TESTING THE INFLUENCE OF POLYGON COUNT IN VIRTUAL REALITY LEARNING APPLICATIONS ON SPATIAL MEMORY AND VISUAL ATTENTION

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Introduction

The necessity for innovative educational solutions has been highlighted by challenges in higher education, particularly in the Netherlands, where there is a reported shortage of approximately 23,000 student housing units in major cities (Koninkrijksrelaties, 2023). Besides housing shortages literature also shows other challenges for educational facilities including accessibility issues, pressure on urban green spaces and overcrowded classrooms, which impact educational performance in a negative way (Andries et al., 2022; Q. Huang et al., 2023; State & Hudson, 2019) This situation has created an urgency for alternative educational modalities that can alleviate the pressure on physical campuses. By transitioning to more online education facilitated through VR, we open up opportunities for students to engage in effective learning without the constraints imposed by physical space.

Virtual Reality (VR) can be used as a tool to optimize to educate more people in a similar sized education area or even in less physical space by translating physical spaces to virtual environments. Over the past ten years, there have been notable technological advancements in the fields of virtual reality (VR), augmented reality (AR), and mixed reality (MR), collectively referred to as extended reality (XR). In VR, users immerse themselves in a virtual world by wearing a head-mounted display and headphones, effectively blocking out their physical surroundings. On the other hand, in AR, users engage with virtual objects overlaid onto the real-world environment, typically using specialized glasses or the screens of mobile devices(H. Lee, 2020). Literature indicates that VR can enhance long-distance teaching, particularly for physical education, thereby broadening access to quality education (Ding et al., 2020).

One field of education where VR can be helpful is training of spatial memory. Traditional 2D learning methods for spatial memory training such as maps, diagrams and graphs have been used in educational settings (Ishikawa & Newcombe, 2021). However research shows that these methods are not optimal for all students because 2D representations are not always easy to read for students, especially for those with low spatial ability (Kozhevnikov et al., 2007). Because those receiving and interpreting this 2D information must rely on their spatial imagination. Since not everyone possesses this ability to the same degree the interpretation of the traditional learning methods can differ because of the varying levels of spatial imagination, this can be a cause of miscommunication of misunderstandings between different parties. Physical spatial models and modern graphical representations, including 3D illusion images, do not rely on the viewer's spatial imagination. They inherently provide a spatial representation – virtual environments that are perceived as "real" even though the observer is aware that they are not actual physical spaces (Kaźmierczak & Szczepańska, 2022) and therefore the differing levels of spatial imagination of the receivers is no longer an issue for the interpretation of the presented data and the communication between different parties will improve. 3D printing has already shown to be beneficial for enhancing the understanding of 3D objects compared to diagrams (T.-C. Huang & Lin, 2017) however the 3D printed models still occupy physical space. VR environments can have the benefits from the 3D printed models but even larger models or environments can be created and additionally no physical space is required.

Literature has already shown great results using VR for spatial memory training purposes and other cognitive skills (Papanastasiou et al., 2019). Research even suggests that VR can completely replace physical educational facilities for the training of spatial memory by creating immersive learning environments (Molina-Carmona et al., 2018). Furthermore, the implications of VR extend beyond conventional educational settings into vital areas such as neurorehabilitation and clinical training. Notably, VR has shown efficacy in improving navigation and orientation skills in patients suffering from spatial memory disorders, suggesting its versatility as a training tool (Montana et al., 2019). Similar advancements are noted in high-stakes training environments, including surgical training and emergency evacuation drills, where VR provides a safe, controlled platform for participants to experience realistic scenarios without real-world risks (Bourhim & Cherkaoui, 2020; Hattab et al., 2021). These applications underscore the transformative potential of VR in enhancing both educational and therapeutic outcomes through immersive experience.

However, the effectiveness of VR-based training is closely linked to the quality of visualization within these environments. Visual realism plays a big part of the display fidelity of a VR environment, it is consisting of multiple factors namely: geometry, shadow softness, rendering techniques, lighting and texture quality and research indicates that higher levels of visual realism significantly enhance knowledge transfer and comprehension, raising the question of how to optimize VR environments for educational purposes ((J. Huang & Klippel, 2020)). Balancing the need for realism against the costs of development and computational demands presents a challenge. While higher levels of realism can improve the immersive experience, they can also lead to increased expenses and potential performance limitations, such as lag and stuttering, adversely affecting the user experience (Soliman et al., 2021). This research aims to bridge the gap in the optimal level of visual realism required for certain VR learning methods and will focus specifically on the geometry. The polygon count of a VR environments will be used as variable to manipulate the level of geometric realism. A low polygon count will be classified as low level of geometric realism and a high polygon count will be classified as a high level of realism.

To evaluate the optimal level of geometric realism in VR for spatial memory training applications the sense of presence of participants will be tested. In literature presence is defined as the sense of being in a mediated environment (Draper et al., 1998; Steuer, 1992) or being in a computer-generated world such as in VR (Sheridan, 1992; Slater & Wilbur, 1997). The sense of presence of participants is important because literature shows that a higher sense of presence is linked to better learning (Grassini et al., 2020), and therefore a better understanding of the environment. Which is the goal for the spatial memory applications.

To evaluate whether information is better recalled in a VR environment with a high level of geometric realism compared to an environment with a low level of geometric realism the concept of spatial memory is used. Spatial memory is referred to as the facet of memory responsible for recording information about the environment. It is usually reflected in a person's orientation and navigation skills (Montana et al., 2019; Rodríguez et al., 2022) Spatial memory is a good indication for how well a space is understood as a three dimensional form rather than a series of recalled images. As stated earlier, higher levels of realism can improve the immersive experience which can lead to better learning and understanding of the environment. However, research also shows that a higher level of detail can overwhelm users because of the amount of information they contain and can therefore decrease the level of spatial memory of the users (Lokka, 2020).Therefore the information can also become too overwhelming which can result in lower learning of the environment. (Grassini et al., 2020) Thus, an optimal level of detail is of great importance to improve understanding of the environment of the user.

To gain more insight in how the VR environments were perceived the concept of visual attention is introduced. Visual attention is defined as the cognitive process that mediates the selection of important information from the environment (Lockhofen & Mulert, 2021). Cognition literature has found a positive relationship between visual attention and memory development (Shi et al., 2020). By finding the spatial elements participants in a VR environment are attracted to, the VR environment and its experience can be improved (Kim & Lee, 2020). Therefore visual attention is important in this research, it can show us the differences of importance in the level of geometric detail of objects in a VR environment. This can be used to optimize the usefulness of spatial memory training applications by changing the polygon count for only certain objects for example, in this way the costs of development and computational demands can be minimized.

In this research VR will be used instead of AR. A recent study shows that AR can be a useful tool that creates a higher understanding and engagement of the participants in the environment (Jansen et al., 2023). However, as explained earlier physical space reduction is needed for educational facilities and in AR systems the physical space is still necessary only a virtual layer is shown, therefore the choice for VR was made.

In conclusion, by exploring the interplay of polygon counts, sense of presence, spatial memory and visual attention, this research aims to identify the optimal level of geometric realism in VR environments. The findings may help refine VR applications, thereby enhancing educational outcomes and furthering the potential of VR as a dynamic learning tool for students across various fields.

Research Questions

Research objective

The aim of this research is to gain more insights into the influence of polygon count in VR environments for virtual reality learning applications on spatial memory and presence. This will be done by testing the influence of polygon count in VR environments for virtual reality learning applications on the participants spatial knowledge of the VR environment. This knowledge will be tested by the sense of presence and the spatial memory of the participants. Besides the knowledge the aim is also to gain more insight in how this spatial knowledge is acquired by looking at the visual attention of the participants. This will be done using the following research questions.

