheses

According to the ability-as-compensator-hypothesis (Mayer & Sims, 1994), low spatial ability learners tend to obtain more benefit from 3D models because they have difficulties reconstructing visualisations on their own. Another hypothesis, the ability-as-enhancer hypothesis (Mayer & Sims, 1994) states that high spatial ability learners should benefit from the VR-based application as they would use less cognitive efforts in the environment, thus freeing power for mental model construction. In this section the results will be reviewed relative to these hypotheses. The results of informants 1-12 are examined, as these were the only ones who used 3D models through the MPA. For this analysis, informants were grouped into low and high spatial ability learners. Their memory scores will be reviewed, and also by how many memory items their score increased from the pre-test to the experiment.

The low spatial learners (those that got spatial ability scores between 1-2) remembered on average 12.2 items and had an average increase in 2.6 when using the MPA. The high spatial ability learners (those that got spatial ability scores between 3-5) remembered on average 14.8 items, and had an average increase of 5 items when using the MPA. It is thus clear that these results do not support the ability-as-compensator hypothesis, because the high spatial ability learners obtained more benefit from the 3D model delivered by the MPA. Rather, it supports the ability-as-enhancer hypothesis, stating that high spatial ability learners should benefit from the VR-based application as they would use less cognitive efforts in the environment. This suggests that those who possess strong spatial abilities have an easier time reconstructing the VE during recall of the memory items.

### 6.3.3 Allocentric View

This section will review the use of the allocentric overview of the VE during recall. While the informants were asked to write down the items they were able to recall on a sheet of paper, they were provided with an allocentric overview, a map, of the Mind Palace on a sheet of paper. They were informed that they could use this if they wanted to assist them in the recall process. In the post-questionnaire, they were asked whether they used it, and if they used it, whether they found it helpful. In the total of the IVR and DVR groups, fifty percent used the map, and fifty percent did not use the map. All those who used the map felt that it aided them in the process, which of course was most likely why they used it. None of the groups had a higher percentage of map users than the other.

Those who used the map, had an average spatial ability score of 2.83 while those who did not use the map had an average spatial ability score of 2.33. It does not seem that the spatial ability of the informants was a big indicator on whether they wanted assistance in the form of the overview in recalling the VE.

## 6.4 Order of the Recalled Words

The MOL is a mnemonic which is especially used to retrieve memory items in a certain order. This was not specified to the informants, and they were only asked to write the memory items in the order they placed them if they liked to. 16 out of 18 informants found this to be natural, and most of these informants also listed the order correctly, although some informants made some minor mistakes. As almost all the groups attempted to list these in order, it seems that this was not something that followed some groups rather than others.

## 6.5 Immersive Tendencies

In this section the relationship between the different groups scores on the test of immersive tendencies and the scores from the experiment will be presented. The IVR group scored 7.6 points on average, while the DVR group scored 7 points on average. This score was created by assigning a numerical value of 0-2 to each of these answers on the questions from the Immersive Tendencies Questionnaire. The 0VR group did not take questions from the ITQ as they were only relevant for the VR applications. No differences were found between the DVR and the IVR from which immersive tendencies was relevant.

## 6.6 Presence and Engagement

In this section the relationship between perceived levels of presence and engagement, and the scores from the experiment will be reviewed. When the IVR group were asked how involved they were in the VR experience, five out of six informants explained that they were completely involved, while one were somewhat involved. When asked to what degree they felt present in the VR environment rather than where they actually physically were present, five of six informants answered that they felt "completely" present in the VE, while one informant felt somewhat present.

In comparison, when the DVR group was asked how involved they were in the VR experience, two of the informants felt completely involved, while four informants felt somewhat involved. When asked to what degree they felt present, two informants felt completely present, while three informants felt somewhat present, and one informant did not feel present at all. Based on these results we see that the IVR group was most involved and had the strongest sense of presence. Therefore, presence and involvement in the VR can not be said to increase memory of the VE, as the DVR group who scored the least on these tests scored better than the IVR group. Rather, it suggests the opposite, that those who do not feel present will recall more items.

