GEO 511 Master's Thesis

Judging spatial relations in Virtual Reality

A case study with indoor visualizations comparing stereoscopic 3D VR with monoscopic 3D VR

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Abstract

Virtual Reality Head-Mounted-Displays offer the possibility of stereoscopic 3D visualization in a very immersive way. Previous research claims that the addition of binocular depth cues is helpful for judging spatial relations. The aim of this master thesis is to empirically evaluate the differences between stereoscopic 3D Virtual Reality and monoscopic 3D Virtual Reality. The differences are tested with indoor visualizations for relative spatial judgement tasks, absolute spatial judgement tasks and memorability tasks. The spatial judgement tasks include height-, volume- and distance-estimation tasks. For all tasks the influence of different perspectives (planar view, oblique view, first-person view) is analysed. The results are also tested on correlation with the spatial ability (MRT-Score) of the participants.

The results reveal that there is no significant difference between stereoscopic 3D Virtual Reality and monoscopic 3D Virtual Reality for indoor visualizations. There is no significant difference in response accuracy and response time visible for both spatial judgement tasks and memorability tasks. Different perspectives do not show significant differences between stereoscopic 3D Virtual Reality and monoscopic 3D Virtual Reality. Further, there is no significant correlation between the results and the spatial ability of the participants. Based on these results it can be said that for indoor visualizations, the addition of stereoscopic 3D does not significantly benefit judgement of spatial relations. Further research is needed to test trends suggesting a small benefit of stereoscopic 3D in response accuracy and response time for certain tasks.

Keywords

Virtual Reality, Head-Mounted-Display, Oculus Rift, stereoscopic 3D, monoscopic 3D, indoor visualization, relative spatial judgement, absolute spatial judgement, height-, volume-, distance-estimation, memorability, planar view, oblique view, first-person view, response accuracy, response time

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1. Introduction

1.1 Motivation

Since the invention of interactive 3D computer graphics and the first Head Mounted Display (HMD) by Ivan Sutherland in the 1960's, Virtual Reality (VR) has come a long way. The technology has long been driven by military and scientific purposes, due to its high cost (Shepherd 2008). Only in 2013 with the emergence of the Oculus company and the first development kit of the Oculus Rift, VR has been made available for a large consumer base at a relatively low cost. Since then the HMD technology for VR is evolving rapidly, and VR is growing in popularity in many different fields. The question arises, if this popularity is justified. Is VR useful, or is it just new and exciting?

VR HMDs are typically built with stereoscopic displays. Stereoscopic displays take advantage of human stereoscopic vision through *binocular parallax* (which is based on retinal disparity), and visualize the phenomena of interest in immersive 3D with very high levels of fidelity (true to realism) (Howard 2002). VR HMDs also often have a larger field of view than monoscopic displays. These are the main visual differences between a monoscopic display and a VR HMD. Additionally, VR HMDs come with motion tracking which allows the user to look around in the virtual world by moving the head. This adds the depth cue of *motion parallax*, making VR HMDs even more immersive and interactive than monoscopic displays. Because of these features, VR HMDs give the environment a more realistic feel than monoscopic displays do; thus, the feeling of presence is higher with VR HMDs than with monoscopic displays. It is often argued that the higher immersion and interactivity may cause the user to be more active and alert (paying more attention), and this should help processing information more effectively (Mehrabi et al. 2013, Van der Land et al. 2013).

While many of the arguments found in the literature are not necessarily backed up with user studies, several empirical studies have been conducted comparing stereoscopic 3D (S3D) visualizations with traditional monoscopic 3D (M3D) visualizations. A comprehensive literature survey conducted by McIntire et al. (2014) shows, that S3D is most beneficial for depth-related tasks in close spatial proximity, and the benefit of S3D is highest if the task at hand is unfamiliar and complex. The literature survey suggests, that S3D is beneficial for several tasks including the judgement of distances and memorability tasks (McIntire et al. 2014). Furthermore, according to McIntire et al. (2014), S3D provides additional information through improved depth perception that can increase personal understanding of a scene. However, when working in groups, M3D visualizations have shown to be more effective than S3D visualizations, because of the information overload caused by S3D (Van der Land et al. 2013).

While these studies focus on comparing the benefits of S3D vs. M3D; little is known about how VR HMDs compare with monoscopic displays for judging of spatial relations. VR HMDs are different than other stereoscopic displays, because they completely occlude the outside world from the user's visual field. Most previous studies focus on comparing the effect of adding single depth cues like binocular parallax or motion parallax (Norman et al. 1996, Van Beurden et al. 2010, Willemsen et al. 2008). This study will investigate the effect of binocular parallax offered by VR HMDs as opposed to VR HMDs without binocular parallax through a controlled user study. The effect of binocular parallax on judging spatial relationships in this specific VR HMD setup has not yet been thoroughly studied. This research gap will be addressed by empirically measuring the effect of VR HMDs for several tasks ranging from spatial operations to memorability.

1.2 Thesis Structure

The thesis starts with the Introduction in Chapter One, which describes the motivation of this thesis as well as the structure. In Chapter Two, an introduction to virtual reality is given and the current state of research of the thesis is presented. Chapter Three presents the research questions and their hypotheses. In Chapter Four, the methodology of the experiment is described with all its components from experiment design, participants, materials, procedure and statistics. Moving on to Chapter Five, all statistical results and charts of the study are presented. In Chapter Six, these results will be discussed and analysed. And lastly in Chapter Seven, the conclusions are drawn. There is also an appendix at the end of the thesis with all materials concerning the experiment.

2. Literature Review

2.1 Reality-Virtuality Continuum

Before Virtual Reality (VR) can be defined, an interesting concept to understand is the *Reality-Virtuality Continuum*. It has been developed by Drascic and Milgram (1996) and it describes the continuous transition from the real environment to the virtual environment (Drascic et al. 1996). Real environments only include real physical objects. Virtual Environments (VEs) on the other side only include virtual objects (computer-generated representations). VEs are the fully virtual visualization of reality by computer graphics as seen in video games. In between a real environment and a VE lies the Mixed Reality (MR) which includes Augmented Reality (AR) as well as Augmented Virtuality (AV). They are both a mixture of real and virtual elements. Augmented Reality has its focus on reality while Augmented Virtuality focusses on the Virtual Environment. The term of Augmented Virtuality is barely used in literature nowadays, while the term Augmented Reality is often used synonymous for Mixed Reality (Slocum et al. 2010: 461-463).

Figure 2.1: Reality-Virtuality Continuum

2.2 Virtual Reality

On the Reality-Virtuality Continuum this thesis will focus only on the fully virtual environment also known as Virtual Reality (VR). VR can be defined as a simulation of reality, created by computer graphics. Immersion and interactivity are important criteria for virtual reality. The simulation is supposed to create a feeling of presence, so that the brain thinks that the seen environment is the actual reality. The better the immersion, the more realistic does the virtual environment appear and if a natural interaction with the virtual objects is possible (as in a real environment), the immersion is improved (Ghadirian 2009: 37-39). Interactivity includes the possibility to navigate in the virtual environment, and the possibility to move and manipulate virtual objects. A common problem in VEs in relation to interaction is orientation. VR users often take wrong turns and get lost in the virtual space. Using an overview map in the virtual world can help solve this problem. There are various factors that can affect the visual experience of a user in a VE other than immersion and interaction, and need to be considered for designing virtual environments. One of these factors of virtual worlds is the level of detail. To simulate reality, there should be as many details as possible. The necessary level of detail varies according to the purpose of the application. A problem with the level of detail is the missing automatic generalization with scale changes (Slocum et al. 2010:466-467).

To create the VR experience with the listed criteria above, special hardware is needed. Virtual reality hardware can be categorized in two categories: input- and output-devices.

Output-devices of virtual reality systems usually focus on visual perception. Sound, taste, smell and touch play a subordinate role for virtual reality systems. There are two types of visual displays for virtual reality: Head-Mounted-Displays (HMDs) like the Oculus Rift (Figure 2.2) and room-scale-projections like CAVE (Cave Automatic Virtual Environment) (Figure 2.3). The user wears the HMD on their head, and their visual field therefore is fully surrounded by the virtual reality. The real surroundings are removed from the field of view. An HMD creates a separate image for each eye, which enables stereoscopic vision. The HMD also reacts to head movement and transfers this movement into the virtual reality. This allows the viewer to look at his surroundings in a natural way (Slocum et al. 2010: 462-464). A common second display type is the room-scale-projection. In the example shown in Figure 2.3 the VE visualization is projected to three walls and the floor. A CAVE can also project the visualization to four walls, the floor and the ceiling. CAVEs also use stereoscopic displays. The user wears glasses, which filters the shown image so that the left eye sees the left image and the right eye sees the right image. Typically, CAVEs are equipped with motion tracking systems that track the head movement of the user (like in the HMDs). The advantage compared to HMDs is, that multiple people can enter and see the virtual reality at the same time and therefore they can interact with each other. (Slocum et al. 2010: 462-464).

Figure 2.2: Oculus Rift DK 2

Figure 2.3: CAVE

Interactivity of VEs is provided through different input-devices. Traditionally, mouse, keyboard and gamepads are used on computers. These devices (mouse, keyboard, gamepads) only allow an indirect input by pressing buttons which does not feel very natural in a VE where the user needs to move and interact naturally. In addition to these devices, special controllers for virtual reality (Figure 2.4) have been developed which allow motion gestures (Slocum et al. 2010: 462-464). For example, infrared cameras measure the position of the controller and simultaneously transfer any hand motion from the real world to the virtual world. These controllers do a great job in simulating the hands of a user in HMDs, and allow natural ways to interact with virtual objects. For navigation in the virtual world, there are some solutions to transfer real body movement into the VR. For example, HTC Vive uses infrared cameras to measure the body position in the real environment, and transfers any movement to the virtual environment. The problem here is that the movement in the virtual environment is limited to the room size of the physical environment (Pino 2016), these physical limits are relevant also for a CAVE. To address this problem for the HMDs, various experimental approaches have been proposed. For example, one solution is the Virtuix Omni (Figure 2.5), a treadmill like device where the user is fixed to a 360° treadmill. The user, thus, can navigate the VE by simply walking on the treadmill and adjust the speed accordingly (Matney 2016).

Figure 2.4: HTC Vive Controller

Figure 2.5: Virtuix Omni

2.3 State of Research

Three-dimensional spatial visualizations represent space in all spatial dimensions (height, length and depth). Therefore, they show space as it is seen in reality. Many believe verismilitude makes it easier for most people to understand spatial phenomena with 3D visualizations in comparison to 2D visualizations of space (maps) (Bodum 2005). If stereo vision is added to these 3D visualizations, the sense of depth is further augmented. However, some people (up to 20 % of the population) may not be able to see in stereo due to stereo blindness or double vision (Fabrikant et al. 2014).

Mostly, we are used to M3D visualizations. These 3D visualizations on 2D displays (also known as 2.5D visualizations) use monocular depth cues to give us depth information. Monocular depth cues are also visible with only one eye. There are eight monocular depth cues: *familiarity, linear perspective, texture gradient, overlapping, aerial perspective, shadowing, colour differences, monocular parallax*. In addition to these monocular depth cues, VR also offers binocular depth cues (*binocular parallax, binocular motion parallax*) that can only be seen with two eyes. Binocular parallax uses the fusion of two slightly different images for stereo vision. Binocular motion parallax uses the change of perspective trough head movement to give more depth information (Boyd 2000, Mehrabi et al. 2013).

Adding these binocular depth cues helps depth perception of 3D visualizations. They are additional hints that the human brain uses to process depth information. For some tasks, monocular depth cues might already be sufficient (Westheimer 2011). It is argued by St. John et al (2001) that the benefit of S3D is depending on the task at hand and the perspective used to complete the task. For relative distance estimations, it is usually easier when the object is seen in 2D or 3D from the top (planar view) without any distortion of the proportions (St. John et al. 2001).

S3D VR has advantages over M3D for exploring complex multidimensional VEs. The user does not only see what would be visible in the real world, but also otherwise invisible information. There are four factors that contribute to a VE, the so called “4 I’s of VR”. VR brings Immersion, Interactivity, Information Intensity and Intelligence of objects (MacEachren et al. 1999).

There have been several studies comparing M3D with S3D over the past 50 years in several fields. A literature survey by McIntire et al. (2014) shows, that out of 160 experiments, the performance improved in 60% of them while using S3D. In 40% of the experiments, S3D showed only a marginal or no effect. Negative effects on performance were only found in very rare cases. Tasks that benefited most from S3D are identifying objects, manipulating objects, judgement of position, spatial understanding and memory recall (McIntire et al. 2014). The effect of immersion and presence that S3D VR offers is regarded as mostly positive. The user can generally relate better to visual stimuli since they appear closer and seem more realistic (Van der Land et al. 2013).

A negative aspect of the S3D VR technology that often appears in related literature, is the so called “simulator sickness” (McIntire et al. 2014, Boyd 2000). This is caused by a conflict between the visual input and the vestibular input. Since the person using HMDs only moves in the virtual environment and not in the real world, the brain senses a conflict between visual information and the information of the body. With more experience using VR HMDs, the body can adapt to this situation. Another problem of S3D VR is, that converging the eyes to refocus like in the real world, does not work in S3D VR. This may also cause simulator sickness, because the real-world correlation between depth and blur or depth and vergence needed for single vision is missing (Boyd 2000). In this study, these problems will not specifically be studied, but will be taken into account while designing the experiment

3. Research Questions

This master thesis investigates the influence of stereo vision on successfully using VR HMDs for spatial judgements and memorability, using Archilogic's 3D architectural apartment visualizations (Archilogic 2017) as a case study. Indoor visualizations and similar scale environments are a good fit for showing in S3D, because the benefit of S3D is best for depth related tasks in close proximity (McIntire et al. 2014). The comprehensive literature survey by McIntire et al. (2014) shows that in most cases spatial judgement tasks and memorability tasks benefit from S3D. The performance of the participants will be measured for several tasks and visual stimuli (detailed in later sections). The results will be statistically analysed to validate or falsify the set hypotheses. Specific research questions addressed in this thesis are detailed below.

3.1 Research Question 1

What are the differences between stereo 3D VR (Oculus Rift / both eyes) and mono 3D VR (Oculus Rift / one eye) visualizations for judging spatial relationships in a 3D scene, specifically for height-, volume- and distance- estimations in terms of response accuracy and response time? In this context, how strong is the influence of:

1. Different perspectives (planar view, oblique view, first-person view)?
2. Spatial ability of participants?

Hypotheses:

H1.1: S3D VR will positively influence depth perception and therefore have better results with judging spatial relationships (height- volume- and distance-estimations) than with M3D VR (Westheimer 2011).

H1.2: Both the first-person view and the oblique view will benefit from S3D VR, due to the binocular depth cues. There will be no benefit of S3D VR for the planar view, since the monocular depth cues are sufficient for the task (St. John et al. 2001).

H1.3: Participants with lower spatial ability scores will benefit more from S3D VR than participants with higher spatial ability scores (McIntire et al. 2014).

3.2 Research Question 2

Which visualization (S3D VR or M3D VR) is more suitable for memorability in the case of indoor visualizations as measured by response accuracy and response time? How strong is the influence of:

1. Different perspectives (planar view, oblique view, first-person view)?
2. Spatial ability of participants?

Hypotheses:

H 2.1: S3D VR will enhance memorability compared to M3D VR due to the stronger feeling of presence (Van der Land et al. 2013).

H2.2: Both the first-person view and the oblique view will benefit from S3D VR, due to the binocular depth cues. There will be no benefit of S3D VR for the planar view, since the monocular depth cues are sufficient for the task (St. John et al. 2001).

H2.3: Participants with lower spatial ability scores will benefit more from S3D VR than participants with higher spatial ability scores (McIntire et al. 2014).

