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Cognitive Transfer of Spatial Awareness from Immersive Virtual Environments to Reality

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An individual's prior experience will influence how new visual information in a scene is perceived and remembered. Accuracy of memory performance per se is an imperfect reflection of the cognitive activity (awareness states) that underlies performance in memory tasks. The aim of this research is to investigate the effect of varied visual fidelity on the *transfer of training* to the real-world after exposure to immersive simulations representing a real-world scene. A between groups experiment was therefore carried out to explore the effect of rendering quality on measurements of location-based recognition memory for objects and measurements of any associated states of awareness. The immersive simulation consisted of one room that was either rendered flat-shaded or using radiosity rendering. The simulation was displayed on a stereo head-tracked Head Mounted Display. After the immersive simulation, participants completed a recognition memory task in a real-world scene by physically arranging objects (in their physical form) in a real world room In addition to the recognition memory task, participants also reported one of four states of awareness following object recognition. Participants were given several options of awareness states that reflected the level of visual mental imagery involved during retrieval, the familiarity of the recollection and also included guesses. The scene also incorporated objects that 'fitted' into the specific context of the real-world scene (an academic's office), referred to as *consistent* objects, and objects which were not related to the specific context of the real-world scene,referred to as *inconsistent* objects. A follow-up study was also conducted a week after the initial test. Interestingly, results revealed a higher proportion of correct object recognition that was associated with an awareness state based on mental imagery when the immersive simulation was flat-rendered rather than radiosity rendered This supports similar results from previous studies and extends them to the transfer of training. Memory psychology indicates that awareness states based on visual imagery require stronger attentional processing in the first instance than those based on familiarity. A tentative claim would therefore be that those immersive environments that are distinctive because of their variation from 'real', such as flat-shaded environments, recruit stronger attentional resources. This additional attentional processing may bring about a change in participants' subjective experiences of 'remembering' when they later transfer the training from that environment into a real-world situation.

Categories and Subject Descriptors: H.1.2 [**Models and Principles**]: User/Machine Systems - Human factors; I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism - Virtual Reality;
General Terms: Design, Experimentation, Human Factors
Additional Key Words and Phrases: Human-computer interaction, perception

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1. INTRODUCTION

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The utility of Virtual Environment (VE) technologies for training systems such as flight simulators is predicated upon the accuracy of the spatial representation formed in the VE. Spatial memory tasks, therefore, are often incorporated in benchmarking processes when assessing the fidelity of a VE simulation. Spatial awareness is significant for human performance efficiency of such tasks as it is derived from spatial knowledge of an environment (Lathrop & Kaiser 2002; Dihn, Walker & Hodges 1999, Williams, W. Narasimham, G., Westerman, C., Rieser, J. and Bodenheimer, B. 2007). A central research issue therefore for real-time VE applications for training is how participants mentally represent an interactive computer graphics world and how their recognition and memory of such worlds transfer to real world conditions (Mania, Troscianko, Hawkes & Chalmers 2003, Mania, Adelstein, Ellis & Hill 2004, Fink, W., Foo, P.S., Warren, W. 2007). Previous research has examined the variables that communicate transfer of spatial knowledge acquired in a simulation environment, in the real-world and discuss the form and development of spatial awareness in VE training compared to either real-world training or training with maps, photographs and blueprints (Bliss, Tidwell & Guest 1997; Bailey & Witmer 1994). The suitability of VE systems as effective training mediums was examined and was concluded to be as effective as map or blueprint training. Specifically, research reported by Bliss, Tidwell and Guest (1997) concluded that configurational knowledge acquisition based on estimation of absolute distances and directions between known points could yield training effects similar to training with photographs and real world training. Furthermore, estimation of travel distance from optic flow is subject to scaling when compared to static intervals in the environment, irrespective of additional depth cues (Frenz, H. Lappe, M., Kolesnik, M., Bührmann, T. 2007).

Past research often aims to identify the minimum system characteristics relevant to rendering computations and interaction interfaces that would yield the maximum performance on a task or the greatest sense of presence. For example, search objects rendered in global or ambient illumination have been shown to take significantly longer to identify than those rendered in a local illumination model, (Zimmons 2005). However, there is still the need for a study based on an overt task with the characteristics that is can be learned and it can be assessed in a quantitative manner. What if the visual fidelity of a system could be assessed across a range of applications? In this context we can ask: Can we interrogate the human cognitive systems that are activated when training within VE scenes of varied visual or interaction fidelity is transferred into a real-world situation?