Research Questions

1. How can a differing polygon count in a VR environment affect the spatial memory of users?

2. How can a differing polygon count in a VR environment affect the sense of presence of users?

3. How can a differing polygon count in a VR environment affect the visual attention of users?

Methodology

Experiment

To investigate the impact of polygon count on spatial memory, sense of presence and visual attention a controlled experiment will be conducted where each participant will experience two

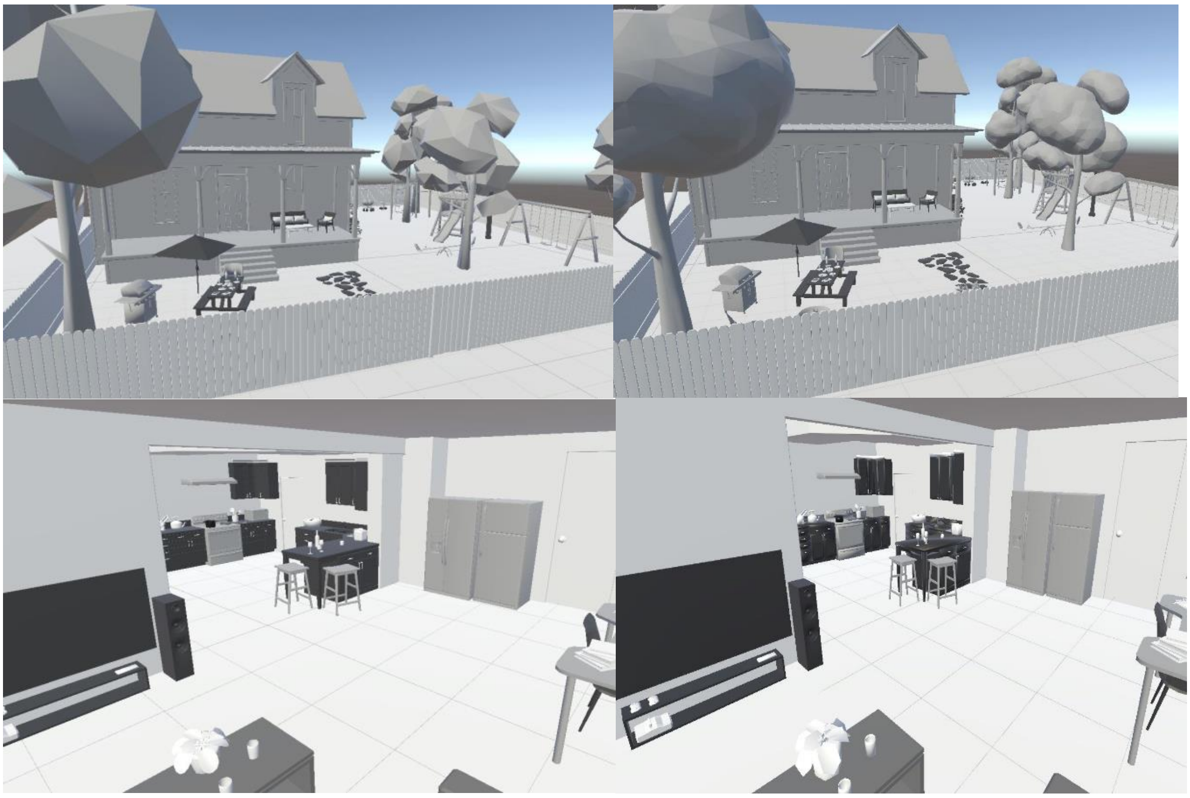

Figure 1: Environments of Experiment, where upper left is LowPoly Garden, upper right is HighPoly Garden, lower left is HighPoly Kitchen and lower right is LowPoly Kitchen

different VR environments. Environment A is a living room combined with a kitchen and environment B is a garden and both were created in a low and high polygon count variant as shown in figure 1.

One of the reasons for choosing a small indoors and outdoors environment was the time needed to develop them while at the same time being able to have sufficient means to gather data for the project's research questions. Moreover, these environments, as opposed to for example an open area, allow for the addition of small objects with more detail which would visually vary more when adjusting the polygon count and thus deemed more appropriate for the presented research. The kitchen and garden also differ in size of environment and general size of objects in the environment which will be analysed in the results. Lastly, the choice for developing specifically a living room and a garden was made because the living room consists of more squared and flat objects where the garden contains more natural and round objects. This difference was chosen because natural and round objects tend to differ more visually then flat and square objects. Therefore these visual changes related with the change in polygon count could be analysed in this research.

Each participant will experience both a high and low polygon count environment. During the experiment, participants were randomly divided into four groups as follows:

- Group 1: Enter the high polygon count living room, then explore the low polygon count garden
- Group 2: Enter the low polygon count garden, then explore the high polygon count living room
- Group 3; Enter the high polygon count living room, then explore the low polygon count garden
- Group 4: Enter the high polygon count garden, then explore the low polygon count living room.

The participants are divided into four groups instead of two to account for the effect of order the participants experience the environment.

Figure 2 shows the outline of the experiment. The experiment is the same for all four groups, only environment 1 and environment 2 that the participant enters is different for the groups as explained above.

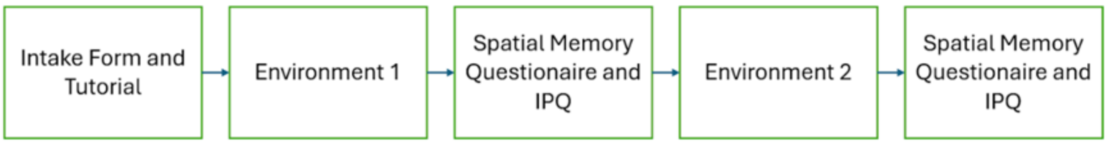

Figure 2: Outline of the Experiment

Based on earlier research 21 (J. Huang & Klippel, 2020) participants were recruited based on convenience sampling, with the inclusion criteria of normal or near normal sight. 16 participants were male and 5 participants were female with a mean age of 23.5 in an age range of 19-26.

The change in polygon count was only made for objects that would visually change because of this varying polygon count, therefore completely flat or squared objects like walls or the floor were kept the same. For the low polygon count environment objects polygon count were reduced until the minimum point where the objects would still be visually recognisable. For the high polygon count environment objects polygon count were increased until the maximum point where the objects would not create any issues according to the framerate of the virtual reality experience. Besides the polygon count other variables like the textures and lighting are kept the same in both low and high polygon count environments. At first all textures in the environment were made the same colour to keep this variable the same, however the objects were hard to distinguish in the spatial memory images, therefore objects got differing grayscale values as their texture. Table 1 summarizes the characteristics of each created scene with a differentiation of low and high polygon count.

	Number of objects	Average polygon count of objects
Low polygon count garden	37	293.9
Low polygon count living room	34	218.6
High polygon count garden	37	3216.3
High polygon count living room	34	2498.4

Table 1: Characteristics of manipulated objects in VR environments

The VR environments were made using Unity version 2022.3.38f1. and were presented to the participants using the Meta Quest 2 headset.

The experiment will consist of 5 steps as shown in figure 2. In step one, the participants will be asked to fill in an intake form (see appendix A). This form consists of a consent form, experience using VR and questions about the participants demographics and gaming experience. Secondly, after finishing the intake form participants will be informed about the experiment and how this will take place. Among other things, they will be told that they will enter two different environments and have to explore and remember those environments to the best of their ability. Thereafter, participants will be given a head mounted display and help will be provided if needed to adjust the device on their heads. The display will remain on stand-by until the participant is comfortable with the display on their head and ready for the experiment.

Once participants are ready to enter the VR environment, there will first be time to get familiarized with the experience by looking around and moving their controllers in the VR menu. When familiarized with the experience the participants will spawn in the middle of the environment and will be standing, so the participant is able to rotate completely to look around in the environment, with the camera positioned at eye level, and able to move around in the environment with their controllers. The exploration phase will be 4 minutes based on experiments in similar research (J. Huang & Klippel, 2020), after these.4 minutes in the environment the participants will leave the environment and the head mounted display will go into standby mode.

Spatial memory assessment

For the third step the spatial memory and Igroup presence questionnaire will be held. For the spatial memory questionnaire the participants will be shown a series of 10 images to test their spatial memory. These images will consist of either the whole environment the participant just left or a smaller part of this environment as done by LEKAN (Lekan, n.d.) The camera position that is used in these 10 images will be different from the camera position the participants were used to in the environment, the camera will either be set to a lower position or a higher position then eye level which is used in the environment. Because of this change in camera position the participants cannot solely rely on their visual memory and therefore have to use their spatial memory and knowledge to visualize the environment to the camera position they were used to. Besides the change in camera position in 5 of the 10 pictures there is also a minor change made in the objects in the environment. These changes are categorized in 4 different categories namely: rotation in object, position change in object, switch of position of 2 objects and deletion of object. Figure 3 shows examples of images of different categories of change.

