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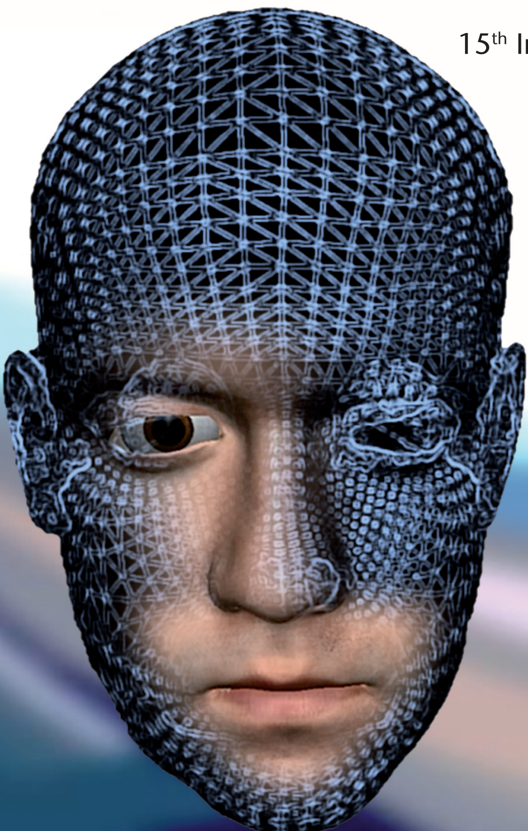

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Psychological Effects on 3 Dimensions Projection Mapping Versus 2 Dimensions: Exploratory Study

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Abstract. In this study we examine psychological perception and learning from a form of augmented or mixed reality called projection mapping. Projection mapping warps an image to conform to the shape of real world surfaces. In this way the virtual texture or image has physical presence and, potentially, tangible affordances. Three-dimensional projection mapping technology is frequently used for psychological effect in large scale and small scale performance applications by lending virtual, dynamic properties to physical objects. However, the psychological effect of this kind of 3D mapping has not been well studied. In this experiment we directly compared user responses to 3D projection mapping and to the same content in 2D within the same room and same location in the room. We found the 3D projection mapping of the physical environment elicits significantly greater spatial presence across several dimensions. Users find the experience of the same projection content almost 25% more satisfying in 3D mixed reality than on 2D surface. Furthermore, the movement of images into the physical 3D environment increased the accuracy of the viewers' recognition memory by over 230% for pattern location. In general users were more accurate and faster at the sufaces, textures, and forms of the objects by over 20%, but not the color. These effects were elicited from participants in this study even though we restrained the environment to simple primitive physical shapes and projected only impoverished abstract patterns that have little representational meaning. These findings have implications for the use of 3D projection mapping for training, persuasion, and other applications.

Keywords. Projection Mapping; Augmented Reality; Digital Art; Presence; Spatial Presence

Introduction

Transforming the perception of space and materials

Three-dimensional (3D) projection mapping is a medium for mixing the virtual with the physical. Within Milgram's continuum from reality to virtuality projection 3D mapping is a form of augmented reality.

In projection mapping textures and videos are warped in a 3D virtual environment conform to the shaped of a physical object or environment. Projector algrorthms and techniques are used to fit the 3D projected textured environments to the shape constraints of the physical objects or environments (Milgram and Kishino, 1994; Raskar and et al., 2001; Halskov and Dalsgaard, 2011; Soltani, 2011).

