

**Wijnand A. Ijsselsteijn\***

**Willem Oosting**

Eindhoven University of Technology  
5600 MB Eindhoven  
The Netherlands

**Ingrid M. L. C. Vogels**

Philips Research  
The Netherlands

**Yvonne A. W. de Kort**

Eindhoven University of Technology  
5600 MB Eindhoven  
The Netherlands

**Evert van Loenen**

Philips Research  
The Netherlands

# A Room with a Cue: The Efficacy of Movement Parallax, Occlusion, and Blur in Creating a Virtual Window

---

## Abstract

In indoor environments, having a view from a window plays an important role in human physical and psychological well-being—particularly if the view contains natural elements. In places where physical windows are absent or the view is highly artifact-dominated, virtual windows can potentially play a beneficial role. The current paper presents a research experiment on the efficacy of three monocular depth cues, that is, movement parallax, blur, and occlusion, in engendering a window-like “see-through experience” using projected photorealistic scenes. Results indicate that all three cues have a significant main effect on the viewer’s see-through experience, with movement parallax yielding the greatest effect size. The effects of the remaining two cues are largely qualified by their interactions with each other and with movement parallax. These results provide a first step in identifying and testing the perceptual elements that are essential in creating a convincing virtual window.

## I Introduction

Nature matters to people. Big trees and small trees, glistening water, chirping birds, budding bushes, and colourful flowers—these are important ingredients in a good life. To have these available only rarely, when and if one can afford to leave the city, deprives people of tranquility and of spiritual sustenance.

Rachel Kaplan, 1983, p. 155.

The ubiquity of windows in places designed for human occupancy suggests that people attach special importance to the collection of functions that windows may serve in their environment. Indeed, several studies have shown the importance of windows on people’s psychological and physical well-being. For example, Finnegan and Solomon (1981) report that employees in work environments without windows report higher levels of work-related stress and lower levels of job satisfaction than those with access to windows.

Of all window functions (e.g., view to the outside, light source, knowledge of weather and time of day, regulating air quality, providing situational and orientation cues), the view out appears among the most significant (Nagy,

1998). In cases where windows are available, the content of the view outside is of particular importance. Several studies have shown that people have a clear preference for views onto natural scenery (e.g., a lake, a forest, mountains, a park, the sea). This preference for natural scenes has been explained from an evolutionary perspective, in terms of potential access to resources such as food and safety (Ulrich et al., 1991).

Several studies have reported on beneficial and restorative effects of views onto a natural scene (Ulrich et al., 1991; Tenessen & Cimprich, 1995). Views onto human-built environments yield effects that are similar to having no window at all (Kaplan, 1993). For example, Ulrich (1984), in one of the classic studies in this area, reports on an experiment where patients recovering from gallbladder surgery were either assigned to rooms overlooking a natural setting or rooms facing a brick wall. The ones with the view to nature had shorter post-operative stays, received less negative evaluation from nurses, and took fewer narcotic analgesics after surgery, than matched patients in rooms facing a brick wall. In addition to such beneficial physiological effects, others have argued for the role that natural scenes may play in the restoration of depleted attentional resources (Kaplan & Kaplan, 1989).

Despite the known benefits of views onto natural scenes, the majority of the world's population lives and works in increasingly urbanized environments, looking out of their windows onto other housing blocks or apartment buildings, shopping malls, parking lots, and roads, or having no window view at all. Heerwagen and Orians (1986) investigated how people in office environments compensate for the lack of windows. They found that people without access to a real window view tended to use more visual materials (e.g., posters) than those with access to a window (even when compensating for the potential effect of extra wall space available through the absence of a window), and that the content of such materials was more likely to contain natural scenes and landscapes than urban scenes. For a detailed review of studies on the effects of windows on work and well-being, we refer to Farley and Veitch (2001).

In addition to urban home and office environments, a number of specialized environments exist in which ac-

cess to a window view is limited or entirely absent. For instance, in prison, many cells do not have a window view for control or safety reasons. In a number of hospital settings, such as intensive care units, patients only have a very limited view outside, if at all. And in spite of Jules Verne's visionary descriptions of the *Nautilus* providing an all-around view to its crew through several large bi-convex glass windows, submarines are in fact quite claustrophobic places where the only direct view outside is provided through a small periscope, and people have to live and work in such a confined space for long periods of time. Similar observations can be made for long-haul space flight, such as potential future manned missions to Mars. What is noteworthy here is that these particular environments can all be quite stressful to their inhabitants, for a variety of reasons (e.g., imprisonment, medical conditions, military operations), implying that the stress-reducing and restorative effect of a window view onto nature could potentially be quite significant, even if such a view is provided artificially.

