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The DreamScreen
see through experience in a 2D setting

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- The DreamScreen -

See through experience in a 2D setting

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Master of Science thesis
University of Technology of Eindhoven

On behalf of
Philips Research

The DreamScreen

See through experience in a 2D setting

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Master of Science thesis:
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Preface

"Finis coronat opum"

With much interest, I followed the masters course Human Technology Interaction at the faculty of Technology Management of the University of Technology Eindhoven. I experienced it a valuable addition to my knowledge, beside my mechatronical background. During my career as a student I had my fun times as well as difficult times and above all I had my intellectual experiences. These experiences attributed in one way or another to my person and contributed to my thesis research for Philips Research, of which this report forms the crown of my academical education.

Naturally, I could not have completed my thesis research without the help of many people. First of all I would like to thank Ingrid Vogels for her amazing input and her excellent guidance during my project. Secondly, I would like to thank Wijnand IJsselsteijn and Yvonne de Kort for introducing me to the DreamScreen project and their critical reviews. Thirdly, I would like to express my thankfulness towards the DreamScreen project leader Evert van Loenen along with the rest of the DreamScreen members, especially Rick van Haasen for his effort in technical support. My fellow students and colleagues deserve some credit as well for the good ambience and the inspiring discussions leading to many creative thoughts. And finally, I would like to express deep gratitude to my parents for all the possibilities they created for me in life and for supporting me during tough times.

Please note that due to readability of this report references to persons in third person are done by the word 'he', which can be substituted by a 'she' at almost all occurrences.

Sumary

Many psychologists acknowledge a positive effects of windows on humans. The effects range from the influence on mood to the influence on task performance. Even effects on stress and post surgical recovery have been demonstrated. Most scientists agree that views of nature are causing these positive effects, however many buildings are built in urban environments or do not have windows at all. Philips' DreamScreen project focuses on window-sized video (and audio) while keeping transparency functionality, in order to create or (partially) replacing a window view. Although merely beaming large images over the full width of windows already gives some impression of a real window view, it lacks depth. This causes the scenes to be perceived *on* the wall instead of being watched at *through* a window. This causes the DreamScreen unrealistic as a view-replacement.

The aim of this study is to investigate how to enhance the see-through-experience of a virtual window by displaying a 2D image.

First a literature study on depth perception was performed, then 2 experiments were done to test different depth cues for their influence on the see-through experience and finally a focusgroup study was done to gain insight into what the experiment results means for the total window experience of a DreamScreen user.

To gain more insight in depth perception, an overview of perceptual depth cues is given from literature. Three of these depth cues: motion parallax, occlusion and blur, are studied in particular due to their technical feasibility in the DreamScreen project and because these are expected to enhance the 'see through experience' when observers watch an outside scenery "through" a DreamScreen. Motion parallax is the change of angular position of two stationary points relative to each other as seen by an observer, due to the motion of that observer. From this shift the perceptual system extracts information about the three dimensional world surrounding us. Besides this, when an object blocks another out of our sight, called occlusion, it gives us specific information about the relative position of the objects. Additionally, when watching objects at different distances they cannot all be in focus at the same time. This means that when one focuses on an object, other, blurry objects must be located at different layers of depth.

To ensure a certain amount of realism, images of photographical quality, instead of 3D computer graphics or dot diagrams, are used in the experiments to test the influence of the three depth cues on see-through-experience. Image Based Rendering can make a photographical window view with full motion parallax possible, but it is computational very demanding. In this project only a parallax between window frame and a 2D photograph window is created. This is done by translating a photograph as a function of the (tracked) head motion of an observer. This is expected to create a perceptual distance between window frame and the scenery view. Since no relative depth *within* the picture is possible in this way, an experiment was performed to determine the translation speed for the whole scenery (and the influence of other depth cues on this speed). In a within subjects experiment 22 participants were shown a virtual window. They are asked to regulate the translation speed of 5 different photographed views, by tapping keyboard keys to change the head/image ratio. The experiment resulted in an average gain-factor of 0.58. The occluding frame did not have a significant influence and no influence of image content was found on the determination of this gain factor. In the second experiment the

three chosen depth cues were therefore tested for their influence on the 'see through experience' with the gain factor determined in experiment 1.

One hypothesis in the second experiment was that all three depth cues (simulated motion parallax, occlusion and blur) increase the 'see through experience'. An additional hypothesis was that motion parallax and occlusion strengthen each other's effects. These hypotheses were tested by letting 20 observers assess their 'see through experience' for different conditions: with or without motion parallax, with or without an occluding crossed window frame and with or without blurring the borders of the frame. Results showed that all three cues have positive main effects on the 'see through experience'. Also the strengthening interaction between motion parallax and occlusion is found. Unlike in the gain factor determination, a main effect of image content has been found this time.

Although the three depth cues have a positive influence on the 'see through experience' it was unsure what this meant for the total window experience. A focusgroup study was performed to determine which functions windows have in daily life and how well the DreamScreen suited with respect to these window functions. Participants were asked to keep a diary for a couple of days about their usage of windows. The noted activities and the function(s) of the windows were discussed in the actual focus group session. The suitability of the DreamScreen could to fulfill these functions and what measures should be taken to improve the DreamScreen, were discussed. This resulted in 8 categories of window functions: a light source, explicit information gathering, ventilation, protection / separation, atmosphere creation / entertainment, communication, escaping from the average and orientation, each with their own applicability and problems when a DreamScreen is used.

During their visit, participants were also asked to asses their satisfaction of the window (DreamScreen) in the Homelab Kitchen in a quasi experimental setup. They were asked to do this 3 times: without, with slow- and with fast motion parallax. The aim of this study was to find out whether the implementation of simulated motion parallax, actually means something for the 'total window experience'. The results do not show an impact of either a slow or a quick motion parallax on the satisfaction of the participants. All assessment scores are slightly negative, which means that people in general are skeptical in using the DreamScreen. According to the focus groups the best way to use DreamScreen technology, is to use it in an augmented way, as a gadget, toy or as a digital painting. However, when the DreamScreen *will* be used as a real window replacement the DreamScreen should be able to display the actual situation outside. Furthermore the system should emit light that approximates sunlight. In general, although participants stated that the motion parallax gave them a better feeling of naturalness while watching through the DreamScrean, it still missed "realness". Suggestions for further research are made.

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1 Introduction

1.1 Previous research

During the energy crisis in the early seventies, windowless architecture was proposed as an energy conserving measure, because buildings lose most of its warmth through windows. However architects, backed up by environmental psychologists, soon warned that the lack of windows would have a negative influence on people's well-being. Hollister (1968), for instance, concluded from a survey that the public would be reluctant towards living in windowless residential buildings. Collins (1975) found out in several studies that not only living in windowless spaces, but also working in windowless offices is not preferred.

Lack of windows also has a more direct, measurable, effect. Patients in windowless intensive care units, for instance, were more likely to develop a post-operative delirium in comparison to similar patients in units with windows, according to both Wilson (1972) and Ulrich (1984). Also task performance increased in windowed conditions compared to windowless conditions (Sato and Unui, 1994). These are examples out of many research projects concluding that windows have positive influence on humans.

Many scientists have investigated the cause of these positive effects of windows on people's well-being. Heerwagen and Orians (1986) concluded from an experiment that people wanted to see nature even if it was a surrogate. Sommer already noted this in 1974, when he mentioned that windowless office workers tended to place landscape posters on the wall, apparently to try to compensate for the lack of real windows. This preference to see nature is now thought to be the main cause of the positive influences of windows on people. Ulrich et al. (1991) argue that historically humans had to turn to nature for food and flee routes and, therefore, have an evolutionary need to see nature. Kaplan and Kaplan (1989), however, build a slightly different model, explaining the positive effects of nature views by a mechanism based on restoration of depleted attention capacity. They argue that in modern life cognitive attention is forced by unnatural signals (beeps of computers, alarm clocks, traffic lights, telephones ringing, etc.), which exhausts the attention reserves. These reserves get restored when watching nature.

However research in this area is still ongoing and some theories differ from each other in explanation (there are also other widely supported causal theories about sunlight, but this falls out of the scope of this project). Most scientists agree on the positive effects of windows and that views of nature are causing them.

1.2 The DreamScreen

Although psychological literature describes how windows with a view on nature enhances people's well-being, many buildings are built in urban environments or do not have windows at all. The DreamScreen is a concept that is developed by Philips Research and aims to enable people to (re)place a window view. This is not a new idea. Trompe l'oeil already made paintings such as displayed in Figure 1 to create an illusion of watching through a window.

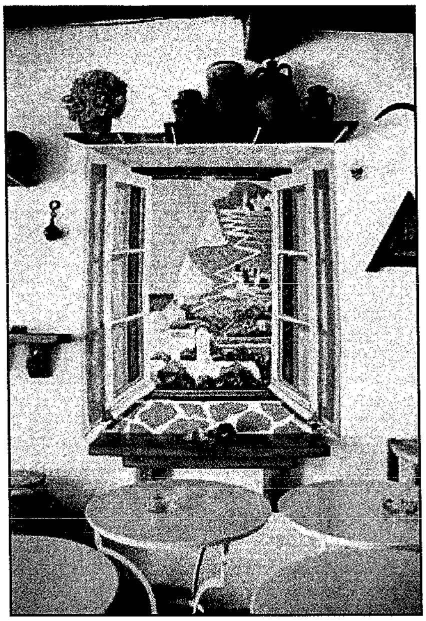


Figure 1 – Trompe l'oeil van de Panagia op Folegandros

Many modern companies trie to create virtual window views. One example, the TESS Round skylight, is shown in Figure 2. Semi-transparent photographs are placed in front of a light source to simulate a window in a medical facility where in fact is none.

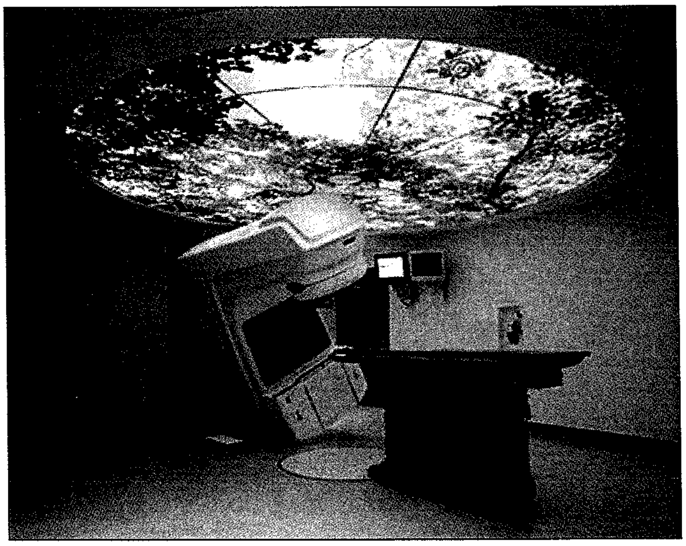


Figure 2 – TESS Round skylight taken from the TESS website

Because placing transparent sheets with photos needs physical effort the content cannot be changed easily. Armas tried a more dynamical approach resulting in their Armas Magic Window system, as presented in Figure 3. They tackled the problem by linking an array of eight TFT-screens to a computer system. This enables the end user to change the content of the window view relatively easy.

Figure 3 – Armas Magic Window taken from the Armas website

Philips' DreamScreen project focuses on how window-sized video (and audio) can create immersive experiences in different applications. In its present state it consists of 5 high-resolution beamers. These are mounted in the ceiling next to each other in such a way that they project onto 5 window screens. When the beamers are activated, white screens are lowered in front of the windows, making the beamers able to project an image view over the full width of 9 meters. This display in combination with directional sound and location awareness systems should create an intuitive interaction with the system in the near future (Philips Homelab website).

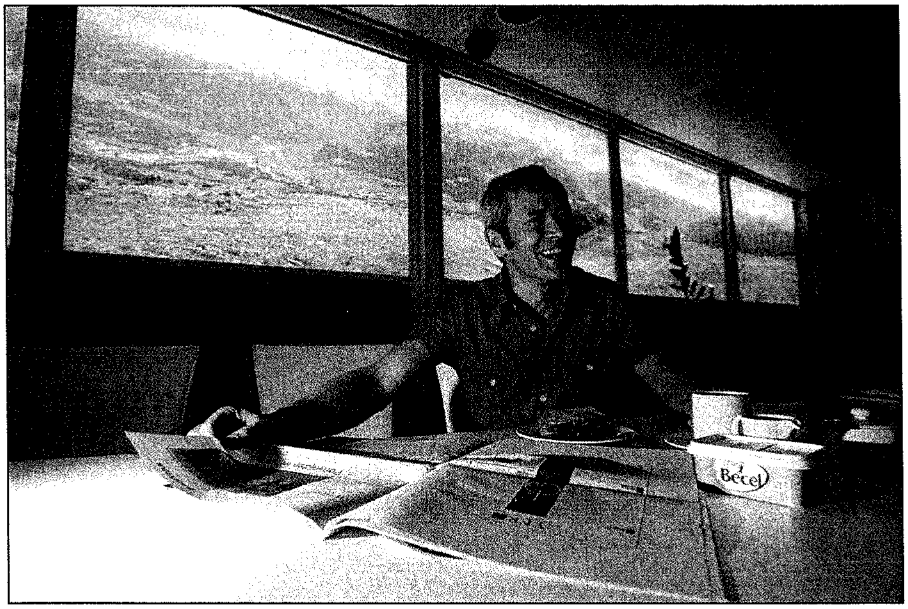


Figure 4 – The DreamScreen

Projection technologies that make images visible without the projecting screens being white are investigated in the DreamScreen project. In this way the transparency function of a window is preserved, and at the same time text and images can be placed on the window. What applications this might serve is still under research. Within this report the focus will be on view creation and replacement.

Although merely projecting large images on a wall can already give some impression of a window view, it is thought that one of the most important things that is missing is depth. This causes the scene to be perceived *on* the wall instead of watched at *through* a window, making it unrealistic as a view-replacement. Philips has done already quite a bit of research regarding enhancement of depth impression fo 2D displays. For instance, M. Ciacci (2001) investigated how to increase depth impression of broadcast video on standard CRT's with video processing algorithms. The results showed that two algorithms, one basted on the change of depth of focus in images, the other based on "pseudo rendering", were the most effective in conveying depth. Another example is a study of Rajae-Joorens and Heyndrickx (2002) where naïve viewers were asked to rank different TV sets with different settings on the basis of overall impression of depth. Resolution, sharpness and contrast were found to be important factors contributing to depth impression while the contribution of luminance was less clear. The effect of luminance on depth impression was further investigated on a 2D LCD-TV (Rajae-Joorens & Heyndrickx, 2003). Subjects were asked to adjust the brightness setting until they obtained either the maximal depth impression or the maximal image quality. They concluded that a high dynamic range is required to optimize both image quality and depth impression.

1.3 Project goals

To create a better window experience and to flirt with Ulrich's 'need to flee' theory (paragraph 1.1), the DreamScreen should give a realistic impression of depth. In other words, a three-dimensional experience of 'seeing through' should be elicited to enhance the experience watching of a window when watching the DreamScreen.

The primary goal of this research project is to select several depth cues, that can be used in combination with the DreamScreen technology, and measure their influence on the 'see through experience' of observers. In the end, this project will give insight into what perceptual depth cues should be used to further improve the DreamScreen technology from a user-centered perspective. It will also provide more fundamental insight into the perceptual mechanisms underlying depth perception, like possible interactions between different depth cues.

A secondary goal is to find out whether depth cues that positively influence 'see through experience' also contribute to the 'total window experience' and to finding out what functions windows have in daily life. This gives insight into which aspects of the DreamScreen should be improved or included during further development of the DreamScreen as a view creator or replacer.

1.4 Report structure

This report will be a chronological description of the whole project. Chapter 2 will give an overview on the perceptual depth cues described in literature. Different cues will be chosen on both theoretical and practical feasibility grounds and for their influence on the 'see through experience' will be tested.

In order to compare the effect of depth cues on ‘see through experience’, some parameters need to be optimized first. How these are determined will be described in the third chapter. The influence of the chosen depth cues will be presented in chapter four.