More levels of presence is thus connected to a decrease in recalled items. Presence, however, is a feature only connected to the IVR group. As it is a chance that time, interaction, spatial- and memory ability is at fault for these low scores, the connection between presence and low scores should be viewed quite critically. This is because the IVR group had the lowest spatial- and memory scores. The factor of time will be discussed in section 6.8.5.

## 6.7 Enjoyment

In this section the relationship between enjoyment and the scores from the experiment will be reviewed. When the IVR group was asked how well they enjoyed the experience of the VE, five out of six informants "really liked it", while one informant "liked it somewhat". When asked whether they experienced anything annoying or agitating about the VR experience, five out of six informants answered no, and only one answered yes. To compare these results to the DVR group, we can give each informant a score from 0-2 based on the three alternatives or the three-point-scale of the question. This score would then indicate their level of enjoyment. The IVR group would receive a score of 11.

For the DVR group, three out of six informants "really liked" the experience of the VE, two informants "liked it somewhat", and one informant did not like it at all. Calculating the score in the same manner, this would give the DVR group an enjoyment score of 8. In the DVR group, two informants reported annoying elements compared to one in the IVR group.

Considering these scores, we see that in terms of enjoyment, the VR group had a better time with the application. According to the interviews as well, the IVR group had most satisfaction of the experience in general, describing it with words such as "fun" and "very exciting ", while the DVR group leaned more towards descriptions like "OK" and "alright". As the DVR group outperformed the IVR group, it does not seem that enjoyment helps the memorisation process. Just as with the feeling of presence, which also accompanies the IVR group, it seems to be the other way around, as enjoyment and presence are features of the Immersive VR technology following the IVR group who had the poorest performance. As enjoyment mainly follows the IVR group, and is then automatically connected to lower memory scores, it is hard to distinguish at this stage which are the factors influencing the memory scores. It is deemed more likely that IVR groups poor spatial- and memory ability is the reason for the low recall scores, than enjoyment and presence.

## 6.8 Interaction

In this section, the impact of interaction with the VEs and the success of applying the MOL will be reviewed in relation to memory experiment scores. First the IVR group will be reviewed, second the DVR group, and finally the 0VR group. In the end of the section, the factor of time in interaction will be discussed as well.

### 6.8.1 IVR Group

When the IVR group were asked how proficient in moving and interacting with the VE they felt at the end of the experience, three of the informants felt very proficient, while two felt reasonably proficient, and one felt not proficient. When asked how much the touchpad interfered with their ability to perform tasks, three informants felt that it did not interfere with any performance, while three others felt that it interfered somewhat. When asked how well they could concentrate on the assigned tasks, rather than the mechanisms necessary to perform them, five out of six informants meant they could completely do so, while one informant felt he could only somewhat do this. When asked how natural their interactions with the environment seemed, only two users said they felt natural. Three of the users said the interaction felt neither artificial nor natural, while one user meant they felt artificial. When asked about how much they were able to control the events, all of the informants felt that they could do this "completely".

If we calculate a numerical score based on these answers the IVR group is given a score of 47 in terms of successful interaction.

### 6.8.2 DVR Group

In this section the interaction for the DVR group will be reviewed. When asked how proficient in moving and interacting with the VE they felt at the end of the experience, four of the informants felt very proficient, while two felt reasonably proficient. When asked how much the touchpad or keyboard interfered, all of the informants answered that it did not interfere at all. When asked how well they could concentrate on the assigned tasks, all the informants felt that they could "completely" do this. When asked how natural they found their interactions with the environment, two informants found it to be natural, one found it to be artificial, and three found it to be neither artificial nor natural. When asked about how much they were able to control the events, four informants felt they could do this completely, and two informants felt they could do this somewhat. Calculating this to a score would give the DVR group a score of 51. Compared to the IVR groups score of 47, the DVR group had somewhat better interaction. This is consistent with the memory experiment results, in that the DVR group outperformed the IVR group in the experiment.

### 6.8.3 0VR Group

In this section the "interaction" for the 0VR group will be reviewed, in so far it can be called interaction. The 0VR group did not really interact with anything but their own minds, so this section concerns the groups execution of the MOL. When asked how well they were able to perform the method, all of the six informants answered that they were completely able to perform the method, and that all of them were completely involved in their visualisations.