Based on these observations, there appears to be a solid basis for investigating whether artificial views from virtual windows could provide beneficial effects similar to those of real views. However, before such comparisons can be realistically made, we need to identify and test the perceptual elements that constitute a "window experience."

### 1.1 Creating Virtual Windows

Perhaps the earliest examples of pretend views from nonexistent windows can be found in antiquity. Trompe l'oeil paintings, dating as far back as 400 BC, were meticulously detailed paintings created to look entirely realistic in texture and dimensionality when observed from a particular vantage point. More recently, a number of commercial efforts are being developed aimed at (re)placing a window view. One example, the TESS Round Skylight, is shown in Figure 1. Semi-transparent photographs are placed in front of a light source to simulate a window in windowless medical facilities.

Such a virtual view to the sky and trees is expected to have a relaxing effect on patients as they undergo treat-



**Figure 1.** TESS round skylight (from: <http://www.tessusainc.com>, TESS Virtual Windows, 2008).

ment. In line with the findings of Ulrich (1984), TESS has specifically targeted its virtual window application toward windowless health care environments, such as critical care units and MRI environments (see Figure 2).

Other innovative ways to bring the benefits of nature views into health care settings include the electronic window of nature that simulates the passage of daylight from dawn to dusk, created by Joey Fischer/Art Research Institute Limited and used first in the United States at Stanford (Seligmann & Buckley, 1990). SensoryScapes Panels even provide multisensory stimulation, combining nature views, soothing sounds, and botanical aromas. They are specifically targeted toward windowless health care and interior office environments (see Figure 3).

The examples discussed thus far typically rely on transparent photo sheets with a light source placed behind them. Replacing content in these cases requires additional effort, and printing new photographic sheets can also be time-consuming and costly. In contrast, other manufacturers utilize electronic displays for the purpose of simulating window views in a more flexible manner. For example, the Armas Magic Window systems, as presented in Figure 4, are linking an array of eight TFT-screens per window,



**Figure 2.** TESS virtual window at an intensive care unit (from: <http://www.tessusainc.com>, TESS Virtual Windows, 2008).

enabling the user to change the content of each window view dynamically using a computer. Note how the physical separation between the different TFT screens is resolved by suggesting a window frame.

The current project was carried out in the context of the larger DreamScreen project of Philips Research, which has the aim to study how wall- and window-sized video displays in combination with directional audio cues and other sensory stimulation may create a convincing and beneficial immersive experience to users in their homes. The DreamScreen prototype, as presented in Figure 5, is based on five front-projected displays.

When comparing real space to virtual space, limiting ourselves to visual media for the time being, we find that real world perception has several critical features (Ijsselsteijn, 2003), which we will briefly discuss here in the context of creating virtual windows.



**Figure 3.** SensoryScape panel at an office environment (from: <http://www.sensoryscapes.com>, SensoryScape Panels, 2008).



**Figure 4.** Armas Magic Window (from: <http://www.superdisplay.com.tw>, Armas Magic Window, 2008).

- i. *Static depth information is provided via several independent mechanisms that are consistent with each other and the observer's viewpoint.*

For a static observer, natural scenes already contain a rich variety of monocular and binocular cues to depth,



**Figure 5.** Philips DreamScreen prototype (from: [http://www.research.philips.com/technologies/misc/homelab/Philips\\_DreamScreen](http://www.research.philips.com/technologies/misc/homelab/Philips_DreamScreen), 2008).

including linear perspective, occlusion, texture density gradients, and binocular disparity. For a review, see Cutting and Vishton (1995). Each individual cue on its own is an ambiguous indicator of distance, layout, and surface structure. However, when multiple cues combine in a consistent fashion, they tend to disambiguate and strengthen each other (through a process known as depth cue integration), uniquely specifying layout as seen from the observer's vantage point. Although none of the virtual window examples discussed earlier employ binocular disparity as a cue, most other static depth cues are consistent in relation to one another, which is of course more challenging to create in the case of trompe l'oeil paintings than in cases where photographic projections are being employed.

Most current window substitutes, however, do not take into account that the frame surrounding the window is perceived at a different depth layer than the view from the window. Assuming one is attending to the view outside, the frame will disappear in an increasing optical blur as a consequence of the accommodation mechanism of the eye. Although adaptive blur generation based on gaze tracking would be the ideal solution, there are other, more practical options. One has been explored some years ago by CRL, a company that produced the Vistral screen surround which was placed over the screen edge like a picture frame. It generated a

Moiré effect from two layered patterns of dots on either side of a glass plate and was extremely difficult to focus the eyes on. This tricked the accommodative system to signal that the Vistral screen surround and the screen itself belonged to different depth layers. As a consequence, it made the image on the screen appear to float in depth.