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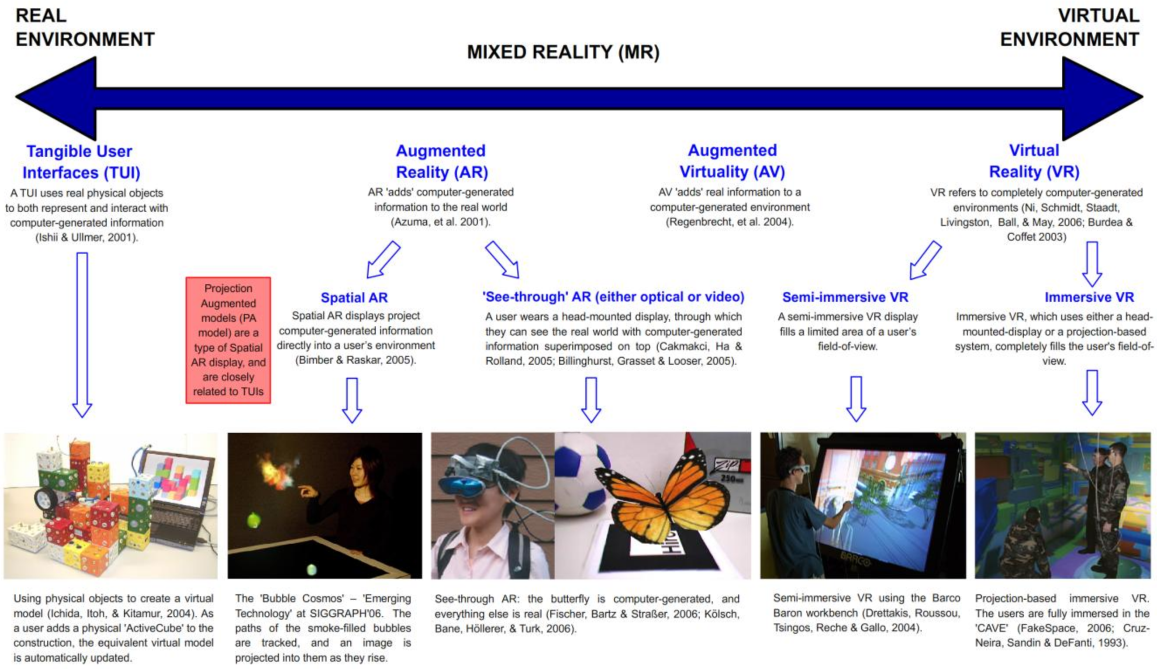

Figure 1. Milgram and Kishno's (1994) continuum of display technologies from real environments to virtual environments. Note that 3D projection mapping is a form of augmented reality. Courtesy Wikipedia.

As an expressive medium 3D projection mapping has been used extensively for a variety of artistic and commercial projects. Typically mapping software and high luminosity projectors are used to project an illuminated image onto a physical object such as a building, a car, or a set of interior room surfaces. In previous studies of the technology, projection mapping installations were developed either for researching the technological potential of such installations or for exploring the meaning of new visual representations from an artistic perspective (Halskov and Dalsgaard, 2011; Dalsgaard and Halskov 2011; Dalsgaard and Halskov 2012). The eye-catching nature of 3D projection mapping technology has made it a popular choice for promotional displays and advertising. However, the psychological effects of 3D projection mapping and how it draws the audience's attention have not been studied.

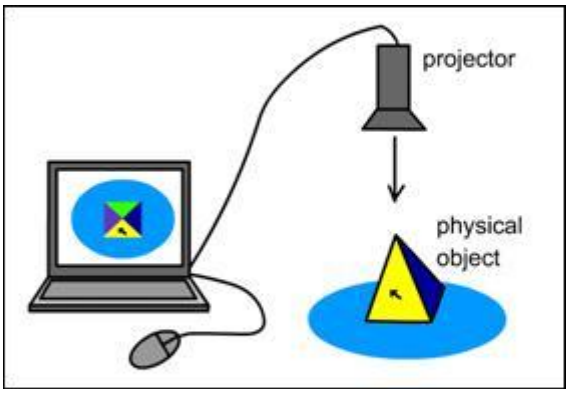

Figure 2. In projection mapping textures and videos are warped in a 3D virtual environment conform to the shaped of a physical object or environment. Projection algrorthms and techniques are used to fit the 3D projected textured environments to the shape constraints of the physical objects for environments. *Courtesy Wikipedia*.

a. 3D Projection Mapping by Arkbell (2011)	b. 3D projection mapping car by coolux	c. “How it would be if a house was dreaming” by 555 Kubik by UrbanScreen (Rossa, 2009).