### 6.8.4 Group Comparison of Interaction

To the degree that the 0VR groups execution of the MOL is comparable to the successful interaction with the IVR and DVR group, it is clear that 0VR group performed the best, the DVR group next best, and the IVR group performed the worst. Also, in this way, the degree to which they were able to perform it successively follows the amount of memory items the group were able to remember. Therefore it seems that good interaction may positively impact the results.

### 6.8.5 Time

Another relevant factor is the time it took interacting with the MPA or performing the method. During the experiment of the IVR and DVR group, it was not recorded when each informant were finished placing all the items within their Mind Palaces. The only data available on this is the general impression of the person who leaded and observed all the experiments. According to this, the IVR group were the slowest group in placing these items, while the DVR and 0VR group was harder to distinguish between. Two informants reported stress due to time in the IVR group, and none did this in the other groups. The IVR group were the only group for whom time seemed to be an issue. In conclusion, the general impression of time and interaction between groups, shows that at least the IVR group had a disadvantage because the interaction takes time. It is natural to assume that the more time one has present with the memory items, the more likely one is to remember them. It is worth noticing also that the 0VR group were the only group who were presented with a sheet of paper containing all the items to remember in text. For the IVR and DVR group, certain memory items would not be visible before several minutes has passed. This may have had an impact on the results.

## 6.9 Age

In this section, the relation between age and memory scores are reviewed. To compare with age, we divided the informants into groups, one group consisting of people under 25 (U25) and another group consisting of people over 25 (O25). The U25 group had an average age of 22.75 years, and the O25 group had an average age of 26.9 years. The average score of the U25 group was 15 memory items, that is, they all recalled 15 memory items. The average score of the O25 group was 13.5. Thus, the results suggest that age may impact the results somewhat.

## 6.10 Control Factors

Questions regarding back problems, vision, balance disorders and high susceptibility to motion sickness were factors recorded to account for the IVR group, in case some informants should have extra bad experiences with the VR software in terms of extreme dizziness, fear, confusion etc. No such cases took place, however, and these factors are not used in the analysis as they are superfluous at this stage. Three out of six informants in the IVR group, however, reported mild simulator sickness symptoms. The group who did not experience SS remembered on average 13.6 items, while those who experienced SS recalled 12.6.

## 6.11 Use of Additional Mnemonics

In this section, we will review how those who used additional mnemonics in the memory experiment performed, compared to those who just used the MPA. This is important, as it is a factor that very clearly may influence their scores. Summarised, ten informants used a narrative technique on top of the MOL, while 8 did not. The ones who did not use a narrative technique, remembered on average 11.6 items, while those who used a narrative technique remembered on average 14.7 items. This clearly suggests that combining the MOL with a narrative technique may aid the memorisation process.

## 6.12 Previous Experience

### 6.12.1 Method of Loci

In this section, the informants previous experience with the MOL will be reviewed relative to the memory scores. In the pre-test before the experiment, each informant was asked whether he or she had previous experience with any mnemonic, and if so, which one. In the IVR and DVR group, three out of six in each group had experience with the MOL. In the 0VR group, only one had experience with the MOL. The informants who knew of the MOL beforehand remembered on average 14.2 items, while the informants who did not know of the MOL remembered on average 14.0 items. As for the memory results after one week, the informants using the MOL recalled on average 12.14

items, while those who did now know the MOL recalled 12.18 items. It seems then that previous knowledge of the MOL did not have an impact on the memory results.

### 6.12.2 VG & VR

In this section, the informants previous experience with video games and VR will be reviewed, relative to the memory scores. The five informants who seldom played video games recalled on average 12.6 items. The three informants who played every week recalled on average 12.6 items, and the two informants who played every day recalled on average 14.5 items. The two informants who never played video games recalled on average 15 items. As for VR experience, all but one in the IVR group had VR exp., and the one who had no VR experience scored 15 out of 15 points in the memory experiment. These results do not indicate that prior experience of the mediums involved have impacted the results.