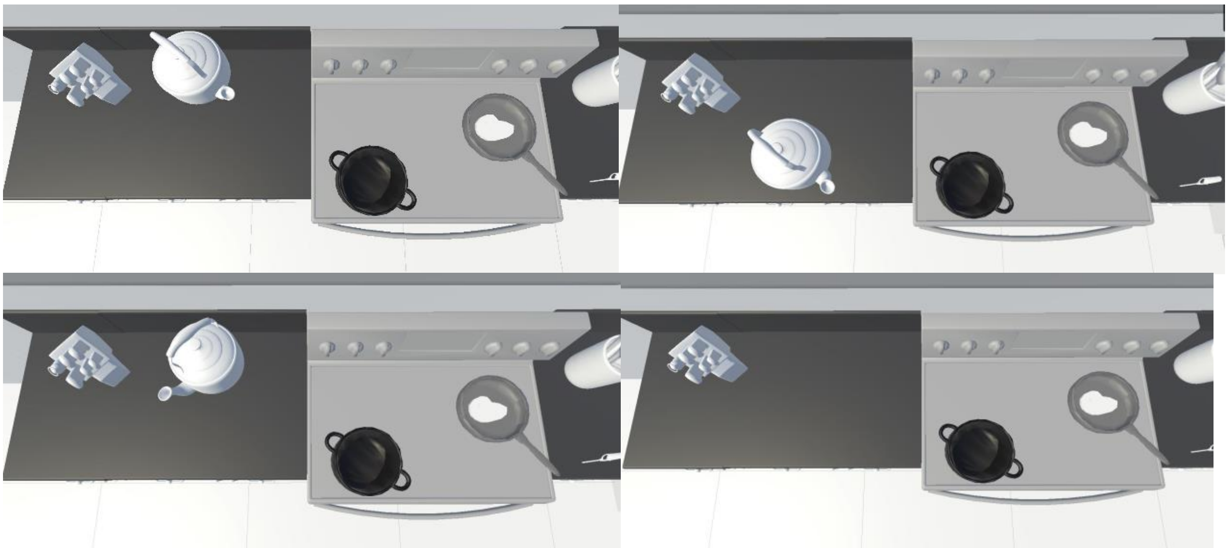

Figure 3: Example images were upper left is the real environment, upper left shows a movement of an object, lower left shows a rotation of an object and lower right shows deletion of an object.

The changes are also classified in 3 different sizes, these sizes are relative to the size of the experiment so for the kitchen smaller objects were classified as large compared to the garden. The participants will have to declare if a change was made in the picture compared to the environment they left by answering “changed” or “unchanged” to the 10 images. The polygon count in the 10 pictures the participants will see will be similar to the environment of that participant, so for example a participant that left the low polygon count living room will get 10 pictures of the low polygon count living room. However the camera position of the 10 images made of the high polygon count environment will be the same compared to the low polygon count environment, Therefore, besides the polygon count the pictures of the high polygon and low polygon environment will be the same. To test whether the 10 images were too hard or too easy to classify there will be 3 test participants, based on findings on their answers possibly a category of changes could be changed or removed (Lekan, n.d.). The pilot experiment showed that object deletion in the kitchen, which is smaller compared to the garden, was too easy to classify. Therefore these images were changed to either rotation or object movement. The 10 wrong images that a participant got to see were divided as follows: in 4 images object movement was used, in 2 images 2 objects were switched in location, in 2 images an object was rotated and in the last 2 images an object was deleted. The 10 images were also divided in the size of the changed objects, the sizes were divided as follows: in 4 images a large object was changed, in 4 images a medium object was changed and for the last 2 images a small object was changed.

Presence assessment

Directly after the spatial memory test the participants will be asked questions from the Igroup presence questionnaire (IPQ) (Schubert et al., 2001). This questionnaire was chosen because research showed that the IPQ provides the presence scores with the highest reliability within a reasonable timeframe (Schwind et al., 2019) and this questionnaire also contains a subsection about experienced realism, which fits well with this experiment. The questionnaire consists of 14 categorized as follows: 5 questions about spatial presence, 4 questions about involvement, 4 questions about experienced realism and 1 question about presence. All 14 questions use a 5 point likert scale. Where 1 means a low presence score and 5 means a high presence score. Except for question 3, 9 and 11, where 1 means a high presence score and 5 means a low presence score. Therefore these values will be reversed in the analysis. The questionnaire is provided in appendix B.

To measure the visual attention of the participants I used the method used by Yangming Shi et all. (Shi et al., 2020) where eye tracking is used. Review fixation time will be used as indicators for visual attention of the participants. The method uses techniques earlier implemented in computer graphics literature to render camera directions or paths. These techniques use the Raycast function of Unity, the raycast technique records the gaze position data and camera position data for a X, Y and Z axis. This 3 axis data is recorded in a csv file. An invisible ray is projected from the center of the participant's camera or gaze focus point on the screen, and it provides a three-axis vector value when it intersects with any virtual object in the 3D environment. To implement these functionalities, Unity's application programming interface is utilized (API), using C# for programming.

Data analysis

Spatial Memory

First the spatial memory data will be tested for normality using a Shapiro wilk normality test. Based on this normality a parametric or non-parametric test will be chosen. After the normality test the effect of order of environments will be tested, bases on the results of this test groups of the same environment will be either kept apart of be combined into one group. To identify the potential of differing polygon count in affecting the spatial memory of the participants the number of images classified correctly will be counted and tested on significance by performing an independent sample T-test. The percentage of correctly classified images will then be analysed, also the distribution of these percentages will be analysed and the images that were classified wrongly will be explored by looking at which kind of changes in the scenario were perceived the least.(Lekan, n.d.)

Presence

For the analysis of the questionnaire, Cronbach Alpha will be used as a preliminary test to investigate the reliability of the questionnaire. This will be done for all subsections combined, as well as for all subsections separately. In case of a correlation > 0.70 the questionnaire will be regarded as representative for evaluating presence. If the correlation is > 0.60 < 0.70 the analysis will be performed, however the results must be read with caution. If the correlation will be < 0.60 for as well the sections combined as separately, the questionnaire questions will be analysed individually. Consequently, the mean value of the questionnaire subsections will be checked for normality (Schwind et al., 2019).

Then the effect of the order of environments will be analysed by a one-way ANOVA. If this effect is significant then all 4 groups will be analysed. When the effect of the order of environments is not significant then the 4 groups can be combined into two groups and these will be analysed.

To identify the difference in presence with low and high polygon counts, a paired independent sample T-test will be performed (if the scores are normally distributed). The mean value for the questionnaire (in case all the Cronbach Alpha correlation is > 0.70) will be taken as an independent variable for the two groups: low and high polygon count.

Visual Attention

For visual attention the review fixation time is calculated as shown in the table below where the fixation time for each gaze visit to a certain object is calculated by subtracting the time of the first frame where the invisible ray hits a certain objects from the last frame where the invisible rays hits that same object.

Indicator	Unit	Equation
Review fixation time	Seconds (s)	$T = \sum_{i=1}^{n} t_i$

Table 2: Fixation Time Equation where ti = Fixation time for each gaze visit to an object, n = Number of gaze visits to a certain object.

Then the distributions of the review fixation time are reviewed by a Shapiro-Wilk normality test. After these pass the normality tests they will be analysed using a one-way ANOVA to test the differences between the groups. Also the relationship between characteristics of objects and their review fixation time will be analysed by using linear regression models, specifically the size, the colour and the amount of polygons of an object. The number of fixations will be analysed where the thresholds for a fixation will be a change in viewing angle of less than 1 degree and a fixation time of more than 0.1 seconds. Also heatmaps of the moving patterns of participants and the fixation time will be created.

Results

First the Cronbach Alpha test was done on all results from the presence questionnaire to test for reliability. The test resulted in a score of 0.845237. This high reliability coefficient indicates strong internal consistency of the questionnaire, suggesting that participants' responses are stable and reproducible across the items assessed. This establishes a solid foundation for further analysis, validating the tools used for measuring the constructs in question.

After the Cronbach Alpha all datasets were tested on normality using the Shapiro-Wilk test, this was done for the presence, spatial memory and visual attention data. The results of the test are shown in table 3-5. Table 3 systematically present the results of the Shapiro-Wil test applied to the data concerning presence. For the presence data all groups showed normally distributed data. Therefore the ANOVA test and independent T-test were chosen for further analysis of the presence data.

Test	Statistic	P_Value
Shapiro-Wilk Group 1 Garden LP	0,932033	0,595888
Shapiro-Wilk Group 1 Kitchen HP	0,853043	0,166544
Shapiro-Wilk Group 2 Garden LP	0,910023	0,467729
Shapiro-Wilk Group 2 Kitchen HP	0,96492	0,841754
Shapiro-Wilk Group 3 Garden HP	0,893485	0,374929
Shapiro-Wilk Group 3 Kitchen LP	0,932887	0,616189
Shapiro-Wilk Group 4 Garden HP	0,956338	0,782284
Shapiro-Wilk Group 4 Kitchen LP	0,87065	0,269067

Table 3: Shapiro-Wilk Test Results Presence Data

Table 4 systematically present the results of the Shapiro-Wilk test applied to the data concerning spatial presence. Notably, while most groups exhibit normal distribution characteristics ($p > 0.05$), the Shapiro-Wilk test for Group 1 Garden LP and Group 4 Kitchen LP indicate non-normality with a p-value of 0.032767 and 0.00647, suggesting the potential need for non-parametric analyses in specific cases. Therefor Kruskal test were chosen for the spatial memory data instead of the ANOVA test and instead of the independent T-test a Mann-Whitney U test was done.