Chapter five covers a focus group study. The aim of this study was to find out if the implementation of the depth cues actually contribute to the ‘total window experience’. The study focuses also on the purposes windows have in people’s daily life. In other words: does the ‘see through experience’ have a notable impact on the overall window experience of the DreamScreen and what makes a window ‘a window’. Each typical window function will be evaluated to see whether the DreamScreen is suitable in that typical situation.

In the sixth chapter the overall conclusions for this project will be discussed and it will be pointed out what the findings mean for further research and development.

2 Visual depth perception

The early stage of the human visual perception system works much like a photo camera. Light reflected by objects falls onto the eye's lens, which focuses the image onto the retina like a photo camera's lens focuses on the light sensitive film. The light reaching the retina creates a two dimensional projection of the world from the viewpoint of the eye, like the image on the light sensitive film of a camera. However, where a photo camera stops the human perception system has only just begun.

A complex system of photoreceptors, ganglion cells, nerves etc., transports the information of both eyes to the brain where the bigger part of the processing takes place. The brain interprets the physiological stimulations to create a three dimensional representation of the world. It does so by transforming and combining the two dimensional information it receives from both retinas. This enables us to respond to events around us, like for instance catching a ball or follow the correct trajectory of a curve in the road while driving a car.

Much research has been done about depth perception, which has resulted in a lot of insight in the different cues humans use to determine the absolute and relative distance from objects. Both Palmer (1999) and Drascic & Milgram (1996) have made an overview of depth cues. Sekuler & Blake (2002) divide these different cues according to the following hierarchical scheme:

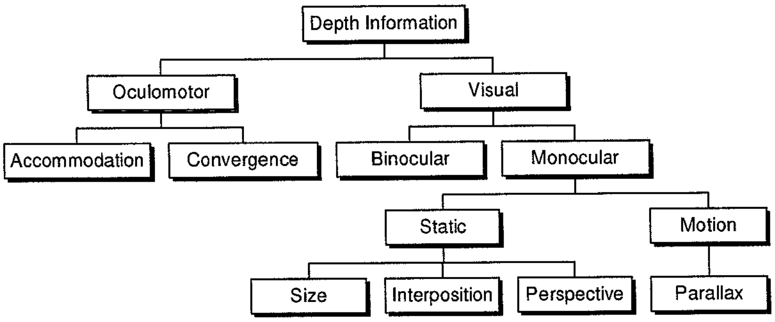


Figure 5 – Classification scheme of depth cues from Sekuler & Blake (2002)

This chapter will describe the most accepted theories about depth cues presented in Figure 5 and will speculate on which cues can be used to create a better 'see through experience' when introduced into the DreamScreen.

2.1 Oculomotor depth cues

Accommodation

In order to focus an object on the retina with as little blurring as possible, oculomotor muscles have to make sure that the lens has the right shape. The contraction of these oculomotor muscles connected to the eye's lens is monitored in the brain, for the lens' curvature gives information about the distance of the object. The right sketch in Figure 6 shows that when an object is closer to the eye the oculomotor muscles should contract to make the lens less convex. So, from a higher contraction factor of the oculomotor muscles the brain "knows" that the object must be closer.

Convergence

Convergence is defined as the angle the eyes make when looking at the same object. The left sketch of Figure 6 shows that oculomotor muscles must contract or relax more to make the eyes turn to objects that are closer. These muscular contractions form a second oculomotor cue for the brain to derive depth information from.

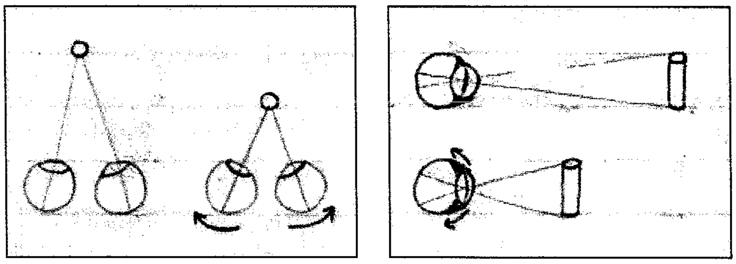


Figure 6 – Convergence (left) and accommodation (right)

Accommodation and convergence are valuable cues to determine absolute observer of an object. Both Sekuler & Blake (2002) and Cutting & Vishton (1995) however, have found that oculomotor cues soon drop to marginal importance from ca. 5 meters distance.

2.2 Binocular depth cues

Binocular disparity

Usually humans have two eyes fixated on the same object. Because each eye is located at a slightly different geometrical position in space, both eyes watch the object from a laterally different vantage point. This means that the 2D representations of the real world on both retinas slightly differ (Figure 7). The brain fuses the two images together and, from the difference between the left and right eye's image, it extracts depth information (Figure 8). When the disparity (difference between the images of the left and right eye) is large the brain will interpret this as being a different distance with respect to the fixation point (closer or further when the disparity is crossed or uncrossed).

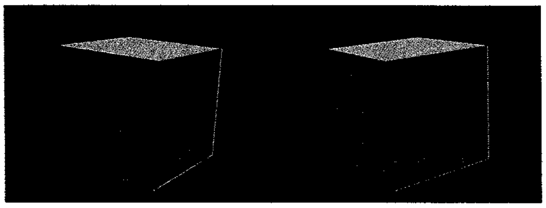


Figure 7 – Left- and right eye image of a cube in 3 dimensional space

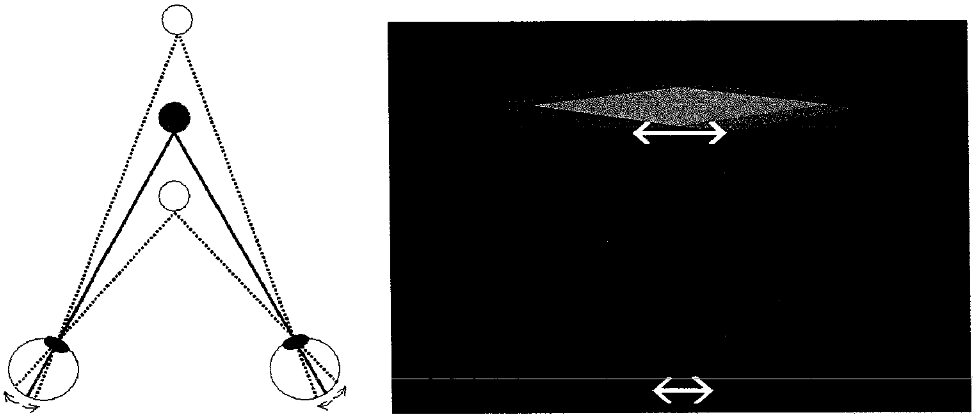


Figure 8 – Explanation of disparity and merging the images of the left and right eye

2.3 Monocular - Static depth cues

Monocular static cues are those that can be captured in photographs. They are therefore sometimes called pictorial cues.

Occlusion

Yonas (1984) found that from the age of about seven months, humans are already able to determine the interposition of objects by interpreting the (partially) occlusion or obscuration of objects by others. In other words, we have learned that when an objects blocks another out of our sight, the occluding object is the one closer to us. An example of interposition by occlusion is given in Figure 9. Occlusion only provides ordinal distance information but no absolute distances.

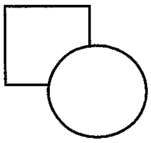


Figure 9 – Interposition by occlusion

Retinal Image Size

We have a general idea of the size of objects surrounding us. When the projection of an object on our retina get smaller, we experience the object as being further away. Because the squares in Figure 10 are abstract figures, we have no information about their size. Usually people assume that the squares have equal sizes and hence the difference in size can be interpreted as the objects being at different distances from the observer, the smallest square being the furthest.

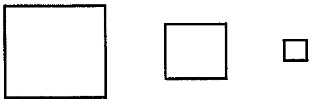


Figure 10 – Retinal image size creating distance information

Perspective

Parallel lines do not intersect in reality. However, they do seem to intersect in the plane of a picture. In other words, when two geometrically parallel lines recede in distance from an observer, they converge to a point on the horizon. This is called perspective. Along with this linear perspective comes the difference in texture. The closer we are to objects, the more detail can be seen of its surface texture. When watching Figure 11, I a photograph of a metro station in Prague, the receding lines clearly converge towards one point. Also the tiles get smaller with increasing distance from the camera position, showing an obvious gradient in texture of the wall.

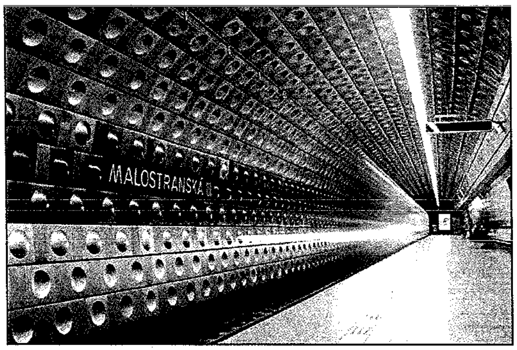


Figure 11 – Linear perspective, texture gradient and geometrical shading

Height in visual field

Objects located near the horizon are perceived as more distant than objects that are further away from the horizon.

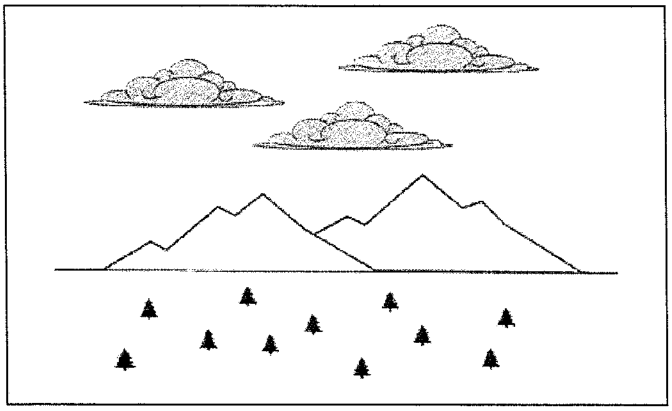


Figure 12 - Height in visual field taken from Palmer, 1999

Shading

Shadow tells us a lot about object geometry and relative placement. As almost all illumination comes from above, we tend to resolve geometrical ambiguities using this information. This is why the circles in the wall of Prague's metro system (Figure 11) are perceived as being convex and concave. This is also used on many websites and various computer interfaces. Buttons appear to bulge out of the page when they have a light top and a dark bottom. By reversing the shadow when clicked, it seems like the button is pressed inwards, as displayed in Figure 13.

Figure 13 – Geometrical shading

Recall that occlusion only gives information about the ranking of objects. When an object casts shadows on other surfaces, the further the shadow is cast laterally from the object, the further the object is probably away from the surface cast upon. Hence shadows give additional information about the distance between objects. However this information is still not absolute.

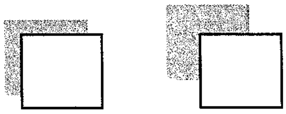


Figure 14 – Shadow creating sense of relative distance

Aerial Perspective

The atmosphere always contains small particles like water drops, dust etc. This causes light to scatter. At large distances many particles are between the object and the perceiver. The cumulative character makes objects further objects hazy in respect to closer ones. Figure 15 is a photograph of roof tops in Prague where the effects of this haze is very obvious. Houses in the distance seem hugged by more haze than the houses in the front of the picture.

Figure 15 – Aerial perspective making distant objects hazier

2.4 Monocular – Motion depth cues

Motion parallax

The greek word παραλλαγή (parallagê) or in its modern form: parallax means alteration. Motion parallax is the change of angular position between two stationary points as seen by an observer, due to the motion of that observer (Figure 16-A). Or more simply put, it is the apparent shift of an object against a background due to a change in observer position (Wikipedia).

Since motion parallax is about relative movement of objects with respect to an observer, one should realize from which perspective one is reasoning to describe or understand the phenomenon. On possibility is from the observer's perspective. This is equivalent to a coordinate system that moves along with the observer, so that the observer stands still and the rest of the world moves. Since the angular movement of objects close to the observer is larger then of objects at larger distances (Figure 16-a) the movement of objects can be described by a motionfield like in Figure 16-b.

Hence, when an observer moves, closer objects are perceived as moving faster than the more distant objects. Objects at infinity appear to stand still relative to the observer's point of view (Figure 16-b). To clarify this, imagine the following practical situation where one is traveling by car at night. The silhouettes of the trees next to the road seem to swiftly pass by, while the distant lights of a city in the valley slowly pass by and the moon (almost at infinity) seems to stand still, no matter how fast or slow or in what direction one travels. In other words (from a third person's perspective) the moon seems to travel along.

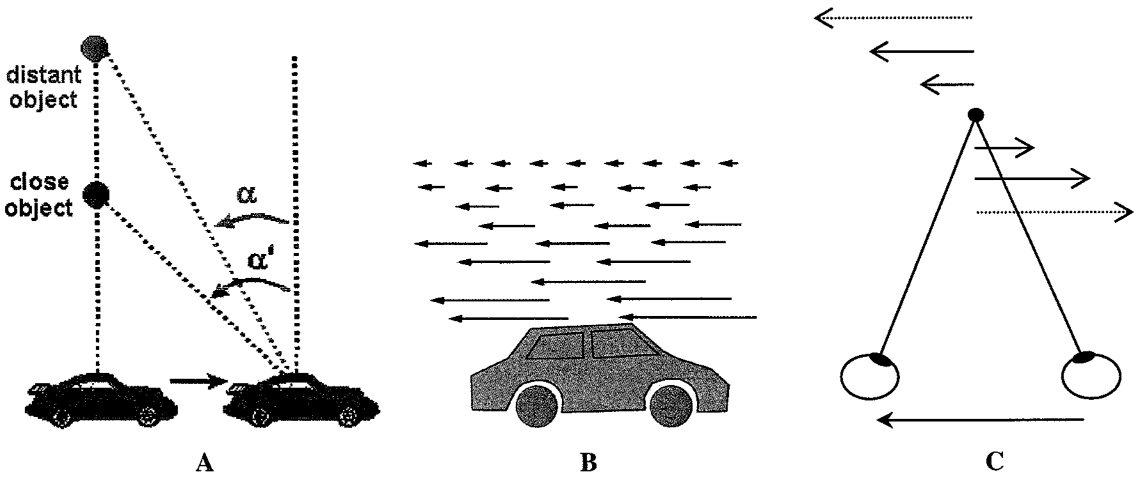


Figure 16 – Different ways to depict Motion Parallax

Figure 16-C shows another way to look at motion parallax. As Nawrot (1997) pointed out: when one moves, slow tracking eye movements (smooth pursuit) try to keep one object or location still on the retina. Perceptually it seems as if the world is moving around that focus point. Objects behind that point seem to move in the same direction as the observer, whereas objects in front of that point seem to move in the opposite direction. This can be easily viewed when watching through the side window of a moving vehicle through as Figure 17.

The apparent relative motion is used for instance to correctly maneuvering in traffic. Nawrot (2004) also found that alcohol intoxication has a negative impact on depth judgments made on the basis of motion parallax and suggests that this, in addition to the impact on reaction times, is one of the main factors causing accidents due to alcohol intoxication.

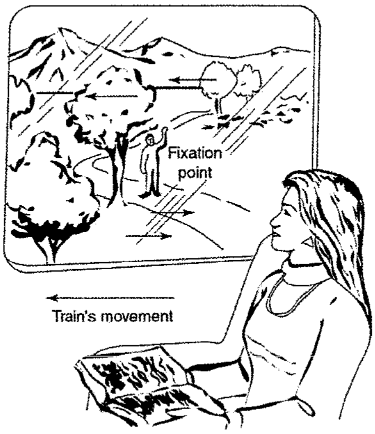


Figure 17 – Apparent relative motion due to fixation from Sekuler & Blake (2002)

2.5 Selection of depth cues

Now that an overview of depth cues is described the cues that are most applicable in the DreamScreen can be chosen for further investigation.