## 6.13 Summary

This chapter reviewed factors and features attributing the different groups memory scores on the experiment, to try to explain what had impact on the memory scores. Connections are seen between high memory recall scores and 1) high spatial ability, 2) successful interaction, 3) the use of additional mnemonics in combination with the MOL and 4) high memory ability. The group with the poorest memory scores were the group with highest levels of enjoyment and presence. In conclusion, it is hard to thoroughly isolate which factors or features are responsible for the memory scores. Results indicate however, that the poor memory experiment scores of the IVR group and the high memory experiment scores of the 0VR group may be explained by the groups scores on the spatial ability test and memory pre-test. As discussed, another possible influence may be the interaction, where the IVR group scored lowest and the 0VR the highest, and the time used in this interaction.

# 7 Conclusion and Future Work

In this chapter, the thesis will be concluded. First the thesis is summarised, before limitations of the study are presented and future work discussed.

## 7.1 Summary of Results

This thesis investigated the design of the MOL adapted to the medium of Desktop VR and Immersive VR, and the effects this application had on memory. The application was designed as part of the research methodology, as a means to answer the research questions. By comparing groups that were given different approaches to the same task, comparisons could be made to isolate influencing factors relating to memory score, enjoyment, interaction and immersion. By measuring individual characteristics such as spatial ability, memory ability, immersive tendencies etc., it was possible to compare both within and across from groups. This enabled the study to see what people and groups benefited the most from the MOL, with or without a technological adaptation of it.

In terms of spatial ability, the results indicate that informants with high spatial ability benefit the most from using the MPA. This supports the ability-as-enhancer hypothesis, and the reason for this may be that the informants with high spatial ability would use less cognitive efforts in the environment, thus freeing mental power for memorising or remembering the spatial characteristics.

In terms of presence, it does not seem that presence increases the memory capacity, but rather the other way around. The reason that those with higher presence and enjoyment remember less, may also be explained by the poor spatial- and memory abilities of the IVR group, and the poor interaction relative to the other groups. In terms of interaction, better and consistent interaction correlates with higher levels of remembered items.

Gender, or previous knowledge of the MOL, did not seem to impact any of the results. Finally, informants using other mnemonics, first and foremost narrative techniques, in combination with the MOL, remember a significant larger sum of memory items.

The most important contribution of this thesis was to find out that high spatial ability benefit more from the MOL in VR.

## 7.2 Limitations of the Research

The main limitations of this research are: 1) time constraints due to the nature of a master's thesis, 2) cost due to a limited budget, 3) the cap of 15 memory items in the research experiment, 4) an error causing slight overlap on questionnaire alternatives and 5) the factor of time in comparison between groups.

With more time and a greater budget it would be possible to take an iterative approach following the research experiment, implementing features discussed further in the section of Future Work. This would enable better optimisation and better design based on the feedback from the research experiment. The mentioned error in the questionnaire occurred during translation of the Immersive Tendencies Questionnaire from English to Norwegian. While the original alternatives were "Often, No, Occasionally", in this questionnaire the alternatives became "Yes, No, Occasionally". In this case, there is an overlap between "Yes" and "Occasionally", as both alternatives are a positive answer to e.g the question, "Do you ever become so involved in doing something that you lose all track of time?". Thus the Immersive Tendencies Score that is generated for each informant, may not be as correct it should be. There is still reason to believe that "Yes" is a *more* positive answer than "Occasionally", however, these alternatives do overlap.

The biggest area for improvement in this study is the cap of the memory items, which substantially influence the quality of the results. Many informants reached the maximum amounts of items to remember, and this limits the data. It is recommended that for future studies, none of the informants should be able to reach the maximum cap. Because of this cap, it is impossible to know whether the informants who reached 15, could have reached 20, 25 or 30 memory items, etc. There should, ideally, be no cap on how far one could go in this experiment. If a similar experiment is to be done in the future, more sufficient and thorough pilot testing will be necessary to find the correct proportion between time and memory items. A solution to try to tackle this challenge, would be to let the user place as many items as he or she wanted within a given amount of time, however, this would cause major differences not only in memory scores – but in the mere size of the individual Mind Palaces, making it harder to compare. That is, the conditions are not set or fixed, and therefore the factors for comparing will be skewed. Possible changes to tackle this challenge is presented in the next section.