Test	Statistic	P_Value
Shapiro-Wilk Group 1 Garden LP	0,77248	0,032767*
Shapiro-Wilk Group 1 Kitchen HP	0,863374	0,201045
Shapiro-Wilk Group 2 Garden LP	0,914078	0,492481
Shapiro-Wilk Group 2 Kitchen HP	0,90202	0,42115
Shapiro-Wilk Group 3 Garden HP	0,960859	0,813952
Shapiro-Wilk Group 3 Kitchen LP	0,955627	0,777253
Shapiro-Wilk Group 4 Garden HP	0,960859	0,813952
Shapiro-Wilk Group 4 Kitchen LP	0,684029	0,00647*

*Table 4: Shapiro-Wilk Results Spatial Memory Data *indicates significance using $p < 0.05$*

Table 5 systematically present the results of the Shapiro-Wilk test applied to the visual attention data. All groups showed non-normality for this dataset. Therefore the Kruskal test and Mann-Whitney U test were chosen instead of the ANOVA and the independent T-test.

Test	Statistic	P_Value
Shapiro-Wilk Group 1 Garden LP	0,693017	0,000000*
Shapiro-Wilk Group 1 Kitchen HP	0,732538	0,000021*
Shapiro-Wilk Group 2 Garden LP	0,564924	0,000000*
Shapiro-Wilk Group 2 Kitchen HP	0,764539	0,000047*
Shapiro-Wilk Group 3 Garden HP	0,586798	0,000000*
Shapiro-Wilk Group 3 Kitchen LP	0,689931	0,000003*
Shapiro-Wilk Group 4 Garden HP	0,607449	0,000000*
Shapiro-Wilk Group 4 Kitchen LP	0,782019	0,000088*

*Table 5: Shapiro-Wilk Results Visual Attention Data *indicates significance using p<0.05*

Table 6 provides an analysis of variance (ANOVA) results assessing the difference in presence scores due to the order of environments. The test resulted in no significant differences because of the order of environments. Therefore the data of group 1 and 2 were combined for both the low polygon garden data and the high polygon kitchen data. Also the low polygon kitchen data and the high polygon garden data for the third and fourth group were combined into two datasets.

Test	F_Statistic	P_Value
ANOVA Group 1 & 2	3,232946	0,087285
ANOVA Group 3 & 4	0,129007	0,723643

Table 6: ANOVA Test Results Presence Data

Table 7 and 8 provide the analysis of the Kruskal Test for both the spatial memory and the visual attention dataset. The test resulted in no significant differences between any groups and therefore also the data for spatial memory and visual attention were combined per environment.

Test	Statistic	P_Value
Kruskal Group 1 & 2	0,028259	0,866501
Kruskal Group 3 & 4	0	1

Table 7: Kruskal Test Results Spatial Memory Data

Test	Statistic	P_Value
Kruskal Group 1 & 2	0,499689	0,479637

Kruskal Group 3 & 4	0,000139	0,990585

Table 8: Kruskal Test Results Visual Attention Data

Presence Data

Table 8 shows the T-test results of the presence data for both the overall presence score and the 4 different sub scores of presence namely: general, involvement, experienced realism and spatial presence. Only the spatial presence sub score in the garden environment shows significant differences between a low polygon and a high polygon environment.

Test	Statistic	P_Value
T-test Garden	-0,7175	0,481796
T-test Kitchen	0,532893	0,600395
T-test Garden General	-1,45681	0,16313
T-test Kitchen General	1,048162	0,308068
T-test Garden Involvement	0,611446	0,548336
T-test Kitchen Involvement	0,11097	0,912804
T-test Garden Experienced Realism	-0,29712	0,769601
T-test Kitchen Experienced Realism	-0,1798	0,859246
T-test Garden Spatial Presence	-2,20227	0,040197*
T-test Kitchen Spatial Presence	1,2811	0,215879

*Table 9: T-Test Results Presence Data. * indicates significance using p<0.05.*

Besides the overall presence score and the sub scores also t-tests were done for all individual questions to look into more detail into the differences between low polygon environments and high polygon environments. The results of those t-tests are presented in tables 10 and 11 were table 10 shows the differences for the kitchen environment and table 11 shows the differences for the garden environment. The questions that show significancy are listed below, the other questions can be found in appendix B.

Q3. I felt like I was just perceiving pictures.
Q4. I did not feel present in the virtual space.
Q6. I felt present in the virtual space.

Subscore	Statistic	P_Value
Q1	1,048162	0,308068
Q2	1,145547	0,271215
Q3	-2,19601	0,041134*
Q4	0,281442	0,781582
Q5	-0,14984	0,882476
Q6	1,33188	0,201215
Q7	0,795052	0,436408
Q8	-0,60226	0,554125
Q9	0,306534	0,762801

Q10	0,638573	0,530758
Q11	-0,81306	0,42804
Q12	-0,44443	0,661774
Q13	-0,17092	0,866187
Q14	-1,13691	0,271001

*Table10: T-Test Results per Question Kitchen Presence Data *indicates significance using p<0.05.*

For the kitchen environments a significant difference was found for the third presence question.

Subscore	Statistic	P_Value
Q1	-1,45681	0,16313
Q2	-0,4215	0,678327
Q3	1,756806	0,095151
Q4	-2,29089	0,033876*
Q5	-1,36355	0,188986
Q6	-2,33697	0,031636*
Q7	0,847344	0,407705
Q8	0,696614	0,494692
Q9	-0,76634	0,452906
Q10	-0,27018	0,789938
Q11	1,178913	0,253473
Q12	-0,15423	0,879071
Q13	1,00513	0,327509
Q14	-0,39397	0,698764

Table 41: T-Test Results per Question Garden Presence Data

For the garden environments a significant difference is found for both the fourth and the sixth questions of the presence questionnaire.

Spatial Memory Data

Table 12 shows the results of the Mann-Whitney U test for the overall spatial memory data for the garden and kitchen environment. The results show no significant differences for both environments.

Test	Statistic	P_Value
Mann-Whitney U Test Garden	59	0,801432
Mann-Whitney U Test Kitchen	52	0,853772

Table 12: Mann-Whitney U Test Results Spatial Memory Data

Obtaining significant results is more difficult because of the small sample size, therefore also the data is checked visually to look for trends in the data. Figure 4 and 5 show the differences between the low polygon and high polygon spatial memory data for the kitchen and the garden environment.

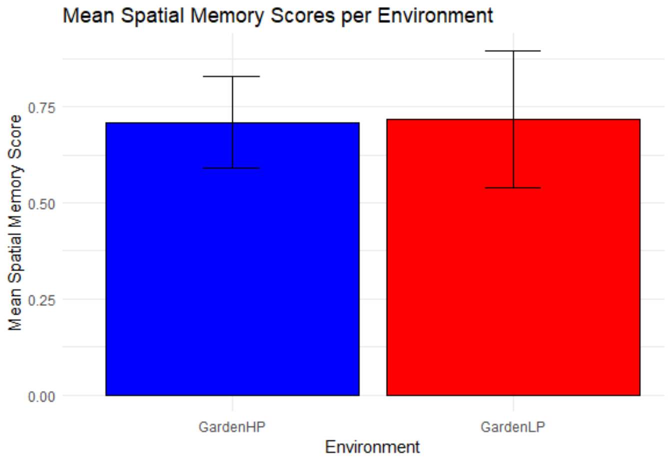

Figure 4: Spatial Memory Scores for Garden Environment

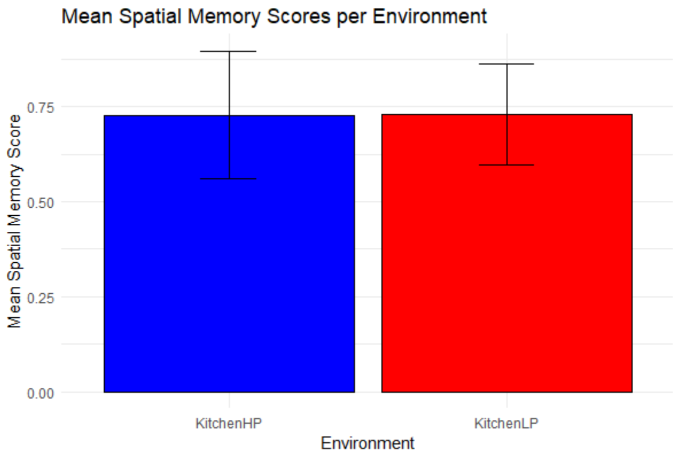

Figure 5: Spatial Memory Scores for Kitchen Environment

The results show no clear trend, only the standard deviation is larger for the low polygon garden environment and the standard deviation is larger for the high polygon kitchen environment.

Table 13 looks into the spatial memory data in more detail. It shows differences between the images that were “changed” and the images that were “unchanged” for both environments.

Test	Statistic	P_Value
Garden Changed	60,5	0,709837
Garden Unchanged	45	0,442203
Kitchen Changed	57,5	0,882572
Kitchen Unchanged	54,5	1

Table 13: Mann-Whitney U Test Results for Changed/Unchanged questions

No significant results were found between the “changed” and “unchanged” images. The results were further analysed for trends that were not significant by looking at the visualizations of differences shown in figure 6.