4. Methods

4.1 Experimental Design

For this project, the main method is a controlled experiment. The experimental design is a between-subjects design (Martin 2008). The *independent variable* is the presence or absence of stereoscopic view. Participants are only exposed to either the stereo experiment or the mono experiment. The same tasks are completed by all participants either in stereo 3D Virtual Reality (S3D VR) or in mono 3D Virtual Reality (M3D VR) using the same HMD (Oculus Rift DK2). The only difference between the mono and the stereo experiment is, that the participants in mono can only see with one eye, while the participants in stereo can see with both eyes.

The *dependent variables* are response accuracy and response time. For most of the tasks, there is only one correct answer. This leads to a response accuracy of either 1 (correct) or a response accuracy of 0 (wrong). An exception to this are the absolute spatial judgement tasks were the response accuracy is scaled based on how close the answer is to the correct result. Here the accuracy can range from 1 (correct), 0.9 (+/- 5%), 0.8 (+/- 10%), …., 0.1 (+/- 45%), 0 (>45% off). If the participants give no answer or answer with “I don’t know”, the response accuracy is set to 0 (wrong).

The response time of each task is recorded with a stopwatch. The time is measured in a precision of a tenth of a second. The response time is always recorded after the task is vocally given and stopped with the first answer given by the participants. The participants are not allowed to change their answer once the time has stopped. There is no time limit for any task.

4.2 Participants

A total of 30 voluntary participants took part in this experiment (age range 18-49, 12 females, 18 males). Participants were neither preselected based on their professional expertise, nor were other inclusion or exclusion criteria applied. Any adults (above 18) were considered suitable to take part in the study. The study was conducted using a between-subjects factorial experiment design. This was necessary because learning would be involved in the experiment if the participants were to do the same tasks twice, and in this case the learning effect was considered too strong for a within-subject design (Martin 2008).

4.3 Materials

The main experiment featured an Oculus Rift DK2 VR HMD, which was made available by the Chair of Information Architecture (ETH Zürich). The VR HMD was used for both S3D and M3D. For the pre-questionnaire, the mental rotation test (MRT) (Vandenberg et al. 1978) and the post questionnaire SurveyMonkey online surveys were given to the participants to complete on a desktop computer at the lab. The stereo ability test was also given on the same desktop computer on the website of the Department of Ophtalmology of McGill University (Hess et al. 2015) wearing anaglyph glasses.

Visual Stimuli

For the comparison of stereo 3D virtual reality (S3D VR) with mono 3D virtual reality (M3D VR), Archilogic's 3D apartment visualizations (Figure 4.3.a, Figure 4.3.b, Figure 4.3.c) are used as virtual environments. These VEs are presented in three different perspectives (planar view, oblique view, first-person view) in both S3D VR and M3D VR. Besides the apartment visualizations, there is a part where only abstract shapes (Figure 4.3.d, Figure 4.3.e, Figure 4.3.f) will be shown without context as a control variable to measure the influence of the apartment context on the results of relative depth estimation. These abstract shapes will also be shown in the same three perspectives (planar view, oblique view, first-person view) and they are used to measure the effect of absence of some monocular depth cues like familiarity and shadowing in contrast to the apartment visualizations. Motion is restricted to head motion in the S3D VR visualizations and M3D VR visualizations. The participants can look around by moving their head, but there will be no navigation for both visual stimuli.

Figure 4.3.a Archilogic apartment for spatial judgement tasks (planar view)

Figure 4.3.b Archilogic apartment for spatial judgement tasks (oblique view)

Figure 4.3.c Archilogic apartment for spatial judgement tasks (first-person view)

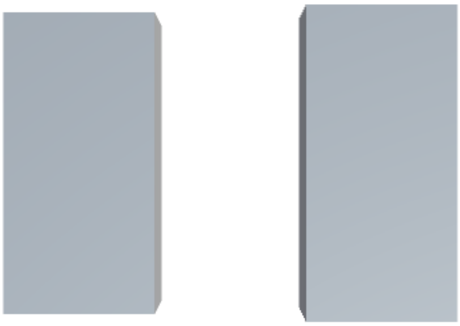

Figure 4.3.d Abstract shapes for spatial judgement task (planar view)

Figure 4.3.e Abstract shapes for spatial judgement task (oblique view)

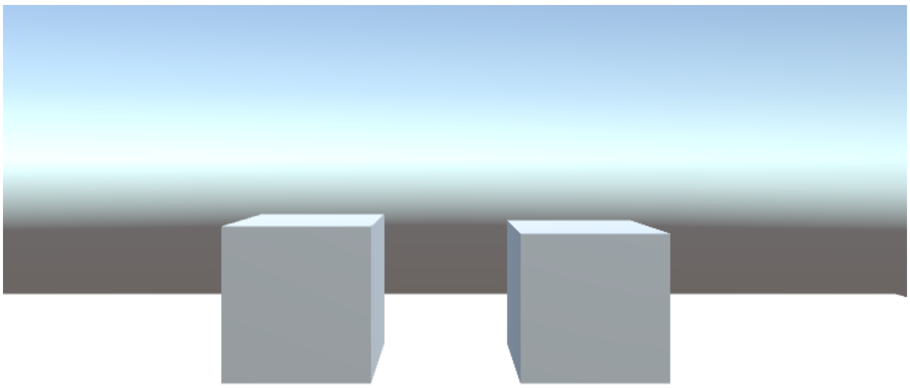

Figure 4.3.f Abstract shapes for spatial judgement task (first-person view)

Tasks

There are 36 tasks in total presented to each participant in four blocks with nine tasks each. Blocks are organized so that nine tasks are concerned with relative spatial judgement of abstract shapes, nine with relative spatial judgement of an apartment, nine with absolute spatial judgement of an apartment and another nine tasks concerned with memorability of an apartment. The nine tasks in each of the four blocks are further sub-categorized as three tasks for each perspective (planar view, oblique view, first-person view).

These 36 tasks are always the same, but the order in which they appear is randomized. First, the order of the four blocks is randomized and second the order of the perspectives within a block is randomized. The order of the tasks within a perspective is not randomized. The tasks can be separated according to the two research questions. The first task category is concerned with *spatial judgement* tasks. Both relative and absolute depth perception will be measured. The spatial tasks concern height-, volume- and distance-estimation.

Specifically, participants were given the questions below:

Relative depth estimation:

- Task Type 1 (height): Is object A higher or object B? (A or B)
- Task Type 2 (volume): Is the volume of object A bigger or object B? (A or B)
- Task Type 3 (distance): Is object A or object B closer? (A or B)

Absolute depth estimation:

- Task Type 1 (height): What is the height of object X? (x m)
- Task Type 2 (volume): How big is the volume of object X? (x m^3)
- Task Type 3 (distance): How big is the distance between object X and object Y? (x m)

The second task category is concerned with *memorability* tasks. For these tasks the participants were given one minute to remember an apartment. After that minute, the visualization was removed and the participants answered the questions according to their memory. The memorability tasks range from remembering whether an object was in room A or B, remembering the count of objects, or simply remembering whether an object was present in the apartment.

Questions were as follows:

Memorability:

- Task Type 1: Was object X in room A or B? (A or B)
- Task Type 2: How many objects of X were in the apartment? (count)
- Task Type 3: Was there an object X? (Yes or No)

Figure 4.3.g Archilogic apartment for memorability tasks (oblique view)

4.4 Procedure

The experiment was conducted at the Eye Movement Lab of the Department of Geography at University of Zürich to guarantee similar circumstances for all participants. After the participants were welcomed and given the consent form for signing, the experiment started with a pre-experiment questionnaire about demographic information of the participants and questions about familiarity with stereo 3D media, virtual reality and video games. Thereafter, a stereo ability test was conducted to determine the ability of the participants to see in stereo with anaglyph glasses. This test was necessary to assign the participants to the S3D group or the M3D group based on their stereo ability. Therefore, 15 participants used only S3D VR and the other 15 only M3D VR. Participants with a high stereoscopy score (lower being better) are automatically selected for the M3D experiment. Next, the participants were given a spatial ability test (the mental rotation test) to be able to compare the participant's spatial ability with the results of the main experiment. This was followed by the main experiment using either S3D VR and or M3D VR. The participants of the M3D group used only one eye to view the VE. After determining their dominant eye, the other lens of the HMD was sealed up, so that nothing could be seen through the second lens. The main experiment was recorded using computer screen capturing software, so that the view of the participants in the VE could be comprehended afterwards. The answers were also simultaneously recorded over a microphone. At the end, there was a post-experiment questionnaire where the participants had to rate the difficulty of perspectives and tasks. The participants were also asked about their comfort level and tiredness due to possible simulator sickness. At the end of the experiment, the participants were given a small present.

4.5 Statistics

The data of the whole study including the Pre-Questionnaire, Stereo Ability Test, MRT-Test, Main Experiment and the Post-Questionnaire were gathered in Microsoft Excel spreadsheets for overview, processing and chart visualisation. Further, the statistics were created with IBM SPSS Statistics 21. For the descriptive statistics, the mean (M) and standard error (SE) are reported. For the Mann-Whitney test the z-score (z) and probability (p) are reported. For the independent t-test the t-test value (t), degrees of freedom (df) and probability (p) are reported. By having two samples (mono and stereo) the Mann-Whitney test is chosen for not normally distributed data and the independent samples t-test for normally distributed data. For the correlation analysis between the overall results and the MRT-Score, a bivariate correlation analysis after Pearson is used. For this test, Pearson’s correlation coefficient (r), the coefficient of determination (R^2) and the probability (p) is reported. Results with a probability (p) of less than 0.05 were considered as statistically significant. All the results are reported as suggested by Field (2009). The Box-Plot for the MRT-Score and the Scatter-Plots for the correlation analysis are created with IBM SPSS Statistics 21.

5. Results

This chapter describes the results from the main experiment, the mental rotation test as well as the pre- and post-questionnaire data. The stereo ability test results are not represented here, since they were only used to determine whether or not a participant could take the stereo 3D VR test.

5.1 Pre-Questionnaire

5.1.1 Gender / Age

A total of 30 participants took part in this experiment. As written in Chapter 4.2, participants were not preselected on any criteria. Gender differences were not taken into consideration for the analysis. 12 participants were female (40%) and 18 participants were male (60%). The age ranged from 18-49 years old (Figure 5.1.1). Most participants were between 20-29 years old (73.3%). Two participants (6.7%) were in the age group of 19 or younger, five participants (16.7%) ranged from 30-39 years old and one participant (3.3%) belonged to the age group of 40-49 years old. The participants only selected their age group and did not give their specific age. The influence of age on the results was not further analysed.

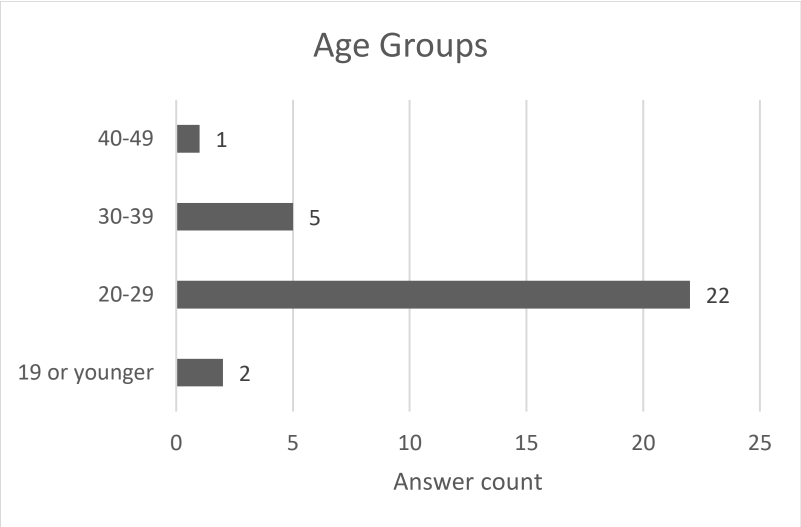

Figure 5.1.1 Age groups of the participants

5.1.2 Experience with VR Devices

11 participants (36.7%) had never used any virtual reality device before the experiment. 19 participants (63.3%) were familiar with one or multiple VR devices (Figure 5.1.2). Most common was the CAVE with 10 participants familiar to it, due to its availability for the geography students at the department. Of the Head-Mounted-Displays (HMDs) the Oculus Rift and Google Cardboard are most familiar with nine participants familiar with it, followed by HTC Vive and Samsung GEAR VR with seven participants each. No one had experienced the newly released Playstation VR yet. In addition, one participant noted that he used Microsoft Hololens.

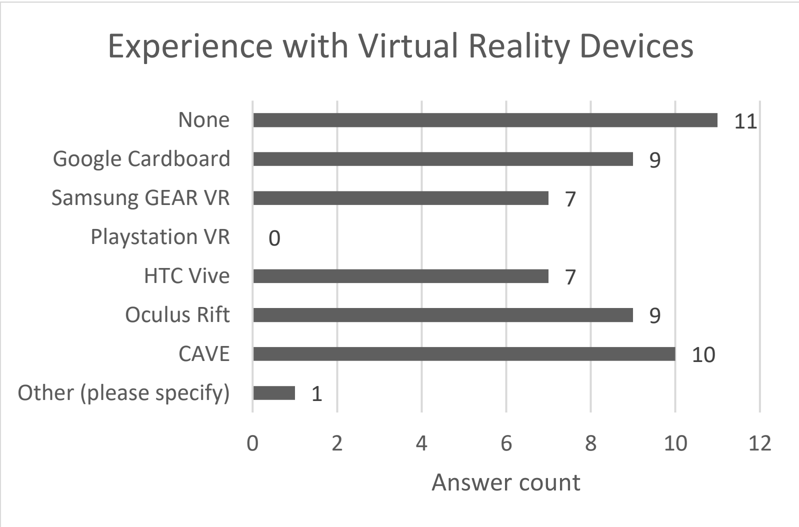

Figure 5.1.2 Experience with Virtual Reality Devices

5.1.3 Experience with stereoscopic media and video games

All participants had used stereoscopic media like 3D TV or 3D cinema before. All 30 participants (100%) have been to a 3D cinema before and only seven participants (23.3%) have watched stereoscopic media on a 3D TV.

When asked about the participant's familiarity with video games, 14 participants (46.7%) said they never play video games and 16 (53.3%) said they play video games regularly. The platforms they regularly play video games on can be found in Figure 5.1.3.a. The PC is the most common video game platform with 14 of the 16 participants, who play video games, using it. Home consoles come in second place with seven participants and the least common video game platform is Mobile/Tablets with four regular users.

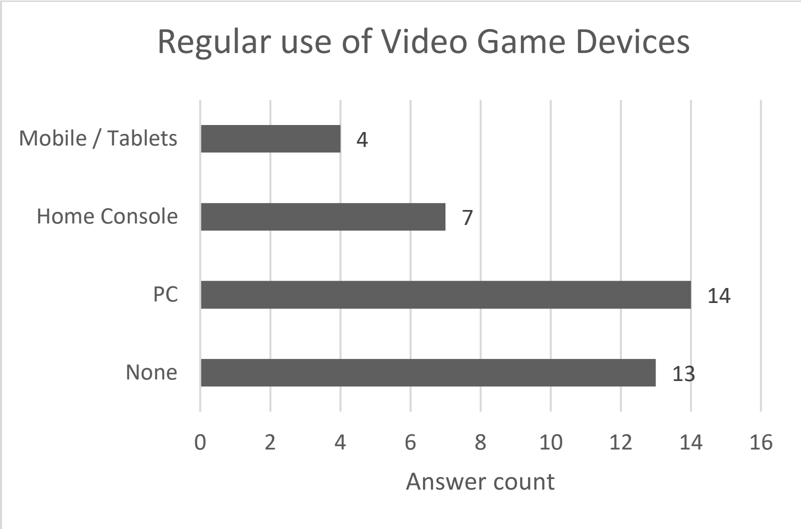

Figure 5.1.3.a Regular use of Video Game Devices

The participants video game play time can be found in Figure 5.1.3.b. Of the 16 participants who play video games, the majority of them (10 participants) play less than five hours a week. Only one participant plays between five and 10 hours a week, two participants play between 10 and 15 hours a week and three participants play for more than 15 hours a week.