Figure 3. These tend to represent the typical current applications of 3D projection mapping for augmented reality applications: a) pattern projections on physical blocks, b) adding dynamic visual effects or interactivity to physical objects from small items to cars, etc., and c) adding visual effects and sometimes percpetual interactivity to bigger physical environments such as buildings or whole city blocks.

Applications of 3D projection mapping

The applications of 3D projection mapping have been added virtual interacivity to physical objects and environments. See Figure 3. Artists have started to use 3D projection mapping technology to make new forms of visual representations. Among the most famous installations of 3D projection artworks are Pablo Valbuena’s Augmented Sculpture series exhibited at Ars Electronica (2007) and 555 Kubik’s employment of 3D projection to mimic the third dimension on 2D surfaces (Rossa, 2009).

Three-dimensional projection mapping technology has come into wide use within the promotional realm. A popular Audi advertising campaign in Korea (2011), for example, featured the car as its projection mapping art object, leading a trend in 3D projection mapping technology use that has become common among car companies introducing new models. On a larger scale projection mapping is often used to create illusions of shape, motion, and drama by distorting the perceived surfaces and shapes of buildings or adding dynamic properties to objects to suggestion motion or changes in form.

The psychology of augmented reality and transformed physical objects.

While dynamic images on flat surfaces are as old as film, these projections interact with the shape of the object. To put is another way film is virtual while projection graphics interacts with the object and the physical space augmenting the physical object and space with virtual properties. The perceptual properties are not as well studied as the classic perception of flat surfaces (i.e., film) (Hochberg, 1986).

Several studies have discussed and explained the technical features, basic perception, and some novel perceptual illusions associated with the augmentations of 3D projection mapping (Dalsgaard, 2011, 2012).

Although there have been many studies of psychology responses to virtual reality (Schuemie, Van Der Straaten, & Van Der Mast, 2001;) and to lesser degree augmented reality (Tang, Biocca, & Lim, 2004Tang, Biocca, & Lim, 2004; Tang, Owen, Biocca, & Mou, 2003), there are few psychological studies of responses to this type of mixed reality. Specifically, there are few studies of the effects of this kind of mixed reality on psychological responses such as the sense of physical presence, satisfaction, enjoyment, and involvement.

Tang, Biocca, and Lim compared augmented reality (AR) versus virtual reality (VR) using head-mounted displays (HMD) (2004). In this study, they found some evidence that AR environments enhance spatial presence because AR provides more direct experiences of the objects. Augmented reality brings virtual information and spatially maps it to the viewer's physical world with potentially significant psychological effects and additional affordances.

In 3D projection mapping it is possible to present the virtual layer directly on the physical object without any screens or lenses such as in head-mounted displays (HMD) or on smartphone screens. Because the augmented reality generated is linked direction to physical, tangible objects, 3D projection mapping provides viewers with a spatial presence that is both unique in itself and stronger than that created by the ghostly overlays of some head-mounted augmented reality and hologram technology. According to Satoshi, hologram technology's low fidelity reduces viewers' perceptions of its realism (1994).

However, augmented reality in a 3D object-based environment may improve the perceived fidelity, realism, and a sense of spatial presence and, therefore, viewer perception as well. The experience within the physical world may be more memorable. The application of this technology for training, learning, and other areas of interacitivity are yet to be fully explored.

Research question

In this study, we attempted to directly compare 3D projection mapping versus 2D projection to measure the psychological effects of 3D projection mapping. We asked whether this form of augmented reality, 3D projection mapping, significantly enhances user experience and cognition. Specifically, we asked:

- Does the experience of the virtual and physical information affect user satisfaction with the experience?
- Does 3D projection mapping enhance the sense of presence in which the virtual seems part of the physical environment of the user?
- Does spatializing this virtual information into the physical environment make it more memorable and accessible?