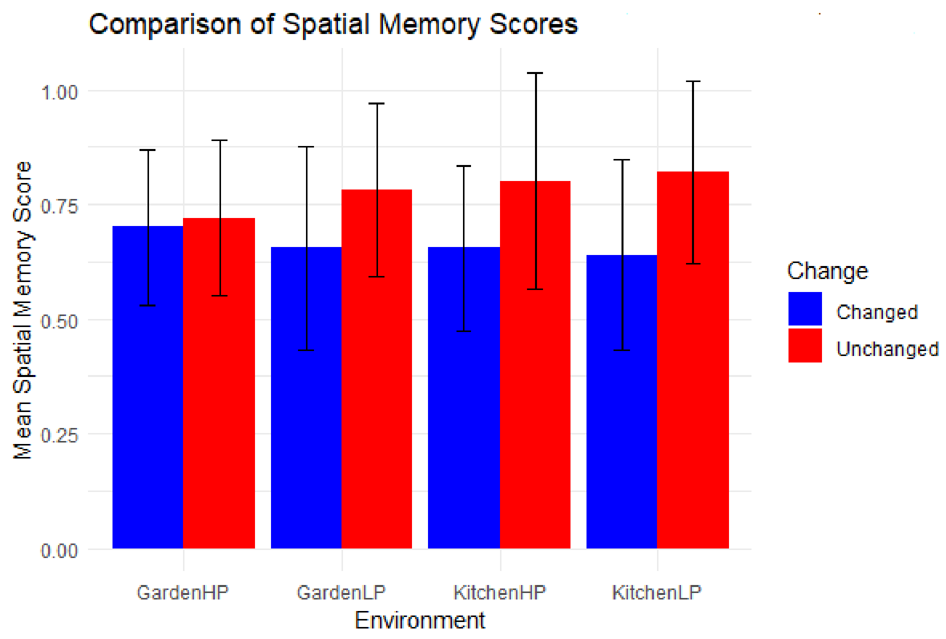

Figure 6: Spatial Memory scores for changed and unchanged images per environment

The results show a trend, the unchanged images were classified better than the unchanged images in all environments where the low polygon environments show larger differences then the high polygon environments.

The changed images were then further analyses by the type of change and the size of change. The results of the Mann-Whitney U tests done are shown in table 14 and 15.

Test	Statistic	P_Value
Large Size Test	819	0,489463
Middle Size Test	945	0,508655
Small Size Test	189	0,305961

Table 14: Mann-Whitney U Test Results for different Size of Change

Test	Statistic	P_Value
Deletion Test	174	0,152528
Position Test	930	0,601977
Rotation Test	220,5	1
Switch Test	210	0,761873

Table 15 : Mann-Whitney U Test Results for different Type of Change

No significant differences were found for either a type of change or a size of change. The results were further analysed for trends that were not significant by looking at the visualizations of differences shown in figure 7 and 8.

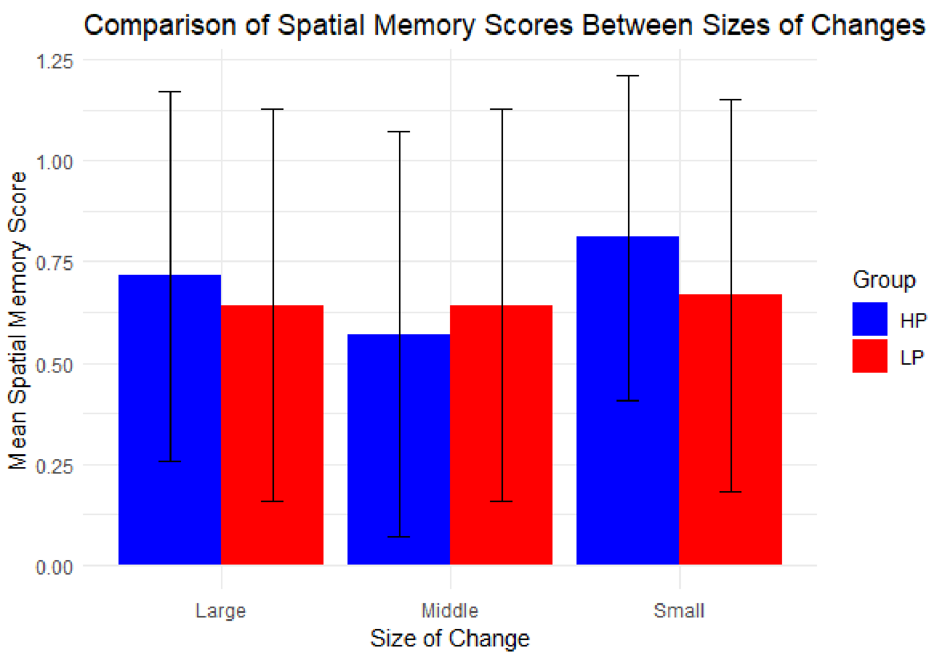

Figure 7: Spatial memory scores per size of change per environment

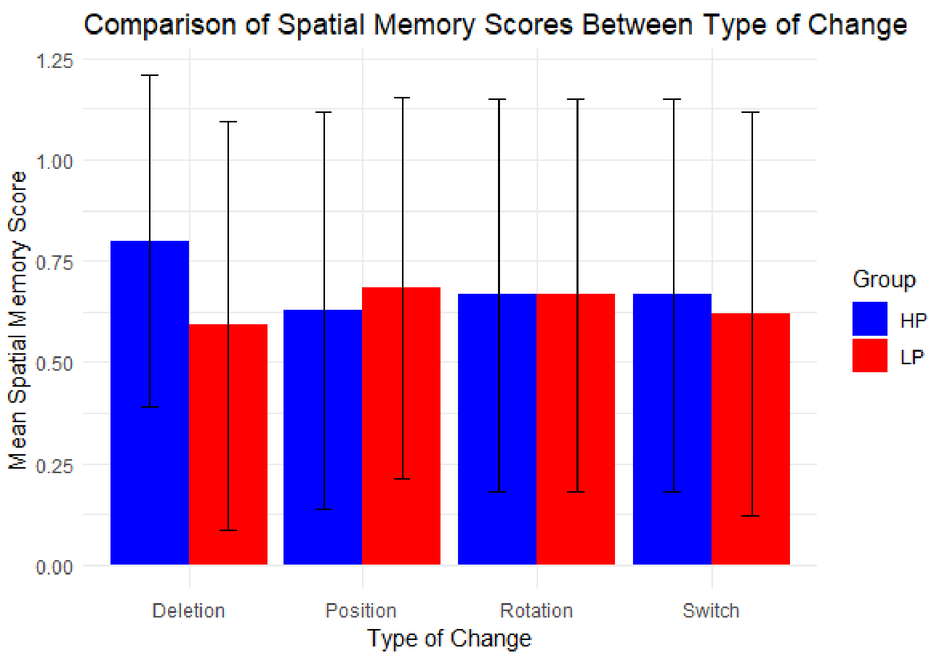

Figure 8: Spatial memory scores per type of change per environment.

The different type of changes do not show a clear trend in the data. However, deletion shows a relatively large difference between the variating polygon count environments.

Figure 9 and 10 looks at the trend between VR and gaming experience and the related spatial memory scores.

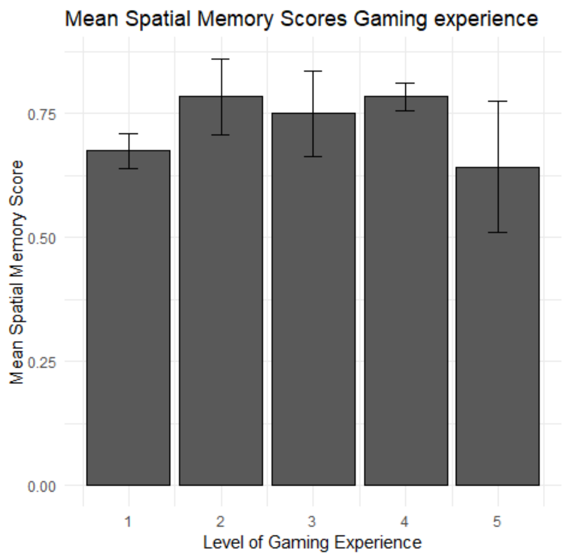

Figure 9: Spatial memory scores per level of gaming experience

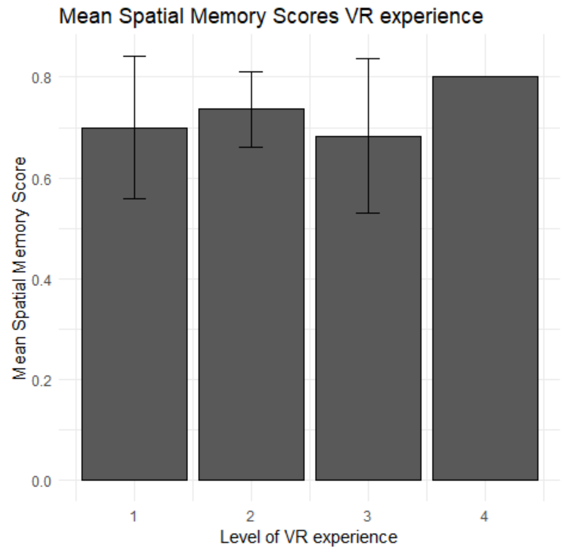

Figure 10: Spatial memory scores per level of VR experience

For both gaming and VR experience no clear trend is shown in the spatial memory data. For VR experience an improvement is shown for the one participant who had a lot of VR experience but this is not a clear trend.