Although binocular disparity is one of the strongest cues at a certain distance until about 30 meters distance, auto-stereoscopic techniques, that create binocular disparity on a display making it 3D , are not yet feasible in combination with the DreamScreen technology. This might be possible in the future, but for now we will have to stick to the monocular cues. Most monocular cues are already inherent to a picture (pictorial cues). Since the goal is to create a better 'see through experience' than a picture on the wall (i.e. a poster seems to be a flat representation of another environment rather than to be a view of a window) these cues do not seem to be appropriate to manipulate in the DreamScreen.

Motion parallax, on the contrary, can form a tool to enhance depth impression since the DreamScreen is able to display video content (in contrast to a poster or painting on the wall). Redert (2000) concluded that participants disliked three-dimensional scenes based on stereoscopic cues in virtual reality research. When there was no motion parallax while moving in a virtual reality watched through a head-coupled display, they reported the scene to be "elastic" (shear distortion). This emphases the importance of the use of motion parallax, even when displaying stereoscopic 3D images. So, motion parallax seems to be a very important depth cue. Since the DreamScreen is able to display video content, motion parallax can be implemented and possibly create more 'see through experience'.

Cutting & Vishton (1995) have good reasons to believe that depth-contrast due to motion parallax declines with distance. This seems logical knowing that dept contrast is a ratio of the relative distance between objects and the absolute distance to the observer. To grasp this, imagine an observer with two rocks in front of him. One rock lying at 2,0 meters distance and the other at 2,5. In this situation the depth contrast is high (from the observers perspective it is clearly visible that the stones are located at other distances from you). However when these rocks are located near the horizon (say at 1002,0 meters and 1002,5) the contrast is very low (the observer cannot see the distance difference between the stones). In other words objects at large a large distance are perceived as part of one depth layer (when the relative distance between the objects is relatively small in comparison to the absolute distance to the observe) with marginal motion parallax between objects on that layer. As shown in Figure 18 the 'motion perspective' (or motion parallax) line crosses the 'utility threshold' (the amount of contrast needed to be able to see depth difference between objects) around 36 meters distant. This means that objects beyond 36 meters do not offer depth information by the motion parallax and seem to be on the same depth layer, if it weren't for other depth cues like aerial perspective to take over (Figure 18).

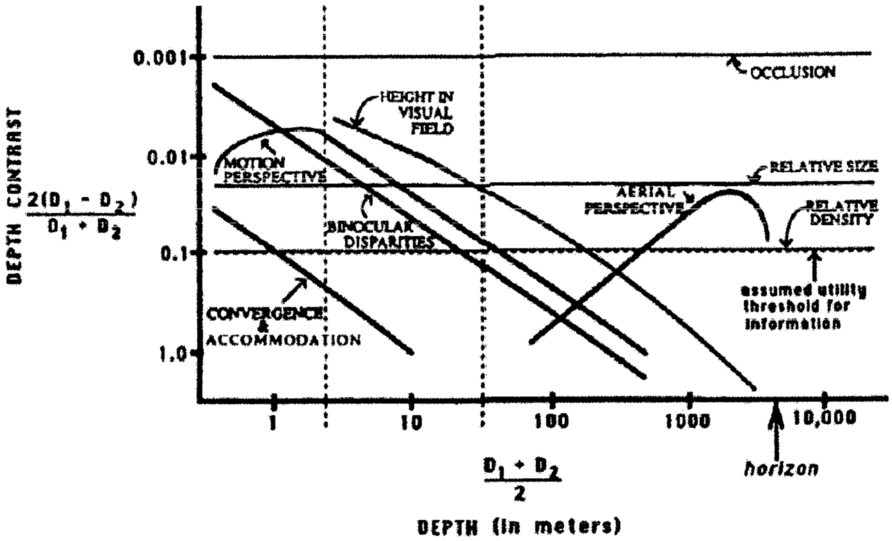


Figure 18 – Depth contrast as a function of distance from: Cutting & Vishton (1995)

What does this mean when watching out of a window? A window frame is generally much closer to the viewer than the outside scenery which is at a large distance. Therefore a slight lateral shift of the head seems to cause the scenery to move 'as a whole' relative to the window frame, since there is a large distance between the window frame and the objects in the scenery.

Consider the top view of two situations in Figure 19, where an observer, represented by the circle, is watching a scenery view through a window, while moving from left to right. The first horizontal line represents the layer of the view, assuming that the objects in the scenery are at large distance and therefore the view is perceived as one layer. The second horizontal line is the plane of the wall with the perpendicular lines marking the beginning and ending of the window. The figure shows that when an observer moves in front of the window, other parts of the scenery become visible due to a change in vantage point. In the left position the view is visible from C to D and after the motion to the right.

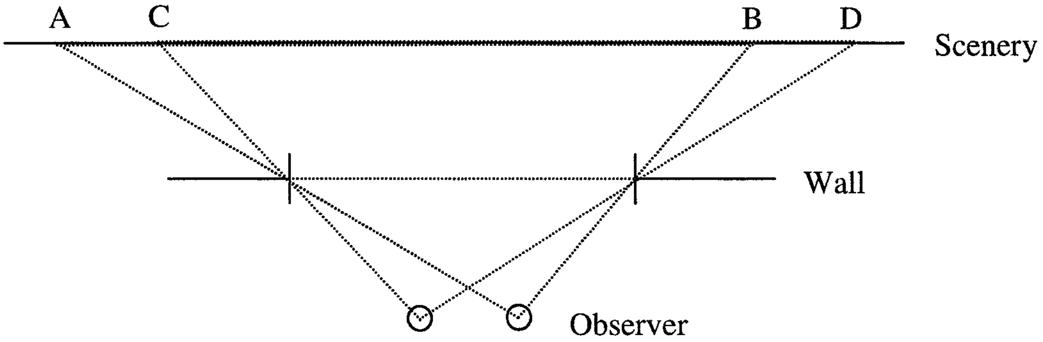


Figure 19 – Top view of a moving observer in front of a window.

Realize that motion parallax between view and window frame seems to be most apparent at the edges of a window, due to the occlusion of scenery parts by the framework of the window, while only slightly nudging the head. Adding more occluding framework in more prominent places of the screen might make the motion parallax more apparent and make the 'see through experience' potentially even stronger. Hence, besides the interposition effect explained in paragraph 2.3, the occluding frame may have an interaction with motion parallax and strengthen the effects caused by motion. Hence, even though it is a pictorial cue, when applied together with motion parallax, occlusion might still have added value in 'see through experience' caused by the interposition effect *and* by a possible interaction with motion parallax.

Oculomotor cues, however, (specifically accommodation) tell us that the view in fact is in the plane of the wall especially when the viewer is close to the wall. Part of this contradiction may be addressed by blurring the (occluding) window frame, when watching "out" of the window. This does of course not change the information given by the oculomotor muscles and nerves, since the image is still located on the plane of the display. However, the blur suggests a difference in depth because objects at different depth layers than the objects that are focused on, are normally blurred. This in combination with the occlusion the window frame may be experienced as being closer to the observer then the scenery does.

Concluding; motion parallax, occlusion and blur may form usable tools to elicit a depth experience resulting in a stronger feeling of seeing "through" a window using a DreamScreen. To test whether these cues (or combinations) have a significant effect on the experienced 'see through experience' an experiment will be conducted.

3 Experiment 1 – Gain factor determination

3.1 Simulation of motion parallax

Random-dot-diagrams are often used in perception research to introduce motion parallax in laboratory experiments. In a more meaningful way, 3D computer graphics are often used as well because in this case real motion parallax can easily be created. However Young concluded in 1998 that the computer rendering technology could not, yet, calculate computer graphics in real time to create an acceptable virtual view that is perceived as natural. Although microprocessors and video cards get more powerful each day, the current state of the art computer are still not able to do so. Therefore Radicovic (2005) made some compromising efforts to create a believable window-view on an electronic display. He used Image Based Rendering (IBR) to create full motion parallax from a series of 2D pictures while preserving the naturalness of photo realistic images. His results showed that IBR motion parallax indeed had a positive influence on various emotional states. But since IBR is still very computationally demanding and can not be done in real-time either, photographical pictures (or video) seem to be preferred in order to keep a certain amount of naturalness and computer graphics should not be used. Another, more marketing oriented, advantage of using photographs as the view material in the DreamScreen, is that it enables customization by the consumers, for instance, by using their holiday pictures to look at through their DreamScreen. Another possibility to offer real-time streams of other locations of the world.

This can be implemented by using a digital photograph with a much higher resolution and field of view than the DreamScreen can display. In Figure 20 is depicted that this way only a part of the photo can be seen and the rest is occluded. Which part is displayed depends on the position of the observer relative to the window.

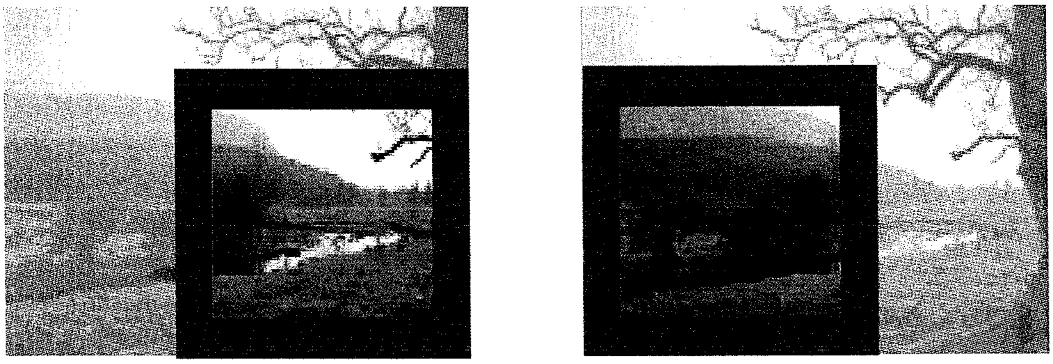


Figure 20 – High resolution photographs being occluded by a frame or wall.

As explained in paragraph 2.5, in a realistic situation the window frame would be much closer to the observer than the scenery outside. When one moves in front of the DreamScreen the window frame should therefore move faster with respect to the observer than the objects in the scenery at a larger distance. In theory, objects at infinity should even stand still relative to the observer. Since the picture of the scenery is displayed on the DreamScreen it will move as fast as the window frame when nothing else is done. The scenery's motion should be compensated to simulate the parallax between the displayed scenery and window frame. Therefore when the observer moves to the right, the image of the scenery should be corrected by moving it slightly to the right on the screen so that other parts of the picture becomes visible (recall Figure 19).

The picture moved to the right to display the correct view seems counter intuitive. Therefore look at Figure 21. It shows a top view, where an observer, represented by the circle, is watching a virtual object through a DreamScreen, while moving from left to right. The horizontal line is the plane of the wall with the perpendicular lines marking the beginning and ending of the window. **A** is the virtual object. The dotted lines represent the observers' line of sight. The intersections of these lines of sight with the window glass are marked by **a** and **a'**. These are respectively the locations where the object in reality are displayed on the screen before and after the movement of the observer. So, when the observer moves to the right, the projection of the object on the screen should indeed move to the right as well, although still to a somewhat lesser degree than the traveled by the observer.

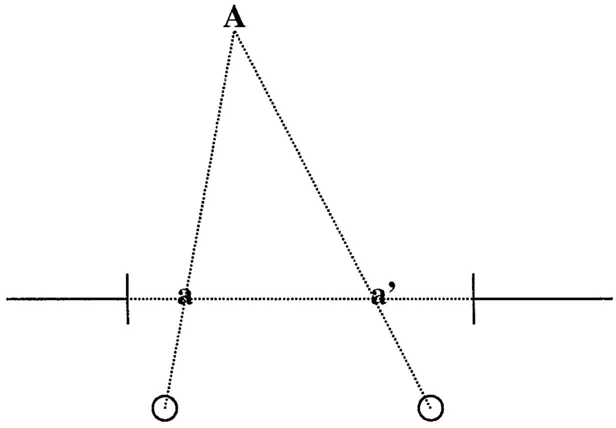


Figure 21 – Top view of a moving observer watching a virtual object in the DreamScreen.

A disadvantage of using 2D photographs is that objects within a photograph cannot easily be moved relative to each other. This makes relative depth by motion parallax *within* the picture difficult to achieve where computer graphics, on the other hand, could easily introduce full motion parallax. To understand this, consider a similar top view as described earlier, however this time the observer, is watching *two* virtual objects through the DreamScreen. **A** and **B** are two objects located at different distances from the window (Figure 22). The intersections of the lines of sight with the window glass are marked by **a**, **b** and **a'**, **b'**. These are respectively the locations where in reality the objects should be displayed on the screen before and after the movement of the observer. This means that the projection of A should move faster over the screen than the projection of B.

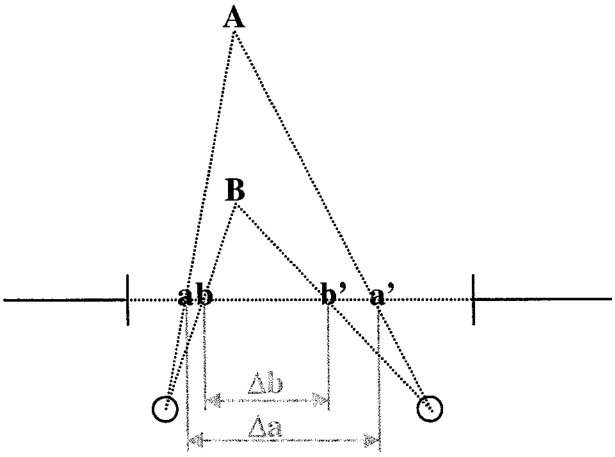


Figure 22 – Top view of a moving observer watching 2 virtual objects in the DreamScreen.

In the DreamScreen the difference between Δa and Δb is impossible to create because only the picture as a whole can be translated (at this time in the project). Hence, all objects in the scenery (no matter how far or close they are in the displayed scene) will be translated with the same amount, when the observer moves laterally in front of the DreamScreen. In short, there is only motion parallax between the window frame and the displayed scenery, but no motion parallax between objects within the scenery.

3.2 Aim of the experiment

Before commencing into the experiment about the effects of the three depth-cues (motion parallax, occlusion and blur) on the 'see through experience', a ratio between image-translation and head-translation should be determined. This ratio should simulate motion parallax that creates a view that perceptually is experienced as the most natural. In this report this translation ratio will be further referred to as the gain-factor. A secondary aim is to investigate the hypothised influences of scenery content and the effect of additional occlusion caused by a cross in the window frame (further referred to as 'the cross') on the selected gain-factor. The following questions will therefore be answered:

- What is the gain-factor that creates a window view that is perceived as most natural?
- Does the content of the image, used as a scenery view, have an influence on the gain-factor that creates a window view that is perceived as most natural?
- Does a superimposed, occluding, crossed framework have an influence on the gain-factor that creates a window view that is perceived as most natural?

The first hypothesis to be tested in order to answer these questions was more like an axioma. It was thought that people are able to identify the compromised gain-factor within a picture in a relative easy and intuitive way, but this should be verified.

The gain-factor should fall within the theoretical limits. The lower limit is the situation where the window frame abd the view have the same distanceand and hence no correction needed. The upper limit is the situation where objects ar placed at infinit distance from the observer and should therefore move along with 1 on 1 with the observer, to create a natural window view:

H1: The gain-factor that creates a window view that participants perceive as most natural falls within 0 and 1.

It was expected that the gain-factor, creating the most natural view, varies with presented scene due to differences in content. More precisely, there will be a relation between the distance of objects of interest in the presented scene and the size of the gainfactor.

H2: If there are more objects of interest "close by" in the displayed scene, the gain-factor that creates a window view that participants perceive as most natural, is lower than when the objects of interest are "far away".

Another assumption was that adding an occluding framework in a prominent place of the screen would make the motion parallax between the window frame and scenery more apparent (see paragraph 2.5). This could manifest itself in the determination of the most natural gain-factor as well:

H3: If the cross is present the gain-factor that creates a window view that participants perceive as most natural, will be lower than when the cross is absent.