Figure 5.1.3.b Video Game Play Time / Week

5.1.4 Attitude towards VR Devices

The participants were also asked in advance of the study what their attitude towards VR devices is. As seen in Figure 5.1.4.a, most participants had a positive attitude towards VR devices before the experiment. No one had a very negative attitude towards VR devices and only one participant had a negative attitude.

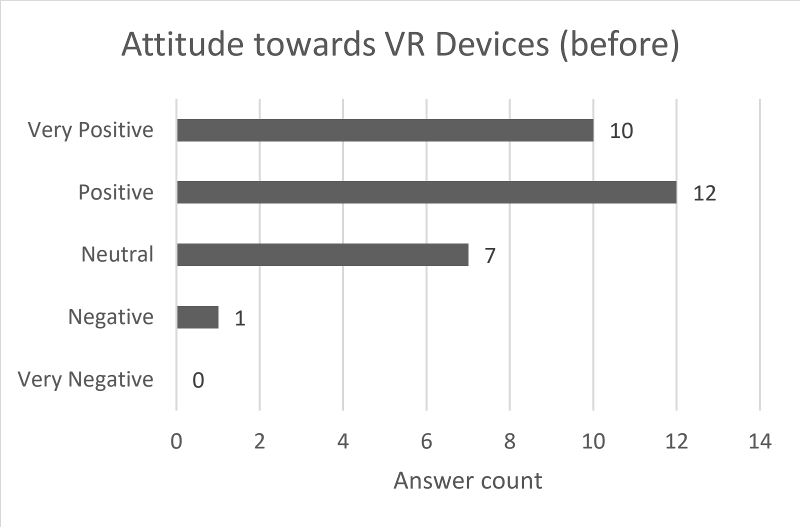

Figure 5.1.4.a Attitude towards VR Devices before experiment

Their attitude towards VR got only slightly lower after they experienced the VR experiment as can be seen in Figure 5.1.4.b. There were only two participants who changed their attitude from very positive to positive. No participants had a better attitude towards VR devices after the experiment.

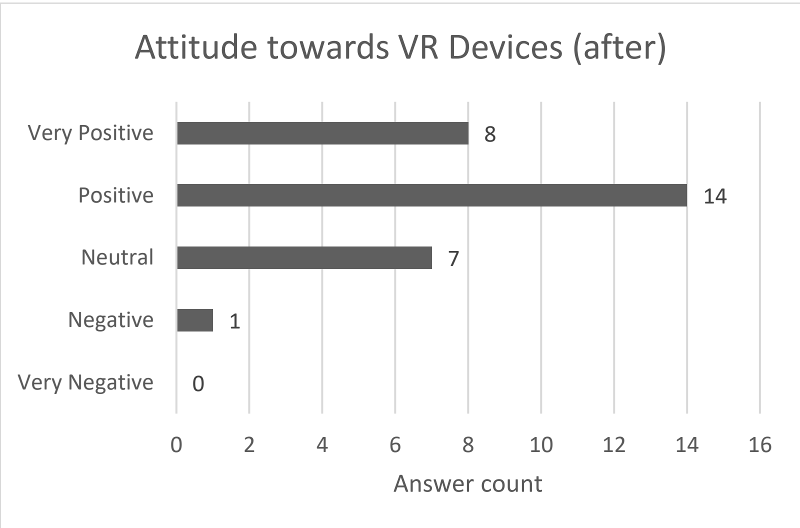

Figure 5.1.4.b Attitude towards VR after the experiment

5.1.5 Professional expertise in related fields

The participants were also asked about their professional expertise in fields related to the experiment. As seen in Figure 5.1.5.a, the average expertise was highest for the field of geography with 3.5 on a scale from 1-5 (1 = very low, 2 = low, 3 = middle, 4 = high, 5 = very high). The participants had the lowest average expertise in the field of interior design with an average of 1.9.

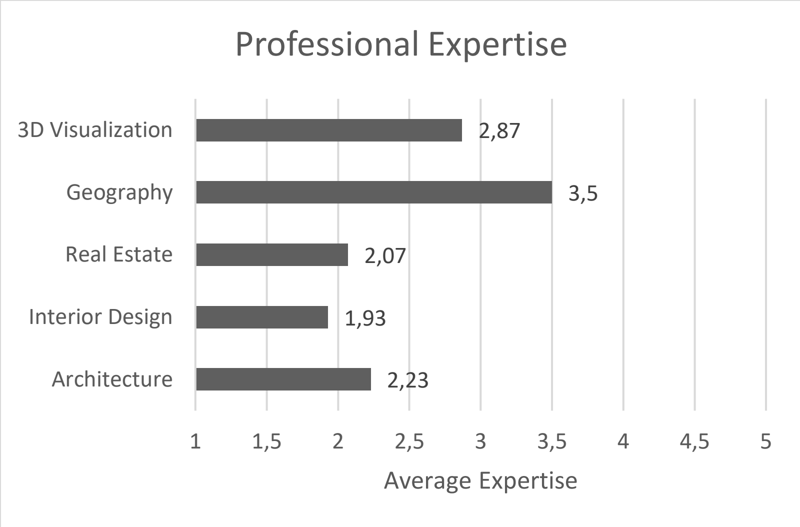

Figure 5.1.5.a Average professional expertise in fields related to the experiment

The percental distribution of the participant's expertise in fields related to the experiment can be seen in Figure 5.1.5.b. The expertise in 3D visualization and geography in general is high. In real estate, interior design and architecture, the expertise is generally lower.

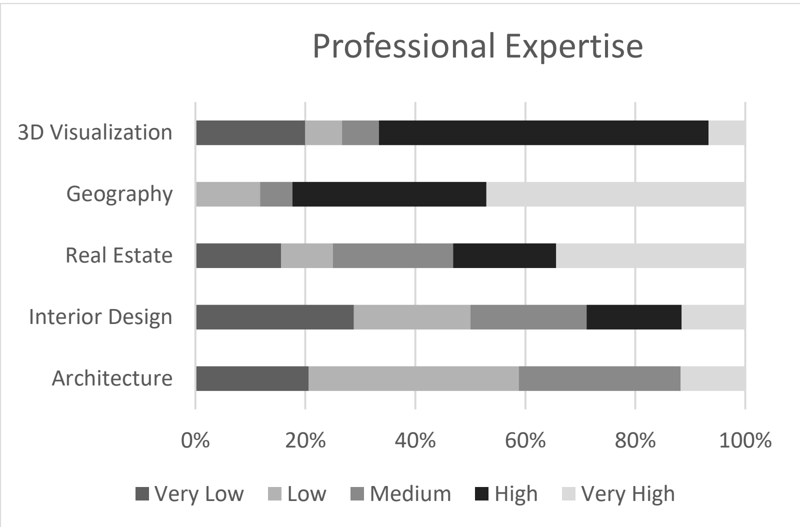

Figure 5.1.5.b Percentage of participants with professional expertise in fields related to the experiment

5.1.6 Spatial Ability / Mental Rotation Test

All participants took a Mental Rotation Test (MRT) after Vandenberg and Kuse (Vandenberg et al. 1978) to test their spatial ability. The MRT-Scores (N = 30, Min = 13, Max = 40, Range = 27, M = 26.2, SD = 7.924) show, that there is a big range of the participant's spatial ability. The participants MRT-Score will later be used to measure the influence of the spatial ability on the main experiment results.

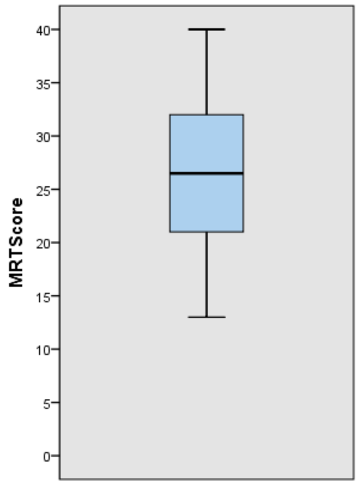

Figure 5.1.6 MRT-Score Boxplot

5.2 Main Experiment

In the main experiment response accuracy and response time (dependent variables) are measured for each task. The objective of this study is to compare the effect of stereoscopic view or absence of it (independent variable) on the response accuracy and response time (dependent variables). The different sections of this chapter show the results of different task blocks. The results are presented in charts and descriptive statistics. With a statistical analysis, the results are tested on statistical significance.

5.2.1 Overall results

If we look at the overall results over all 36 tasks, we see in Figure 5.2.1, that the overall response accuracy is slightly lower for mono (M = 0.787, SE = 0.012) than for stereo (M = 0.788, SE = 0.017) and the overall response time is longer for mono (M = 268.20, SE = 31.44) than for stereo (M = 240.79, SE = 14.93). An independent samples t-test shows no significant difference between mono and stereo for response accuracy (t = -0.68, df = 28, p = 0.946) and response time (t = 0.788, df = 28, p = 0.438).

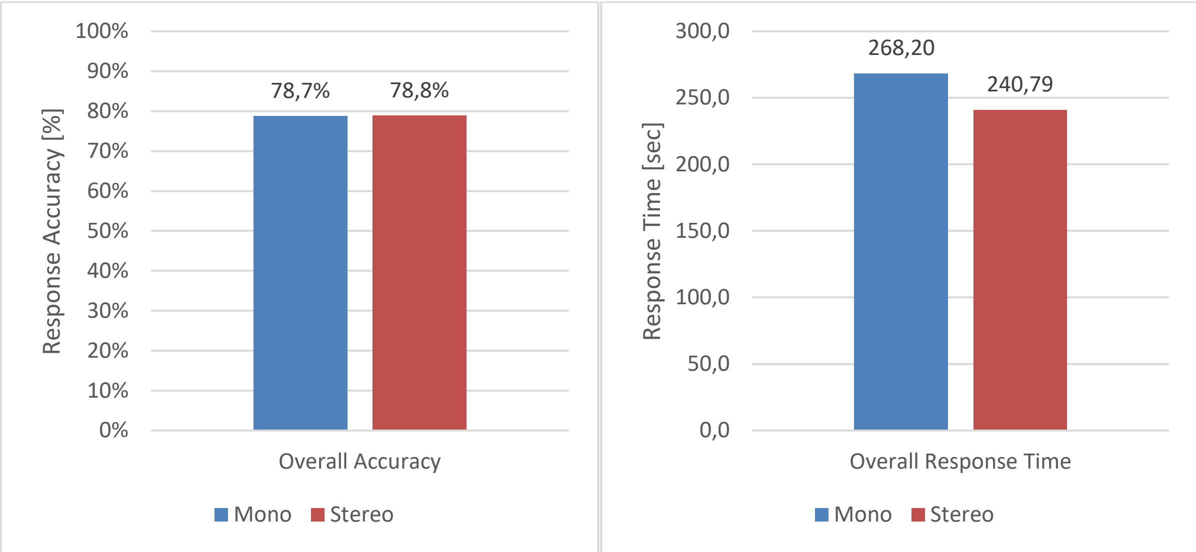

Figure 5.2.1 Overall response accuracy and response time

5.2.2 Relative spatial judgement tasks (abstract shapes)

In this section, the nine tasks concerning relative spatial judgement of abstract shapes are shown. As seen in Figure 5.2.2.a, we are interested in the differences between mono and stereo. Because the response accuracy data is not normally distributed, a Mann-Whitney test is used to compare the difference. It shows, that the response accuracy of the abstract shapes tasks is not significantly lower for mono (M = 0.933, SE = 0.021) than for stereo (M = 0.970, SE = 0.023), with z = -1.802, p = .072. For the response time, an independent samples t-test is used. The response time for the abstract shapes tasks is not significantly longer for mono (M = 29.7, SE = 3.8) than for stereo (M = 27.8, SE = 2.5), with t = .427, df = 28, p = .673.

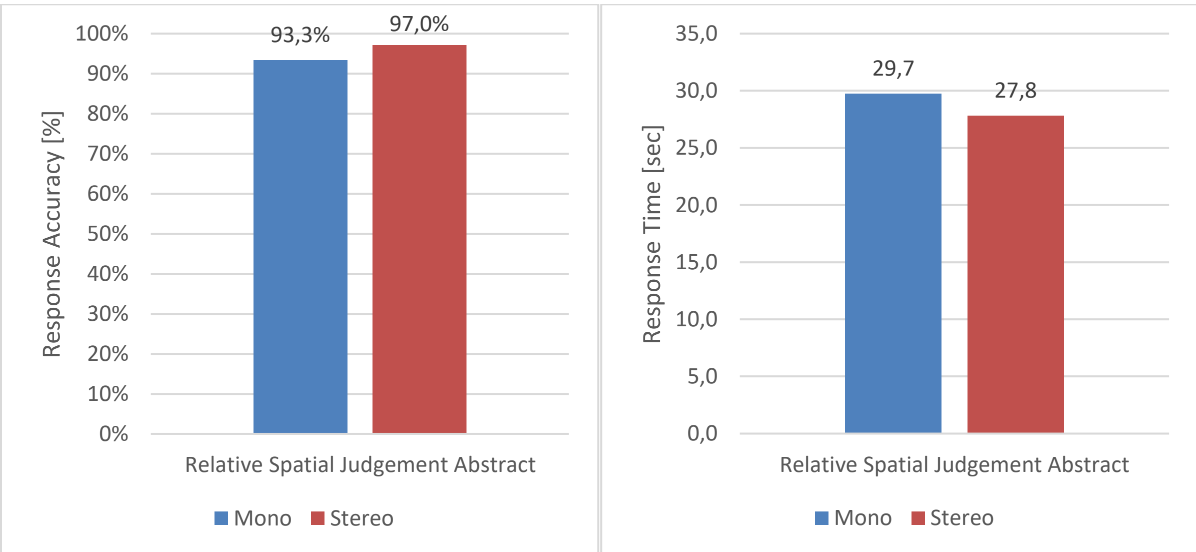

Figure 5.2.2.a Response accuracy and response time of relative spatial judgment tasks with abstract shapes

If the nine task are separated by perspective (planar view, oblique view, first-person view) and task type (height-, volume-, distance-estimation), we get the results for each single task. Figure 5.2.2.b shows the response accuracy and response time for each perspective and task in mono and stereo for the abstract shapes. There are no differences in response accuracy between mono and stereo for most perspectives and tasks. Only with distance estimation in the first-person view, a Mann-Whitney test shows that there is a significant difference between mono ($M_{Distance} = 0.6$, $SE_{Distance} = 0.131$) and stereo ($M_{Distance} = 0.93$, $SE_{Distance} = 0.067$), with $z = -2.122$, $p = 0.034$. Response time varies strongly between perspectives and tasks. There are no tasks that have a significant difference between mono and stereo in terms of response time. For some tasks mono is faster and for others stereo is faster.

Figure 5.2.2.b Response accuracy and response time of relative spatial judgment tasks with abstract shapes for each perspective

5.2.3 Relative spatial judgement tasks (apartment)

In this section, the results of the nine tasks concerning relative spatial judgment in an apartment context are presented. The difference between the apartment and the abstract shapes is found in their difference in complexity and additional depth cues. The apartment context shows multiple objects in the same room compared to only two objects in the abstract shapes visualization. The apartment visualization also adds more depth cues like shadows or familiarity with the scene. The response accuracy of the apartment context tasks is the same for both mono ($M = 0.911$, $SE = 0.012$) and stereo ($M = 0.911$, $SE = 0.027$). A Mann-Whitney test shows no significant difference between mono and stereo with $z = -.563$ and $p = .573$. The response time is longer for mono ($M = 50.5$, $SE = 7.6$) than for stereo ($M = 46.4$, $SE = 3.7$). An independent samples t-test shows, that the response time for mono is not significantly longer than for stereo with $t = .492$, $df = 28$, $p = .627$.