Based on these questions and previous literature we hypothesize the following:

H1. An audience watching a representation with 3D projection mapping technology will experience greater satisfaction with the experience than an audience viewing a 2D projection.

H2. An audience watching an object with 3D projection mapping technology will experience greater spatial presence than an audience viewing a 2D projection.

H3. Three-dimensional projection mapping technology elicits greater audience memory for the experience and virtual objects.

Method

A between-subjects experiment was conducted manipulating one factor type of visual projection with two levels: 1) augmented reality using 3D projection mapping and 2) the standard 2D projection of video and images. As mentioned below we used neutral content.

Participants

Sixty-two college students from a university in Seoul, Korea, participated in the study. The experiment used a between-group design in which participants were randomly assigned into two groups, a 2D screen viewing group (N=28), and a 3D projection mapping viewing group (N=34).

Materials

A between-subjects experiment was conducted manipulating one factor type of visual projection

Figure 4. Stimuli: (left) standard 2D projection of patterns on a flat surface; (right) 3D augmented realtity projection mapping onto mapped 3D surfaces.

In an effort to explore projection mapping itself rather than specific, meaningful representations, we explored the psychological responses to 3D projection mapping using a semantically neutral presentation mapped to primitive physical shapes. In this study we controlled our stimuli to non-interactive environments to more purely focus on the effects of *visual augmentation* of 3D projection mapping only. Furthermore, to focus on perceptual differences we added additional control by retricting the experiment to abstract environments only to control for the effects of object representations as a biasing factor. So the study focuses on abstract projection environments only.

Projection hardware and environments. This 3D projection mapping process consists of three strategic points: projector, computer, and the 3D objects. The projector is a 1510X model from Dell. This projector for the room exhibition had a resolution of 1024 x 768, a maximum brightness of 3500 ANSI (American National Standards Institute) Lumens, and a high 2100:1 typical (full on/full off) contrast ratio. Because of the brightness and resolution it was appropriate for our experiment.

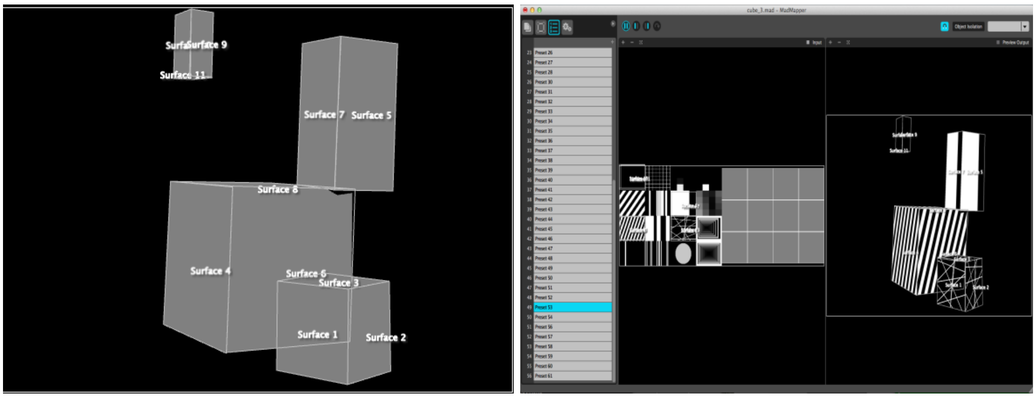

Figure 5. 3D modeling on MadMapper (left) and Patterns on objects (right).

The distance between the object and the projector in the experimental installation was about 5 meters, and the size of the whole object was about 3 meters by 2 meters. This projector offers vivid image display quality on objects. A DVI-RGB line was used as a connection cable between projector and the computer for high quality of definition. An ordinary MacBook laptop running MadMapper software supported the design and control of projection stimulus content.
Physical objects. We created a simple neutral environment consisting of simple rectangular boxes which sat in a neutral corner of experimental room.