- ii. *The resolution and intensity of the image is only limited by the sensitivities of our visual system.*

In unmediated situations our visual perception of the environment is dependent on our naturally limited visual abilities (e.g., unaided human vision is not sensitive to the full electromagnetic spectrum, such as infrared light, and our visual acuity is fairly limited in comparison to some other animals), attenuated by environmental factors (e.g., ambient light levels, fog, atmospheric pollution). Visual media, however, are hard-pressed to match the bandwidth of our natural perception. In the case of backlit photographic sheets, such as the TESS virtual window, the resolution can be high enough for our visual system not to detect any grain. For electronic displays, the resolution will likely be lower, but may be compensated for by the fact that one view is composed of a combination of multiple displays, as well as the likelihood that these images will be viewed from distances of more than half a meter or so, which substantially increases the resolution per visual angle. However, low brightness levels (as compared to daylight) can still be a serious showstopper for electronic windows at this point in time, although arrays of ultra-bright LEDs show promise in this respect.

- iii. *The effective image size fills our entire field of view, limited only by our facial structures, but without an externally imposed frame.*

Although we are not usually aware of it, our facial structures impose a natural frame that limits our field of view, as is illustrated in the classic drawing by Ernest Mach (see Figure 6). This is true in general when perceiving the world around us, although the interesting exception, of course, are windows, where we have



Figure 6. Ernst Mach's self-portrait, 1871.

learned to perceive a framed view as part of reality, and not as a mediated representation. The effect of different types of framing on the virtual window experience is a matter of empirical research. Some guidelines are available from prior work in office settings where shape and size of windows were manipulated using apertures (Keighley, 1973). Windows occupying less than 10% of the window wall were regarded as extremely unsatisfactory, whereas window sizes of 20% and larger were deemed most satisfactory. In addition, participants preferred a wide lateral scan, selecting wider windows over taller ones.

- iv. *Dynamic depth information is coupled to observer movement.*

As we move our bodies through the world or just move our heads from side to side, more distant objects will traverse smaller angles across the retina than do objects closer by. This source of visual depth in-

formation is known as movement parallax,<sup>1</sup> and none of the examples of virtual windows discussed earlier presently support movement parallax. Markus (1967) argued that 2D “artificial windows” (i.e., screens that presented nature scenes) are ultimately unsatisfactory as a view replacement because of a lack of dynamic depth cues. He states: “Another criterion for successful window design might be a dynamic one—i.e., the amount of change in the view that takes place for a given change in the viewing position of the observer. As a result of this movement parallax, not only do objects at a different distance within the view change their relative position, but also the window-view relationship changes. This is why two-dimensional artificial windows, even when very carefully contrived, are unrealistic and soon cease to satisfy; they lack the ‘depth’ within the view and the parallax of window aperture-view is also absent.”

Of course, in the area of interactive computer graphics known as virtual reality, head-tracked or head-coupled displays have been in use since they were introduced in the 1960s by Ivan Sutherland, providing the user with the movement parallax cue. Later, head-tracked desktop systems (Fisher, 1982), sometimes also referred to as fish-tank virtual reality (Ware, Arthur & Booth, 1993), provided the user with a window-like view onto a computer-generated, virtual world. However, only when combining the elements of photorealism with appropriate viewpoint-dependent transformations of the displayed scene can a window-like see-through experience become convincing. With the limits in current tracking and rendering speeds, real-time interactivity still trades off against photorealism, making a fully interactive photorealistic view difficult to attain at present, particularly when the content presented on the window is captured live.

1. Sometimes the term motion parallax is used. This also includes, however, differential motion between objects that does not depend on observer movement, as is the case, for instance, in movies. Thus, movement parallax is a more accurate term for the observer based motion we are studying.

## 1.2 Rationale of the Current Study

The aim of the current study was threefold. First, we wanted to investigate if, in comparison to displays of static scenes, we could create a more convincing see-through experience using a simplified approach to generating movement parallax in relation to a photorealistic scene, that is, only transforming the relationship between the window frame and the outside view, based on head movements, without transforming the relation between objects contained within the view. Secondly, we wanted to investigate the potential effects of window framing, as the addition of a frame is expected to provide additional depth information regarding the position (depth layer) of the frame vis-a-vis the outside view, via the occlusion or interposition cue, particularly in the case where movement parallax is present. Thirdly, we wanted to investigate whether the addition of blur to the boundaries of the frame would add to the see-through experience as it would signal to the visual system that the frame was located at a different depth layer than the view being displayed.

Recent work most similar in spirit to our own is that of Radikovic, Leggett, Keyser, and Ulrich (2005), who created a window substitute using a tracked wall-mounted display. Using a repeated measures design, they had 14 students assess this interactive virtual window showing a nature scene against a static picture of that same scene. They found that the virtual window supporting movement parallax was considered superior as a window substitute, also having a stronger effect on well-being (positive mood) than the static picture.