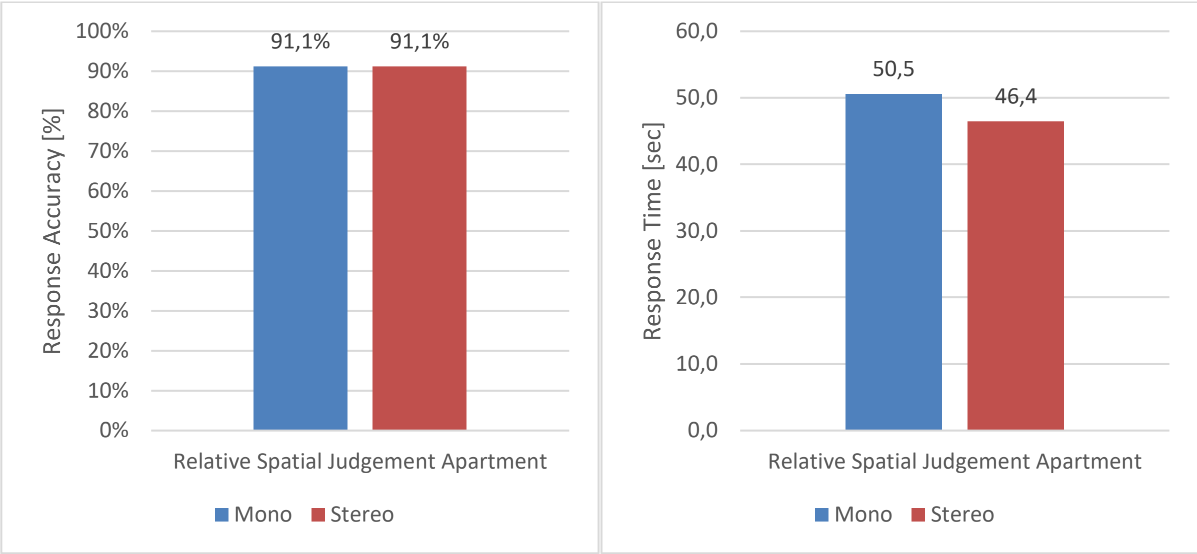

Figure 5.2.3.a Response accuracy and response time of relative spatial judgement tasks in the apartment context

In Figure 5.2.3.b the results of each perspective and task type are shown for all nine relative spatial judgement tasks in the apartment context. Concerning the response accuracy there are mainly differences between mono and stereo in the planar view perspective. For height- and distance-estimation tasks, stereo (M_{Height} = 1.0, SE_{Height} = 0.00, $M_{Distance}$ = 0.80, $SE_{Distance}$ = 0.107) has a higher response accuracy than mono (M_{Height}= 1.00, SE_{Height} = 0.091, $M_{Distance}$ = 0.73, $SE_{Distance}$ = 0.118), but for volume-estimation tasks, mono (M_{Volume} = 0.67, SE_{Volume} = 0.126) has a higher accuracy than stereo (M_{Volume} = 0.53, SE_{Volume} = 0.133). None of these differences are statistically significant. While there was a significant difference for distance estimation in the first-person view of abstract shapes, there is no difference found in the apartment context. Response time varies from task to task between mono and stereo. As for the abstract shapes, there is also no significant difference in response times in the apartment context.

Figure 5.2.3.b Response accuracy and response time of relative spatial judgement tasks in the apartment context for each perspective

5.2.4 Absolute spatial judgement tasks

Moving on from the relative spatial judgement tasks to the absolute spatial judgement tasks, we see in Figure 5.2.4.a, that the response accuracy gets lower and the response time gets longer. For these nine tasks the participants had to estimate absolute height (m), volume (m^3) and distance (m) in the same apartment as the relative spatial judgement tasks. As written in chapter 4.1, the response accuracy was scaled on how close the participants got to the actual size of an object. According to independent samples t-test, the response accuracy of the absolute judgement tasks is not significantly higher for mono (M = 0.540, SE = 0.028) than for stereo (M=0.509, SE= 0.028), with t = 0.787, df = 28, p = 0.438. Also, the response time is not significantly longer for mono (M = 149.1, SE = 22.9) than for stereo (M = 128.2, SE = 9.8), with t = 0.841, df = 28, p = 0.408.

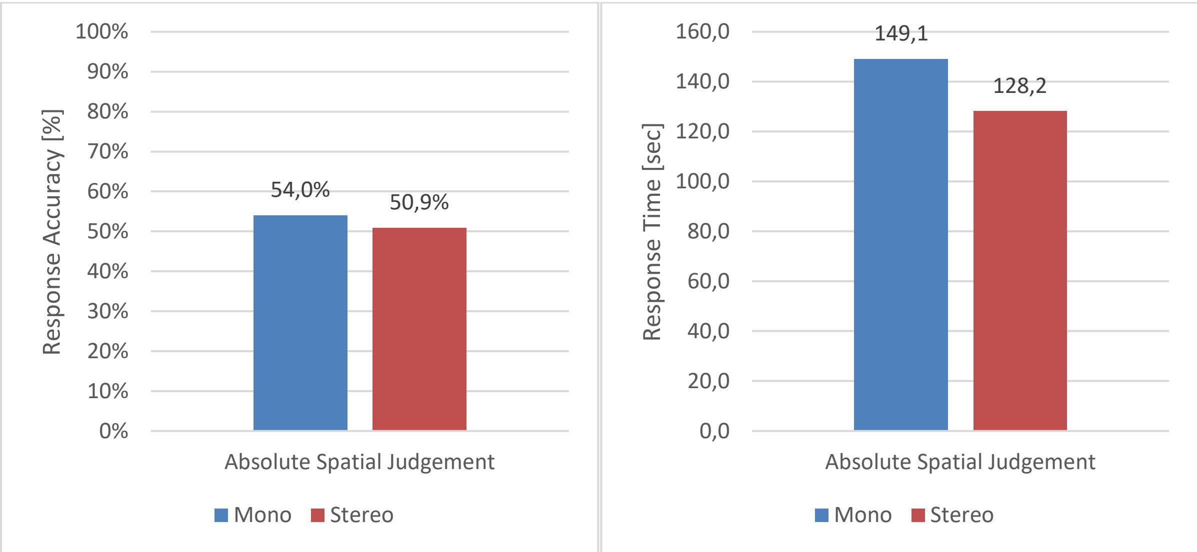

Figure 5.2.4.a Response accuracy and response time of absolute spatial judgement tasks

Figure 5.2.4.b shows the results of all nine tasks for each perspective and task type. There are differences between the tasks. Absolute volume estimation was the most difficult in terms of response accuracy and response time for all perspectives in both mono and stereo. There are no significant differences between mono and stereo in terms of response accuracy and response time.

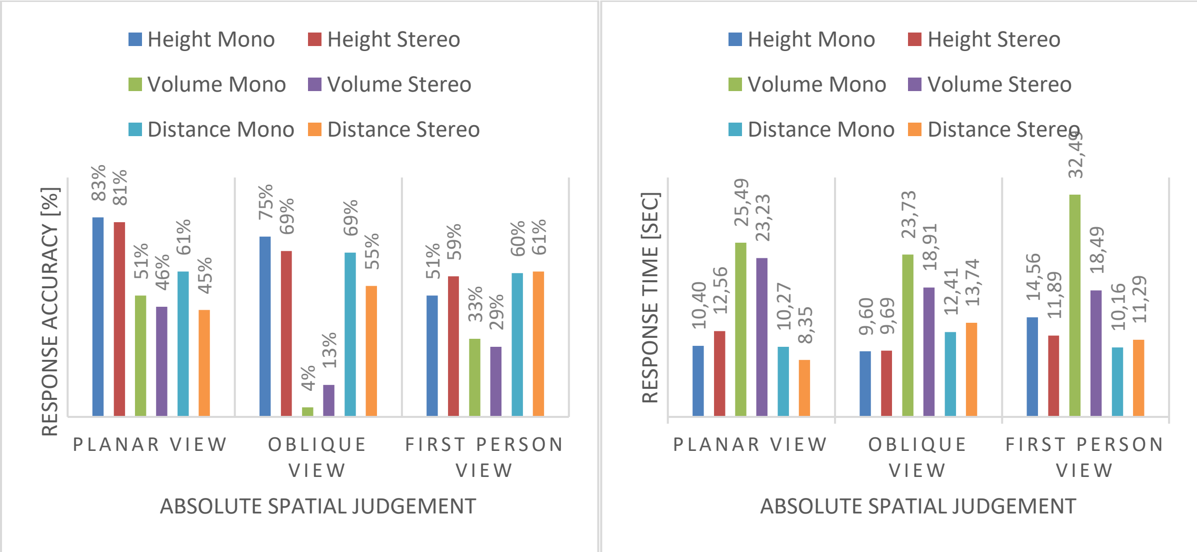

Figure 5.2.4.b Response accuracy and response time of absolute spatial judgement tasks for each perspective

5.2.5 Memorability tasks

In this section the results of the nine memorability tasks are presented. As described in chapter 4.3, the participants were shown a different apartment for one minute in each perspective. They got the task to remember the apartment in a way that they could describe it to someone else afterwards. Figure 5.2.5.a shows that the response accuracy of the memorability tasks is the same for both mono (M = 0.763, SE = 0.024) and stereo (M= 0.763, SE = 0.030). A Mann-Whitney test shows that there is no significant difference between mono and stereo with z = -0.509, p = 0.611. The response time is longer for mono (M = 37.8, SE = 5.5) than for stereo (M = 37.4, SE = 5.0). An independent samples t-test confirms that there is no significant difference with t = 0.55, df = 28, p = 0.957.

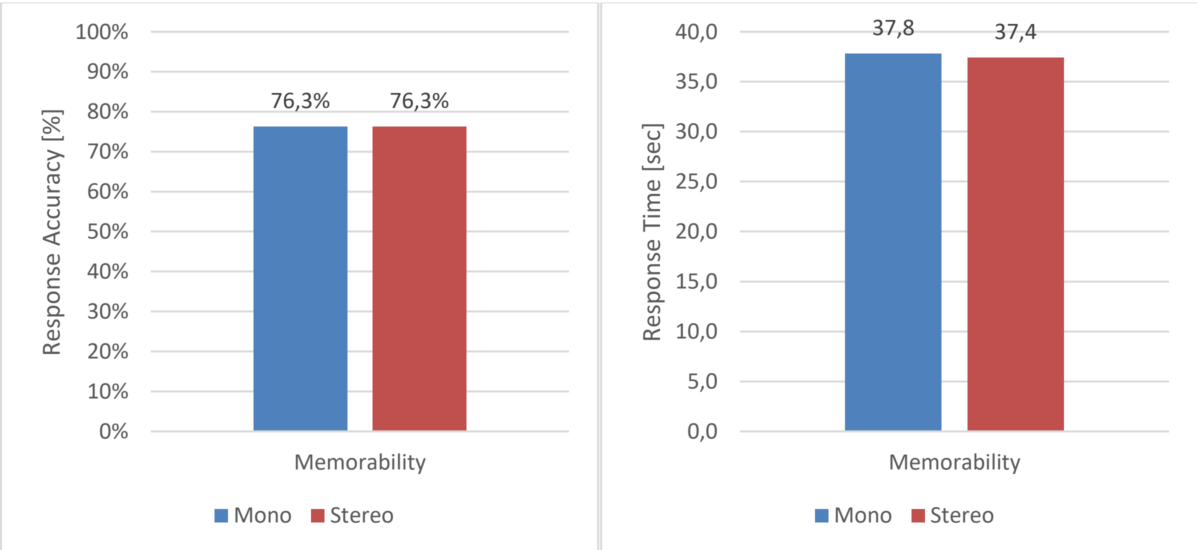

Figure 5.2.5.a Response accuracy and response time of memorability tasks

Looking at all task and all perspectives (Figure 5.2.5.b) we see some differences in response accuracy and response time over all tasks and perspectives but no significant ones. Task 2 (object count) for the oblique view was most difficult with the lowest response accuracies and the longest response times.

Figure 5.2.5.b Response accuracy and response time of memorability tasks for each perspective

5.2.6 Correlation of results to MRT-Score

Overall Correlation

A bivariate correlation analysis after Pearson between the MRT-Score of the 30 participants and the overall response accuracy shows a positive correlation of $r = 0.309$ and $R^2 = 0.096$ with a significance of $p = 0.096$. With $p \geq 0.05$ there is no statistically significant correlation between the MRT-Score and the overall accuracy. For the mono participants, there is a positive correlation of $r = 0.290$ and $R^2 = 0.084$ with a significance of $p = 0.294$. For the stereo participants, there is a positive correlation of $r = 0.348$ and $R^2 = 0.121$ with a significance of $p = 0.204$. The overall accuracy of S3D correlates stronger with the MRT-Score than the overall accuracy of M3D, but the values are not statistically significant.

Overall response time shows a positive correlation of $r = 0.046$ and $R^2 = 0.002$ with a significance of $p = 0.811$. There is no statistically significant correlation between the MRT-Score and the overall response time. For the mono participants, there is a positive correlation of $r = 0.154$ and $R^2 = 0.024$ with a significance of $p = 0.583$ and for the stereo participants, there is a negative correlation of $r = -0.112$ and $R^2 = 0.013$ with a significance of $p = 0.691$. The overall response time of S3D gets slightly lower with higher MRT-Scores. In contrast, the overall response time of M3D gets slightly higher with higher MRT-Scores, but the values are not statistically significant.

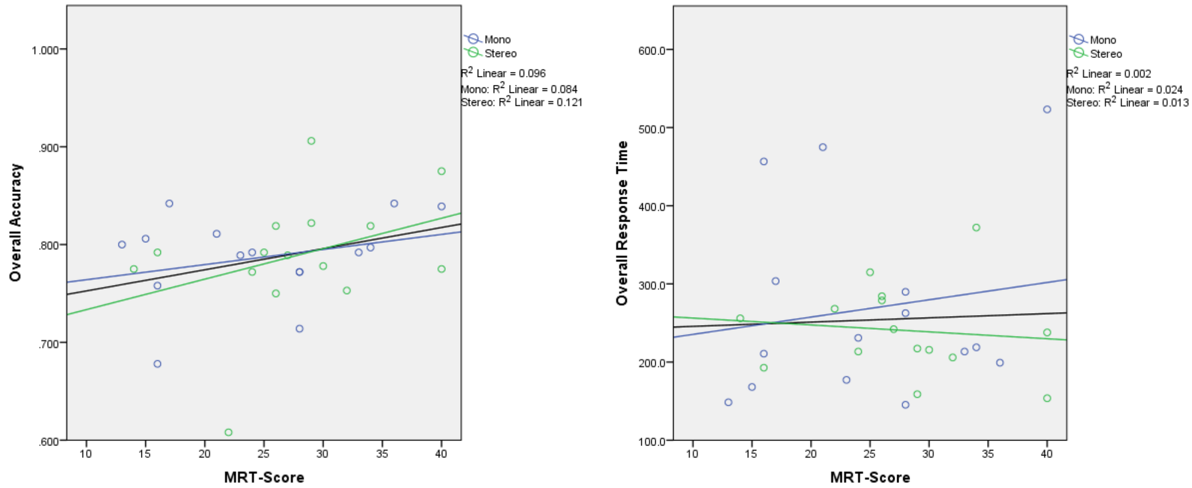

Figure 5.2.6.a Scatter plots with linear regression lines of overall response accuracy and response time

Spatial Judgement Correlation

If a bivariate correlation analysis after Pearson is carried out between the MRT-Score and the response accuracy of all spatial judgement tasks, there is a positive correlation of r = 0.196 and $R^2 = 0.038$ with a significance of p = 0.299. The correlation between response accuracy for spatial judgement tasks and MRT-Scores is not statistically significant. For the mono participants, there is a positive correlation of r = 0.261 and $R^2 = 0.068$ with a significance of p = 0.347 and for the stereo participants, there is a positive correlation of r = 0.156 and $R^2 = 0.024$ with a significance of p = 0.578. The response accuracy of S3D correlates more with the MRT-Score than the accuracy of M3D, but both correlations are not statistically significant.