Visual Attention

Table 16 shows the results of the Mann-Whitney U test for the visual attention data. The garden environment shows a significant difference between the high polygon and low polygon version. For the kitchen no significant difference is found between the two.

Test	Statistic	P_Value
Garden	2424	0,02711
Kitchen	1494	0,35583

Table 16: Mann-Whitney U test Results for Visual Attention Data

After the Mann-Whitney U test linear regression is done for all 4 environments to see if there is a linear relationship between review fixation time as dependent variable and polygon count, size of an objects, colour of an object and the average viewing distance of an object. The results of these linear regression models are shown in table 17-20.

Variable	Estimate	tValue	pValue	R2
PolygonCount	0,0000	0,3011	0,7646	0,0018
Size	0,2187	3,5953	0,0008	0,2087
greyvalue	-0,0093	-3,0547	0,0036	0,1600
AvgDistance	0,0064	22,6947	0,0000	0,9131

Table 17: Linear Regression Results for different variables from the High Polygon Kitchen

For the high polygon kitchen environment significant relationships are found between review fixation time and size of an object, colour of an object and the average viewing distance of an object. The viewing distance shows the most significance and R-squared value. Size shows most impact on the review fixation time and only the greyscale value of an object shows a negative relationship, so objects with a lighter colour seem to show lower review fixation times. For the size and distance a positive relationship is shown.

Variable	Estimate	tValue	pValue	R2
PolygonCount	0,0086	2,6164	0,0117	0,1183
Size	0,2939	4,1207	0,0001	0,2574
greyvalue	-0,0103	-2,7580	0,0082	0,1344
AvgDistance	0,0057	27,9630	0,0000	0,9388

Table18: Linear Regression Results for different variables from the Low Polygon Kitchen

The low polygon kitchen environment shows significant relationships for all four variables. Average viewing distance shows the most significance and R-squared value. Size shows the most impact on the review fixation time and again only the greyscale value of an object shows a negative relationship.

Variable	Estimate	tValue	pValue	R2
PolygonCount	0,0002	5,0643	0,0000	0,3141
Size	0,0643	5,0640	0,0000	0,3141
greyvalue	0,0022	0,7588	0,4512	0,0106
AvgDistance	0,0026	45,6732	0,0000	0,9739

Table 19: Linear Regression Results for different variables from the High Polygon Garden

The high polygon garden environment shows significant relationships between the review fixation time and the polygon count, size of an object and the average viewing distance of an object. The Distance shows the most significance with a very high R-squared value. All relationships are positive however the estimates are all very low.

Variable	Estimate	tValue	pValue	R2
PolygonCount	0,0057	10,4675	0,0000	0,6241
Size	0,0938	5,7984	0,0000	0,3375
greyvalue	0,0037	1,0684	0,2893	0,0175
AvgDistance	0,0028	43,1974	0,0000	0,9658

Table 20: Linear Regression Results for different variables from the Low Polygon Garden

For the low polygon garden environment there are positive relationship for the review fixation time and the polygon count, the size of an object and the average viewing distance of an object. Size shows the most impact on the review fixation time. The distance shows the highest R-squared value so the distance explains almost all variation in the review fixation data.

Because the average viewing distance of an object seems to have a very significant relationship to the review fixation time the average distance of all objects for the four different environments is calculated and shown in table 21.

Environment	AvgDistance
GardenLP	352,2154
GardenHP	239,723
KitchenLP	369,3202
KitchenHP	265,7283

Table 21: Average Viewing Distance per Environment

There seems to be a difference between the high polygon and low polygon environments where the viewing distance to an object is higher in the low polygon environment. The distance measurements are local variables, because the kitchen and the garden are different environments with different local variables the distances between the garden environment and kitchen environment are not comparable. However, the trend is true for both environments.

The total fixations per environment and the average fixation duration is also calculated and shown in table 22.

Environment	Total Fixations	Average Fixation duration
GardenLP	508,4545	0,490018
GardenHP	275,5	1,280124
KitchenLP	53,2	5,170259
KitchenHP	65,45455	4,261811

Table 22: Mean Value of Total Fixations and Average Fixation Duration per Environment.

The garden and the kitchen show different trends in the data. For the garden the low polygon version shows a lower fixation duration and therefore more total fixations. For the kitchen this is reversed, the low polygon version shows a higher fixation duration and therefore less total fixations. Also the average fixation duration is much higher in the kitchen environments and therefore the total fixations is much lower in the kitchen environment. For all environments also the moving patterns of participants and the viewing data is visualized in heatmaps. These heatmaps are shown in figure 11. The red lines are the coordinates of the camera origin for every frame captured and represent the moving patterns of the participants. The heatmap shows the coordinates where the visible ray collided with an object in the scene for every frame captured. Where the yellow dots represent the coordinates that have been looked at more times or for longer periods of time, the blue spots represent the coordinates that have been looked at less or for shorter periods of time. Because in both the garden and kitchen environment there were some fixation hotspots a logarithmic scale has been used for the fixation data. This made the high values in the fixation hotspots lower compared to the rest of the fixation data and made sure that the fixation data of the rest of the area was distinguishable.

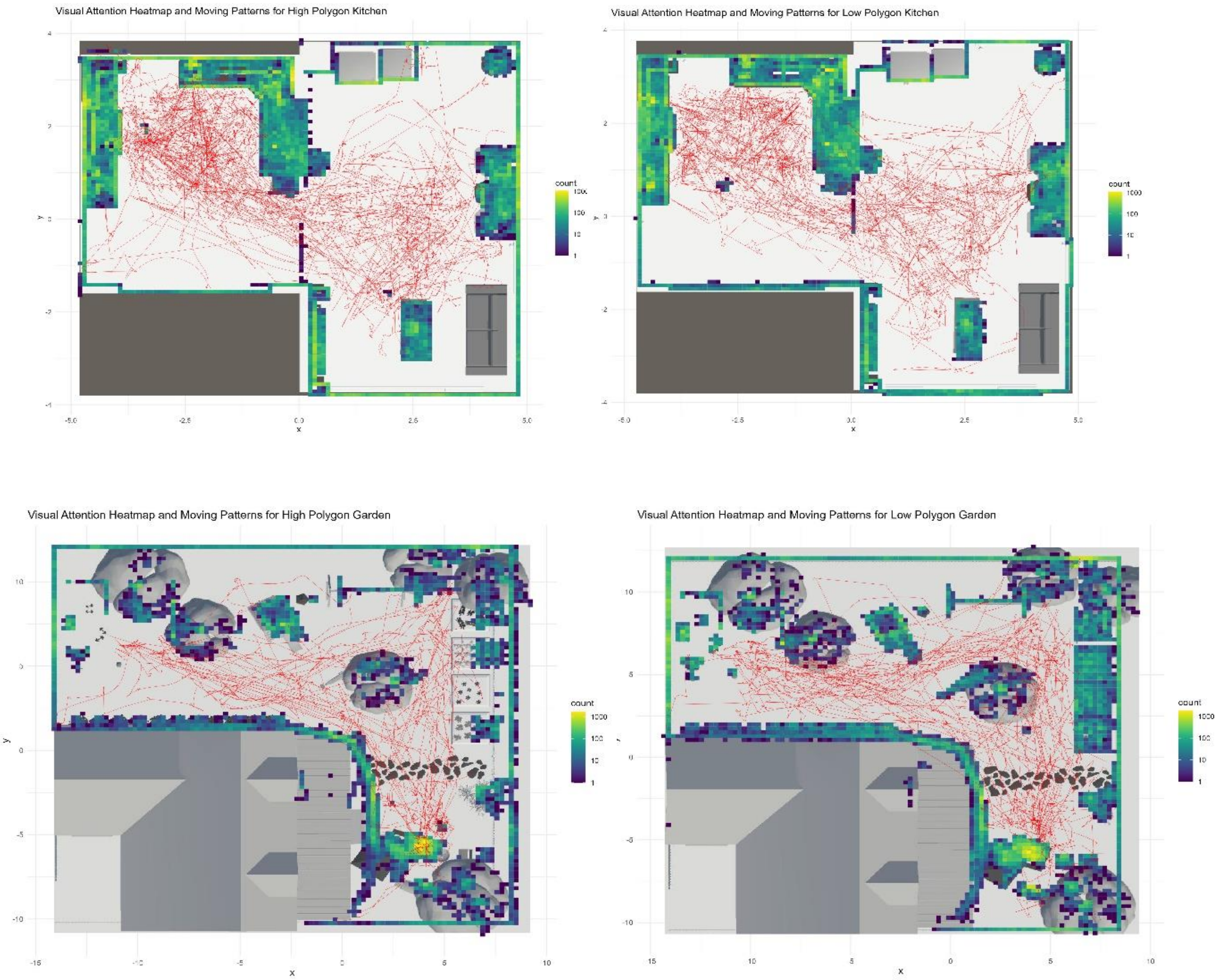

Figure 11: Heatmaps of participants moving patterns and fixation data. Upper left shows the High Polygon Kitchen Data, Upper Right shows the Low Polygon Kitchen Data, Lower Left shows the High Polygon Garden Data and Lower Right shows the Low Polygon Garden Data