Although the Radikovic study usefully demonstrated the added value of movement parallax in simulating a view from a virtual window, in line with Markus' (1967) prediction, their experimental manipulation of a head-tracked versus a static image was quite a basic one. We wanted to investigate whether in addition to movement parallax, other monocular depth cues could be usefully deployed in creating a window substitute, giving rise to a more convincing illusion that one is looking through a window at an outdoor scene, rather than at a flat image projected on the wall.



**Figure 7.** Schematic representation of the experimental  $2 \times 2 \times 2$  design: eight conditions varying in blurring of the frame, the presence of an occluding cross-shaped frame, and the presence of movement parallax.

## 2 Method

### 2.1 Design

The effects of the three types of monocular depth cues on the reported see-through experience were tested in an experiment with a  $2$  (Movement parallax: off vs. on)  $\times 2$  (Occlusion: off vs. on)  $\times 2$  (Blur: off vs. on)  $\times 5$  (Image) within-subjects design. Five different images were used as viewing scenes (see Figure 8, discussed later); the remaining manipulations are represented in Figure 7.

### 2.2 Participants

Twenty persons (12 male, 8 female) participated in the experiment, with ages ranging between 19 and 42. All participants had a (corrected) visus of at least 1 and had little or no experience with perception experiments. All were employees or thesis students at Philips.

### 2.3 Apparatus and Setting

The experiment was conducted in a dedicated perception lab at the Philips High Tech Campus. A virtual window prototype was created using a BARCO Reality

6400 beamer, placed under a table draped with black cloth to make the beamer less apparent. The images were projected 1.70 m wide and 1.28 m high on a 12 m<sup>2</sup> plain white wall at a resolution of  $1280 \times 960$  pixels and 24 bit color. The virtual window thus covered 18% of the wall size, approximately in line with Keighley's (1973) recommendations regarding preferred window size. Furthermore, a chair was placed behind the table at 5 m distance from the projected window, resulting in a horizontal viewing angle of  $19.3^\circ$  and a vertical angle of  $14.6^\circ$  and providing participants a desktop to work on.

A Polhemus PATRIOT system was deployed to keep track of the participant's head location. A fixed magnetic field generator in combination with a magnetic field receiver attached to a headphone determined the 6 DOF. The system had a refresh rate of approximately 120 Hz and a tracking latency of around 0.7 ms. The end-to-end system latency was approximately 15 ms. Pilot tests showed that when participants did not make highly accelerated head movements, movement parallax could be simulated without too much delay. The range of the transmitter/receiver was about 0.75 m, forcing the participants to remain seated during the experiment.

Custom software was engineered to interface the information supplied by the head tracker over the



**Figure 8.** Five different images used as viewing scene: hairdresser, first floor, creek, night skyline, and Africa.

RST232 port of a PC. Another program was written to interpret the readings of the tracker and superimpose the occluding cross-frame. In a pilot experiment, the optimal gain factor (ratio between image-translation and head-translation) was determined at 0.58. When viewing the scenes, the lighting level in the laboratory was 40 lux (as measured on the desk) to ensure that the projected view would appear brighter than the laboratory and the black occluding cross would form a silhouette similar to that of a window frame.

#### **2.4 Stimuli and Monocular Cue Manipulations**

Five different images were chosen, depicting a varied set of scenes and with varying distances at which interesting objects were displayed. The images are depicted in Figure 8.

Movement parallax was created by using digital photographs with a very high resolution, of which the virtual window only showed a small part. The picture was virtually placed at some distance behind the window frame, such that viewpoint-dependent transformations differed between the window frame and the outside view as a whole. Tracked head movements of the participant resulted in matched translations of the image (the

picture being moved in the same direction as the head to display the correct view), thus simulating movement parallax.

Occlusion was implemented by superimposing a cross-shaped frame, as shown in Figure 9. The black bars of the cross were 5 cm wide, as measured on the wall. Lastly, blur was manipulated by introducing a transparency gradient ranging from 0 to 1 over a distance of 1 cm starting at the edges of the frame and the edges of the cross.

#### **2.5 Measurement**

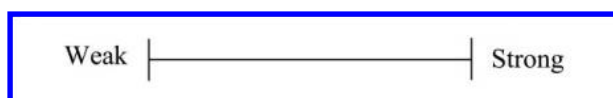
Participants were asked to rate their “see-through experience,” which was defined as “the feeling that you are watching through a window, that is, the feeling that the view is beyond the ‘window’ instead of a slide of a window-view on the wall.” They marked their assessment on the scoring form using the scale depicted in Figure 10. After the experiment the scores were measured with a ruler. The full length of the scale was given 5 points.