3.3 Methodology

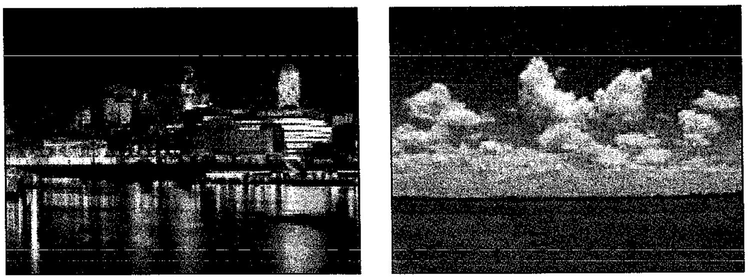
Design

A within subjects design was used. The dependent variable was the gain-factor and the independent variables were image content and the occluding cross. Five different images were used to test the second hypothesis, that predicts an influence of image content on the gain-factor. All images were shown twice, once with and once without the occluding cross, to test the influence of the occluding cross as predicted by the third hypothesis. This created 2x5 = 10 conditions. In each condition the participant was instructed to increase or decrease the gain factor, in order to find the gain-factor that created the window view in which the movement of the scenery was perceived as most natural.

Stimuli

The five different images are displayed in Figure 23. They were chosen based on two criteria. The first criterion was that the scenery views varied in having interesting objects at different distances. The secondary criterion was that they should vary as much as possible on other variables, e.g. day and night scenes, with and without people, rural to non rural, to make the results fairly generalizable.

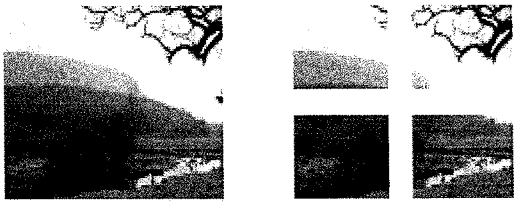
Hairdresser Firstfloor Creek



Night Skyline Afrika

Figure 23 – Five different images used as DreamScreen view.

To make motion parallax between the window frame and the scene possible, participants only saw a subsection of the scene, hiding parts behind the frame and making other parts of the scene visible. Translation of the images (like explained in paragraph 3.1) simulated the motion parallax. A crossed window frame was implemented like a super imposed layer, which could be switched on and off to introduce extra occlusion as shown in Figure 24). When the layer was switched on parts of the view were not projected that resulted in a cross with bars of 5 centimeters wide measured on the wall. The room had to be dimly illuminated to create enough contrast because the view was projected. This way the occluding crossed frame was darker than the projected outside scene to create a natural sight. This way the cross seemed to be a silhouette of an occluding crossed windowframe.



Uncrossed Crossed

Figure 24 – Visible part of the scene crossed and uncrossed.

Participants

Fourteen male and eight female participants volunteered to participate in the experiment. Nineteen participants were employees of Philips from the High-tech campus in Eindhoven and recruited from different divisions. Three participants were recruited outside the campus. Their ages ranged from nineteen to forty-eight. All participants had a visus or corrected visus of at least one (tested with the landholt C test). Most participants had none or little experience with perception experiments and had little or no knowledge about visual perception. Some of them had participated previously in perception experiments, however no influence of these experiences were expected in this experiment.

Apparatus

A prototype of the DreamScreen was created in a visual perception experiment room. It consisted of a BARCO Reality 6400 beamer, placed under a table draped with black cloth to make the beamer less apparent. The images had a resolution of 1280x960 pixels and 24bits colors and were projected 1,70 meters wide and 1,28 meters high on a plane white wall. Furthermore a chair was placed behind the table at 5 meters distance from that wall. Therefore the images had a horizontal viewing angle of 19.3° and a vertical angle of 14.6°.

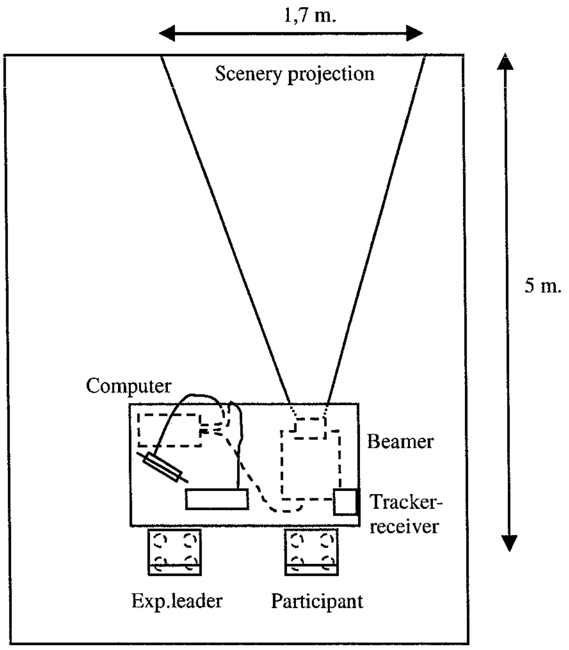


Figure 25 – Apparatus setup of experiment 1 and 2 (not on scale).

To keep track of a participant's head location, a Polhemus Fastrak system was deployed (for technical specifications see the Polhemus website). A fixed magnetic field generator in combination with a magnetic field receiver attached to a headphone tracked the six degrees of freedom of the participant's head. The Polhemus system had a refresh rate of about 120 Hz and a latency of about 0.7 milliseconds. The total latency (including the whole line of communication through the computer and display output) was approximately 15 milliseconds. Although latency times should be kept as small as possible for the view to be experienced as realistic, a pilot showed that when participants did not make highly accelerated head movements, the image could be translated while the delay was not disturbing. The range of the transmitter/receiver was about 0.75 meters. Therefore, the participants were forced to remain seated during the experiment.

Special software was engineered to interface (TRACK-D) the information supplied by the Fastrack system over the RST232 port of a computer (also hidden from sight by the draped table). Another program was written to interpret the readings of the Fastracker. This program also took care of superimposing the occluding cross and facilitated the default and adjustable gain-factor. To monitor the used gain-factor, a 17''TFT screen was connected to the secondary output of the computer's video card. It was placed slightly tilted on the table to make sure that the participant was distracted by it as little as possible. A Matlab program was written to make sure that each participant saw the condition in a different order.

Procedure

Participants were welcomed in front of the experimental room, where the set-up was ready to start. To make the participant comfortable, he was offered a drink before entering the room.

Inside, the participant took place behind the desk and received a paper with instructions (Appendix I). After a short introduction about the DreamScreen, they read that the experiment would take ca. 15 minutes and that they had to make lateral head movements for each presented view (not too large or too quick to stay within the range of the head tracker receiver and to minimalise the latency). To be consistent with the second experiment, participants were asked to watch out of the windows and not to look directly at the frame (as explained in paragraph 4.2). The final instructions on the paper were that the participant had to tap the up and down keys in order to adjust the gain-factor until the movement of the window scene was most natural way.

Once the participants had read the instructions, placed the headphone on their head the experiment leader dimmed the light to a pre-set light condition. It consisted of spotlights that illuminated the walls and resulted in a room illumination of ca. 40 lux (on the desk). Then the program was started by the experiment leader. The first image that was shown contained a scenery-view with a gain-factor of 0.5. Each participant was encouraged to try some extreme values of the gain factor. The participant had to select the gain-factor for which the window view was perceived as most natural. Once the participant signaled that he was ready for the next image the experiment leader noted the selected gain-factor and started the next view. During the loading time of the next view an inter stimulus adaptation field was displayed. This is a neutral gray image between stimuli to eliminate possible influence of a previous stimulus due to inheritance.

This procedure was repeated until all conditions were presented. Finally the participants were asked if they had any remarks and they were offered a small token of appreciation (a lollypop). Those who were interested were informed about what they actually had done and how it contributed to the whole research project.

3.4 Results

The participants were able to find a gain-factor that created the most natural window view fairly easy. No questions were asked during the experiment and participants did not need much time to make a selection discussion.

The results are presented in Figure 26. Each data-point represents the chosen gain-factor averaged over all participants per view and with and without the cross. The vertical whiskers represent the 95% confidence intervals per data point.

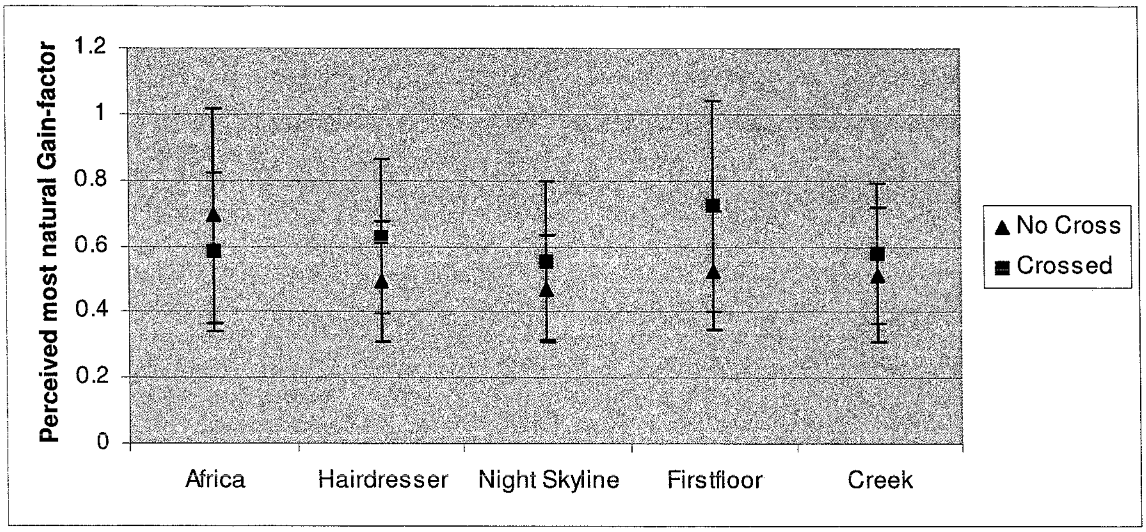


Figure 26 – Most natural perceived Gain-factor per view (crossed and uncrossed)

Data analysis

Visual inspection of the figure suggests that there are no differences between the different images used as scenery views. Also the manipulation of switching the cross on or off does not seem to have an effect on the gain factor. This was confirmed by a General Linear Model (GLM) full factorial Univariate analysis (with participant as random factor). No significant effect of view and occlusion was found. Other interaction effects weren't significant either (all P values > 0.05). The overall average gain-factor was 0.58 with a standard error of 0.04.

Classes of participants

The data was analysed in more detail by looking at the differences between participants. Figure 27 presents the gain-factor per participant averaged over all conditions. The data suggests that there are two classes of participants: one class that selected a relatively low gain factor, and one group with a relatively high gain.

An interesting pattern shows during visual inspection of the data. Graphical representation of the data of both tests (depicted in Figure 27) suggests two classes of participants differing in the size of the chosen gain-factors.

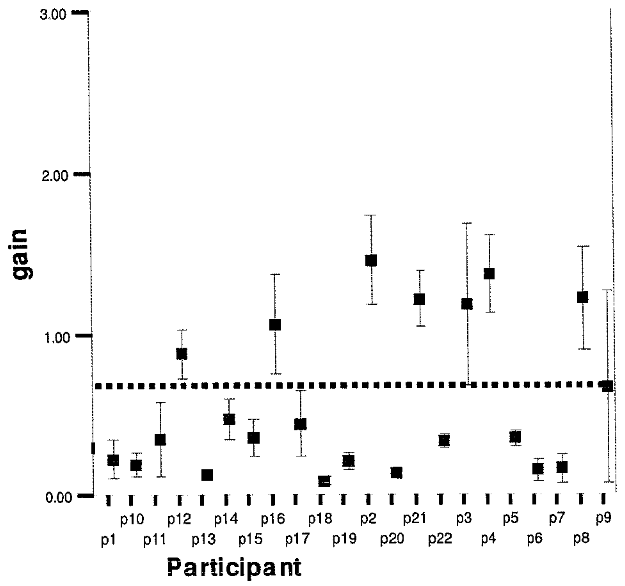


Figure 27 – Average determined gain-factors per participant

Visually dividing the data in Figure 27 in two separate groups (excluding p9, which fell in between) results in a mean of 0.26 and a standard error of 0.02 for the first group. The second group has a mean of 1.20 and a standard error of 0.44. Although these two groups are obviously different (and by an independent sample T-test proven to be significantly different, $P < 0,05$), a separate analysis of the two groups shows that there is no significant effect of image content and occluding cross for each of the groups.

3.5 Conclusions and discussion

Although the first hypothesis seems to be supported on average, the analysis of the experiment data shows no evidence supporting the second or third hypothesis. This means that the average gain-factor falls within the interval of [0,1]. Furthermore, no difference was found between the scenery-views and crossed versus un-crossed conditions.

In addition, two groups of participants with relatively, high and low gainfactor, seems to be identifiable. No viable scientific explanation can be given at this point. However, some of the participants, who selected high gainfactors, made remarks in the line of "I liked that the image moved a lot, so I could see more than initially shown". This gives rise to the suspicion that maybe these participants did not select the gain-factor they perceived as most natural, but rather the one they preferred most (for other reasons than naturalness). This suspicion was backed up by the experiment-leader who saw over-enthusiastic behavior; during large motion of the scenery-view. However, this explanation is based on speculation and no experimental control was deployed to test this explanation. Therefore, the next experiment will be conducted with the average results.

This means that with the knowledge thus far, an overall average gain-factor of 0.58. These gain factor correspondent to a motion parallax between window and scenery while a participant moves in front of it. From this motion parallax can be geometrically calculated at what distance actual objects would be when they had that motion parallax with the window. The gain-factor of 0.58 corresponds to a distance of about 12 meters. This gain-factor can be used in all the conditions of the next experiment because addition of an occluding cross and switching scenery views has no effect on the experienced naturalness of the image's motion.

One of the criteria on which the scenery-views were chosen, was that objects of interest were located close by or at large distances. However, this choice was made ad hoc without checking if participants actually looked at these distant or close by objects of interest. Hence maybe no significant difference between the scenery-views was found because participants visually scanned all images the same way. They might give less interesting places the same attention as the more interesting parts. This should be checked when more precise conclusions are needed. One way to do so is by means of an eye-tracker or by retrospectively ask the participants to mark on a printout of the different sceneries, where they focused their attention during the experiment. However, one should be cautious when deploying the latter option, since this method is less objective and more sensitive for a bias.

Moreover the starting gain-factor of 0.5 may have biased the participants. They might be tempted to recognize this as the expected value and give the socially desired answer close to the starting value of 0.5. To avoid such a bias in the future, a staircase method with a varying, balanced, extreme (0 or 1) starting point is advised. For more information about staircase methods see Sekuler and Blake (2002).

4 Experiment 2 – Depth cue effects

4.1 Aim of the experiment

Now that the gain-factor that creates a window view that is perceived as the most natural is determined, the main experiment could be conducted. To reach the project goals as stated in paragraph 1.3, this experiment tested whether the depth cues chosen in paragraph 2.5 actually increase the 'see through experience'. The following questions will be answered:

- Does motion parallax, simulated by translating a 2D photograph of a scenery view with respect to the window frame, increase the 'see-through-experience'?
- Does occlusion, implemented by a superimposed crossed window frame, increase the 'see-through-experience'?
- Does blurring the border of the window frame and occluding parts increase the 'see-through-experience'?

In real life, motion parallax is one of the more important depth cues to determine ones and that of other objects' location and trajectory within a 3 dimensional space (Redert, 2000 and Nawrot, 2004). So it seems plausible that adding simulated motion parallax in a DreamScreen set-up enhances experience of seeing through a window, because it gives the impression that the scenery is on another depth layer than the window frame. Thisinsight leads to the following hypothesis:

H1: Motion parallax between a 2 dimensional picture and the window frame, caused by head movement of the observer will enhance the 'see through experience'.

A second observation, namely that occlusion creates a sense of interposition (Palmer, 1999) as explained in paragraph 2.3, creates a second hypothesis. When an object seems to be part of the window-frame and it occludes parts of the scenery, it should elicit the feeling that the scenery is located at a larger distance than the window frame and should enhance the 'see through experience'. Therefore:

H2: An occluding cross that appears to belong to the window frame will enhance 'see through experience'.