For both the kitchen and garden data the fixation data of the floor is deleted to make the fixation data of the objects more visible and clear. For both the kitchen and garden data this was more data for the high polygon version. Looking at the figures no clear differentiations are visible, the hotspots for the fixation data seems to be around the same places for both the low polygon and high polygon environments.

Discussion & Recommendations

Research Question 1

The first research question investigated if a difference in polygon count could affect the VR experience. The sense of presence in VR environments is a critical factor for the effectiveness of these systems. Presence, often described as the feeling of "being there," can be influenced by various factors, including visual realism, user interaction, and system immersion. However, this research suggests that polygon count, a measure of geometric detail in VR environments, may not significantly impact presence levels.

For the overall presence scores of low polygon and high polygon count environments, no significant differences were found.

However the spatial presence sub scores show the highest differences between the groups and for the garden environment this difference was found a significant. For the spatial presence sub score of the kitchen the t-statistic value is large indicating a different experience depending on polygon count, however the p-value shows no significance. This can be explained my small sample size and should therefore be looked into in further research. Spatial presence, being a sub score of presence, describes the user's feeling of being physically in the virtual environment and the ability to interact with that environment and the feeling that the objects in the environment are real (Caroux, 2023).

The difference observed for spatial presence is in line with other research that indicates that polygon count can significantly impact spatial presence. For instance, a study exploring the influence of polygon count on physical and self-presence found that while no significant differences were observed in overall physical or self-presence, specific elements like the user's virtual hands showed a statistically significant difference when polygon count was manipulated. This suggests that higher polygon counts may enhance the spatial presence by making specific virtual elements more realistic and engaging (Volkmann et al., 2020) The results of this research also suggests that the manipulation of polygon count on certain elements in the virtual environment may enhance the spatial presence, in this study we found that the differences in the garden are more significant compared to the kitchen. This could suggest that more natural geometries have a higher impact on the spatial presence when the polygon count is changed. Like the manipulated virtual hands, which are also a natural shape. The differing t-statistic of the garden and kitchen indicates the same conclusion. The garden shows a negative t-statistic and the kitchen shows a positive t-statistic, which means that for the garden environment the higher polygon count results in a higher presence score or sub score and for the kitchen a higher polygon count results in a lower presence score or sub score. This indicates that in the garden, the environment with more natural geometries and the bigger differences in polygon count, the polygon count has more effect on the spatial presence scores of the participants. Earlier research already showed that high geometric realism yielded significantly higher presence scores. However this research used both polygon count and texture resolution and saw a confounding effect when the two were combined (Hvass et al., 2017). This research had no issues with these confounding effect and the results indicate that environments with more natural shapes, which create more visual differences when manipulating the polygon count, and consequently show significantly higher scores for spatial presence. According to this research, the kitchen environment which had more flat surfaces would probably benefitted in a higher extent compared to the garden, from texture resolution manipulation. However, this was kept the same in this research.

The general presence sub scores also show high t-statistic values however no significant result was found due to the small sample size. Also the general presence sub score is based on one question, so this also indicates that an even larger sample size is needed to show significant differences between groups. Besides this, the group that created the presence questionnaire used in this research also stresses that the general presence sub score has an especially strong relation to the spatial presence sub score. Which can explain the more significant differences in both the general and spatial presence sub score.

Looking at the scores of individual questions of the presence questionnaire, question 4 and 6 show significant differences between a low and high polygon count in the garden environment. The kitchen environment shows a significant difference for question 3. Both questions 4 and question 6 are about feeling present in the virtual space, so this indicates the same conclusion as stated earlier. For an environment with more natural shapes the participant feels more present in the environment with a higher polygon count. Question 3 is about perceiving pictures and a higher polygon count in the kitchen results in a higher feeling of perceiving pictures. This can be because relatively flat objects become even more flat when increasing the polygon count because the edges will become more smoothened. The flattened objects in combination with a relatively small kitchen environment which is boxed in by flat walls can decrease the feeling of debt perception and therefore increase the feeling of just perceiving pictures. The feeling of perceiving pictures influences the negative relationship between polygon count and the spatial presence score in the kitchen environment. Literature shows that the display mode in 3D compared to 2D significantly influences the overall presence score but specifically influences the spatial presence score of video games (Caroux, 2023) In the kitchen environment the same phenomenon might happen as in the study from Caroux et al. (2023).

The sensitivity of the chosen measurement tool might also be important for the results of this experiment. The tools used to measure presence, such as the IPQ, might have varying sensitivity to changes in polygon count depending on the context and specific items being assessed (Volkmann et al., 2020). Not all objects were manipulated in the environments, only the objects that would visually differ when changing the polygon count, and even then the visual changed for all objects were differing. The results of the IPQ do not show which objects influenced this score the most which can lead to an effect bias per object. In RQ3 this effect bias will be further investigated.

Research Question 2

In research question 2 we investigated if a different polygon count in a VR environment could affect the sense of spatial memory in users. The results of this research indicate that the polygon count of a VR environment does not significantly influence spatial memory levels. This finding is intriguing, as it challenges the assumption that higher graphical fidelity, often associated with higher polygon counts, would enhance cognitive processes such as spatial memory. This discussion explores the reasons behind this phenomenon, drawing on existing literature to provide a comprehensive understanding.

One reason that is mentioned in literature about spatial memory is the cognitive load. This literature showed that the cognitive load induced by complex VR environments can negatively impact spatial memory. For instance, environments with higher polygon counts can overwhelm the cognitive resources of users, leading to poorer performance in spatial navigation tasks. This is supported by findings that show increased cognitive load in high IVR environments correlates with reduced navigational abilities and long-term memory formation (Juliano et al., 2022; Parsons et al., 2023) Another study about VR shows that it is not a cognitive overload that results in a lower level of spatial memory but it shows that when the cognitive load is high, the high order cognitive resources used for attention allocation are occupied; thus, learners become unable to effectively inhibit their response to task-irrelevant stimuli and subsequently are easily disturbed by task-irrelevant stimuli (Sun et al., 2019). However, the environments used in this experiment showed no heavy cognitive load because there were no bright colours, no moving objects and no sounds. Therefore a cognitive overload is not likely. When looking at the results of gaming experience and VR experience against the spatial memory scores we also see that more experience does not necessarily mean an increase in spatial memory, which also indicates that a cognitive overload is not likely.

Another reason that can explain the spatial memory results besides the environment being too cognitively heavy, but the task the participants had to perform was too cognitively demanding. For instance, a study on visuomotor adaptation in HMD-VR environments found that increased cognitive load was related to decreased use of explicit cognitive mechanisms and long-term memory formation (Juliano et al., 2022) . This implies that if the task is cognitively demanding, the graphical fidelity (e.g., polygon count) of the VR environment may have a negligible effect on spatial memory. Another study comparing memory performance in immersive and non-immersive tasks found that participants who started with an immersive task demonstrated stronger long-term memory performance. This suggests that the nature of the task can significantly influence memory outcomes (Ventura et al., 2019). In this experiment participants were asked to remember everything in the environment to the best of their abilities and there were also multiple types of changes that could occur so the participants would have to remember the rotation and position of the items in the environment. Probably, because the task was too cognitively challenging, the results showed no differences between the high and low polygon count environment. Another explanation could be that the task was not immersive enough. This would also explain why the spatial memory was stable between the two different environments as the task was exactly the same for both environments. If one environment would be too cognitively demanding, then the spatial memory levels would drop instead of staying the same.