3D Modeling Physical and Virtual Models. We used the program MadMapper to create our stimulus materials. MapMapper is a tool for making video-mapping projections and LED mapping. It supports the real time mapping of virtual textures to physical objects. For this task, we used iOS X framework called Syphon. On the input category, any material can be imported as an image, movie or Syphon source. The tools were used to calibrate the perspective transformations with a video warping of the content to the shape of the objects.

MadMapper was used to create a 3D virtual model of physical objects. Textures such as abstract images and moving textures in the form simple geometrical shapes were created and mapped in rectangular blocks to the shape of the objects. Each object face corresponded to a pattern on the virtual 3D model.

Maniplution, Projection Formats. To complete the operation, the set the patterns and their movements were fixed and applied to the faces (planes) of the 3D objects. In the 3D projection mapping condition the faces of the 3D virtual environment corresponded to the faces of the physical 3D objects. In the 2D projection condition the users saw the exact same 3D virtual boxes and textures while tow minutes, but these were projected on a standard flat screen surface.

Measures

Spatial Presence. To measure perceived spatial presence we used a questionnaire based on Measurement Effect Conditions-Spatial Presence Questionnaire (MEC-SPQ) and Lessiter et al.'s scales (2001). Both were modified for this research to provide six dimensions of spatial presence. MEC-SPQ was developed for measuring spatial presence in virtual reality. Because of the research context, in which we were comparing 3D projection mapping and 2D screens, two of the indexes in the questionnaire were not relevant, and we used only the other five indexes: Attention Allocation, Spatial Situation Model (SSM), Spatial Presence: Self Location (SPSL), Domain Specific Interest, and Visual Spatial Imagery.

Participants indicated how well the sentences—for example, "I devoted my whole attention to the [medium]"—described their impressions of the stimulus material, using ten-point Likert scales ranging from "Strongly Disagree" to "Strongly Agree."

According to Vorderer et al. (2004), MEC-SPQ has good internal consistency with respect to the variables Attention Allocation, Spatial Situation Model (SSM), Spatial Presence: Self Location (SPSL), Domain Specific Interest, and Visual Spatial Imagery, with Cronbach's alpha coefficients of .93, .90, .93, .93, and .82 reported. In the current study, the Cronbach's alpha coefficients were .94, 92, .88, .87, and .80.

User Satisfaction. We constructed a scale to measure participant satisfaction with the experience. Participants indicated how well the words "satisfied" and "enjoyable" described their impressions of the stimulus material on a ten-point Likert scale ranging from "Describes Very Poorly" to "Describes Very Well." In the current study, the perception of satisfaction portion of the questionnaire had good internal consistency with a Cronbach's alpha coefficient of .84.

Recognition Memory Test. To measure object recognition, the participants took a forced recognition test in which they viewed rotating images of the 3D shapes used in the study and an equal number of similar distractor shapes not used in the study. The participants were asked to respond as quickly as possible whether they had seen these shapes before. Their responses were measured for their accuracy and the speed of their response.

Procedure

Participants entered a room and were asked to simply observe an "artistic presentation." Depending on the condition participants either saw the environment projected onto 3D objects (3D projection condition) or onto a standard flat screen surface. Both presentations where in the same room and the same location within the room.

Immediately following the viewing of the experience participants were tested for their recognition memory, sense of presence, and satisfaction with the experience.

Results

Independent-sample t-tests were carried out to measure psychological effects on the two groups of participants, including spatial presence and satisfaction, as well as the memory recall test and response times.

Effects of Augmented 3D Projection Mapping on Spatial Presence and User Satisfaction

In this study, we found significant differences in various sub-dimensions of spatial presence: attention allocation, spatial situation model, and spatial self-location between the participants watching 3D projection mapping versus those viewing 2D projections on a screen.

There was a significant difference in attention allocation for the viewing of 3D projection mapping, M=7.09, SD=1.88 versus 2D projection on screen, M=6.07, SD=1.84, t(62)=-2.19, p=.03 (two-tailed). The spatial situation index displayed a significant difference for 3D M=5.32, SD=1.42 compared with 2D projection on screen M=4.30, SD=1.98, t(62)=-2.33, p=.02 (two tailed). Also, spatial presence: self location showed a significant difference between 3D projection mapping M=4.04, SD= 1.65 and 2D projection on screen M=3.21, SD=1.49, t(62)= -.84 (two tailed).