#### **2.6 Procedure**

Upon entering the room, participants were seated behind the desk and received written instructions to



**Figure 9.** Visible scene, without and with occluding frame.



**Figure 10.** Scale used to assess see-through experience.

make moderate lateral head movements when viewing a new scene and to watch “out” of the window, not directly at the frame.

Once the participants finished reading the instructions, they placed a headphone with the head-tracker on their head and the experiment leader dimmed the light. The program first presented a training session with examples of views with different monocular depth cues, to allow participants to get used to the setting as well as the task and calibrate their use of the scale based on the range of variance between the different views.

The experiment leader stayed in the room during the training session to answer possible questions and to check whether the participants interpreted the instructions correctly. Participants were encouraged to use the full scale during the actual experiment. Then the experiment leader left the room and the participant commenced with the experiment. The order of the images and views was counterbalanced between participants. During the loading time of each new view, an inter-stimulus adaptation field (ISAF) was displayed to eliminate influence from a previous stimulus due to inheritance.

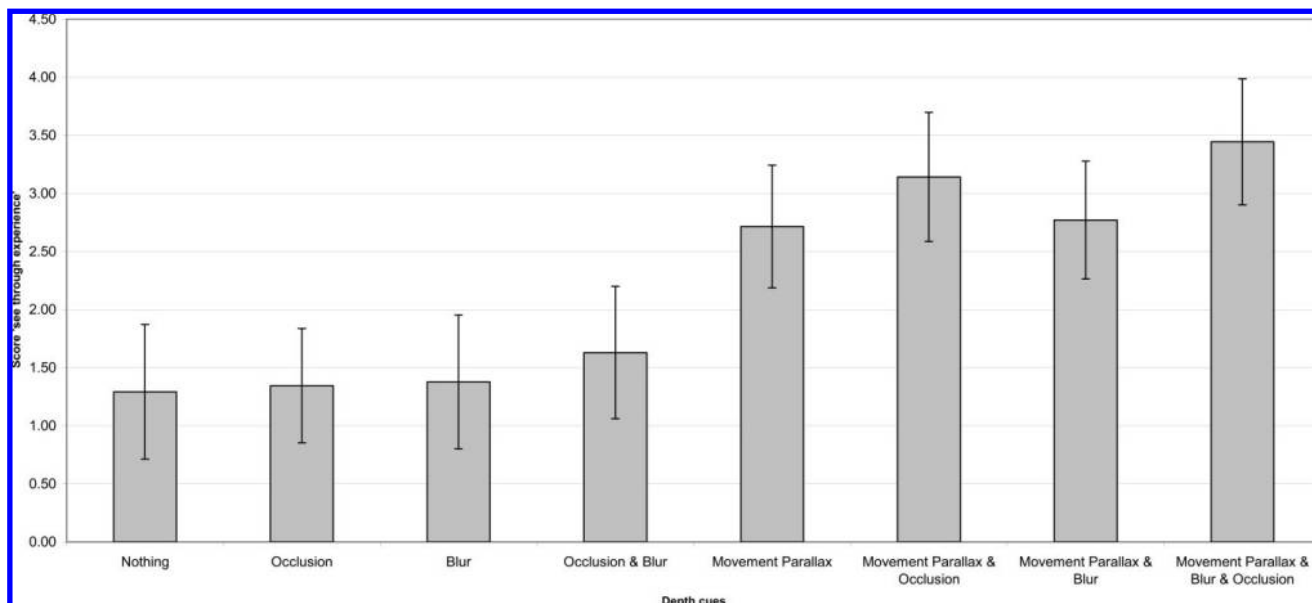
Participants were offered a small token of appreciation (a lollipop) for their time. The experiment lasted approximately 15 min.

### 3 Results

The effects of the three types of monocular cues on the reported see-through experience were tested in an experiment with a 2 (Movement parallax)  $\times$  2 (Occlusion)  $\times$  2 (Blur)  $\times$  5 (Image) within-subjects design. The average scores for the five images in each of the experimental conditions are reported in Figure 11; the average ratings for each individual frame in every experimental condition are reported in Table 1.

All three monocular cues show positive effects on the see-through experience. These results were tested in a repeated measures ANOVA, according to the full model. Movement parallax showed a significant main effect ( $F(1,19) = 24.86, p < .001$ ). The experience without movement parallax was rated lower ( $M = 1.4$ ) than the experience with movement parallax ( $M = 3.0$ ). Although somewhat smaller, the main effect of occlusion was also significant ( $F(1,19) = 8.70, p = .01$ ). Viewing conditions with an occluding frame ( $M = 2.4$ ) were rated higher than those without ( $M = 2.0$ ). The third main effect, of blurred edges, also reached significance ( $F(1,19) = 6.17, p = .02$ ). Blurring the edges raised the see-through experience from  $M = 2.1$  to  $M = 2.3$ . The last potential main effect, of image, did not reach significance.