Since the accommodative mechanism of the eye is driven by blur, objects that are perceived as out-of-focus vis-à-vis the projected images will appear as a different depth layer. Therefore blurring the edges of the window frame and cross might suggest extra depth impression increasing the 'see through experience' forming a third hypothesis:

H3: Making the edges of the occluding frame blurry will enhance the 'see through experience'.

The last, but probably the most interesting hypothesis is that, as explained in paragraph 2.5, the occluding cross may make the motion parallax between the window frame more apparent. Hence:

H4: The combination of an occluding cross in prominent places of the screen *and* motion parallax will enhance the 'see through experience' more than when each of the depth cues are applied separately.

4.2 Methodology

Design

A within-subjects-design was applied. The dependent variable was 'see through experience'. The independent variables were motion parallax (on and off), the occluding cross (on and off), the blur (on and off) and the content of the images used to create the scenery views. Although no effect of content on the gain-factor was found in the previous experiment, there could still be an effect of the content of the images on the 'see through experience'. To control for these effects the same 5 images were used as in the previous experiment. This resulted in: 2x2x2x5 = 40 conditions. For each condition the participant was asked to assess his 'see through experience' on a continuous scale from 'weak' to 'strong'.

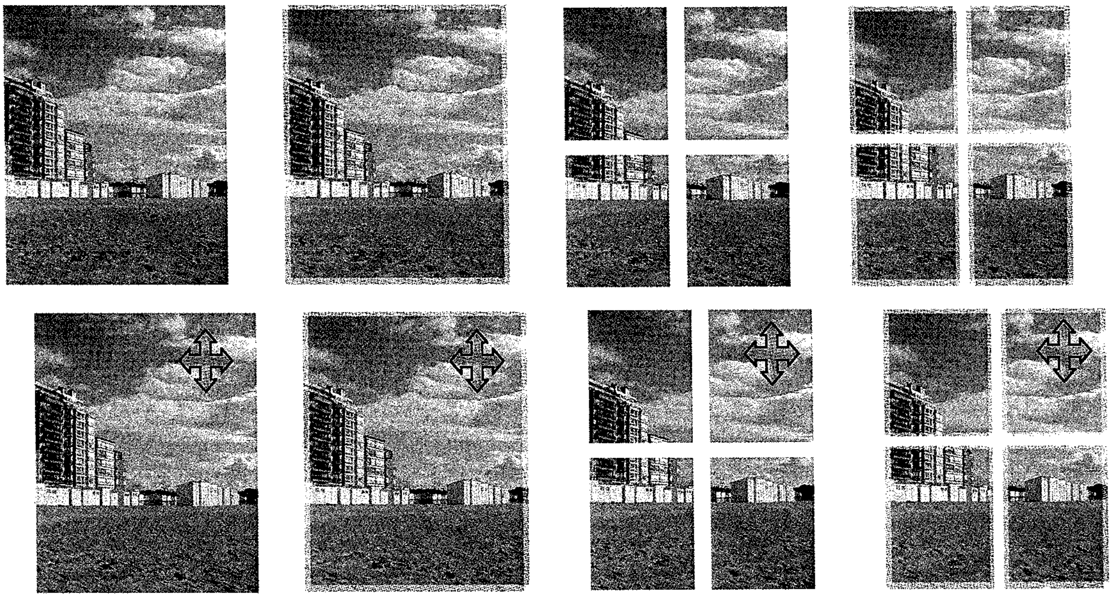


Figure 28 – Eight conditions tested in the experiment

Stimuli

The same 5 images as used in the gain-factor experiment were used as scenery views (displayed in Figure 23). Also the same cross was used. The edges of the window frame and the cross could be blurred or not. The blur was actually a transparency gradient ranging from 0 to 1 over a distance of 1 centimeter starting at the edges of the frame and the edges of the cross.

Participants

Twelve male and eight female participants volunteered to participate in the experiment. All participants were employees or thesis students on the Philips High-Tech Campus in Eindhoven and recruited from different departments. Their ages ranged from nineteen to forty-two years of age. All participants had a (corrected) visus of at least 1. They had little or no experience with perception experiments and had little knowledge about visual perception research.

Apparatus

The same prototype of the DreamScreen as in the previous experiment was placed in the same experiment room. It consisted of a Barco beamer, a computer and a table draped with black cloth. However, this time the Polhemus PATRIOT was used as the head-tracker device. After minor adaptations in the software, this tracker functioned the same compared to the Fastrack tracker in the gain-factor experiment.

Originally the idea was to blur the window frame when a participant watched the scenery, and to blur the scenery view when he watched the frame. However to make this possible a very precise eye tracker was needed with a very low latency, which was not available at that moment. Instructions not to look directly at the frame was given to the participants in the instructions to compensate.

Procedure

Participants were made comfortable by welcoming them and offering them a warm drink. Then they took place behind the desk and received a paper with instructions (Appendix III). After a short DreamScreen introduction, the participants were instructed to gently move their heads back and forth laterally while looking at the view. Participants were asked only to watch outside and not directly to the occluding frame.

Participants were asked to mark their assessment of the 'see through experience' on the scoring form (Appendix IV) using the scales (Figure 29). They were asked to use the full length of the scale, i.e. to place the conditions they experienced as the best and worst at the extremes of the scale. To be able to do this they first saw 6 training images, containing conditions that were expected to elicit the strongest and weakest 'see through experience'. This way they had a notion of the maximum and minimum of the strength of see through experience the were about to experience in the experiment. These could then be placed on the extreme ends of the scale and score the rest relative to them. After the experiment the scores were measured with a ruler. The full length of the scale was given 5 points.

Figure 29 – 'See through experience' scale used to mark the relative assessment on

After reading the instructions the light was dimmed to the pre-set lighting condition and the participants placed the headphone with the mounted receiver on their head. Next the program was started by the experiment leader and the first scenery view of the training session was presented. The training allowed the participants to get used to the setting and the task and to get the feeling on how to use the full range of the scale. All participants received the same training in contrast to the actual test conditions, which were presented in an unique order per participant. This had the aim to balance presentation orders across participants to tackle possible order effects. For each training image the participants marked their assessment on the answering form after some lateral head movements. When they were finished, they pressed the escape key to go to the next condition after they were shown an ISAF.

The experiment leader stayed in the room during the training session to answer questions and to check whether the participants interpreted the instructions in the right way. If participants did not use the full scale during the training session the experimenter verbally emphasized that they should try to use the full scale in the real experiment. Then the experiment leader left the room and the participant started with the real experiment, displaying the different conditions, with ISAFs in between, until all conditions were assessed.

At the end of the experiment, the participants were asked if they had any last remarks. They were offered a lollypop as a small token of appreciation and those who were interested were debriefed about what their role was within the bigger picture of the research project.

4.3 Results

Figure 30 presents the raw results of the experiment. Each data-point represents a 'see through experience' score averaged over the 20 participants per depth cue and per scenery view. The vertical whiskers represent the 95% confidence intervals of the mean.

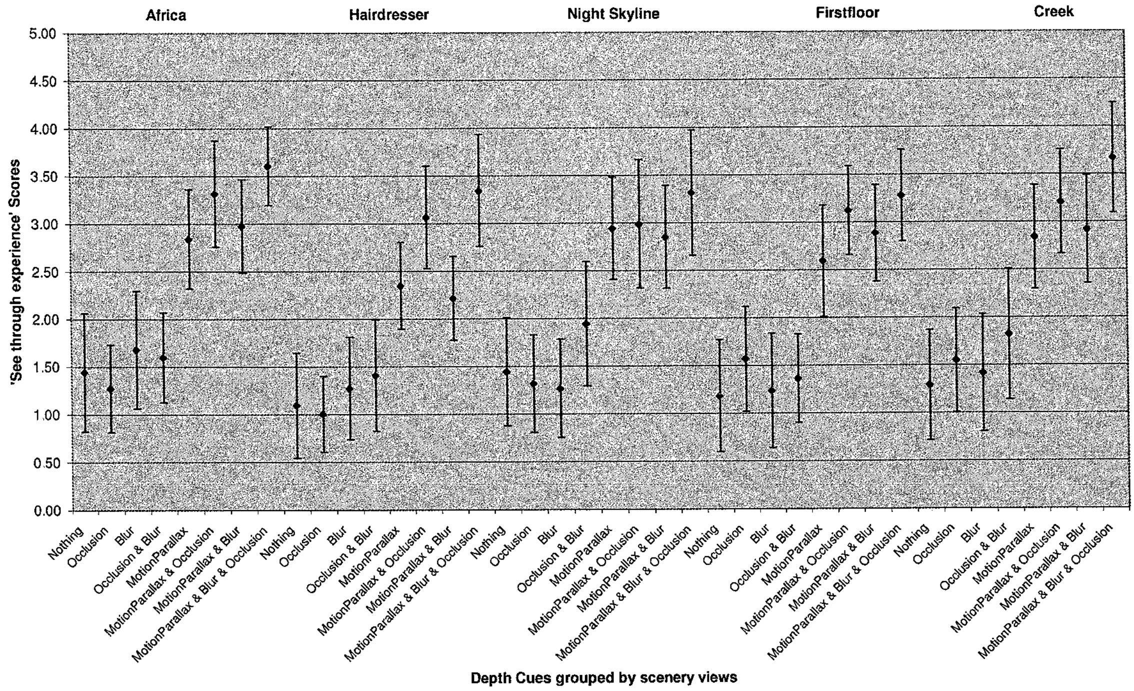


Figure 30 – See through experience scores per depth cue condition and image

The clearly distinguishable cycles in the figure, each consisting of eight data points, correspond to the five different views. Because the differences between scenery views was not the primary interest of this project. De data averaged over the different views is more illustrative and presented in Figure 31.

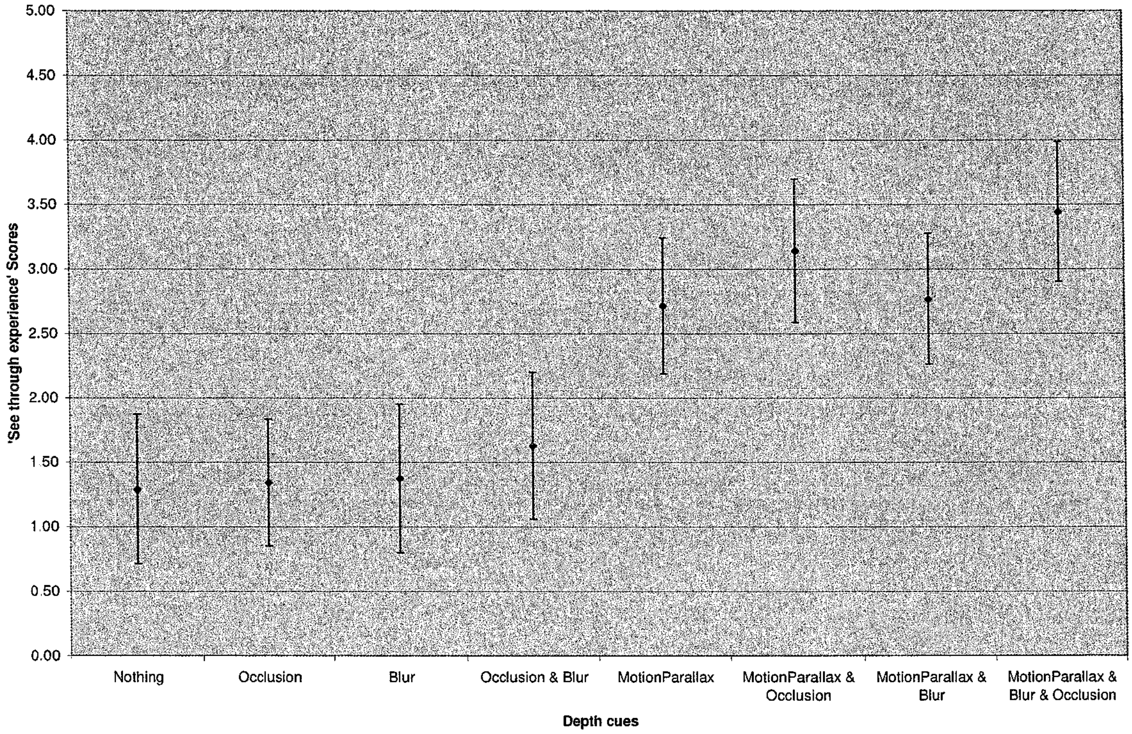


Figure 31 – See through experience scores per depth cue averaged over images and participants

The most noticeable effect on the average score seems to be caused by motion parallax, as expected. The manipulation of Motion Parallax is highly significant. A statistical analysis was performed to test the significance of all of the possible.

A GLM Univariate analysis resulted in a significant main effect of motion parallax ($F_{758,1} = 426$, $p < 0.001$), occlusion ($F_{758,1} = 20$, $p < 0.001$), blur ($F_{758,1} = 5$, $p = 0.020$) and scenery view ($F_{758,1} = 3$, $p < 0.012$). The interaction between motion parallax and occlusion ($F_{758,1} = 7$, $p = 0.011$) was the only significant 2-way effect. No other interaction effects (either 2 nor 3-way) were found.

Not all people appeared to use the answering scale in the same way. Some people *did* use the full scale while others did not. This means that formally the raw scores should be normalized within participants before analysis. This was done by subtracting 'the average within the participant' from the score and then divide the result by the standard deviation. Figure 32 shows the normalized data averaged over scenery views and participants.

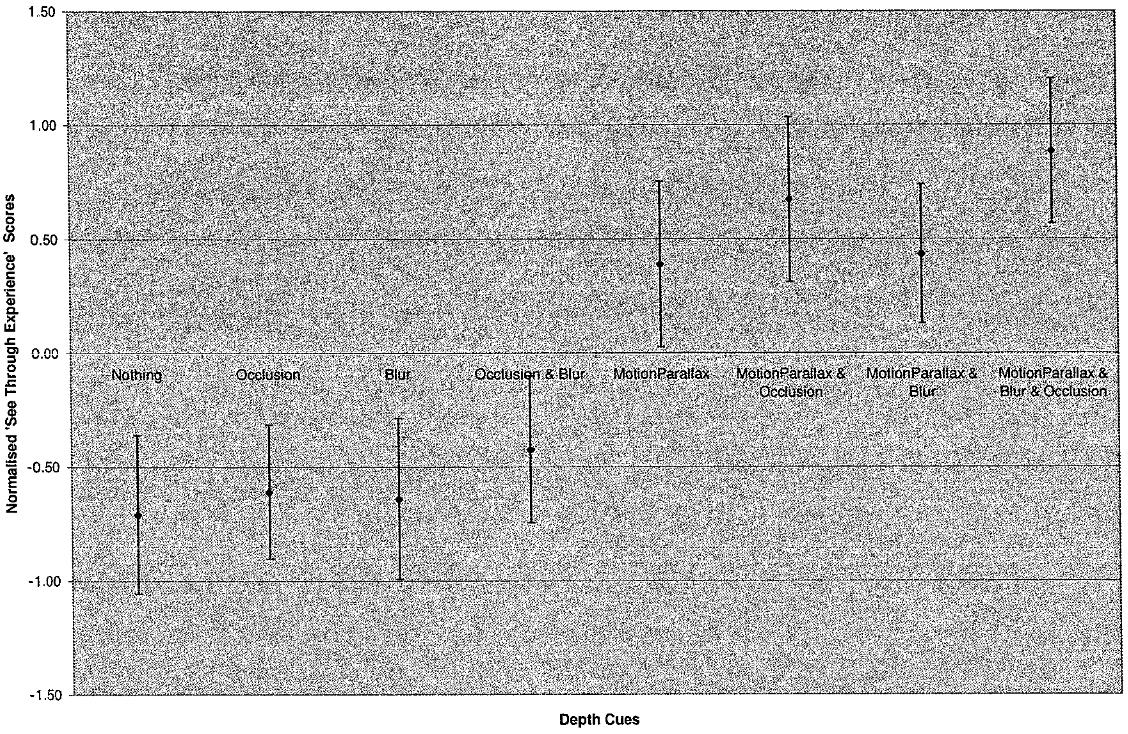


Figure 32 – Normalized scores per depth cue condition averaged over image and participant

When visually comparing Figure 32 with Figure 31 only minimal differences are found. Not much difference with the raw scores is found. A GLM Univariate analysis of the normalized scores confirmed this. The same main and interaction effects were significant with only marginal differences in p-values.