The response time of spatial judgement tasks has a positive correlation of r = 0.042 and $R^2 = 0.002$ with a significance of p = 0.824. It is not statistically significant. For the mono participants, there is a positive correlation of r = 0.148 and $R^2 = 0.022$ with a significance of p = 0.600 and for the stereo participants, there is a negative correlation of r = -0.115 and $R^2 = 0.013$ with a significance of 0.684. The response time of S3D gets slightly lower with higher MRT-Scores and for M3D the response time gets slightly higher with higher MRT-Scores, but the values are not statistically significant.

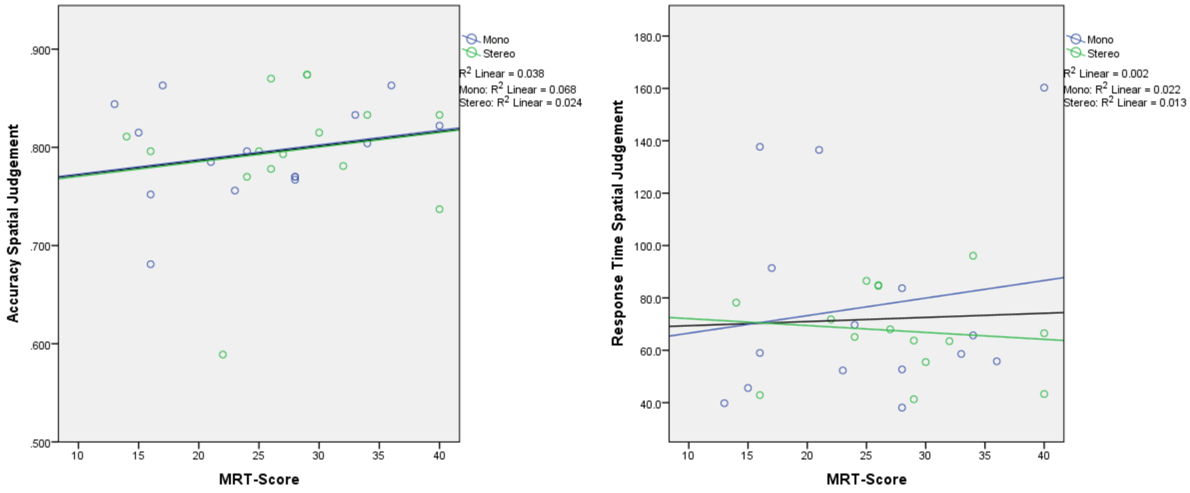

Figure 5.2.6.b Scatter plots with linear regression lines of spatial judgement response accuracy and response time

Memorability Correlation

The correlation between MRT-Scores and the response accuracy of memorability tasks is $r = 0.324$ and $R^2 = 0.105$ with a significance of $p = 0.081$. With $p \geq 0.05$ there is no statistically significant correlation between the MRT-Score and the overall accuracy. For the mono participants, there is a positive correlation of $r = 0.157$ and $R^2 = 0.025$ with a significance of $p = 0.575$ and for the stereo participants, there is a positive correlation of $r = 0.498$ and $R^2 = 0.248$ with a significance of $p = 0.059$. The accuracy of S3D correlates stronger with the MRT-Score than the accuracy of M3D, but not statistically significant.

In terms of response time of memorability tasks, there is a correlation of $r = 0.028$ and $R^2 = 0.0008$ with a significance of $p = 0.883$. There is no statistically significant correlation between the MRT-Score and the overall response time. For the mono participants, there is a positive correlation of $r = 0.081$ and $R^2 = 0.007$ with a significance of $p = 0.775$ and for the stereo participants, there is a negative correlation of $r = -0.034$ and $R^2 = 0.001$ with a significance of $p = 0.904$. The response time of S3D gets slightly lower with higher MRT-Scores and for M3D the response time gets slightly higher with higher MRT-Scores. The difference is not statistically significant.

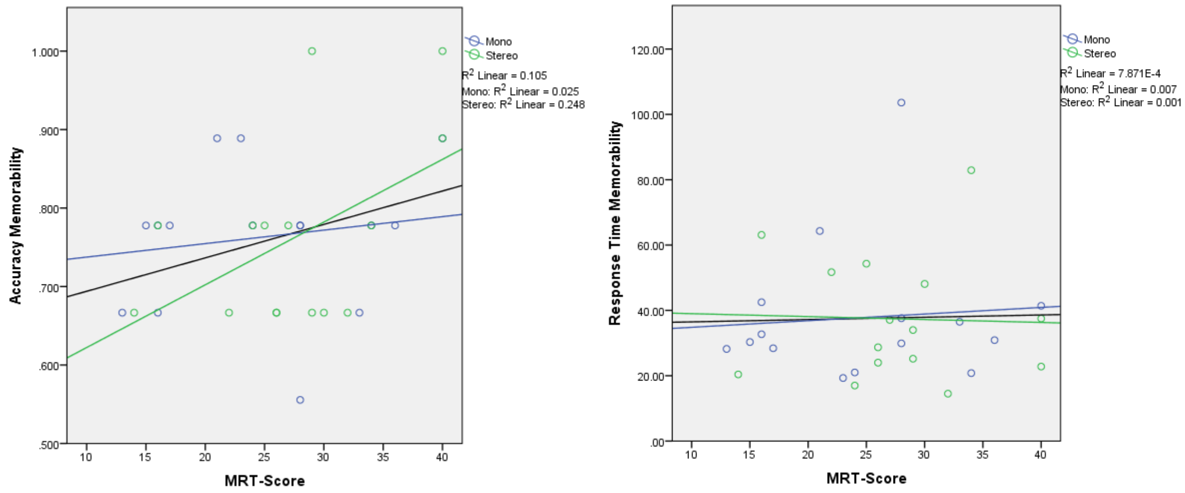

Figure 5.2.6.c Scatter plots with linear regression lines of memorability response accuracy and response time

5.3 Post-Questionnaire

5.3.1 Perspective Difficulty Rating

Figure 5.3.1.a shows that for relative spatial judgement tasks, the planar view was the most difficult with a majority of the participants saying it was the hardest perspective for these tasks. The oblique view lies in between with most participants saying it was moderate in difficulty. The least difficult perspective was the first-person view with a majority of participants saying it was the easiest.

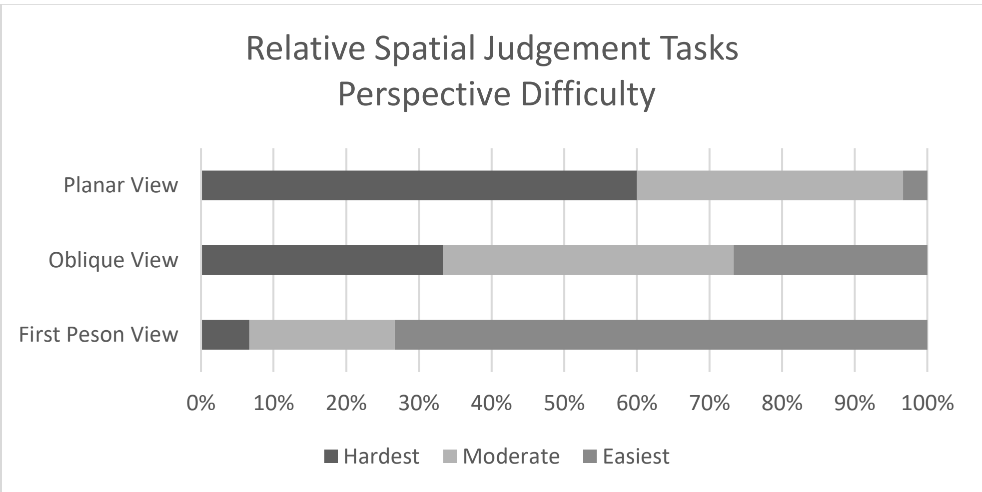

Figure 5.3.1.a Perspective difficulty for relative spatial judgement tasks

For absolute spatial judgement tasks, the planar view was the most difficult perspective with a majority of the participants saying it was the hardest. Most participants assessed the oblique view to be moderate in difficulty. The least difficult perspective was the first-person view with a majority thinking it was the easiest.

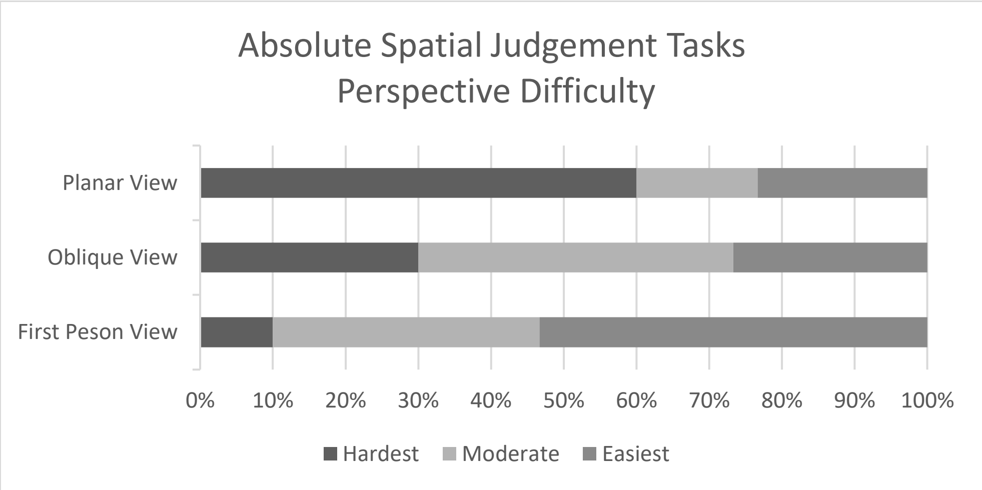

Figure 5.3.1.b Perspective difficulty for absolute spatial judgement tasks

As seen in Figure 5.3.1.c, a majority of the participants rated the first-person view as least difficult for memorability tasks. The most difficult perspective is the oblique view with a high percentage of the participants saying it was the hardest perspective. In between lies the planar view with exactly a third saying it was the hardest, a third saying it was of moderate difficulty and a third saying it was the easiest.

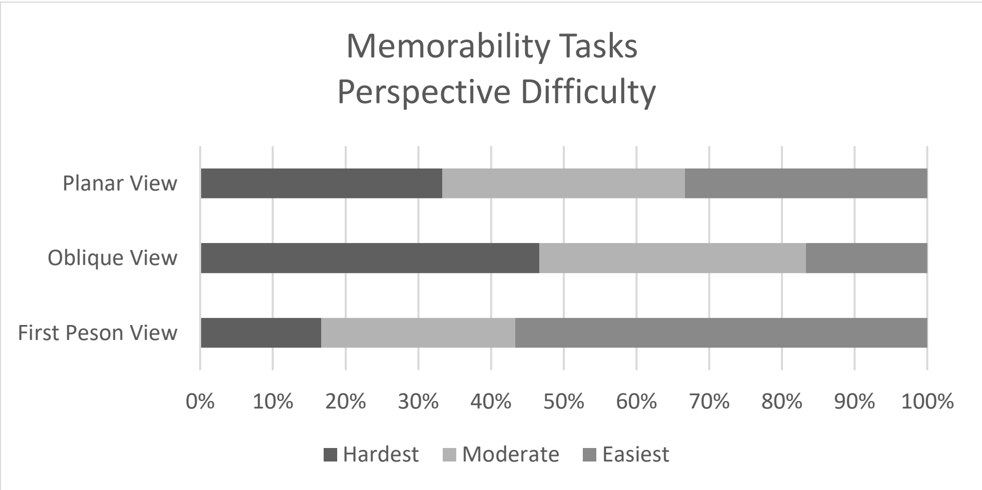

Figure 5.3.1.c Perspective difficulty for memorability tasks

5.3.2 Task Difficulty Rating

When asked about the participant's task difficulty rating, the relative spatial judgement tasks were rated easier by 77% of the participants. Only 23 % rated the absolute spatial judgement tasks to be easier. This goes along with the response accuracy and response time of the two different task blocks. Absolute spatial judgement tasks had a lower response accuracy and longer response time and were therefore rated as harder.

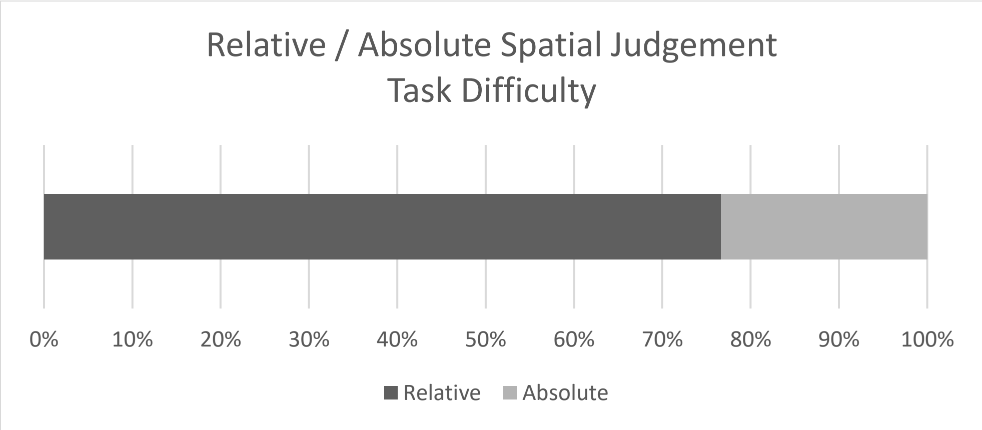

Figure 5.3.2.a Task difficulty for relative or absolute spatial judgement tasks

Figure 5.3.2.b shows what kind of tasks (height-, volume-, distance-estimation) were rated more difficult for the spatial judgement blocks. First of all, it stands out that 80% of the participants judged the volume estimation to be the hardest. Distance estimation was rated slightly less difficult than height estimation with the highest percentage of participants saying it was the easiest task.

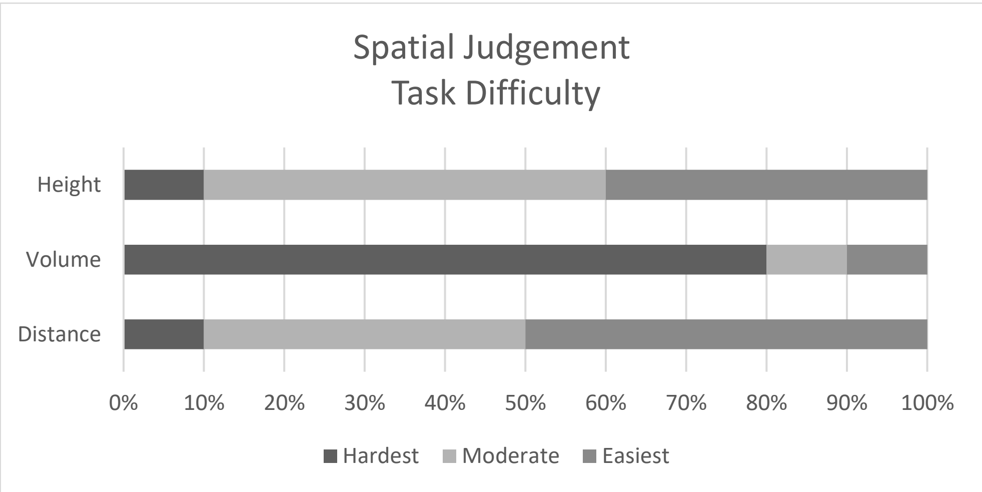

Figure 5.3.2.b Task difficulty for spatial judgement tasks

As for the memorability tasks, figure 5.3.2.c visualizes the task type (A or B, Count, Yes or No) difficulty rating by percentage of the participants. The least difficult were the Yes or No tasks, where the participants had to remember whether or not an object was found in the apartment. Remembering the count of objects in the apartment was considered slightly harder than remembering whether an object was in room A or B.