Which simulation characteristics should we optimize in order to match the capabilities of the VE system to the requirements of these cognitive systems?

Because of the wide-range of VE applications and differences in participants across their backgrounds, abilities and method of processing information, an understanding of *how* spatial knowledge is acquired within a VE, complementing spatial memory performance per se, is significant. Common strategies may be revealed across a range of applications and tasks. The study presented in this paper focuses upon the effect of rendering quality on object-location recognition memory, and its associated awareness states when knowledge is transferred from an immersive environment into a real-world situation. Two visual quality conditions were employed within the immersive environment. These were flat-shaded computer graphics rendering versus radiosity rendering. The main premise of the experiment presented here is that accuracy of performance per se is an imperfect reflection of the cognitive activity that underlies performance on memory tasks in simulation environments. This is in line with past psychology literature (Tulving 1985, Brandt, Gardiner & Macrae 2006, Dewhurst, S.A., Holmes, S.J., Brandt, K.R., & Dean G.M. 2006).

1.1 Memory for Spaces

Accurate recognition memory can be supported by: a specific recollection of a mental image or prior experience (remembering); reliance on a general sense of knowing with little or no recollection of the source of this sense (knowing); guesses. Gardiner and Richardson-Klavehn (1997) explained the 'remembering' as 'personal experiences of the past' that are recreated mentally. Meanwhile 'knowing' refers to 'other experiences of the past but without the sense of reliving it mentally'. The work of Tulving (1985) first suggested that remembering and knowing were measurable constructs. Through a series of experiments, Tulving (1985) reported that participants find it easy to distinguish between experiences of remembering and knowing when self-reporting their experiences. The sense of knowing has since be further divided into two related concepts. Firstly, the correct answer may be just 'known' without the associated recollection of contextual detail associated with 'remembering'. Secondly, the answer may feel more familiar than a un-informed guess, but cannot be considered as being known ('familiar').

According to this theoretical framework derived from memory psychology, measures of the accuracy of memory can be complemented by self-report of states of awareness such as 'remember', 'know', 'familiar' and 'guess' during recognition

(Conway et al. 1997). Previous studies have investigated the relationship between recognition memory and simulation environments of varied visual and interaction fidelity. Such work by the authors of this paper revealed varied distribution of awareness states whilst overall accuracy remained the same across experimental conditions suggesting that measurement of awareness states acts as a useful additional measure to supplement that information provided by accuracy (Mania, K., Wooldridge, D., Coxon, M., Robinson, A. 2006; Mania, Troscianko, Hawkes & Chalmers 2003).

Moreover, it has been shown that memory performance is frequently influenced by context-based expectations (or 'schemas') which aid retrieval of information in a memory task (Minsky 1975). A schema can be defined as a model of the world based on past experience which can be used as a basis of remembering events and provides a framework for retrieving specific facts. Previously formed schemas may determine in a new, but similar environment, which objects are looked at and encoded into memory (e.g., fixation time). They also guide the retrieval process and determine what information is to be communicated at output (Brewer & Treyens 1981). Different theoretical models support specific hypotheses regarding how schemas influence memory. Pichet's & Anderon's (1966) schema model predicts better memory performance for schema consistent items (items that are likely to be found in a given environment) claiming that inconsistent items are mostly ignored. Contrarily, the dynamic memory model (Schank 1999, Holingworth & Henderson 1998) are consistent with the idea that schema-inconsistent information for a recently-encountered episodic event will be easily accessible and therefore would provoke better memory performance.

The work presented here aims to interrogate the mental processes associated with obtaining spatial knowledge during exposure to a simulated scene and transferring such knowledge in the real-world scene simulated. An object-memory task is performed in the simulated real-world environment immediately after VE training and one week after the VE exposure. The virtual scene was rendered with one of two levels of *visual* fidelity (flat shaded vs. radiosity rendering) and displayed on a stereo Head Mounted Display (HMD). A follow-up study explored memory retention a week after the initial study. The experimental scene consisted of one room depicting an academic's office. Central to this work is identifying whether high fidelity or low fidelity scenes are associated with stronger visually induced recollections ('remember' awareness state). A secondary, exploratory goal is to investigate the effect of schemas on memory recognition in the real-world after exposure to the synthetic scene. Memory recognition studies in synthetic

scenes have demonstrated that low interaction fidelity interfaces (such as the mouse compared to head tracking) as well as low visual fidelity scenes provoked a higher proportion of visually-induced recollections ('remember' awareness state), while there was no effect of condition upon memory recognition performance (Mania, Troscianko, Hawkes & Chalmers 2003, Mania, Woodridge, Coxon, Robinson 2006).