Another important limitation is the factor of time. In the research experiment, it was necessary to specify the task in terms of time, and therefore also to a certain extent the amount of memory items, as it takes time to place a memory item. The performing of the MOL takes longer time for the IVR group than the DVR group, and for the DVR group than the 0VR group. Incidentally, these results also indicate that those who used the least time performing the method scored the highest on the memory test.

## 7.3 Future work

This section will present ideas for future work within this research topic.

### 7.3.1 Changes in the MPA

The functionality of the MPA through its development went from fully autonomous in terms of interactions such as user placement and input, to less time consuming solutions such as limited placement and input. Still, the factor of time seem to be a challenge in comparing the MPA to the traditional MOL. Ideally, the factors should be similar when comparing, also for time. A way to solve this, would be to eradicate the user interaction of placement, as this is the most time consuming interaction with the application. Instead, the informant could enter a Mind Palace that is already filled with memory items. A user could then just focus on wandering through each room, and the time of the experiment could probably be lowered from five minutes to one or two minutes. This raises interesting questions again, in comparison, as it might be the 0VR group who are being "treated unfairly", as these have to place the items themselves. That, however, would have to be a discussion for another paper exploring this new way of using the MPA.

### 7.3.2 Changes in the Research Design

For future studies, controlling the spatial- and memory abilities of the informants prior to the group sorting could prove beneficial. In this way, the groups could be sorted in a way in which none of the groups had much higher abilities than the other groups. In this way, it would be easier to identify whether it was the MPA that were responsible for the scores.

### 7.3.3 Higher Quality Gear

In the future it would be interesting to look at how the Mind Palace application would work with more high quality gear. With gear such as Oculus Rift or HTC Vive, there are more possibilities for interaction. Hand controllers could be used to directly manipulate and place objects more correctly. In addition to this, both Oculus Rift and HTC Vive allow for positional tracking, so that one can move a few meters by feet. There is reason to believe that this would increase immersion in the Mind Palace. Traditionally though, even in those systems, movement over larger distances are done either by the hand controls through "teleporting", or other techniques. It is also possible for these devices to render more complex graphics, as they may run on heavy gaming computers, which again could increase the detail of the immersion.

### 7.3.4 Drawing and Writing

An interesting addition to the Mind Palace would be the ability to draw your visualisations/associations yourself. Google introduced 3D drawing to the HTC Vive with their "Tilt Brush", which allows a user to draw in 3D. This would allow for a highly customisable Mind Palace. It would also be interesting with a writing application within this, for further optimisation. If a user could for instance write at the walls of the Mind Palace, or create signs or "notes" at given locations, this could be very interesting. One could perhaps argue that text is slightly harder to remember by nature, but this does not mean that it can not serve a purpose here. In general a Mind Palace can serve as a base for introducing a whole lot of different features for designing your own. This case, however, assumes the absence of the factor of time, and would be relevant only for quite a different research approach, e.g as a supplementary tool for a study class in memorising the curriculum over a longer period of time.

### 7.3.5 Data Generation

When a Mind Palace is created, the visualisations of the memory items and their relation to each other could be exported to a new format, for instance a mind-map or another kind of relational model. From a user point of view, it may not always be convenient to access the Mind Palace, but other formats of the same content could be more convenient to use in certain situations. This could for instance be on a mobile application where the different Mind Palaces could be sorted. In such an application interface, the information could be used to other things as well, for instance to create quizes could be automatically generated, designed to promote repetition of the Mind Palace.

### 7.3.6 Train Rides

As Mind Palaces often have a specific route one should follow, it might be interesting with a "train ride" through the Mind Palace as a way of repetition. This could be a feature for those who have created Mind Palaces, to take a "train ride" through it. This may simplify interaction, at least it certainly minifies it, and one would have the time factor under more control, as each "ride" would have a certain time frame. Examples of games who have solved navigational interaction in this way is the horror game Rush of Blood for Playstation VR. As natural interaction in terms of navigation still has not been effectively solved in this way, and "teleporting" still seem to be the norm in such games and VEs, this is a way to at least solve it, if in a somewhat reducing way in terms of autonomy.