The interaction effect between movement parallax and occlusion was significant ( $F(1,19) = 4.71, p = .04$ ), and the interaction between occlusion and blur almost reached significance ( $F(1,19) = 3.88, p = .06$ ). As the interaction effects described above might qualify the



**Figure 11.** Mean scores and 95% confidence intervals for each of the eight experimental conditions, averaged across participants and images.

**Table 1.** See Through Experience—Ratings for Each Experimental Condition\*

Frame #	No movement parallax				With movement parallax				
	No occlusion		With occlusion		No occlusion		With occlusion		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
No blur									
1	1.45	1.42	1.28	1.05	2.84	1.18	3.36	1.17	
2	1.01	1.07	1.00	0.88	2.35	1.04	3.17	0.98	
3	1.45	1.29	1.32	1.17	2.95	1.23	2.99	1.54	
4	1.19	1.34	1.57	1.25	2.60	1.33	3.13	1.07	
5	1.29	1.31	1.55	1.24	2.84	1.24	3.21	1.25	
With blur									
1	1.68	1.41	1.60	1.07	2.98	1.12	3.61	0.94	
2	1.28	1.23	1.41	1.33	2.22	1.00	3.35	1.34	
3	1.27	1.18	1.95	1.49	2.85	1.23	3.32	1.50	
4	1.13	1.19	1.37	1.05	2.89	1.15	3.28	1.09	
5	1.42	1.41	1.83	1.56	2.92	1.29	3.71	1.22	

\*Note: N = 20.

main effects, additional analyses were performed exploring simple main effects of all manipulations. These analyses indicated that the main effect of occlusion was only significant in combination with movement parallax and/or blur. Similarly, the main effect of blur was qualified by both movement parallax and occlusion.

The three-way interaction which appeared between movement parallax, occlusion, and image ( $F(4,76) = 3.68, p = .01$ ) showed that the effect of movement parallax was enhanced for windows with an occluding frame compared to movement parallax without occluding frame for the hairdresser image, but not for the remaining images.

Finally, the three-way interaction occlusion  $\times$  blur  $\times$  image was significant ( $F(4,76) = 2.49, p = .05$ ). Occlusion was very effective for the hairdresser and first floor scenes, less effective for the creek and Africa scenes, and only effective in the night sky scene when edges were blurred. No remaining effects proved significant.

#### 4 Discussion

Taking the beneficial effects of windows as a point of departure, this paper presents an investigation on the contribution of three monocular depth cues, that is, movement parallax, occlusion, and blur, to the illusion that a wall-projected scene affords a window-like see-through experience. These cues were selected on the basis of an analysis of the role they are thought to play in the visual perception of scenes through a window. Additionally, the three cues we selected are computationally relatively inexpensive, which allows their implementation in a virtual window showing photorealistic images, instead of computer-generated scenes.

A controlled experiment was performed, manipulating the three monocular cues in a  $2 \times 2 \times 2$  within-subjects design. The results indicate that all three manipulations had a significant main effect on the see-through experience. The largest effect was produced by the movement parallax manipulation, in line with our own expectations as well as prior work (Radikovic et al., 2005). Interestingly, the movement parallax effect was highly significant even though the implementation of

movement parallax we used was a simplified one, only transforming the relationship between the window frame and the outside view, without transforming the relation between objects contained within the view. This is a promising result, as such a basic movement parallax simulation can be rendered in near to real-time, allowing people to look from their virtual window at any photorealistic scene, be it a static picture or a moving image. It is easy to conceive how such a window could provide a real-time view onto beautiful or exotic natural scenery through connections with various HDTV cameras placed around the world, much like the current widespread use of webcams that capture various kinds of environments, from homes, street corners, and offices, to the Eiffel tower and the African savannah.

More realistic movement parallax rendering, such as those based on image-based rendering (IBR), as used by Radikovic et al. (2005), are computationally more demanding and do not yet afford the near real-time rendering of such “live” photorealistic imagery. It is an empirical question how our approach compares to IBR in terms of perceptual effect. Our prediction would be that for scenic views without foreground objects to speak of (e.g., views of mountains, deserts, the sea, etc.), the simplified movement parallax approach will yield results similar to those that require more computational complexity. However, when foreground objects are salient, the simplified approach we used may provide cues that the surface one is looking at is, in fact, a flat 2D projection. However, there is the possibility that the advantage of more realistic depth rendering in the case of IBR will trade off against the drawback of perceptible lag. Thus, virtual windows that are placed in locations where observer movement will likely be substantial in terms of range and/or speed (e.g., underground stations, hallways, airport lounges, shops, etc.), our prediction would be that a computationally less expensive approach, such as the one described in this paper, will yield superior results because of its fast view rendering.