Broadly, desirable influences on recognition memory and the associated cognitive states may be ultimately identified and generalized to aid specific applications. To this end, previous studies have not yet explored the effect of visual quality on the transfer of spatial knowledge acquired in a simulated space, to the real world . It could be true, for instance, that for flight simulation applications it is crucial for trainees to remember mental images associated with instruments as opposed to recollections that are confident but not accompanied by similar mental imagery when their experiences are transferred into a real-world flight situation. The following experiment therefore explores the effect of training in immersive environments of varied visual fidelity on the distribution of memory awareness states measured in a real-world task. The fact that it has been shown that interfaces of low interaction or visual fidelity induce a higher number of recollections based on mental imagery when compared with systems of high visual or interaction fidelity, may relate to attentional resources directed to systems that vary strongly from the real-world. We now explore the effect of training in immersive environments of varied visual fidelity on the distribution of memory awareness states acquired in the real-world task situation and we endeavor to explain the consistent pattern of results mentioned above in addition to findings in this paper.

2 MATERIALS AND METHODS

2.1 Participants

24 participants were recruited from the postgraduate population of the University of Sussex, UK and University of Brighton, UK through the use of electronic adverts and they were paid for their participation. A between subjects design was used. The 24 participants were separated into 2 groups of 12 corresponding to two fidelity conditions (flat-shaded vs. radiosity). 62% of the participants in each group were female and all used computers a great deal in their daily activities. The groups were also balanced for age and gender and participants in all conditions were naive as to the purpose of the experiment. Finally, all participants had normal or corrected to normal vision and no reported neuromotor impairment.

2.2 Apparatus

The VEs were presented in stereo at VGA resolution on a Kaiser Electro-optics Pro-View 30 Head Mounted Display with a Field-of-View comprising 30 degrees diagonal. An Intersense Intertrax2, three degree of freedom tracker was utilized for rotation. The viewpoint was set in the middle of the virtual room and navigation was restricted to 360 degrees circle around that viewpoint (yaw) and 180 degrees vertically (pitch). Participants sat on a swivel chair during exposure. The application ran on a standard PC. The frame rate was retained constant across conditions at 14 frames per second.

2.3 Visual Content

According to the training group that they were assigned to, participants completed the same memory recognition task in the real-world after exposure to one of two simulation counterparts:

- *HMD high-quality radiosity condition:* A high quality, interactive radiosity simulation of an office on a stereo head-tracked HMD; referred to as the *HMD high-quality condition*
- *HMD flat-shaded condition:* A low quality, interactive flat-shaded simulation of the same office on a stereo head-tracked HMD; referred to as the *HMD low-quality condition.*

The rendered environments differed with regard to the nature of shadows (Figure 2). Flat-shaded scenes did not include any. Radiosity algorithms display view-independent diffuse inter-reflections in a scene assuming the conservation of light energy in a closed environment. In radiosity, surfaces of objects are divided into patches or elements. Despite transmitting energy to others, a patch will also reflect the energy from other meshes that arrives on its surface into the scene. These processes will be iterated until energy equilibrium in the close space is achieved. Radiosity produces colour-bleeding effects from one surface to another, shades inside the shadow area and creates soft-edge shadow with penumbrae along shadow boundaries. All of these results imitate the physical propagation of light in the real environment. The number of algorithmic iterations of surface light propagation as increased, it improves the radiosity's shading accuracy and polygon count.