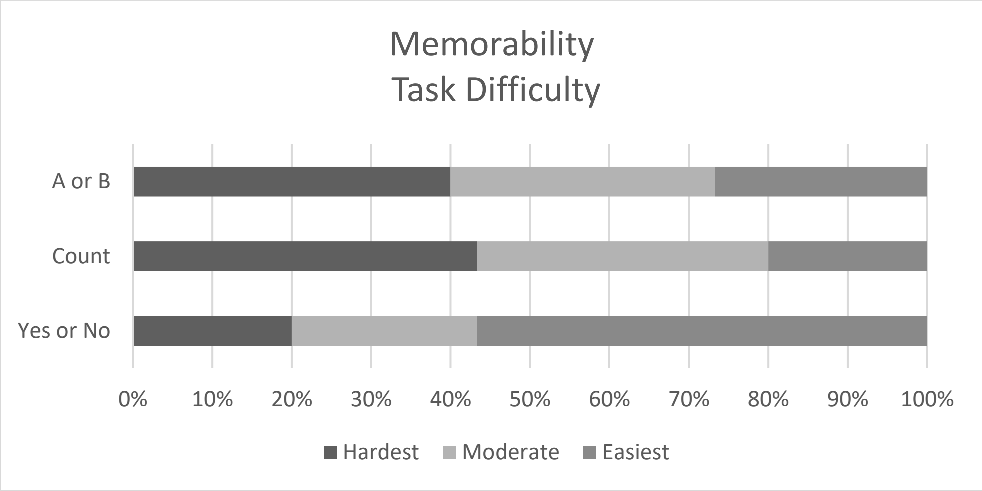

Figure 5.3.2.c Task difficulty for memorability tasks

5.3.3 Discomfort

22 participants (73.3%) had no signs of discomfort after the experiment using the Oculus Rift DK2. Eight participants (26.7%) showed some sort of discomfort after the experiment. Four felt tired (13.3%), two had tired eyes (6.7%), another two felt dizzy (6.7%) and one had slight nausea (3.3%). Since there was no movement involved in the virtual environment and the participants could only look around, the main symptoms of simulator sickness (dizziness, nausea) were only found with three participants (10%). Participants who experienced virtual reality devices before were less likely to have any discomfort after the experiment, since they were already adjusted to it (Boyd 2000).

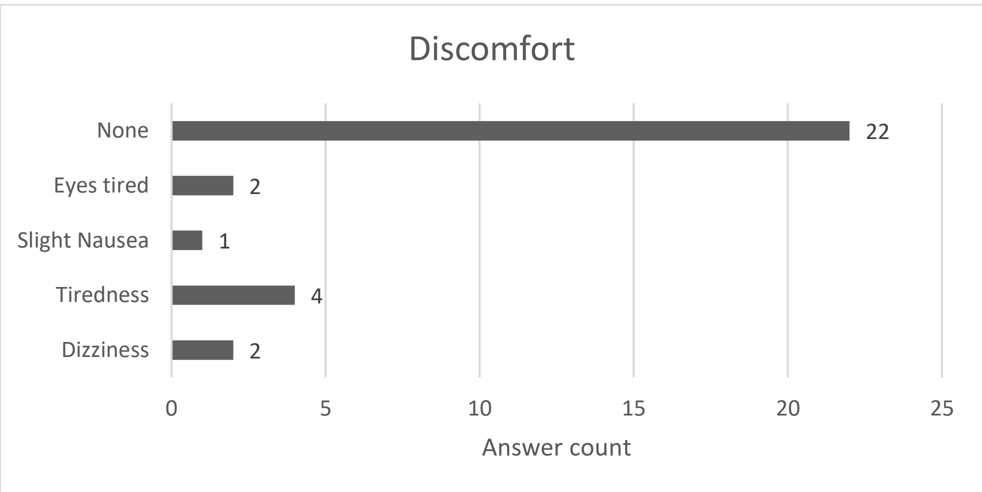

Figure 5.3.3 Discomfort after the experiment

6. Discussion

In this chapter the findings of the study are interpreted and discussed in the context of the current state of research. The research questions one and two will be answered separately with the underlying hypotheses to be confirmed or rejected. Lastly the study's limitations will be explained.

6.1 Research Question 1 – Spatial Judgement

What are the differences between stereo 3D VR (Oculus Rift / both eyes) and mono 3D VR (Oculus Rift / one eye) visualizations for judging spatial relationships in a 3D scene, specifically for height-, volume- and distance- estimations in terms of accuracy and efficiency? In this context, how strong is the influence of:

1. *Different perspectives (planar view, oblique view, first-person view)?*
2. *Spatial ability of participants?*

6.1.1 Hypothesis 1.1

S3D VR will positively influence depth perception and therefore have better results with judging spatial relationships (height-, volume- and distance-estimations) than with M3D VR (Westheimer 2011).

Response Accuracy

The accuracy of S3D VR and M3D VR for spatial operations is mostly depending on the tasks. For relative spatial judgement tasks with abstract shapes there is no significant difference between S3D (M= 0.970) and M3D (M = 0.933). Also for relative spatial judgement tasks within the apartment context there is no significant difference between S3D (M = 0.911) and M3D (M = 0.911). Neither do the absolute spatial judgement tasks within the apartment context show a significant difference between S3D (M = 0.509) and M3D (M = 0.540). The small differences can be seen as trends, but they are not significant enough to confirm the hypothesis.

S3D is more beneficial for the abstract shapes visualisations than for the apartment visualizations due to some missing monocular depth cues like shadowing, familiarity, texture gradient, overlapping, aerial perspective and colour differences in the abstract shapes visualizations. S3D adds the binocular depth cues of binocular parallax and binocular motion parallax to depth perception (Mehrabi et al. 2013).

Therefore, the results of the abstract shapes visualizations show a trend that S3D will positively influence depth perception for spatial operation tasks (Westheimer 2011). The hypothesis still has to be rejected since the difference is not statistically significant.

In the context of the apartment visualizations there is no benefit visible by adding binocular depth cues of binocular parallax and binocular motion parallax (Mehrabi et al. 2013). The monocular depth cues available to participants of the M3D study seem to be sufficient for the task. The addition of the binocular depth cues does not harm the accuracy of the S3D study participants either. For the relative spatial judgement tasks in the apartment context the hypothesis has to be rejected since the response accuracy does not get better with S3D.

For absolute spatial judgement tasks in the apartment context, the trend shows that S3D is less accurate than M3D. Being familiar with the apartment context is a strong help when judging absolute heights, volumes and distances. Therefore, the response accuracy results may be more dependent on the familiarity with objects sizes than the actual monocular or binocular depth cues (Mehrabi et al. 2013). The response accuracy is overall much lower than for the relative spatial judgment tasks. This indicates a higher difficulty of the tasks. The hypothesis has to be rejected for absolute spatial judgement tasks since there is no significant difference between S3D and M3D.

Response Time

Also for the response time of S3D VR and M3D VR of spatial operations the results are highly dependent on the tasks. The results show no significant difference between S3D ($M = 27.8$) and M3D ($M = 29.7$) for relative spatial judgment tasks with abstract shapes. Also for relative spatial judgement tasks in the apartment context there is no significant difference between S3D ($M = 46.4$) and M3D ($M = 50.5$). Neither do the absolute spatial judgement tasks in the apartment context show a significant difference between S3D ($M = 128.2$) and M3D ($M = 149.1$). The differences in response time can be seen as trends, but they are not significant to confirm the hypothesis.

In contrast to the response accuracy results, the trend shows a lower response time for all spatial judgement tasks and visualizations in S3D. These trends correspond with Van der Land et al. (2013), who suggested that a higher immersion and presence offered by the S3D VR setting, helps relate better to the visual stimuli which leads to a higher efficiency (Van der Land et al. 2013). This effect is true for both visualization types (abstract shapes, apartment context) as well as for both task types (relative spatial judgement, absolute spatial judgement). Even though the trend for shorter response times in S3D exists for all spatial judgement tasks, the hypothesis has to be rejected because of the non-significant difference.

6.1.2 Hypothesis 1.2

Both the first-person view and the oblique view will benefit from S3D VR, due to the binocular depth cues. There will be no benefit of S3D VR for the planar view, since the monocular depth cues are sufficient for the task (St. John et al. 2001).

Response Accuracy

Looking at the response accuracy of the different perspectives (planar view, oblique view, first-person view), it is highly dependent on the tasks. For the relative judgement tasks with abstract shapes, the response accuracy is high for all tasks in S3D and M3D with no significant differences between them. An exception is the distance estimation in the first-person view, were there is a significant difference between mono (M = 0.6) and stereo (M = 0.93). This goes along with studies that suggest a benefit of S3D for distance estimations (McIntire et al. 2014). Interestingly, there are no significant differences for distance estimations in the oblique perspective. Also for height and volume estimation, there are no significant differences in any perspective. The first part of the hypothesis has to be rejected, since there is no significant benefit from S3D in the first-person view and the oblique view, besides the distance estimation in the first-person view. The second part of the hypothesis can be confirmed, since there is no significant benefit of S3D in the planar view.

For the relative spatial judgement tasks within the apartment context, the response accuracy is also very high in S3D and M3D. Only in the planar view, the response accuracy is lower for both S3D and M3D. There are no significant differences between S3D and M3D in the apartment context. First-person view and oblique view do not benefit from S3D as the hypothesis states. Planar view does also not benefit form S3D, which confirms the hypothesis.

For the absolute spatial judgement tasks within the apartment context, the response accuracy is generally lower than for the relative spatial judgement tasks for both S3D and M3D. There are no significant differences in response accuracy between S3D and M3D for any perspectives. Both the first-person view and the oblique view do not benefit from S3D, so the hypothesis has to be rejected. In the planar view, there is also no benefit from S3D, so this part of the hypothesis is confirmed.

Over all spatial judgement tasks the first part of the hypothesis has to be rejected, since there is no significant benefit from S3D for both first-person view and oblique view. The second part of the hypothesis can be confirmed. There was no benefit from S3D for the planar view which corresponds with the findings by St. John et al. (2011).

Response Time

In terms of response time, the different perspectives show that there are no significant differences between S3D and M3D. S3D shows a trend towards lower response times compared to M3D for all perspectives. There is no significant benefit of S3D visible for the relative spatial judgement tasks with abstract shapes, the relative spatial judgement tasks in the apartment context nor for the absolute spatial judgement tasks. The response time only shows a trend towards a benefit for all task types and perspectives, which corresponds with Van der Land et al. (2013). The first part of the hypothesis has to be rejected, since both first-person view and oblique view do not significantly benefit from S3D. The second part of the hypothesis can be confirmed, since the planar view does not significantly benefit from S3D.

6.1.3 Hypothesis 1.3

Participants with lower spatial ability scores will benefit more from S3D VR than participants with higher spatial ability scores (McIntire et al. 2014).

Response Accuracy

The correlation analysis between the spatial ability (MRT-Score) and the spatial judgement task response accuracy shows no significant difference in correlation between S3D and M3D. For the mono participants, there is a positive correlation of $r = 0.261$ and $R^2 = 0.068$ and for the stereo participants, there is a positive correlation of $r = 0.156$ and $R^2 = 0.024$. Both of these correlations are not statistically significant. The trend shows, that the response accuracy of S3D correlates slightly less with the MRT-Score than the response accuracy of M3D. This trend does not correspond with the current state of research. S3D is shown to be especially helpful for difficult tasks that are not familiar. Novices benefit more from S3D than experts for unfamiliar tasks (McIntire et al. 2014). It can be argued that the missing significant difference might be caused by the task difficulty. Especially the relative spatial judgement tasks seem to be too easy, since both S3D and M3D have high response accuracies (ceiling effect). On the other hand, the absolute spatial judgement tasks with lower response accuracies for S3D ($M = 0.509$) and M3D ($M = 0.540$) show, that the response accuracy is lower for S3D for more difficult tasks. The hypothesis therefore has to be rejected. Participants with a higher spatial ability score do not benefit more from the additional depth cues of S3D than participants with a lower spatial ability score.

Response Time

In terms of response time, there is no significant difference in correlation between S3D and M3D. For the mono participants, there is a positive correlation of r = 0.148 and R^2 = 0.022 and for the stereo participants, there is a negative correlation of r = -0.115 and R^2 = 0.013. The trend shows, that the response time of S3D gets slightly lower with higher MRT-Scores and for M3D the response time gets slightly higher with higher MRT-Scores. The trend corresponds with McIntire et al.'s (2014) findings, but the differences are not statistically significant. The hypothesis has to be rejected. Participants with a lower spatial ability score do not benefit more from S3D than participants with a higher spatial ability score. Participants with a lower spatial ability score do better in M3D than participants with a higher spatial ability score.

6.2 Research Question 2 – Memorability

Which visualization (S3D VR or M3D VR) is more suitable for memorability in the case of indoor visualizations as measured by recall accuracy and efficiency? How strong is the influence of:

1. *Different perspectives (planar view, oblique view, first-person view)?*
2. *Spatial ability of participants?*

6.2.1 Hypothesis 2.1

S3D VR will enhance memorability compared to M3D VR due to the stronger feeling of presence (Van der Land et al. 2013).

Response Accuracy

There is no significant difference between the response accuracy of S3D VR (M = 0.763) and M3D VR (M = 0.763) for the memorability tasks. The stronger feeling of presence that S3D offers (Van der Land et al. 2013) compared to M3D does not have an effect on the response accuracy of memorability tasks. It is shown that S3D is beneficial for memorability tasks in complex spatial environments when adequate monocular depth cues are missing (McIntire et al. 2014). In this study, memorability was tested only for the apartment context with multiple monocular depth cues (shadowing, familiarity, texture gradient, overlapping, aerial perspective and colour differences) (Mehrabi et al. 2013). Therefore, the hypothesis has to be rejected for memorability tasks.

Response Time

The results show no significant difference for memorability tasks between S3D (M = 37.4) and M3D (M = 37.8). There is only a small trend towards lower response times for S3D. The feeling of presence (Van der Land et al. 2013) has no effect on the response times. The monocular depth cues are sufficient for the task and no benefit from binocular depth cues is observed. The hypothesis has to be rejected.

6.2.2 Hypothesis 2.2

Both the first-person view and the oblique view will benefit from S3D VR, due to the binocular depth cues. There will be no benefit of S3D VR for the planar view, since the monocular depth cues are sufficient for the task (St. John et al. 2001).

Response Accuracy

There are differences from task to task between S3D and M3D, but no clear trend is visible towards one being more accurate for any perspective. The differences are not statistically significant. The planar view has no benefit with S3D as St. John et al. (2001) argues, but neither do the first-person view nor the oblique view. Again, the monocular depth cues seem to be sufficient for all tasks and perspectives (McIntire et al. 2014). The first part of the hypothesis has to be rejected for the memorability tasks, since there is no benefit from S3D visible for the first-person view and the oblique view. For the planar view, there is also no significant difference between S3D and M3D and therefore the second part of the hypothesis can be confirmed.

Response Time

For both first-person view and the oblique view, there is no difference between S3D and M3D in response time of memorability tasks. Some tasks are more efficiently solved in S3D and some in M3D. Overall, the difference is not significant. The first part of the hypothesis therefore has to be rejected, since there is no benefit in response times for S3D. In the planar view, there is a trend towards shorter response times with S3D, but the differences are not statistically significant. This trend goes against the findings of St. John et al. (2001). The second part of the hypothesis still has to be rejected for memorability tasks, since the difference between S3D and M3D is not significant (St. John et al. 2011).

6.2.3 Hypothesis 2.3

Participants with lower spatial ability scores will benefit more from S3D VR than participants with higher spatial ability scores (McIntire et al. 2014).

Response Accuracy

According to the correlation analysis between the spatial ability (MRT-Score) and the memorability task response accuracy, there is no significant difference between S3D and M3D. For the mono participants, there is a positive correlation of r = 0.157 and $R^2 = 0.025$ and for the stereo participants, there is a positive correlation of r = 0.498 and $R^2 = 0.248$. The trend shows that the response accuracy of S3D correlates stronger with the MRT-Score than the response accuracy of M3D. In contrast to McIntire et al. (2014), participants with higher spatial ability score benefit more from S3D than participants with lower spatial ability scores, but not significantly. The hypothesis therefore has to be rejected.