Although the effects of blur and the occluding frame were both much smaller in terms of effect size than movement parallax, and qualified by the other manipulations, their effects were significant nevertheless. This indicates that the see-through experience we used as an

indicator for how window-like the simulation appeared, was indeed influenced by these monocular cues, in line with our expectations. Although none of the virtual window simulations we came across in our research apply selective blurring of the window frame as a depth cue, it appears that this cue yields a moderate effect on the realism of the simulated window, in particular signaling that the frame belongs to a different depth layer than the depicted view. Note that we had not anticipated a strong effect of blur, as accommodation is known to be a fairly ineffective source of information for accurate depth discrimination (Cutting & Vishton, 1995). Subsequent analyses indicated that blur only affected the see-through experience in combination with movement parallax and/or the superposition of a cross-shaped frame across the view.

The occlusion produced by this window frame yielded a slightly larger effect than blur, but was particularly effective in conditions where movement parallax was present as well. The three-way interaction between movement parallax, occlusion, and image was caused in particular by the hairdresser image. This is quite understandable as the occluding frame partially obstructs the view onto the objects of interest in this image, being the people in front of the barbershop. Thus, without movement parallax, that is, the ability to look around the occluding frame, the view would be irritatingly blocked. The effects of framing were also shown to be dependent on blurring of the frame. More generally, the combination of movement parallax and the superimposed frame gave people a convincing illusion that a stable foreground reference frame (the window) was available through which a continuous environment in the background (the scene) could be viewed. This result suggests that providing additional (blurred) framing in head-tracked virtual windows may enhance the illusion of a continuous environment in the background that is distinct from the wall of the room one is located in. This interpretation is in line with other work on foreground occlusion, in particular that of Mergner and Becker (1990) in relation tovection (illusion of self-motion) and Prothero, Hoffman, Parker, Wells, and Furness (1995) in relation to presence. Thus, in the movement parallax conditions, a stable foreground

frame facilitates the perception that the background scene is independent of the window through which it is perceived and continuous beyond the boundaries of the frame. Additional framing then provides more evidence for the stability of the window frame in relation to the outside view.

Although between-subjects designs are less likely to suffer from demand characteristics, a within-subjects design was chosen for the present study, mainly because we felt that judging the see-through experience of a virtual window would be quite a difficult task in a between-subjects setting, as it lacks an absolute anchor, and is more likely to inflate the results for each individual cue, as this would then be the only cue that is manipulated. A comparative setting (i.e., within-subjects) allowed us to get a feeling for the relative effectiveness of each cue in engendering a window-like see-through experience.

Based on the results reported in this paper, one area of future research we would like to pursue is the application of virtual windows to settings where access to windows is problematic, as discussed earlier. We have already seen a number of commercial efforts in the health care domain. However, such companies typically provide little if any data relating to the clinical effectiveness of their “healing windows,” and usually base their claims on studies of the effects of real window views. It needs to be investigated whether virtual windows will have similar beneficial effects as real windows, and which aspects of the window experience most crucially determine such effects (see also de Kort & IJsselsteijn, 2006; de Kort, Meijnders, Sponselee, & IJsselsteijn, 2006). Based on our results, movement parallax will likely be an important factor, but other factors we did not consider, such as lighting levels, may prove to be equally or even more important.

In addition to applications in health-related environments, virtual windows have great potential for leisure and entertainment, for example, as an advanced home theater system or as an enjoyable view replacement which shows, to quote Basil Fawltly, “herds of wildebeests sweeping majestically across the plains” from a Torquay hotel window. Virtual windows can offer relaxing effects in stress-prone underground environments,

such as subways or underground parking lots. For example, the IN-Visible system (Chatzitsakyris, Ducla-Soares, & Zulas, 2004) shows subway travelers a projected view of the exterior urban environment at ground level that one is traveling underneath. Such a virtual subway window can enhance feelings of orientation, but can also make underground traveling much more enjoyable.

The study of artificial windows constitutes a useful case study for presence research, where fundamental and applied issues are intimately linked together. Though clearly delimited, the window experience is quite rich and inherently multimodal. Although the research reported here has only touched upon the investigation of three particular visual cues relevant to window simulations, many other sources of sensory information are of relevance in creating a convincing window substitute, such as stereoscopic imaging, spatial audio characteristics, temperature, light, air quality and flow, and olfactory cues, to name but a few. What is particularly interesting about virtual windows, however, is that they are one of the few simulations where the people confronted with the simulation need not necessarily know in advance that they are looking at a mediated environment. One important characteristic, discussed in this paper, is that windows are generally bounded by a frame, turning one of the intrinsic limitations of most display systems into an advantage. When future virtual windows will use unobtrusive head tracking and will update their high-resolution photorealistic view accordingly in real time, the next generation of trompe l'oeil artifices will have arrived, fooling both the eye and the mind of unsuspecting visitors enjoying the view.