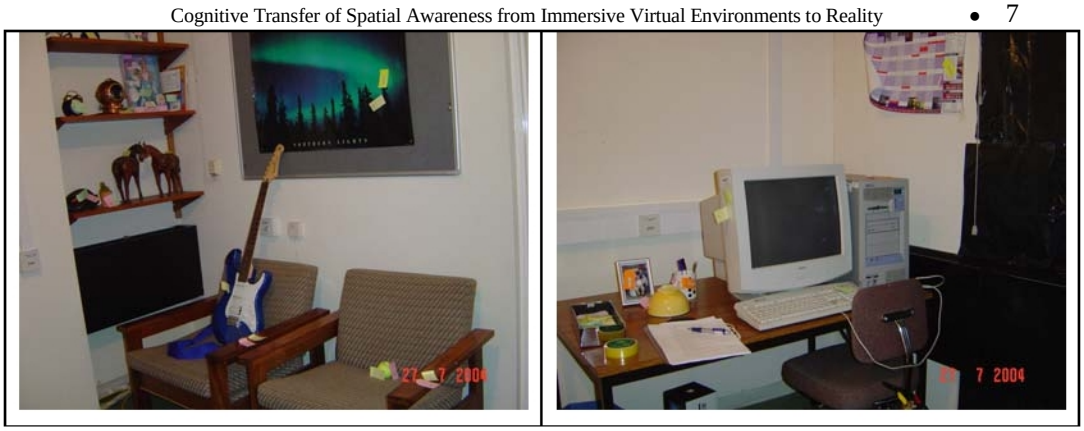

Fig. 1. Real-world experimental space after completion of object arrangement task

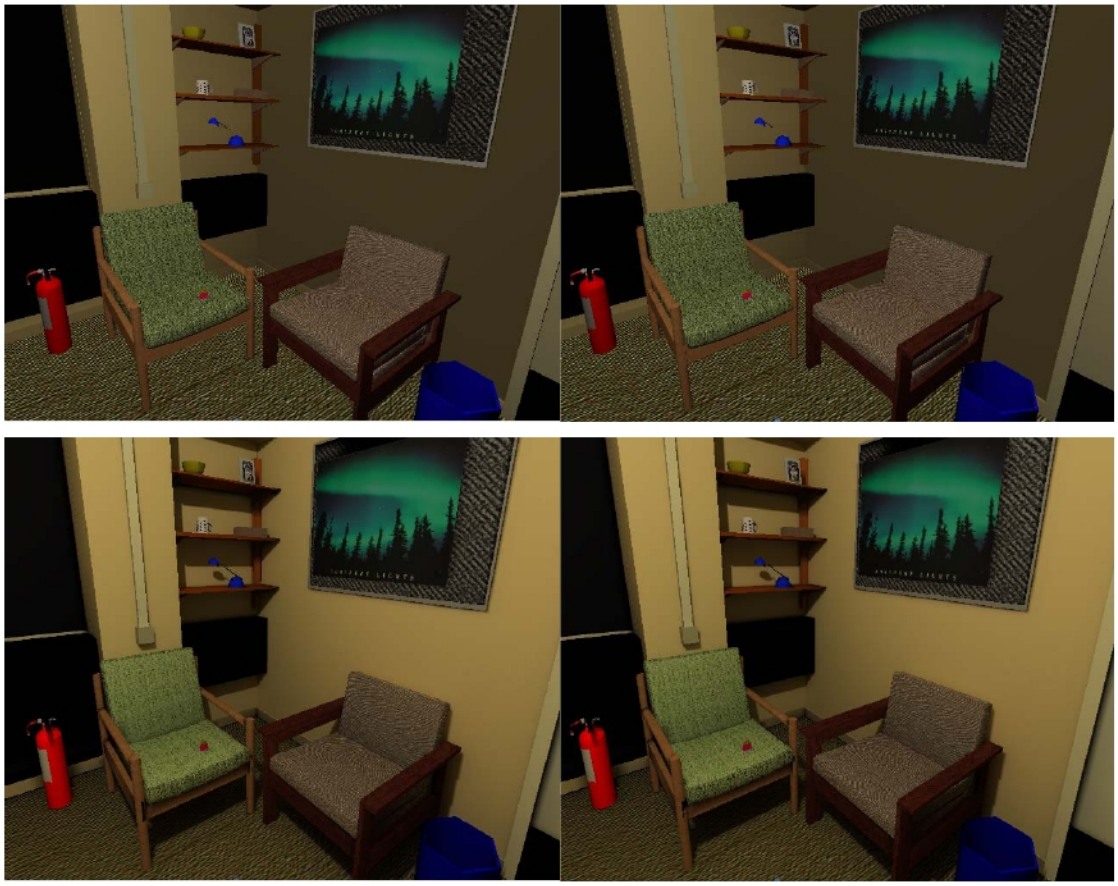

Fig. 2. Flat-shaded (top) and high quality environment (bottom)