However, there were no significant differences for the domain specific interest (DSI) index for 3D projection mapping M= 3.44, SD=1.58 and 2D projection on the screen M=2.72, SD=1.49, t(62)=-1.87, p=.07 (two tailed), or for the visual spatial imagery (VSI) index for 3D projection mapping M=5.26, SD= 1.85 and 2D projection on the screen M=5.23, SD=2.01 t(62)=-.05, p=.96 (two tailed).

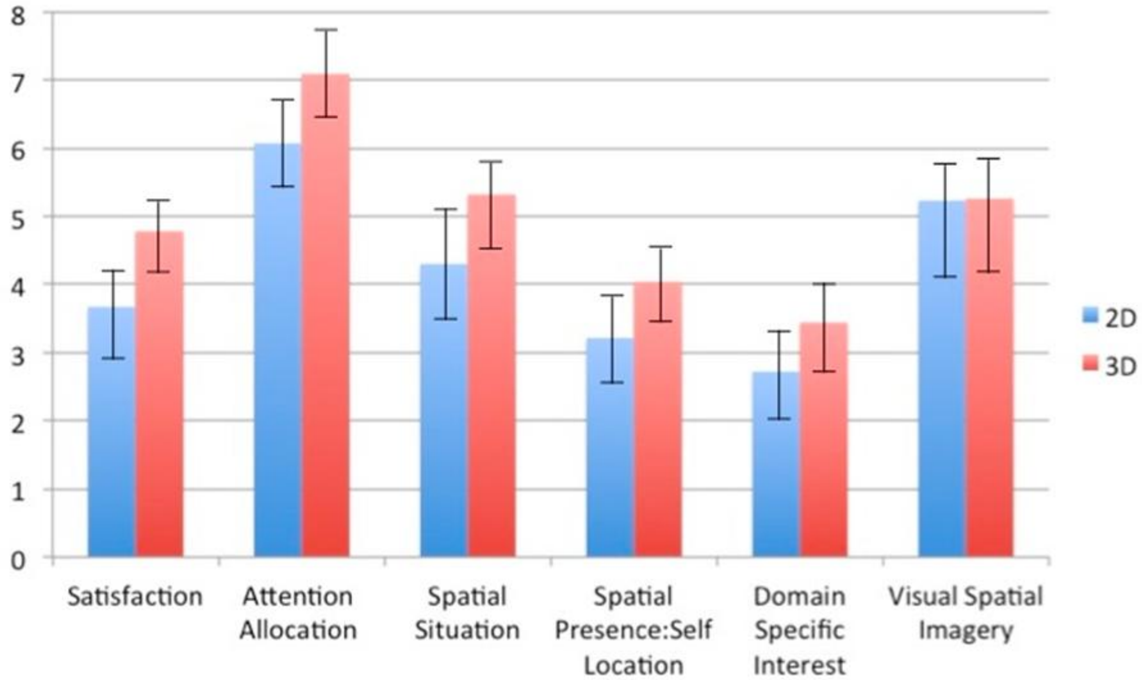

Figure 6. Mean Comparison of the effect of 3D projection mapping versus 2D projection on user satisfaction and various sub-dimensions of Spatial Presence.

The VSI and DSI portions of the questionnaire ask questions to establish the participants' original conditions, such as their own interest regarding the medium or their own ability for visual recognition: "In the past, I have spent a lot of time dealing with the topic of the [medium]," or "When someone shows me a blueprint, I'm able to imagine the space easily." The null effects are consistent with the meaningless stimuli used in this experiment.

Effects of Augmented 3D Projection Mapping on Viewer Satisfaction

Viewers of the 3D projection experience expressed levels of satisfaction that were almost 25% higher on our scale. There was a significant difference in satisfaction scores for 3D M=3.67, SD=1.36 and 2D projection M=4.78, SD=1.27, t(59.82)=-3.36, p=.001 (two-tailed).