Response Time

The response time shows that there is no significant difference in correlation with the MRT-Score between S3D and M3D. For the mono participants, there is a positive correlation of r = 0.081 and $R^2 = 0.007$ and for the stereo participants, there is a negative correlation of r = -0.034 and $R^2 = 0.001$. According to the trend, the response time of S3D gets slightly lower with higher MRT-Scores and for M3D slightly higher with higher MRT-Scores. Participants with lower spatial ability scores do not benefit as much from S3D as participants with higher spatial ability score. This does not correspond with the state of research (McIntire et al. 2014). The hypothesis has to be rejected.

6.3 Study Limitations

First, the study results show a lot of insignificant differences. There are multiple reasons for this. For some results, there is simply no difference observable and therefore they cannot be statistically significant. For other results, there are trends visible, but they cannot be statistically confirmed due to the small sample size of 15 participants for S3D and 15 participants for M3D. A higher sample size could help getting more significant results, since the differences are usually small between S3D and M3D.

Second, some tasks were too easy to answer. There is a ceiling effect for the relative spatial judgement tasks for both abstract shapes as well as the apartment context. Both task types have very high response accuracies close to 100% for both S3D and M3D. The data is therefore not normally distributed for relative spatial judgement tasks.

Third, the chosen apartment visualizations with all monocular depth cues (familiarity, linear perspective, texture gradient, overlapping, aerial perspective, shadowing, colour differences, monocular parallax) (Mehrabi et al. 2013) were sufficient for the mono participants to complete the tasks and the addition binocular depth cues did not make a significant difference. Therefore, the abstract shape visualizations without most monocular depth cues were used to compare the relative spatial judgement tasks. Something similar could have been done for absolute spatial judgement tasks and memorability tasks to test the effect of monocular depth cues on the results.

Forth, the influence of gender and age on the results was not analysed. The sample consisted of mostly young participants from 20 – 30 years old. The professional expertise of the participants was measured and illustrated for an overview of the participants, but not taken into account when analysing the results. The same is also true for the experience with VR devices and video games.

7. Conclusion

The comparison of stereo 3D VR with mono 3D VR in indoor visualisations shows that there is overall no significant difference between stereo 3D VR and mono 3D VR concerning response accuracy and response time. There are only trends indicating small differences for some task types and perspectives. S3D VR does not bring a significant benefit compared to M3D VR.

For the spatial judgement tasks with abstract shapes the trend shows a benefit of S3D in response accuracy since only few monocular depth cues are given. This trend is not visible with the indoor visualization, because the monocular depth cues are already sufficient for the tasks (Mehrabi et al. 2013). For absolute spatial judgement tasks the trend shows a benefit in response accuracy for M3D over S3D. It is argued that binocular depth cues do not help when judging absolute height, volume or distance (Mehrabi et al. 2013). The memorability tasks show no difference between S3D and M3D in response accuracy. The response time shows no significant difference between S3D and M3D, but there is a trend towards S3D being more efficient for all tasks from relative- and absolute spatial judgement to memorability.

The three different perspectives (planar view, oblique view, first-person view) do not have a significant influence on the results. For all perspectives, there is no significant difference between S3D and M3D. It was confirmed that the planar view does not benefit from S3D (St. John et al. 2001), but neither do the oblique view nor the first-person view.

There is no significant correlation between the MRT-Scores and the results. Participants with a lower spatial ability score did not benefit more from S3D than participants with a higher spatial ability score (McIntire et al. 2014). There is rather a trend visible, that participants with higher spatial ability score benefit more from S3D both in response accuracy and response time for all task types.

In future research, these trends listed above would have to be tested with a higher sample size to get more significant results. The influence of monocular depth cues on the results could be further analysed by also testing absolute judgement tasks and memorability tasks without some of the monocular depth cues. This way, one could differentiate the results for different visualization types. Further, the results could be analysed based on the influence of different criteria like gender, age and professional expertise, experience with VR devices and experience with video games. With further advancements in VR HMD technology negative effects of VR like tiredness and dizziness could be eliminated, which could have an effect on the results.

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Appendix

Consent Form

The University of Zurich - **Participant Information Statement and Consent Form** Judging of spatial relationships in Virtual Reality
November 14-27, 2016
Participant No:

Purpose of study

You are invited to participate in a study regarding judging of spatial relationships in Virtual Reality. We hope to learn more about the usefulness of Virtual Reality as a 3D Geovisualization tool.

Description of study and risks

If you decide to participate, we will ask you to begin by filling out a short background questionnaire including demographic information. This will be followed by stereoscopic 3D test and a spatial ability test. For the main experiment you will be wearing a virtual reality device and verbally answer questions concerning the shown visualization. The answers will be recorded with a microphone and the time it takes to answer will be noted. After the experiment we will ask you to fill out a second questionnaire.

The whole procedure should take approximately 40 minutes and there are no particular risks or benefits to you from participating in this experiment. Wearing a Virtual Reality device may lead to dizziness or tiredness and may also lead to photosensitive epilepsy in very rare cases.

Confidentiality and disclosure of information

Any information and that can be identified with you in connection with this study will remain confidential and will be disclosed only with your permission. If you give us permission by signing this document, we plan to publish the results of this research in scientific publications. In any publication, information will be provided in such a way that you cannot be identified.

Compensation

We do not provide any compensation for your participation in this experiment, nor are there any costs for you for your participation.

Feedback to participants

If you would like to be kept informed about the results of this research, please leave your name and contact details with the experiment leader. A copy of publications resulting from this research will be sent to you when available.

Your consent

Your decision whether or not to participate will not prejudice your future relations with University of Zurich. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, please feel free to ask us. If you have any additional questions later, Dr. Arzu Coltekin (044 6355440, arzu@geo.uzh.ch) will be happy to answer them.

You will be given a copy of this form to keep.

Page 1 of 2

The University of Zurich - **Participant Information Statement and Consent Form (continued)** Judging of spatial relationships in Virtual Reality
November 14-27, 2016
Participant No:

You are making a decision whether or not to participate. Your signature indicates that, having read the information provided above, you have decided to participate.

……………………………………. ………………………………

Signature of Research Participant Signature of Experimenter

…………………………………….. ………………………………

Please PRINT name Please PRINT name

……………………………………..

Date and Place

The University of Zurich - **Participant Information Statement and Consent Form (continued)** Judging of spatial relationships in Virtual Reality
November 14-27, 2016
Participant No:

REVOCATION OF CONSENT

I hereby wish to WITHDRAW my consent to participate in the research proposal described above and understand that such withdrawal WILL NOT jeopardize any treatment or my relationship with The University of Zurich.

……………………………………. ………………………………

Signature Date

……………………………………..

Please PRINT name

This section of Revocation of Consent should be forwarded to Dr. Arzu Coltekin, Geographic Information Visualization and Analysis, Dept. of Geography, University of Zurich, CH-8057, Zurich.

Page 2 of 2

Pre Questionnaire

FL_Pre_Questionnaire_EN

1. Participant number (to be inserted by the supervisor)

FL_Pre_Questionnaire_EN

Experience with VirtualReality and Stereo 3D

2. Are you male or female?

- ◯ Male
- ◯ Female

3. What is your age?

- ◯ 19 or younger
- ◯ 20-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60 or older

1

4. Have you used a VitualReality device before? If so, list all VirtualReality devices you've used before!

- [ ] None
- [ ] CAVE
- [ ] Oculus Rift
- [ ] HTC Vive
- [ ] Playstation VR
- [ ] Samsung GEAR VR
- [ ] Google Cardboard
- [ ] Other (please specify)

5. Have you watched stereoscopic media on a 3D TV or in a 3D Cinema?

- [ ] 3D TV
- [ ] 3D Cinema

FL_Pre_Questionnaire_EN

Experience with video games

6. Do you play video games?

- ○ Yes
- ○ No

7. On what platform do you play video games?

- [ ] None
- [ ] PC
- [ ] Home Console
- [ ] Mobile / Tablets
- [ ] Other (please specify)

2

8. How often do you play video games?

	Never	<5 hours/week	<10 hours/week	<15 hours/week	20+ hours/week
Video games	○	○	○	○	○

FL_Pre_Questionnaire_EN

Attitude and Expertise

9. What is your attitude towards VirtualReality devices?

Very Negative	Negative	Neutral	Positive	Very Positive
☆	☆	☆	☆	☆

10. How high is your expertise in the following fields?

	Very Low	Low	Medium	High	Very High
Architecture	○	○	○	○	○
Interior Design	○	○	○	○	○
Real Estate	○	○	○	○	○
Geography	○	○	○	○	○
3D Visualization	○	○	○	○	○

3

Stereo ability test

Test your stereo (3D) vision

McGill

This 3D vision test is a research study being conducted by **Prof. Robert Hess (http://mvr.mcgill.ca/Robert/rhess_home.html)** of the Department of Ophthalmology and **Prof. Jeremy Cooperstock (http://www.cim.mcgill.ca/~jer)** of the Centre for Intelligent Machines of McGill University.

We are conducting this brief, informal experiment to assess the quality of 3D vision (stereopsis) of the general population. Please note that your participation is completely voluntarily and the results are anonymous.

The test itself should only take you a few minutes. At the end of the experiment, your 3D vision or stereopsis score will be calculated and displayed to you, along with some facts about 3D vision.

For further information about 3D viewing, please see this helpful **Viewing 3D on TV: Questions and Answers (http://www.cbc.ca/documentaries/doczone/QE3D/qa.html)** page from the CBC.

Monitor

First, we need to know the size of your monitor. These typically range between 7-12 inches for netbooks, 10-17 inches for laptops, and 15-24 inches for desktops. If you're not sure of your monitor size, please enter the make and model number in the other box.

If you know, or have measured, the size (diagonal) of your monitor, please enter it here: monitor size (diagonal)

or, if you know the make and model of your monitor, enter it here: (e.g., Samsung SyncMaster 2493)

Height

Your height is needed to help approximate your viewing distance from the monitor.

Height in centimeters ____ cm, or

or, in feet and inches ____ ft. ____ in.

Sitting Distance

(2arms_1024.jpg)

Ideally, if your monitor is larger than 15 inches, you should be two arms-lengths away, as shown in the image to the left. Otherwise, the test will be too easy and we won't be able to measure your stereo vision properly.

However, if you can't reach the mouse from that distance, you can sit one arm-length away, as shown here.

(1arm_1024px.jpg)

How far are you sitting from the monitor?

- ○ 2 arms-lengths
- ○ 1 arm-length

Age and Corrective Eyewear

For analysis purposes only, kindly let us know your age and whether you use eyeglasses.

Your age

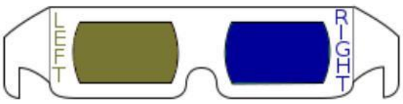
Do you regularly use any corrective eyewear (eyeglasses, contact lenses)? ○ yes ○ no

Get ready...

In the following screens, you will be presented with a number of random dot stereograms in which a box in the center appears either in front of or behind the rest of the image. At first, it should be easy to see the box, but this will become more difficult as you continue the test.

After you've looked at the image for a few seconds, please click on the appropriate button below to continue the test.

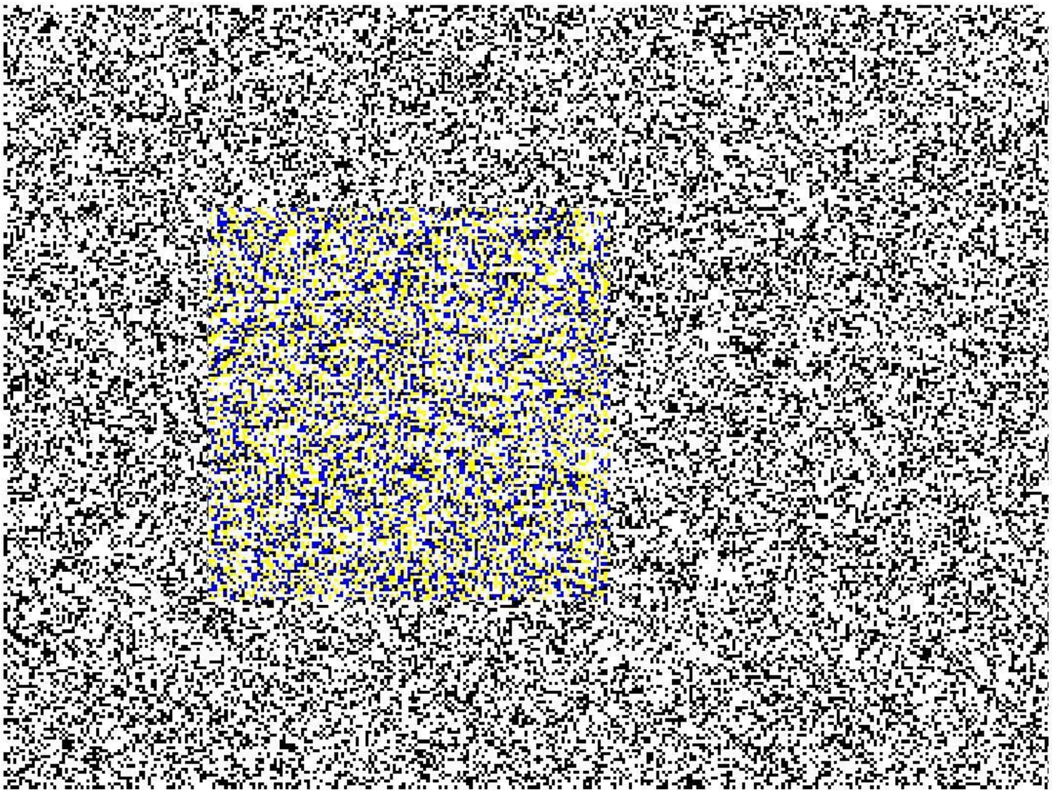
Please do not try to move closer to the monitor during the test as this will invalidate the results.



Now put on your 3D glasses with AMBER and BLUE lenses... you are ready to begin.

Start the test

Stereo Acuity Test http://3d.mcgill.ca/cbc/step2.php



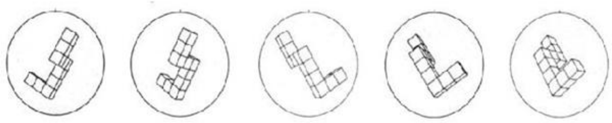
The square is in front of behind the screen. not sure

1 von 1 10.01.2017 15:23

MRT Introduction

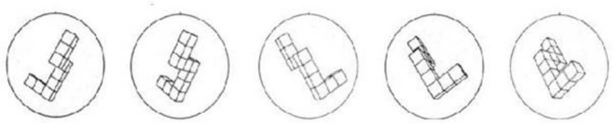
FL_MRT_EN_intro
Image_1

Below, the same single object is given in 5 different positions. Please check for yourself that they are only presented at different angles.