### 7.3.7 MOL Research

Legge et al. (2012) commented on why research on the MOL was hard, because its processes were subjective. In this regard, the MPA may be an interesting tool to do research on the MOL. In the MPA, these internal, subjective processes that Legge et al. (2012) discuss, are to a certain extent made observable. With the MPA, we may store the Mind Palaces themselves, and thus have access to them. It would be possible to store data on how long of a time they spent in their Mind Palace, what they placed, where and when. Although the images sometimes to a certain extent will act as subjective associations, the images can act as references that can be discussed in interviews, etc. This way of research the MOL could enable researchers to outline in more detail how the MOL works, by simulating an access to the mental.

### 7.3.8 Size

A natural way of advancing the MPA, would be to enlargen it, so one could test the recall of a greater number of memory items. One could then have more rooms, or houses, and connect these with doors. It could then be possible that a menu displaying the different Mind Palaces were a long corridor with doors, each to a subject or theme connecting the memory items.

### 7.3.9 3D Bank

More ideal than 2D images in the form of 3D-cubes, would be actual 3D models. For this to be possible to any given association of the user, this would require access to an incredibly large 3D-bank. A temporal solution should this not be possible, would at least be that the software first queries for 3D models, and if this does not succeed, uses an image instead. If the experiment is done with an already determined list of memory items, however, it should be possible to do this without much effort. This was not done in the MPA as it originally was designed to give an illustration for any association the user might have. For future studies, 3D models should be used instead.

### 7.3.10 Sensational Images

Based on input from the interviews, it would be interesting to see the effects of more startling images. This could be done by altering the search algorithm so that it denies photos from stock image sites, as these often are very straight-forward, simple and boring. This, and other ways of making the images more memorable eye catching or absurd, by combining keywords, could be an interesting approach for future experiments.

### 7.3.11 Final Words

This thesis investigated the design of a VR application which goal was to enlighten potential benefits of the medium. Potential use of this exciting medium should continue to be investigated, especially now that development is low treshold due to good frameworks and cheap hardware.

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# Appendix A

## Forespørsel om deltakelse i forskningsprosjektet

## *Mind Palace*

**Bakgrunn og formål**
Forskningsprosjektet presenteres som en masteroppgave ved Universitetet i Bergen, institutt for informasjons- og medievitenskap. Prosjektet tar opp hukommelsesteknikk i kombinasjon med teknologiske hjelpemidler. I prosjektet vil vi se på resultater fra tester om romlig resonneringsevne, minne-tester, og opplevelsen av bruk av teknologiske hjelpemidler. Vi vil også samle informasjon slik som alder, kjønn, og tidligere erfaringer med hukommelsesteknikk og teknologiske hjelpemidler etc.

**Hva innebærer deltakelse i studien?**
Deltakerne må være med i et hukommelseseksperiment. Alle informantene vil få en kort innføring i hukommelsesteknikk. To av gruppene vil få teknologiske hjelpemidler til å utføre denne teknikken. Deltakerne må fylle ut spørreskjema før og etter utførelsen. Informantene må også gjennomgå en liten hukommelses-test og en test for romlig resonneringsevne før selve eksperimentet.

**Hva skjer med informasjonen om deg?**
Alle personopplysninger vil bli behandlet konfidensielt. Kun student og veileder til masteroppgaven vil ha tilgang til personopplysninger.

Prosjektet vil anonymiseres, og deltakere i prosjektet vil ikke kunne gjenkjennes i publikasjon av oppgaven.

Prosjektet skal etter planen avsluttes 01.06.2017. Datamaterialet anonymiseres etter prosjektslutt.

**Frivillig deltakelse**
Det er frivillig å delta i studien, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli anonymisert.

Dersom du har spørsmål til studien, ta kontakt med:
Joakim Vindenes ved epost: joakim.vindenes@student.uib.no / tlf. 977 757 734,
eller veileder Barbara Wasson på epost: barbara.wasson@uib.no / tlf. 555 84 120.

### Samtykke til deltakelse
Jeg har mottatt informasjon om studien, og er villig til å delta.

________________________ ________________________

Signert av prosjektdeltaker Dato