4.4 Conclusions and discussion

The results of this experiment show that all tested variables (motion parallax, occlusion and blur) have a highly significant main effect on the 'see through experience'. To see whether the influence has a positive or negative effect the plots in Figure 33 are illustrative. Note that these plots show the main effects of one factor so the data is averaged over all other factors. Therefore the whiskers cannot be used to indicate whether differences are significant not.

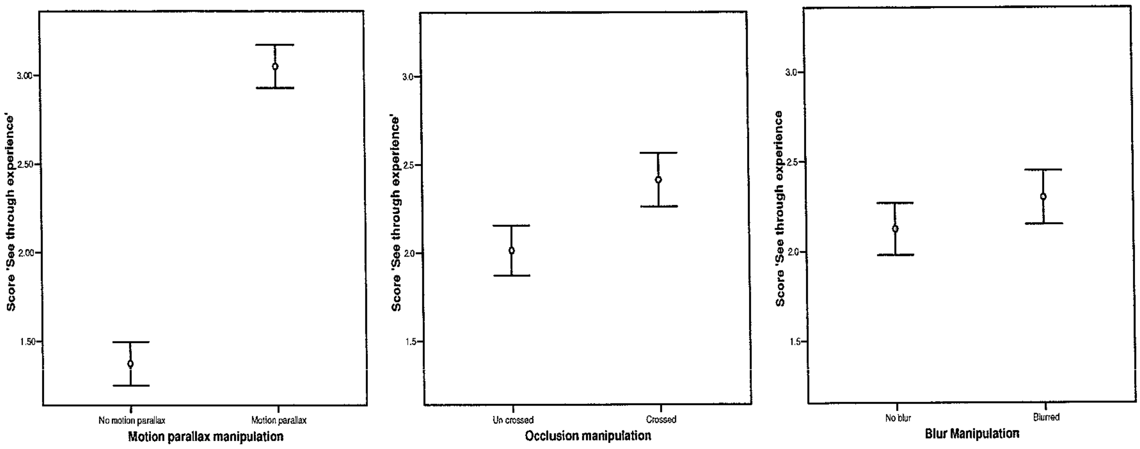


Figure 33 – Influence of motion parallax, occlusion and blur on 'See through experience'

Seeing that the manipulation of the different depth cues resulted in significant positive effect, the first three hypotheses were confirmed. Hence addition of either motion parallax, occlusion or blur all resulted in an *in*crease of the 'see through experience' are confirmed. This means that motion parallax between a translated 2 dimensional picture and the window frame, an occluding crossed window frame and making the borders of the (occluding) frame blurry, all increase the sense of 'see through experience'.

Also the interaction between occlusion and motion parallax was found to be significant. Figure 34 shows that the two depth cues indeed strengthen each other so that the fourth hypotheses can be confirmed as well. This means that the effect of occlusion is larger when motion parallax is present and that adition of motion parallax strengthen the effect of occlusion.

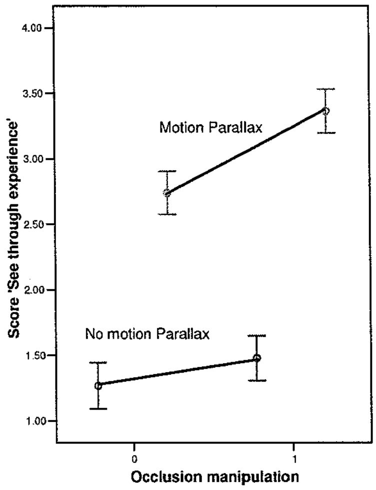


Figure 34 – Illustration of the interaction between MP and Occlusion

The interaction between motion parallax and occlusion was less significant ($F_{758,1} = 4$, p = 0.57) for the normalized data compared to the raw data. But still, when using a slightly less rigid criterion this could be accepted as an interaction effect. To eliminate possible skepticism, this experiment could be replicated with more participants so that the interaction would probably turn out to be significant as well in the normalized analysis.

Scenery view has a significant effect on the 'see through experience'. This means that some images of sceneries created a better 'see through experience' than others. Since no significant 2-way or 3-way interaction effects were found between view and the tested depth cues, the difference between image content does not challenge the main conclusion about the found main effects of the tested depth cues. However a closer look at the effect of scenery view can be interesting. Figure 35 presents 'see through experience' per view averaged over participants. The whiskers are the 95% confidence intervals.

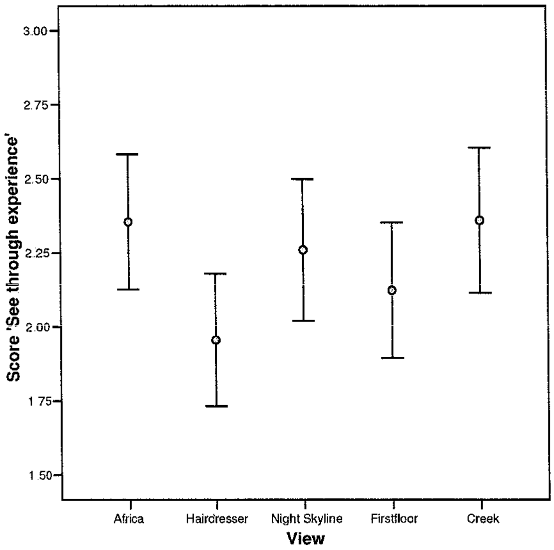


Figure 35 – 'see through experience' scores per view averaged over participants

When looking at Figure 35, one image seems to differ from the rest. When visually inspecting the hairdresser picture, it can be noted that the distance between objects in the image are relatively small (trees and a fence block the view at a very small distance). To further explore the differences between image content, a Tuky Post Hoc test on view was used to see if subsets could be identified. Table 1 shows that Hairdresser was significantly different from all other views except for Firstfloor. Firstfloor was not significantly different from all other views and NightSkyline, Africa and Creek are not significantly different from each other.

Table 1 – Two subsets of views indentified by a Tukey HSD Post hoc test

View	N	Subset	
		1	2
Hairdresser	160	-.2011	
Firstfloor	160	-.0594	-.0594
Night Skyline	160		.0474
Africa	160		.1018
Creek	160		.1175
Sig.		.471	.243

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares The error term is Mean Square(Error) = .596.

Visually inspecting the images if the two subsets of Table 1, the images indeed seem to differ on one major factor: the distance range within the picture. In subset 1 one can hardly look into the distance, while in subset 2 one can look much further away and in some cases even towards the horizon.


Hairdresser
Firstfloor

Figure 36 – Tukey HSD Subset 1

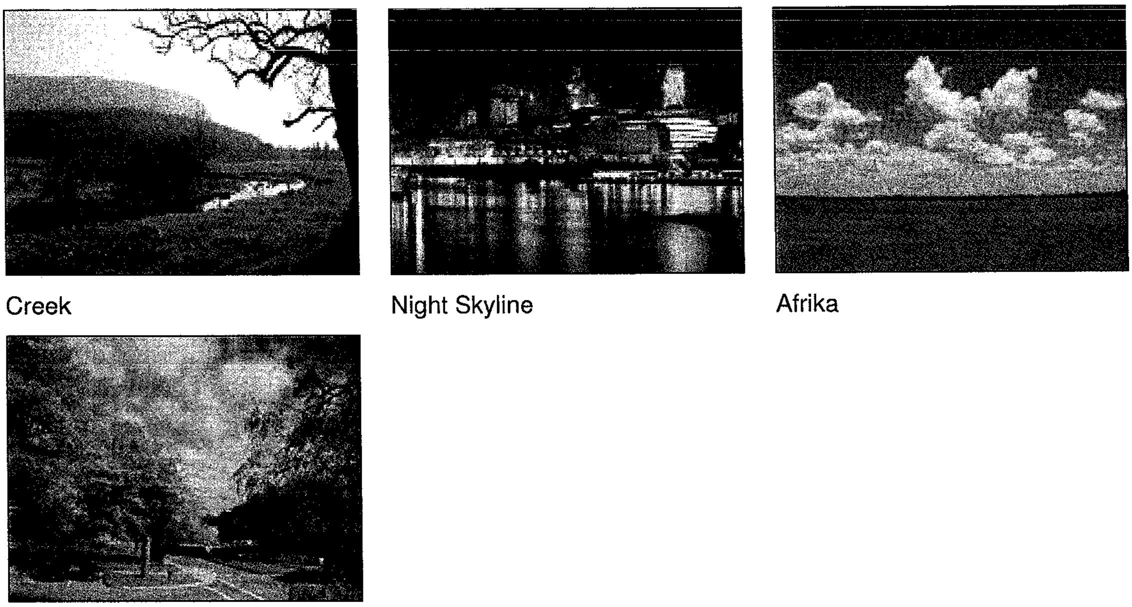

Creek
Night Skyline
Afrika
Firstfloor

Figure 37 – Tukey HSD Subset 2

Assuming that viewable distance is the underlying variable creating the subsets, this could point at the fact that the translation of the image based on the head motion was found to be unnatural for objects close-by as apposed to more remote scenery. This, however, is speculation at this point in time because it is unsure that the 'viewable distance' is *the* underlying factor responsible for the difference between the two subsets. Nevertheless, it can be interesting to test whether viewable distance has a main effect on 'see through experience' in the future.

Although no 3-way interaction between view, motion parallax and occlusion was found to be significant, a general conclusion of a presence of interaction between motion parallax and occlusion is slightly threatened when separately analyzing the different scenery views. However a closer look at pictures can be informative in other ways.

The interaction between Motion Parallax and Occlusion was only found for the hairdresser scenery. An explanation for this could be that the hairdresser image was the only view where objects of major interest were placed on the foreground and maybe even more important, in the occlusion conditions the introduced cross covered the faces of the persons in the view.

Figure 38 – Framework precisely occluding the faces of people

This knowledge gives rise to the suspicion that another mechanism could be the cause of the interaction between motion parallax and occlusion. It can be that, instead of the occluding cross making the motion parallax more apparent, the covered faces of the people in the picture elicited curiosity within participants, making them aware of the fact that they could "look around" the cross blocking their view. Therefore moving one's head to obtain a view of the figures in the scene establishes clear added value for motion parallax in the occlusion condition. This or a combination of the two could be the cause of the found interaction when measuring 'see through experience'. If a causal explanation is important, this hypothesis could be studied in future research.

5 Focus group study - What is still missing?

5.1 Aim of the focus group

The previously described experiments have shown a positive influence of several depth cues on 'see through experience' in a DreamScreen set-up. However 'see through experience' is an abstract term and more importantly there are probably many functions of windows for which 'see through experience' is not an important factor. For instance, being a light source, creating atmosphere etc. A typical example where 'see through experience' *does* play an important role is creating a feeling of space among others. An explorative study could shed light on what direction should be taken to further develop the DreamScreen.

The last phase of the project was mainly about two things. First it gives an overview of the functions windows fulfill in the lives of people and how well the DreamScreen fits in those specific functions. It should give insight into where R&D should focus on. In short; the following questions were addressed:

- What functions do real windows have in daily life?
- How well suited is the DreamScreen in its current state with respect to these particular window functions?

Secondly, it should provide insight into how satisfied the end users are with the DreamScreen as it is shown to them. To test whether the simulated motion parallax has substantial influence on this level of satisfaction, the DreamScreen should be assessed as a whole, in a normal surrounding. Therefore the following questions will be answered:

- How satisfied are people with the DreamScreen as a window in a daily life surrounding?
- Does motion parallax substantially add to the satisfaction of people regarding the DreamScreen?

5.2 Methodology

Design

The primary goal of this last part of the project is to focus more on the end user and start thinking about where future emphasis should be placed when developing the DreamScreen. At this stage of exploring, it is important to get input from as many different kinds of possible end users and to keep in mind not to make any presumptions on their behavior or thoughts. A focus group study seems appropriate because the *end-users* and not the product designers are discussing about the subject. Also many different people can be invited to participate in a focus group. To ensure that participants did not go off topic and to stimulate the less communicative participants, the discussion was guided by questions of the researcher.

In order to measure how satisfied people are with the DreamScreen in its current state and whether motion parallax substantially adds to the overall window experience, a more quantitative approach is more suitable. Since this is only a secondary goal within this last project phase and a focus group is already very time consuming a quasi-experimental setup is used. The effects of motion parallax was studied within subjects with one scenery view. The physical set-up was different then in the previous experiments in two ways: 1 people were seated closer to the DreamScreen (3 meters instead of 5) and 2 the scenery view was scaled (to ensure that the participants saw the same content as in the first set-up although the kitchen window frame was smaller). Because these 2 factors were altered in the set-up it was difficult to determine how large the gain factor should be in this quasi experiment. Therefore two gain-factors were tested. One was determined during a small pilot experiment, repeating the gain factor experiment with 5 participants, and resulted in a gain-factor of: 0.2. The other tested gain-factor was 0.4 to see how people would respond to a slightly higher gain-factor. This results in a within subjects design of 3 conditions: One condition without simulated motion parallax, one with a high gain-factor (0.4) and one with slow gain-factor (0.2). The dependent variable was satisfaction.

Stimuli

A wooden, crossed, framework with a flat screen television behind it displaying the Creek image (Figure 23) was used as the stimulus. The image containing the scenery view on a creek, could be translated in a way that the view changed corresponding to the head movements of participants, with either a gain-factor of 0, 0.2 or 0.4.

Participants

Ten people were invited and split into two groups each containing three male and two female participants each. They were selected from a list of people who were willing to participate. The choice was mainly based on differences in their work, gender and age. Their occupation varied as much as possible: house wives, journalists, managers and students. Their ages ranged from 22 to 55 years. A divergent group will most probably come up with a wide variation of different window functions. None of the participants had experience with perception research, whereas two of them had experience with the Homelab experiments. However, no influence of this experience is expected in this focus group study.

Apparatus

To create a normal daily life situation, a prototype of a DreamScreen was build into the wall of a fully equipped kitchen of the Homelab. The dimensions of the wooden window frame are given in Figure 40.

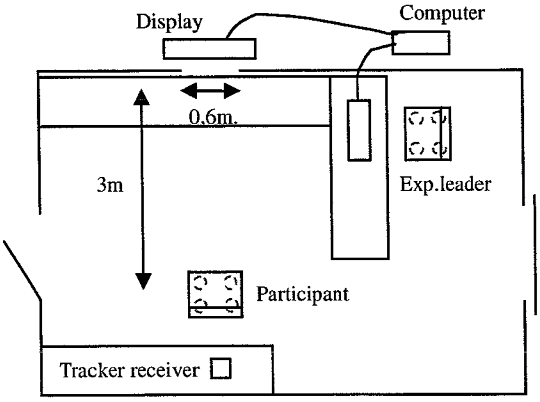


Figure 39 – Apparatus setup of the quasi experiment

A 42" Philips 42PF9952 / 32S widescreen plasma display was mounted behind the frame with a resolution of 1024x768. Because the television display was smaller in height than the wooden frame, blinds were lowered in front of the window such that the blank upper part of the window could not be seen by the participants.

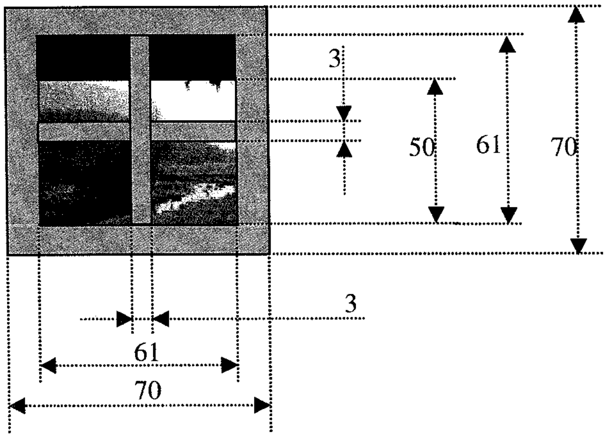


Figure 40 – Dimensions of the kitchen window in centimeters

The display was connected to a computer which was hidden from sight (on the other side of the wall). The computer was operated by a wireless keyboard and mouse that were located at an unobtrusive place in the kitchen, where the experiment leader took place. When needed the Polhemus PATRIOT headtracker was used in the same way as described in the previous experiment. A chair was placed at 3 meters distance from the window. When a participant took place and watched the window from the chair, the horizontal visual angle with the visual part of the scenery view was ca. 12°.