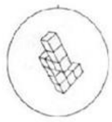


FL_MRT_EN_intro
Image_2

Now check that the object at the bottom is NOT identical to the upper objects:

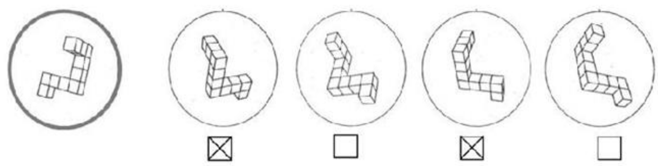


1



FL_MRT_EN_intro
Image_3

Now, you are to determine which 2 of the 4 objects to the right are identical to the object in the green circle. 2 objects are always identical and 2 are not. You are to mark the 2 identical objects. Below, the 2 identical objects are already marked. The other 2 are mirrorized or different in another way. Please check the following images:



FL_MRT_EN_intro
Sample_Task_1

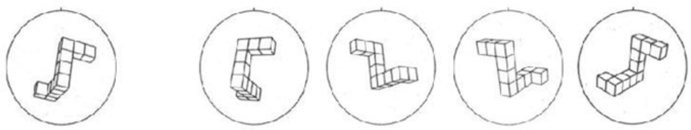
Now let's do sample task 1

2

1. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



FL_MRT_EN_intro

Sample_Task_2

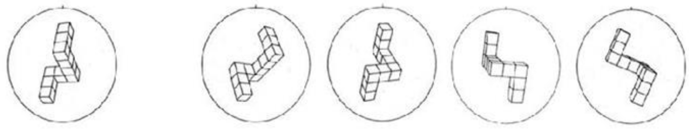
Sample task 2

2. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

3



FL_MRT_EN_intro

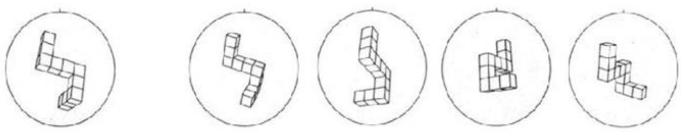
Sample_Task_3

Sample task 3

3. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



4

MRT Test

FL_MRT_EN

1. Participant number (to be inserted by the supervisor)

FL_MRT_EN

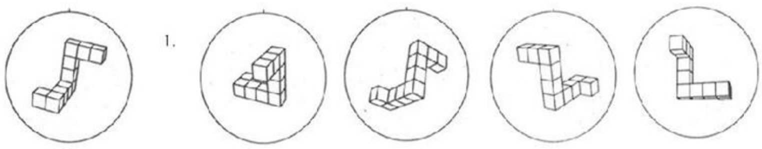
When you feel comfortable, press "Next" to start the rotation test

FL_MRT_EN

2. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



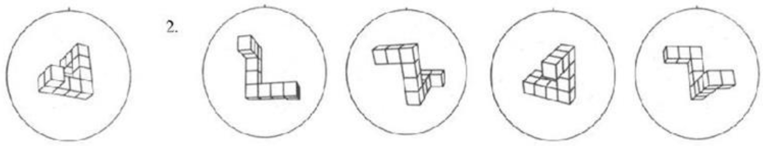
FL_MRT_EN

1

3. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

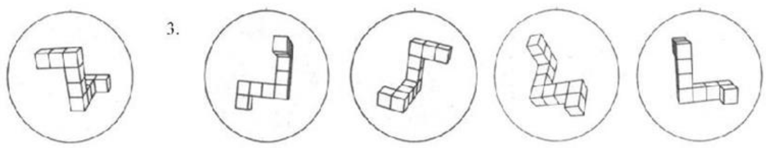


FL_MRT_EN

4. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



FL_MRT_EN

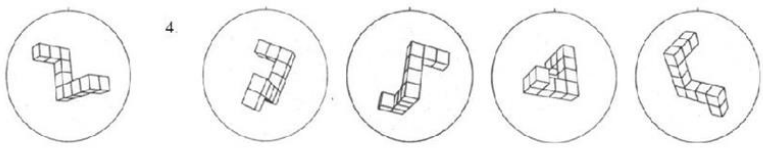
2

5. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

4.



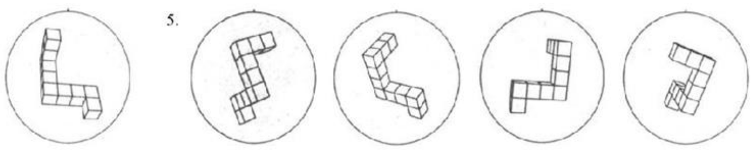
FL_MRT_EN

6. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

5.



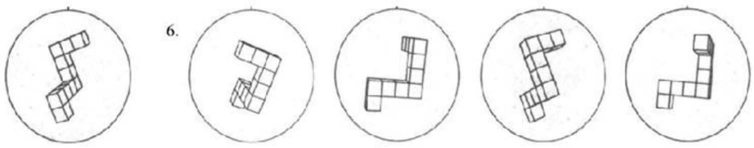
FL_MRT_EN

3

7. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

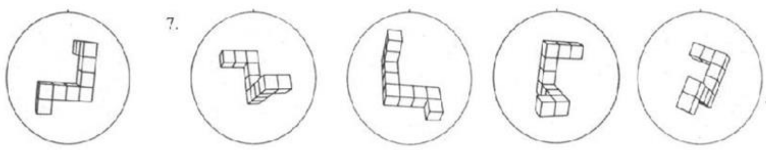


FL_MRT_EN

8. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



FL_MRT_EN

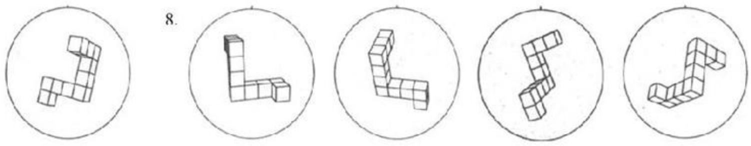
4

9. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

8.



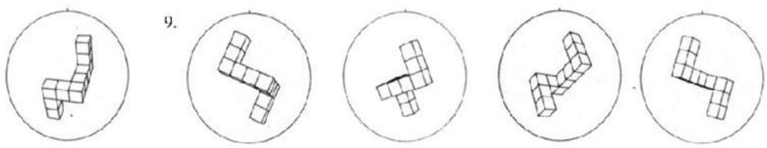
FL_MRT_EN

10. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

9.



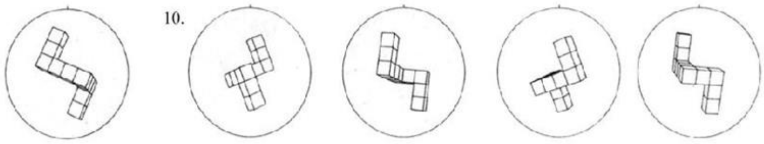
FL_MRT_EN

5

11. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

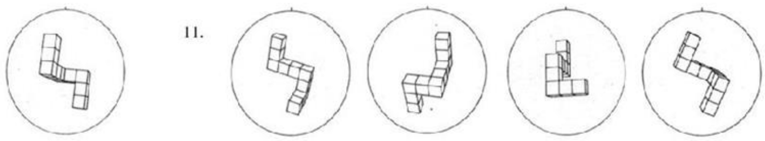


FL_MRT_EN

12. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



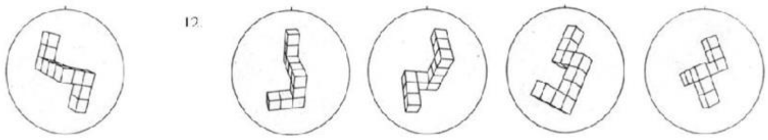
FL_MRT_EN

6

13. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

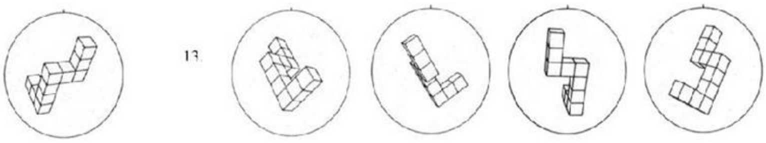


FL_MRT_EN

14. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

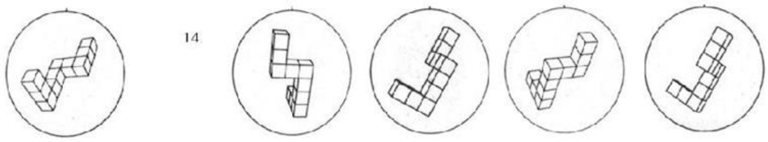


FL_MRT_EN

15. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

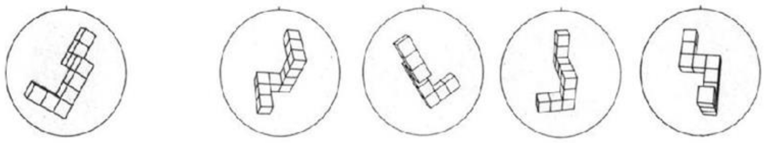


FL_MRT_EN

16. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



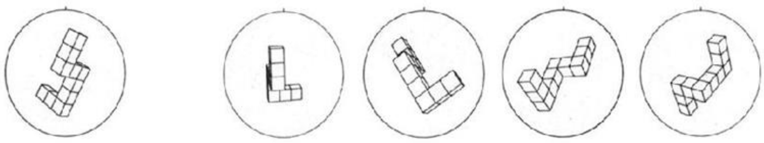
FL_MRT_EN

8

17. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

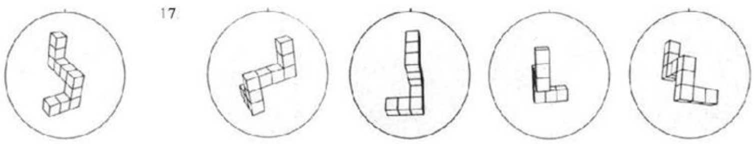


FL_MRT_EN

18. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



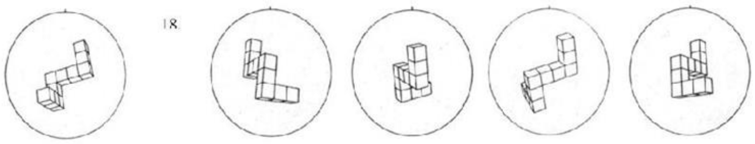
FL_MRT_EN

9

19. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D

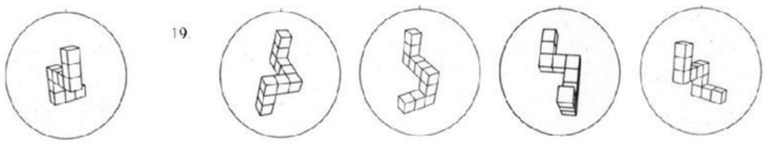


FL_MRT_EN

20. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



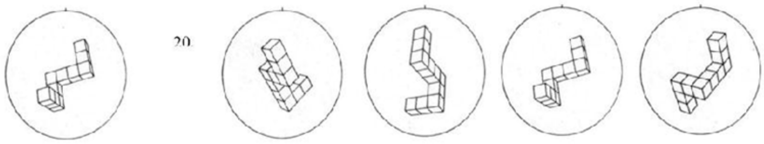
FL_MRT_EN

10

21. Choose the 2 objects that are identical to the figure on the left

☐ A ☐ B ☐ C

☐ D



11

Questionnaire Main Experiment

Part 1: Relative and Absolute spatial judgement

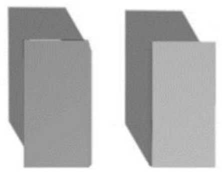
Relative

- Task Type 1 (height): Is object A higher or object B? (A or B)
- Task Type 2 (volume): Is the volume of object A bigger or object B? (A or B)
- Task Type 3 (distance): Is object A or object B closer? (A or B)

Absolute

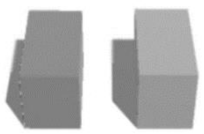
- Task Type 1 (height): What is the height of object X? (x m)
- Task Type 2 (volume): How big is the volume of object X? (x m^3)
- Task Type 3 (distance): How big is the distance between object X and object Y? (x m)

Abstract Visualization: Planar View



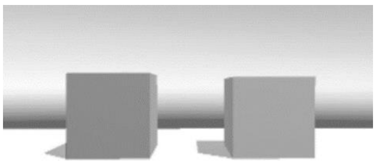
- Is the left or the right box higher? (left)
- Is the volume of the left or the right box larger? (right)
- Is the left or the right box longer? (right)

Abstract Visualization: Oblique View



- Is the left or the right box higher? (right)
- Is the volume of the left or the right box larger? (left)
- Is the left or the right box closer to you? (left)

Abstract Visualization: First-Person View



- Is the left or the right box higher? (left)
- Is the volume of the left or the right box larger? (right)
- Is the left or the right box closer to you? (right)

Halter Development Visualization 1: Planar View

Relative:

- T1: Is the kitchen table (A) higher or the cooking island (B)? (B)
- T2: Is the volume of the bathroom to the left (A) or to the right (B) larger? (B)
- T3: Is the desk in the small bedroom (A) or desk in the office room (B) wider? (A)

Absolute:

- T1: What is the height of the walls? (x m)
- T2: How big is the volume of the office room? (x m^3)
- T3: How big is the distance between the two bushes on the big balcony? (x m)

Halter Development Visualization 2: Oblique View

Relative:

- T1: Is the painting with 3 black lines (A) higher or the world map painting (B)? (A)
- T2: Is the volume of the small balcony (A) or the volume of the office room larger (B)? (B)
- T3: Is the bush to the left (A) or the bush to the right (B) closer? (B)

Absolute:

- T1: What is the height of the telescope on the big balcony? (x m)
- T2: How big is the volume of the TV cupboard? (x m^3)
- T3: How big is the distance between the Computer and the TV? (x m)

Halter Development Visualization 3: First Person View

Relative:

- T1: Is the balcony table (A) higher or the balcony chairs (B)? (B)
- T2: Is the volume of the TV cupboard (A) or the volume of kitchen cabinet above the sink (B) larger? (B)
- T3: Is the open door to the left of the worldmap painting closer (A) or the living room window to the right (B)? (A)

Absolute:

- T1: What is the height of the cooking island? (x m)
- T2: How big is the volume of the cooking island? (x m^3)
- T3: How big is the distance between the two open doors on the left? (x m)

Part 2: Memorability

Give the participants time to remember the scene --> removing visualization!

- Task Type 1: Was object X in room A or B? (A or B)
- Task Type 2: How many objects of X were in the apartment? (count)
- Task Type 3: Was there an object X? (Yes or No)

4 Room Apartment Visualization 1: Planar View

Memorability:

Give the participants 1 minute to remember the scene --> removing visualization!

- T1: Was the swan painting in a bedroom (A) or in the living room (B)? (B)
- T2: How many bedrooms did the apartment have? (3 bedrooms)
- T3: Was there a bathtub? (Yes)

4 Room Apartment Visualization 2: Oblique View

Memorability:

Give the participants 1 minute time to remember the scene --> removing visualization!

- T1: Was there a magazine on the balcony (A) or in the office room (B)? (B)
- T2: How many desks were in the apartment? (2 desks)
- T3: Was there a deck chair? (Yes)

4 Room Apartment Visualization 3: First-Person View

Memorability:

Give the participants time to remember the scene --> removing visualization!

- T1: Was the flower in the kitchen (A) or on the balcony (B)? (B)
- T2: How many bar chairs were at the bar? (2 chairs)
- T3: Did you see a computer? (No)

Post Questionnaire

FL_Post_Questionnaire_EN

1. Participant number (to be inserted by the supervisor)

FL_Post_Questionnaire_EN

Perspectives

2. What perspective was the easiest for relative spatial questions? (Is A or B higher, larger or closer?)

	Hardest		Easiest
Planar View (from the top)	○	○	○
Oblique View (from the side)	○	○	○
First person View	○	○	○

3. What perspective was the easiest for absolute spatial questions? (How big is the hight, volume or distance?)

	Hardest		Easiest
Planar View (from the top)	○	○	○
Oblique View (from the side)	○	○	○
First Person View	○	○	○

4. What perspective was the easiest for memorability questions?

	Hardest		Easiest
Planar View (from the top)	○	○	○
Oblique View (from the side)	○	○	○
First Person View	○	○	○

1

FL_Post_Questionnaire_EN

Tasks

5. Were the relative depth estimation questions easier or the absolute depth estimation questions?

- ◯ relative
- ◯ absolute

6. Were the height, volume or distance estimation questions easier?

	Hardest		Easiest
height	◯	◯	◯
volume	◯	◯	◯
distance	◯	◯	◯

7. For the memorability questions: What question type was easier?

	Hardest		Easiest
A or B	◯	◯	◯
Count	◯	◯	◯
Yes or No	◯	◯	◯

FL_Post_Questionnaire_EN

Discomfort and Attitude

8. Do you have any discomfort after the experiment?

- ☐ Headache
- ☐ Dizziness
- ☐ Tiredness
- ☐ Other (please specify)

2

9. What is your attitude towards VirtualReality devices now?

Very Negative	Negative	Neutral	Positive	Very Positive
☆	☆	☆	☆	☆

10. Would you like to use a 3D apartment visualization if you were searching for an apartment?

- ☐ Yes
- ☐ No
- ☐ Maybe
- ☐ Why?

3

Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Flavio Lutz

Zurich, January 27th 2017