## References

- Armas Magic Window. (2008). Armas Computer Corp. Available at <http://www.superdisplay.com.tw/>. Retrieved February 27, 2008.
- Chatzitsakyris, P., Ducla-Soares, G., & Zulas, A. (2004). IN-Visible: Perceiving invisible urban information through ambient media. *CHI 2004 Late Breaking Results*, 1348–1350.
- Cutting, J. E., & Vishton, P. M. (1995). Perceiving layout: The integration, relative dominance, and contextual use of different information about depth. In W. Epstein & S. Rogers (Eds.), *Handbook of perception and cognition: Vol. 5. Perception of space and motion* (pp. 69–117). New York: Academic Press.
- Farley, K. M. J., & Veitch J. A. (2001). A room with a view: A review of the effects of windows on work and well-being. NRC-CNRC Technical Report IRC-RR-136.
- Finnegan, M. C., & Solomon, L. Z. (1981). Work attitudes in windowed vs. windowless environments. *Journal of Social Psychology*, 115, 291–292.
- Fisher, S. (1982). Viewpoint dependent imaging: An interactive stereoscopic display. *Proceedings of the SPIE*, 367, 41–45.
- Heerwagen, J. H., & Orians, G. (1986). Adaptations to windowlessness: A study of the use of visual decor in windowed and windowless offices. *Environment and Behavior*, 18, 623–639.
- Ijsselsteijn, W. A. (2003). Presence in the past: What can we learn from media history? In G. Riva, F. Davide, & W. A. Ijsselsteijn (Eds.), *Being there—Concepts, effects and measurements of user presence in synthetic environments* (pp. 17–40). Amsterdam: IOS Press.
- Kaplan, R. (1993). The role of nature in the context of the workplace. *Landscape and Urban Planning*, 26, 193–201.
- Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. New York: Cambridge University Press.
- Keighley, E. C. (1973). Visual requirements and reduced fenestration in offices: A study of multiple apertures and window area. *Building Science*, 8, 321–331.
- de Kort, Y. A. W., Meijnders, A. L., Sponselee, A.-M., & Ijsselsteijn, W. A. (2006). What's wrong with virtual trees? Restoring from stress in a mediated environment. *Journal of Environmental Psychology*, 26, 309–320.
- de Kort, Y. A. W., & Ijsselsteijn, W. A. (2006). Reality check: The role of realism in stress reduction using media technology. *CyberPsychology and Behavior*, 9, 230–233.
- Markus, T. A. (1967). The function of windows: A reappraisal. *Building Science*, 2, 97–121.
- Mergner, T., & Becker, W. (1990). Perception of horizontal self-rotation: Multisensory and cognitive aspects. In R. Warren & A. H. Wertheim (Eds.), *Perception and control of self-motion*. Hillsdale, NJ: Erlbaum.
- Nagy, E. (1998). Working in underground offices. Doctoral Dissertation, Lund University, Lund, Sweden.
- Philips DreamScreen. (2008). Philips Electronics N. Y. Avail-

- able at <http://www.research.philips.com/technologies/misc/homelab/>. Retrieved February 27, 2008.
- Prothero, J., Hoffman, H. G., Parker, D. E., Wells, M., & Furness, T. A. (1995). Foreground/background manipulations affect presence. *Proceedings of Human Factors and Ergonomics Society 1995*, 1410–1414.
- Radikovic, A. S., Leggett, J. J., Keyser, J., & Ulrich, R. S. (2005). Artificial window view of nature. *CHI 2005 Late Breaking Results*, 1993–1996.
- Seligmann, J., & Buckley, L. (1990). A sickroom with a view. *Newsweek*, March 26, 61.
- SensoryScape Panels. (2008). SensoryScapes, Inc. Available at <http://www.sensoryscapes.com/>. Retrieved February 27, 2008.
- Tenessen, C. M., & Cimprich, B. (1995). Views to nature: Effects on attention. *Journal of Environmental Psychology*, 15, 77–85.
- TESS Virtual Windows. (2008). TESS USA Inc. Available at <http://www.ssusainc.com/>. Retrieved February 27, 2008.
- 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.
- Ware, C., Arthur, K., & Booth, K. (1993). Fish tank virtual reality. *Proceedings of the INTERCHI '93 Conference on Human Factors in Computing Systems*, 37–42.