Additionally, to the cognitive load, the way the spatial memory was tested could also cause problems measuring the spatial memory in a reliable way. The participants only had to classify the images as “changed” or “unchanged”. Because of this response bias there is always a 50% correct response rate purely by chance, masking true differences in knowledge or ability. Because of this, it is also harder to analyse if some pictures were harder or easier to classify and look into the results in a more detailed way. Because it is not certain that the participant classified an image as “changed” or “unchanged” for the right reasons. For future research it is recommended to address this problem by either increasing the number of questions to increase variability in scores, or by asking the participants to indicate what the change was instead of giving the participant two options: change or no change. All in all, this research question indicates that polygon count does not influence VR spatial memory. However, this should be investigated in future research with more robust methods such as increasing the number of questions or by asking the participant to indicate the exact change.

Research Question 3

The third research question investigated if a difference in polygon count could affect the visual attention of users. The results of this research show a significant difference in visual attention for the garden. For the kitchen no significant differences were found. This can be because of multiple reasons. The first possible reason is the relation between spatial visual attention and spatial presence. Literature mentions a positive interaction between spatial presence and spatial visual attention and the detail of objects in a VR environment (S. Lee & Kim, 2008). This is in line with our results, as for the garden there is more differentiation in polygon count of objects in the low polygon environment compared to the high polygon environment. Also the spatial presence of the garden environments showed a significant difference in the first research question and for the kitchen no significant difference was found, which in line with the findings of Lee & Kim (2008). However, when looking at the average fixation duration for all environments, the kitchen shows a higher fixation duration in the low polygon environments. Which is contradictory to the results of Lee & Kim (2008).

One possible explanation for this could be that the objects in the kitchen already had a low polygon count before the adjustment of the polygon count. Therefore some objects might look strange after the adjustment. The objects were still recognizable but had some distortions in the low polygon count environment. These distortions could be the reason why the average fixation duration time for the low polygon count kitchen was higher. On the other hand, in the high polygon kitchen multiple objects visually did not change anymore when increasing the polygon count. Therefore, these objects were in much detail but the polygon count was relatively low. This could also explain why the linear regression resulted in no correlation between polygon count and visual attention for the high polygon kitchen environment.

Another explanation for the difference between garden and kitchen is the importance of distance. Literature shows a relationship between viewing distance to an object and the visual attention where objects that are close by have a higher visual attention then the objects further away (S. Huang, 2018). The results of this research show that in low polygon environments, the overall distance to objects tends to be higher, which may be due to the reduced visual complexity and detail. This lack of detail can make objects less engaging, leading users to maintain a greater distance from them. Conversely, high polygon environments offer more detailed and visually rich objects, which can attract and hold users' attention more effectively, resulting in closer interaction distances. So, in the low polygon environment participants tend to scan over their environment more and for the high polygon environment participants focus on certain objects. However, the linear regressions show a positive relationship between visual attention and distance to an object which is counterintuitive, as the study of Huang et al. (2018) indicates the opposite. A reason for this could be that object size or contrast act as confounding variables, so very large objects may stand out from a long distance or show higher contrast between the materials colours. When looking at the linear regression of object size this reinforces this, because distance shows a very small estimate value for all environments whereas size shows a relatively large estimate value for all environments. This means that an increase in size has more effect than an increase in distance. However, the correlation between distance and visual attention is more significant than the correlation between size and visual attention. Also, in this research the assumption was made that participants were looking in the middle of the screen of their goggles, this makes the data with a high distance less reliable because small differences in viewing angles result in more deviation over distance.

Recommendations for future research

When looking at the practical implications of this research in different domains such as education and neurorehabilitation, the results show different needs per application. For educational applications, environments designed for spatial memory and navigation tasks benefit from higher polygon counts in complex, natural shapes to enhance realism and engagement. In contrast, simpler applications, such as classroom simulations, might benefit more from improvements in other fidelity factors, such as texture quality or lighting. In clinical and therapeutic settings, VR environments can be optimized to balance engagement with cognitive load, ensuring that patients receive the most benefit without overwhelming their cognitive resources.

Future research should build on these findings by exploring other aspects of visual fidelity, such as textures, lighting, and shading, and their interactions with polygon count. The garden showed significant results for polygon count because of the natural shapes but the kitchen could be a good environment to test textures for example because of the mostly flattened objects.

In further research, experiments could also include more levels of polygon count, so instead of just using high and low polygon count, they could include intermediate levels of polygon count. This would result in a better understanding of the relationship between the polygon count and the results because the current high vs low distinction may miss subtle effects or nonlinear trends.

Another interesting future experiment could make use of abstract or fictional spaces instead of familiar environments like a kitchen or a garden, this familiarity could affect spatial memory, presence or visual attention because of evoked emotions by certain spaces for example. Abstract or fictional spaces control this prior knowledge and emotions of participants.

The use of eye tracking could also be useful in further experiments. In this research this was not used because of time restrictions, however eye tracking would make the data more reliable. This would account for the angular deviations at greater distances but also for the fatigue and discomfort in wearing VR goggles, which could cause participants to look more downward or adopt less central gaze behaviour over time.

Lastly, the polygon meshes used in the experiment could be optimized. Because of time restriction in this research already existing meshes were downloaded and adjusted accordingly. However, these meshes are optimized for a certain polygon count and adjusting these meshes could cause distortions and nonoptimal meshes which could influence the results. For further research it would be better to create original meshes for the experiment which would prevent the distortions and nonoptimal meshes.

Besides these improvements that could be used in further research this research also showed some promising results. This experiment perfectly showed the influence of polygon count on different types of environments for both spatial presence and visual attention. In the case of presence for instance, in a garden environment with rounded and organic shapes, a higher polygon count significantly enhanced the sense of immersion, allowing participants to feel more engaged with the space. Conversely, in a simpler kitchen environment with flat and angular surfaces, the benefits of higher polygon counts were less pronounced and, in some cases, led to diminished spatial presence due to visual inconsistencies or reduced depth perception. These findings underscore the importance of adapting polygon counts based on the specific characteristics of the environment and the intended use. In terms of visual attention, polygon count played a critical role in environments with natural shapes, where higher levels of detail attracted greater focus and engagement. However, in simpler settings, the impact of polygon count on attention was less apparent. This suggests that selectively increasing polygon counts for key objects or focal areas can optimize VR experiences without overburdening computational resources. Such an approach is particularly beneficial for large-scale VR applications, where maintaining performance is critical.

In addition to the significant differences between the two VR environments it is also very promising that with such a small sample size the experiment already showed many significant results. These results can get even more significant when increasing the sample size or differences that show no clear significance in this experiment can become significant when expanding the sample size.

Conclusion

This research has explored the applications of VR environments for spatial learning and investigated how geometric detail, represented by polygon count, influences user experience by testing presence, spatial memory and visual attention. This was done because of different needs for different VR applications thereby emphasizing the importance of tailoring VR environments to specific applications. In this way, VR could optimize both learning outcomes and computational efficiency for these applications.

In terms of presence scores, the results indicate that the influence of polygon count is not the same across all metrics. While general presence and spatial memory were not significantly affected by changes in polygon count, spatial presence showed significant differences between the level of geometric detail, particularly in environments with natural and complex geometries.

The spatial memory results showed no significancy between different levels of geometric detail. This could be because of the to cognitively demanding task the participants were given in the experiment. The demanding task could have a stronger effect on the spatial memory levels making the influence of polygon count insignificant.

The results of the visual attention data shows that differing levels of geometric detail cause significant differences in fixation time for environments with more natural shapes. In environments with more flat objects the influence of polygon count decreased.

In conclusion, this study highlights the importance of tailoring VR environments to align with user needs and application objectives. By strategically managing polygon counts, VR developers can create environments that are not only visually compelling but also functionally effective for a range of applications, from education to neurorehabilitation and beyond. These insights pave the way for more efficient, impactful, and accessible VR solutions in the future.

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Appendix A. Intake Form

1. What is your name?

2. What gender do you identify as?

3. What is your age?

4. What is your profession or current study?

5. How experienced are you with Virtual Reality?

6. How experienced are you with gaming?

7. I hereby confirm that I am willing to participate in the VR experiment and that I am in good health to do so. I am aware of cybersickness that might be occuring and I know what to do in that case. I also agree to my data being used anonymously.

Appendix B. Igroup Presence Questionnaire

1. In the computer generated world I had a sense of "being there".

2. Somehow I felt that the virtual world surrounded me.

3. I felt like I was just perceiving pictures.

4. I did not feel present in the virtual space.

5. I had a sense of acting in the virtual space, rather than operating something from outside.

6. I felt present in the virtual space.

7. How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?

8. I was not aware of my real environment.

9. I still paid attention to the real environment.

10. I was completely captivated by the virtual world.

11. How real did the virtual world seem to you?

12. How much did your experience in the virtual environment seem consistent with your real world experience ?

13. How real did the virtual world seem to you?

14. The virtual world seemed more realistic than the real world.