Procedure

The participants that were that were chosen to participate received an email to thank them for their willingness to participate and to invite them for an explorative study where they would discuss the function of windows in a small group.

Participants were aware of the daily activities that involve windows that normally do not receive much cognitive attention. It was important that before the focus group session started they had already thought about in what way they use windows in their normal life (including the less explicit usage like the light a window provides when reading a book), so they had material to discuss during the focus group. A diary seemed a good probe to create this awareness because the participant is forced to note his experiences during his actual daily business. In this way they are in the mindset of their activities while noting them, instead of thinking about them, days later, in an office during a focus group session. So they were asked to note on a printed diary form (Appendix V) during which activities they used windows and what function the window had in that situation. It was emphasized that they should also note indirect and less explicit window usage and that they would be asked to tell about the noted situations during the focus group session.

The focus group session existed of five different parts: (1) an introduction tour through the Homelab, (2) the judgment of the kitchen window without motion parallax, (3) the judgment of the kitchen window with motion parallax (high and low gain-factor), (4) the drawing of a typical window and (5) a discussion about the various functions of a window and the applicability of the DreamScreen in those functions. Below the procedure will be described in chronological order.

Participants were welcomed in the entrance hall of the Homelab and directed to a meeting room. There they where offered a drink by a second session leader to create an informal atmosphere. When all participants had arrived, they were taken on a small tour through the different rooms of the Homelab. During the tour they were told about the kind of research that is performed in this lab. The tour ended in the kitchen where they were instructed to critically look at the kitchen window, which was actually a display behind a wooden window frame without motion parallax. They were asked to note on a scale, that ranged from very displeased to very pleased (Figure 41 and Appendix VI), how satisfied they were with that kitchen window.

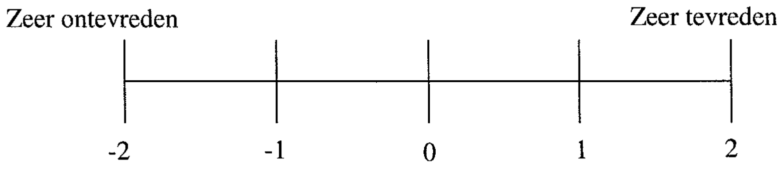


Figure 41 – Answering scale to measure contentness

Also they were asked to explain their assessment, to collect positive and negative feedback. When all participants had finished the first assignment, they were taken to the meeting room again. There they were asked to draw a typical window. The drawings had three purposes: (1) to explore the elements of a typical mental representation of a window, (2) to make the window experience of the last days more salient for a lively discussion and (3) to keep the group busy while the participants were asked to come to the Homelab Kitchen one by one for the assessment of the DreamScreen with the motion parallax. In the mean time one moderator stayed in the kitchen to place the chair and head tracker in front of the DreamScreen. Each participant was asked to take a seat in the chair and to put on the headphones with the mounted head tracker receiver. They were instructed to gently move their heads laterally and to fill out the assessment form. They were asked to do this twice, once for the low gain-factor condition and once for the high gain-factor condition. When the participant was finished, he was brought back to the meeting room and another participant assessed the kitchen window in the two conditions.

In the mean time the drawings were ready and the first discussions took place. One moderator led the discussion while the second moderator took notes about the discussion. The diaries were used as a guide for the discussion. One participant was asked to describe the situation in his diary in which he used a window. In more detail he was asked to tell what activity he was performing and which function the window had during that activity. The other participants were encouraged to participate in the discussion and to talk about that particular situation. The moderator's task was to make sure that *all* participants received enough attention and to stimulate the less communicative ones. Another task was to ladder more into depth, eventually trying to get people to speak in more general terms. When the situation and functions were clear, the moderator turned the conversation to get more insight into *if* and *how* the DreamScreen is suitable in that situation, or could be made more applicable. When the situation was covered the moderator asked about the next point on the diary. This was repeated until all points on each diary were covered. When enough time was left, a more general discussion was initiated about the DreamScreen in more general terms.

5.3 Results

Functions of real windows

Roughly eight types of window functions were revealed during the focus group study. They will be described in a way that the functions that were mentioned most often or emphasized heavily by the participants are placed first.

Windows as a light source

The most important function of a window, according to the focus group participants, is to acts as a light source. This function was mentioned by almost all the participants. Participants liked the fact that a window shed a lot of light into the rooms they occupied. A reasonable window should engulf a room with light. When one of the moderators proposed an artificial window that only produces light, like the Electronic Window system from Philips Lighting, some people were in favor but others were skeptical. The ones in favor spoke about the benefits to treat winter depression by stretching the daytime. However, the more skeptical people remarked that the fact that it did not correspond to the real situation outside could be disturbing. One person made the remark he did not like the fact that he could not watch outside.

The DreamScreen as presented to the participants seemed not very suitable to fulfill this function. Mind that they only saw the DreamScreen made of a mounted television display behind a window frame. So maybe when projection techniques are used, this would be better because more light is involved. According to the participants the system should simulate sunlight to really make the DreamScreen successful. The participants all agreed that the light should be as close as possible to natural sunlight; although they could not exactly define what factors should be met to reach this. One participant mentioned heat and others mentioned color of the light. No one mentioned that the light should bundled as if originating from an infinite distance (making drop shadows possible). One participant also mentioned that the DreamScreen should be big enough to bring in a lot of light.

Explicit information gathering

The second role of a window in daily day life is to explicitly watch through a window to gather information about the outside situation. For example: the state of the weather in situations where people have to leave their house or office. Other examples were monitoring traffic density or keeping an eye on the parked car outside. Also a mother liked to look out of the window to keep an eye on the children playing outside.

For this function a DreamScreen could be a solution in places where no window are present. A requirement following from this application is that the displayed view should be the actual real-time outside situation.

An option to display additional information in the window area, like weather or traffic forecasts, was received well. Displaying those kinds of additional explicit information on the DreamScreen could be an enhancement of a window. However it was strongly stressed that it should not disturb the view and should be placed in peripheral locations on the screen.

Another type of explicit information gathering was not watching *out* off, but watching *in*to a room to check the status. For example, a toilet window (high above the entrance) was used to check whether the toilet was occupied. However, whether this was a window or not did not really matter. A lamp to indicate that the room is occupied would be enough or maybe even better.

Windows can be used to see if people are present inside the room. Although in this case it is mostly about watching into a room instead of out of a room, the same criterion was mentioned as before: the information should be real time and correspond to the real situation at that moment.

Using a DreamScreen for this function seems to be a little overkill according to the participants. However, more information could be displayed, like how many people are in the room, what their status is (can they be disturbed or not, or how long it approximately takes for a properly scheduled meeting to end).

Ventilation

One of the functions of a window that does not involve the visual senses is that of ventilation. Participants agreed that a reason for opening a window was not only to refresh the air, but also to smell the outside odor, to hear the outside sounds and to control the temperature of the room. One participant preferred the manual window opening above a central climate system because she lacked confidence in a central air-conditioning system. She was afraid of building sickness. She also mentioned an urge for control; she wanted to be in charge of what happens in the room she occupied.

One participant made a general statement: he used windows (also when not opened) to “bring the outside inside”. He elaborated that he wanted to have the feeling to be in contact with the outside world. This corresponds to the evolutionary theory about the need to be in a natural surrounding of Ulrich et al. (1991), as mentioned in paragraph 1.1.

The DreamScreen, in its current state, is not able to let in fresh air. Since ventilation together with outside sound and temperature seem to be major factors defining a window, these functions should be considered during future design choices. For example, use the DreamScreen as an intuitive interface controlling the climate system by placing a handle on the frame and make the window slide open. Depending on how far the window is opened, the amount of fresh air the system would let in is determined in a natural way, making use of the right affordances.

Protection / Separation

Just like walls, windows are experienced as spatial dividers. People use windows to delimit territory. Some things can come through windows, like light or sometimes sound, but the rooms are still physically separated in a way. Windows offer protection against influences from outside like weather and noise. One participant specifically mentioned the car's windshield but also in an office setting, like in a conference room, a window forms a barrier for sound and other unwanted influences while it is still possible to view the situation outside the room.

One participant thought the DreamScreen is very usable in this situation because in that case one could choose to simulate a less busy office on the other side of the window. However one woman pointed out that it would distract her if she knew that it was a pre-recording and someone walked by the window in the content of the video. She would be irritated because that should have been taken out to make the DreamScreen content less distracting. Allthough this seems to be a function for a DreamScreen it also creates a high level of expectancy for the displayed view and real windows are still preferred.

Atmosphere creation / Entertainment

Windows enable people to create a cozy atmosphere. One woman liked windows especially because it gave her the possibility to place curtains in her living room. Another participant explicitly drew a windowsill because he liked to decorate it with things like plants or photographs. In more general terms a window has a decorative function and creates the opportunity to decorate further.

One woman liked the fact that she could watch the stormy weather. She enjoyed the atmosphere of the storm (wind blowing and the wild movement it caused of trees and rain crashing on the window) while she was enjoying the safety of her home. She could sit and watch outside for long times to be entertained by the weather like watching television. Others agreed with this, like being able to watch the snow in the garden, which creates a cozy feeling.

A DreamScreen should include opportunities to be cozy as possible and to be fitted with a windowsill and rails to attach curtains to. The main difference with a real window is that the view can be enhanced by a cozier one than what is really outside. Or, in a more augmented way, elements could be added to the view. Like during Christmas, snow or ice flowers could be added to the view. In this setting people were open for a view replacement however they were still very reluctant. When thought of as an entertainment system, the participants were quite positive to use the DreamScreen in the augmented way. One man pointed out that he would like to have the DreamScreen as a gadget. But all participants agreed that it would be more like a toy and that it will not be taken seriously as a real view replacer. However, one man made the remark that a real window easily fogs-up where a DreamScreen would not.

Communication

One of the participants mentioned that she used her windows as a mean of communication. An example was that the neighbor threw a snowball against her window to attract her attention to a tree that was about to break and fall over. More types of communication were mentioned by other participants, making use of both auditory (ticking on the window) and visual (waving or beckoning) signs to communicate.

There was consensus that the DreamScreen was not very suitable in this setting. People liked the direct communication of a real window and disliked the indirect character of the DreamScreen. However, to use a DreamScreen as a window for telecommunication created some discussion. Some did not see the added value in using a "window" for this. They would accept a normal display and teleconferencing computer software in this situation. However, one man would like to have the feeling to be at home when being abroad (business trip). He would like to communicate with his family as if they were standing on the other side of the DreamScreen (where his home situation was displayed) to create the feeling that they are near, in a natural way. This means that proper actions should be taken to make the communication natural like possible eye contact, hidden microphones etc. People should really have the feeling that the other person is actually standing on the other side of the wall.

Escaping from the average

The focus groups participants thought that windows give the opportunity to escape from their present business by staring outside. Most participants thought of this behavior as micro pauses to relax between mostly mental tasks, especially at work. People said they liked to see something totally different. One woman thought that in this setting she watched through the window to stimulate her creativity. She thought it might be nice to see dynamical views that slowly change while watching out of the window.

Participants thought that for this situation a DreamScreen would be suitable. To escape from the actual situation, the DreamScreen could show contrasting scenery. This corresponds to Kaplan and Kaplan's theory of restoration of depleted attention capacity (paragraph 1.1). So by displaying natural views people can daydream and let their attention drift naturally, which restores their attention capacity. This is a possible explanation of the arguments of the participants who stressed that there should be subtle changes in the view when staring outside, like the waving and lapping of water and tree-branches rustling in the wind. The woman who mentioned the stimulation of her creativity would like the images to be even more dynamic, maybe changing the scenery or abstract images totally. In short, a dynamic natural view seems an important factor for 'escaping the average'.

One of the participants said he liked to relax his eyes by looking far away. This could mean a need to focus on infinity. He strengthened his idea by adding that he wanted to experience space.

In that perspective, the DreamScreen can create a feeling of space by presenting views towards the horizon while in fact there is nothing more than a wall or a real view against a wall. The cues from the previous experiment can be used to create a spatial feeling.

Orientation

Another, less obvious, function of a window is to provide people with information to orient themselves. In closed surroundings, people tend to lose track of where they are located with respect to the outside world. For instance, in a parking garage windows can be used instead of information signs, to find the correct exit when one wants to leave the building. Also in office buildings with many similar corridors, windows serve the same function.

A DreamScreen could form a solution in places where no windows can be built. In this case, it is important that the displayed view corresponds to the actual outside situation because otherwise people would get confused. Additional information about one's location or other guidance information was an addition to the DreamScreen that participants thought to be helpful in these situations. An example is DreamScreen usage in subways. People traveling cannot see where they physically are within the city. The windows of the subway could be switched on when they are in the tubes and display the scene on the surface so people get a sense of presence. These can be switched off again when the train nears a station to show the actual underground situation again.

Influence of motion parallax on satisfaction

Figure 42 presents the satisfaction scores of the quasi experiment averaged over participant for the conditions with and without motion parallax. The condition without motion parallax scored -0.13 on average, with a standard error of 0.43. The condition with the high gain-factor scored -0.41 with a standard error of 0.22 and condition with the low gain-factor had an average satisfaction score of -0.11 with a standard error of 0.27.

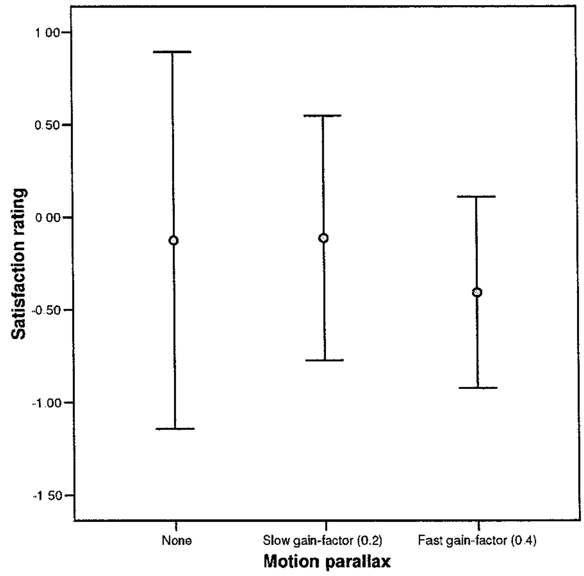


Figure 42 – Mean assessment scores of window satisfaction

Both a visual inspection and a one-way ANOVA test showed no significant differences between the different conditions. As this was not expected, it is interesting to look at the remarks about why they gave a certain score.

Participants liked the fact that they had a nice view in the kitchen that created a good atmosphere. Also they liked the fact that they could replace the view. However, one participant noted he felt being fooled because he knew a view like that did not correspond to the real situation outside. Some of them noted it gave them a sense of space although lack of depth in the system still gave them the feeling it was not real. Also most participants noted that the view was unrealistic because the view was a still image and that they would rather watch video material because they want to see the tree's rustle in the wind and see the water in the picture move. They thought a still image would bore them soon. They also thought the view looked to much like a display because they could see the pixels, sometimes the color balance changed and the screen flickered. Also lack of audio was mentioned. No birds or wind could be heard. One participant linked the sound to the fact that she was unable to open the window. And finally, a majority thought the DreamScreen did not generate enough light to be experienced as a real window.

The fast motion parallax was experienced as very unnatural, but when the slow gain-factor was used participants mentioned that it created a feeling that they were watching through a window instead of watching at a picture displayed on a screen. However it was still not good enough to be as believable as a real window.