Effects of Augmented 3D Projection Mapping on User Recognition Memory

There were significant differences in recognition memory for the spatial information, i.s., the ratio, location, and number of blocks, but not for the non-spatial information such as color. The rate of right answers and their response times showed significant differences between 3D projection mapping as compared to the standard 2D screen projection. Notably, participants where more than twice as accurate (230%) in correctly recognizing the location of remembered surfaces in the 3D projection mapping condition. For the size or number of objects represented participats in the 3D condition were between 15 to 25% more accurate.

Forced Choice Recognition Response Time. We tested the degree to which the patterns viewed were accessible in memory, or the speed of recognition of patterns viewed by the viewer. Viewers who watched the patterns on a 3D projection mapping were over 20% faster in recognizing the patterns than participants who viewed the same patterns on a 2D screen. For 3D projection mapping, M= 2759, SD=1465, and for 2D projection mapping, M=3362, SD=2248; t(31)= -3.09, p= .00 (two-tailed).

Table 1. Recognition Accuracy as a Function of the Type of Projection.

Recall	Type	Correct Answer Ratio	t
Number of Block	2D	86%	-2.03
	3D	99%	-1.859*
Location	2D	25%	-4.475
	3D	58%	-4.371***
Size of block	2D	66%	-2.053
	3D	85%	-1.973*
Color	2D	38%	0.422
	3D	36%	0.423

p<.10*, p<.05**, p<.01***

Discussion

Does 3D projection mapping, a form of augmented reality, have significant psychological effects on presence, experience, and memory? It appears that this medium does alter the perceptual experience and that the differences in experience and memory can be quite large. In this study we explored whether 3D mixed reality projection on physical surfaces significantly altered used experience of the virtual information and their memory. To add control we restricted the experience to abstract neutral shapes and primitive surfaces. Nonetheless, the results suggest that 3D augmented reality spatial mapping generate an experience of spatial information that appears to be more satisfying, makes users feel more present, and makes the spatial aspects of the information significantly more memorable.

Users found the experience of the spatial environment more satisfying in the 3D augmented reality.
The 3D projection environment appears to have moved the virtual information successfully into the user's physical space. Viewers of the 3D projection environment felt as if they were inside the space (spatial self location). The environment was spatially coherent (sptial situation model). The experience was as a whole over 25% more satisfying in the 3D projection environment. We can interpret this as a feeling that these patterns appeared to be in their space and seemed more real to the participants. These effects occur in this study even with impoverished abstract patterns that have little representational meaning.

Projection mapping makes information more spatial and embedded in the space relative to the user's body. The spatial configuration of the information appears to make is easier for users to remember what they have seen, even for complex abstract patterns. The effect appeared to be focused on the spatial features of the information. Viewers of the 3D environment were able to recall the location of patterns more than twice (230%) as well as those viewing a standard 2D (filmic) presentation. They also had superior memory for objects number and size. All this information was more accessible to memory showing recognition levels that were over 20% faster.

The spatial information is augmented by 3D projection by not other aspects. The results of the memory recall and recognition tests were associated with faster and better memory of objects' locations, the ratio of the patterns, and their number, but not their color. So 3D project mapping appears to improve memory for spatial information and patterns but not for non-spatial information such as color. The fact 3D projection augmented reality facilities memory has implication for the use of these spaces for interfaces, training, and other learning applications.

There are some potential limitations. We cannot rule out that some of the effects may be due to the novelty of the displays and experience, even though several participants reported seeing 3D projection graphics before seeing them in the experiment.

Implications

According to our findings, 3D projection mapping, as compared with 2D projection, has greater effects on satisfaction and spatial presence, as well as recognition and memory for objects. All of these psychological effects could be relevant for the use of 3D projection mapping for designing effective learning, advertising, and persuasion environments as well as other experiences as compare to standard projection technologies.

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