5.4 Conclusion and Discussion

Experiment 2 showed that motion parallax has a highly significant influence on the 'see through experience' of a window the results presented in Figure 42 indicate that motion parallax has no effect on the satisfaction of the participants with respect to the window as a whole, at least for the DreamScreen prototype that was tested.

As participants indicated there are many elements of a window that contribute to the total window experience. Since some of the elements are not implemented in the DreamScreen, the added value of motion parallax becomes less noticeable. Since the Satisfaction scores were slightly negative, other requirements should be met before end users will be satisfied with the DreamScreen as a window. In other words, people are skeptical about using the DreamScreen. However, for situations in which real windows are not possible or difficult, they seem to be less reluctant towards the requirements, which are not met yet.

According to the two focus groups, the best way to use the DreamScreen technology is to use it as an augmented window. The DreamScreen could be transparent and a display at the same time. Such a transparent display can be used, for instance, to offer additional information at peripheral locations on the window overlaying the real view or to add interesting features to the view (snow flakes etc.). Most participants did not like the DreamScreen for replacing their window view, only as a gadget or a painting. Participants stressed that when the DreamScreen *is* used as a real window replacement much work needs to be done.

The most important is that the DreamScreen should be able to display the real situation outside, except for atmosphere creation or creating an escape from the average, because in many situations the actual information is essential. When the view does not correspond to the actual situation, people tend to get the feeling that they are being fooled, which irritates them.

Furthermore the system should emit more light and, maybe more important, the light it generates should approximate sunlight. The participants could not exactly define what was missing in the light emitted by the DreamScreen. Some participants thought the colors were not warm enough (too bluish). But more sunlight features could be missing (warmth, direction etc.). Therefore research is needed to find the perceptual features of sunlight. A cooperation between the Electronic window and the DreamScreen project groups might prove interesting.

The third aspect that participants missed was naturalness of the view. They thought this was caused by severeal factors. The major factor was depth. Although the motion parallax enhanced the depth impression, participants still had the feeling they were watching a 2D picture. This made the DreamScreen too unreal to accept as a real window. Maybe this was caused by the lack of relative depth within the picture or by the lack of stereoscopic depth. More experiments focusing on 'see through experience' or the perception of spatial experiences can shed more light on this subject. Adding relative depth, for instance by using multiple layers or a full motion parallax computer model, should be studied to see whether this could make a significant difference on the window experience as a whole.

Another factor that participants noticed was the flicker of the television display and slight color and brightness shifting over time. However, these are easily reduced by either using a better display system.

6 Future research and Project conclusions

In the preceding chapter some suggestions for further research were given. Here we describe some interesting points that could be investigated further within the scope of the primary goal of this thesis project.

One interesting issue is the relation between head movement and image movement. In theory, the more distant objects in a scenery view should move more than closer objects to create a correct motion parallax with respect to the observer, as explained in paragraph 3.1. However, from the participants' remarks in the latter two experiments, this seems to be counter intuitive. Participants reported that objects at a large distance in the scenery should move less than objects in the front. Especially the scenes where one could look into the far distance, towards the horizon, provoked a feeling that the motion was not natural. It seems like a mechanism in this set-up creates a false feeling that more distant objects move too much, while in fact the motion should be that fast.

An explanation could be the lack of relative motion parallax within the scenery. In paragraph 2.5 was argued that from a certain distance, depth contrast from motion parallax falls below a usability threshold (Figure 18). However, photographs almost always contain objects that are close by, like a floor. This means that an error is made when the scenery is moved as a whole. Although these objects generally are not very interesting they might be looked when an observer scans the translated photograph and judges the correctness of the motion parallax. This means that in a scene where one can look into the far distance the relative motion parallax error *within* the picture is much larger than for scenes where the horizon is blocked from view (for instance by the wall in the hairdresser scene in Figure 23). This could mean that when participants can look until the horizon, the experienced motion parallax error within the picture becomes too large and the scenery is experienced as moving to quick. This hypothesis seems to be worthwhile to be studied further in the future.

In a future experiment images could be divided in different parts that are located at different "depth" layers. These layers can then be translated accordingly to their distance. The effects of different parameters (amount of layers, parallax between layers etc.) on 'see through experience' and especially naturalness of motion can then be studied. Besides using different layers a full 3D model of an outside world could be created to make full motion parallax possible in contrast to translating the image as a whole.

Another point that could be studied is the difference between participants in determining the gain-factor that creates a simulated motion parallax in a way that the scenery view is experienced as most natural. Some participants seem to have determined the gain-factor that they *preferred* instead of the one that creates the *most natural window view*, resulting in a very high gain-factor (as discussed in paragraph 3.5). It should be investigated whether the two groups identified in the gain-factor experiment can be reproduced, and what the reason is of the difference between the two groups. This could result in a better estimation of a suitable average gain-factor to be used in the depth cue experiments.

In conclusion, the primary goal of this project as described in paragraph 1.3. is reached. Motion parallax, occlusion and accommodation, and the combination of motion parallax and occlusion were proven to enhance the feeling of seeing "through" the DreamScreen even, when the motion parallax was simulated by merely translating a 2D photograph with respect to a window frame. Those cues can therefore be used when more ‘see through experience’ is needed in the DreamScreen.

However, the results of the experiments were obtained from relative measurement the quasi experiment during the focus group session showed that, although these depth cues had an effect on the ‘see through experience’. Motion parallax had no effect on the window experience as a whole. The discussion of the focus group session raised many issues where participants had criticism on the DreamScreen. So even though motion parallax, occlusion and blur increase the ‘see through experience’ the raised criteria should be met before the DreamScreen is accepted as a real window.

Bibliography

Armas website. http://www.armas.com.tw/2005/

Ciacci, M. (2002). *Video processing to increase the depth impression of mono sequences onto 2D screens.* Nat.Lab. Unclassified Report 2001/821

Collins, B. L. (1975). *Windows and people: A literature survey. Psychological reaction to environments with and without windows.* Washington DC: National Bureau of Standards.

Cutting, J. & Vishton, P. (1995). *Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth*, in W. Epstein & S. Rogers (eds), Perception of Space and Motion, San Diego, Academic PRESS, CA, pp. 69-117.

Drascic, D. & Milgram P. (1996). Perceptual Issues in Augmented Reality. *SPIE: Stereoscopic displays and Virtual reality Systems III,* San Jose, Carlifonia, (2653) pp 123-134.

Heerwagaen, J. H., & Orians, G. H. (1986). Adaptations to windowlessness: A study of the use of visual dĕcor in windowed and windowless offices. *Environment and Behavior*, 18, (5), 623-639.

Hollister, F. D. (1968). *A Report on the problems of windowless environments.* Greater London Council, London: Hobbs the Printers Ltd.

Jajae-joordens, R. J. E. & Heynderickx, I. E. J. (2002). *Depth impression and overall image quality on 2D TV.* Nat.Lab. Technical note 2002/479

Jajae-joordens, R. J. E. & Heynderickx, I. E. J. (2003). *Effect of luminance on depth impression and image quality.* Nat.Lab. Technical note 2003/247

Kaplan, R., Kaplan, S., & Ryan, R. L. (1998). *With people in mind: Design and management of everyday nature.* Washington D.C.: Island Press.

Nawrot, M. (1997). *Role of slow eye movements in depth from motion parallax.* Invest. Ophthal.Vis. Sci., 38, 3230.

Nawrot, M. (2000). *Viewing distance, eye movements, and the perception of relative depth from motion parallax.* Invest. Ophth. Vis. Sci., 41, 233.

Nawrot, M., Nordenstrom, B. & Olson, A. (2004). Disruption of eye movements by ethanol intoxication affects perception of depth from motion parallax. *Psychological Science*,15(12), 858-865.

Palmer, S. (1999). *Vision science: photons to phenomenology.* MIT Press, Cambridge.

Philips Homelab website. http://www.research.philips.com/technologies/misc/homelab/

Polhemus website. http://www.polhemus.com/

Radikovic, A.S., Leggett, J.J., Keyser, J. & Ulrich, R.S. (2005). Artificial window view of nature. *CHI 2005 Late Breaking Results*, 199301996

Redert, P.A. (2000). *Multi-viewpoint systems for 3-D visual communication.* Veenendaal, Universal Press

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, 224, 420-421.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, 11, 201-230.

Sato, M., & Inui, M. (1994). Human behavior in windowless office spaces. *Journal of Light and Visual Environment*, 18, (1), 26-37.

Sekuler, R. & Blake, R. (2002). *Perception*, fourth edition, McGraw-Hill Higher Education, pp. 305-351.

Sommer, R. (1974). *Tight spaces: Hard architecture and how to humanize it.* New Jersey: Prentice Hall.

TESS website. http://www.hospitalmanagement.net/contractors/general/tess/

Wikipedia. http://en.wikipedia.org/wiki/Parallax

Wilson, L. M. (1972). Intensive care delirium: The effect of outside deprivation in a windowless unit. *Archives of Internal Medicine*, 130, 225-226.

Yonas, A. (1984). Reading as a measure of infant spatial perception. In G. Gottlieb and N.A. Krasnegor (eds.), *Measurement of audition and vision in the first year of postnatal life: A methodological review*. Norwood, N.J.: Ablex.

Young, P. (1998). http://vrg.dur.ac.uk/misc/PeterYoung/cg-notes/lecture1/

Appendix I List of terms

Binocular depth cues	Depth cues in which information from both eyes is used in combination in the perceptual system.
Cross, the	The part of the framework of the DreamScreen, that is superimposed on the scenery picture, to create occlusion in prominent places of the view.
Gain-factor	The ratio of 'image-translation / head-translation'
GLM	General Linear Model
Image Based Rendering (IBR)	Techniques that generate new images from other images, rather than from geometric primitives.
Inter Stimulus Adaptation Field (ISAF)	A neutral gray image used between stimuli to eliminate influence from a previous stimulus due inheritance.
Monocular depth cues	Depth cues in which information from one eye is used in the perceptual system.
Motion Parallax	The change of angular position of two stationary points relative to each other as seen by an observer, due to the motion of that observer.
Oculomotor depth cues	Depth cues derived by the brain, from information supplied by the nerves connected to the muscles, responsible for the movement of the eyeball or lens deformations.
Optical disparity	The difference between the images of the left and right eye while watching the same object.
Retina	A delicate, multilayered, light-sensitive membrane lining the inner eyeball connected by the optic nerve to the brain, converting incoming light into nervous signals to be interpreted by the brain.
See through experience	The feeling that when one looks through a structure caused by perception of depth difference, between the structure that is looked through (in the case of this project the window frame) and the objects looked at (the scenery view).

Appendix II Gain-factor Experiment – Instructions

Introduction

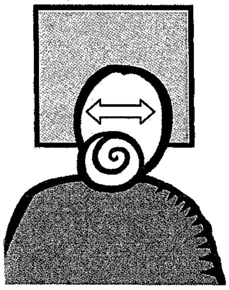
Thank you for participating. This is an experiment on behalf of the DreamScreen project. The DreamScreen is the concept of transparent displays, being developed by Philips Research. One of the applications is to replace the "view" of a window or to place a window where there is none at all. The apparatus used in these experiments is not the real DreamScreen. Therefore there is a noticeable difference in realness of the presented windows in comparison with a real DreamScreen. However this poses no problem within the scope of these experiments.

The experiment will take approximately 15 minutes in total.

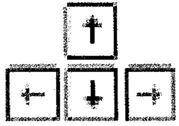
Task

You will be shown different window views. While the view is displayed you are asked to laterally (sideways) shift your head gently. Please do not move too quickly and not too far (approximately 10 cm. left and right) and please hold your head in a neutral position each time a different view is started.

You are asked to watch "out" of the "window" while making the head movements. **Please do not look at the frame!** Instead, focus on specific objects in the view, do this with different objects within one task.



You are asked to use the "up and down keys" to modify the movement-gain to the one that seems the most natural (it will never be perfect). When you have reached the most natural gain-factor tell the experimenter and he will note the result and start the next view.



Please tap the keys and do not hold them to control possible overshoot. There is no upper or lower boundary due to technical limitations.

You may now place the headphones on your head. Please take notice of the grey plastic cube on the desk. This cube is not to be moved during the experiments.

Please tell the experimenter that you are ready and assume your neutral head-position.

Appendix III Depth-Cue Experiment – Instructions

Instruction

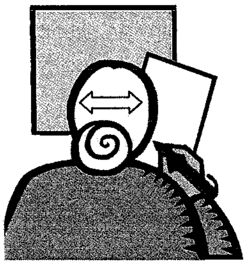
Thank you for participating. This is an experiment on behalf of the DreamScreen project. The DreamScreen is the concept of transparent displays, being developed by Philips Research. One of the applications is to replace the "view" of a window or to place a window where there is none at all. The apparatus used in these experiments is not the real DreamScreen. Therefore there is a noticeable difference in realness of the presented windows in comparison with a real DreamScreen. However this poses no problem within the scope of these experiments.

Different implementations of the DreamScreen will be presented. While a window-view is displayed you are asked to laterally (sideways), *gently*, shift your head left and right while watching straight ahead. Even do so when you might think this has no effect. Between the different window-views the view will turn grey for a short period of time. During this time please hold your head in a neutral position.

With each presented window-view you are asked to watch "out" of the "window" while making the head movements. **Please do not look directly at the frame** (if there is any)! Instead, concentrate on specific objects "outside" in the window-view and do this with different objects within one task.

Task

With each window-view you are asked to rate your "see through experience" (the feeling that you are watching *through* a window). In other words; you are asked to assess how strong or weak you have the feeling that the view is *beyond* the "window" instead of a dia of a window-view *on* the wall.



Your assessment can be marked with a pen on the answering form, anywhere on the scale. You will be presented 6 training images containing the best and the worst ones to give you a feeling of the full range. Naturally the scoring will be difficult since at that point you will have no reference, but this is no problem since this is just a training.

However in the actual experiment, *try to use the full range in the actual test*, for there will be no better or worse than those you have seen in the training.

Please take notice of the grey plastic cube on the desk. This cube is not to be moved during the experiments.

Appendix IV Depth-Cue Experiment - Answering form

Proefpersoon nr: ....

Training:

With each view please rate how strong or weak you have the feeling that you are watching *through* a window instead of watching a picture *on the wall* (you can place your mark everywhere on the scale).

1.

Weak |______________________| Strong

2.

Weak |______________________| Strong

3.

Weak |______________________| Strong

4.

Weak |______________________| Strong

5.

Weak |______________________| Strong

6.

Weak |______________________| Strong

Actual experiment:

1\.

Weak ├────────────────┤ Strong

2\.

Weak ├────────────────┤ Strong

3\.

Weak ├────────────────┤ Strong

....

....

....

40

Weak ├────────────────┤ Strong

Thank you for your participation!

Appendix V Focusgroup – Diary form

Probeer zoveel mogelijk *verschillende* functies op te schrijven (druk zoveel pagina's af als u nodig heeft). Denk hierbij ook aan 'minder direct' gebruik van een raam, bijvoorbeeld als u aan het werk bent in een ruimte met een raam maar niet expliciet naar buiten kijkt!

Datum	
Tijdstip	
Activiteit	
Functie v.h. raam	

Datum	
Tijdstip	
Activiteit	
Functie v.h. raam	

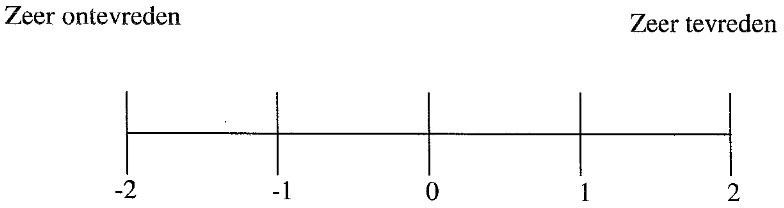
Datum	
Tijdstip	
Activiteit	
Functie v.h. raam	

Appendix VI Focusgroup - Answering form

Participant nr: ....

Naam: ....

Hoe tevreden of ontevreden zou u zijn met dit raam (u kunt uw beoordeling overal op de onderstaande horizontale lijn neerzetten afhankelijk van uw oordeel)?



Ik heb dit antwoord gegeven omdat:

....

....

....

....

....

....

....