The colours of the basic frame of the scene (ceiling, walls, floor) were based on chromameter's readings based the CIE(x,y) chromaticity and luminance (Y) values of the light and surfaces of the actual room (Figure 1). These readings were converted to RGB in order to be used for the rendering (Travis, D.1991). The CIE (1931) colour space is based on colour matching functions derived by human experimentation and it incorporates the trichromacy of the Human Visual System (HVS). The usefulness of the CIE(x,y) representation is that it allows colour specification in one language, however, equal geometric steps of CIE(x,y) space do not correspond to equal perceptual steps.

Before specifying display colours, it is necessary to compute the tristimulus matrix of the display in question. In order to compute the RGB tristimulus matrix, the chromaticity co-ordinates of the three display phosphors in CIE(x,y) space are required. In addition, the chromaticity co-ordinates of the white that the three phosphors of the display produce when turned on at their maximum are also required (Travis, 1991). Generally, the RGB system is a means for describing colours on a display monitor. It does not take into account the energy that is produced in the physical world in terms of the distribution over wavelength and also how the HVS responds to this distribution. In order to render the scene, the materials' diffuse colour needs to be specified not the colour observed under a particular light source. The final colour for each measured material in the scene was estimated by dividing its RGB value by the RGB value of the observed white in the scene, which is the colour of the light source in the scene. Using the relevant geometry and surfaces and illuminant measurements converted to RGB triplets as input, the rendered model was created using a radiosity rendering system (Figure 2). The final radiosity solution consisted of a finely meshed model which could be interactively manipulated. This was the basis for the application displayed on the desktop monitor and on the HMD.

In order to maintain the parity of the environments with regard to the display update speed of each simulation given the different computational loads of flat shading and radiosity techniques, the maximum frame rate for both environments was set at 14 frames per second (fps) using a simple frame rate counter. This frame rate counter function calculated the actual frame rate of the environment was running at, compared it to the desired 14 fps and paused the simulation for the amount of time corresponding to the differential in the frame-rate. Each environment was presented in stereoscopic 3D by applying a dual channel video technique.

The synthetic scene consisted of an academic's office (Figure 1). The objects were provided in their physical form in the real-world scene, placed on one side of the real-world scene randomly, and came from four categories:

- Twelve consistent objects that were present (computer, monitor, desk, paper bin, etc.)
- Twelve consistent objects, that were absent (telephone, pens, computer mouse, etc.)
- Twelve inconsistent objects that were present (skull, Viking helmet, etc.). • Twelve inconsistent objects that were absent (soldering iron, wrench, etc.)

The collection of these objects was largely based on a previous real-world study by Brewer & Treyens (1981). Consistent objects were related to the office schema, e.g. it is likely that they are found in a graduate's office. Inconsistent objects are not likely to be found in an academic's office, therefore, they were not associated to the office schema. This categorisation was the result of a pre-exposure study by Brewer & Treyens (1981). There was a total of forty-eight objects provided to participants in the real-world room. A subset of those is listed in Table 3. The test objects were roughly of equivalent size in order of them to be easily grasped and placed in appropriate positions, but also to control for variations in memory performance based on the size of the objects.

2.4 Procedures

The Inter Pupilary Distance (IPD) of each participant was measured prior to exposure and the stereo application's parallax was adjusted accordingly for each individual. The exposure time was 120 seconds in each condition. Once the HMD was fitted, participants were instructed to look around the room at their own pace and to examine it in all directions. At the start of the simulation, a pop-up window was generated utilised to acquire each participant's ID. Once the ID had been entered, the window was removed and a timer started. When this timer indicated that the 120 seconds of exposure had expired, the simulation was shut down automatically, ensuring that each test participant was restricted to exactly 120 seconds of exposure to the environment. During the simulation exposure, the room where the simulation viewing took place was kept dark in order to block any peripheral disturbance.

Exposure time was determined by pilot studies that explored the relationship between exposure time, floor effects (the task being too hard) and ceiling effects (the task being

too easy). Participants were led to believe that this was a practice phase of the main experiment, thus, they were not aware of the experimental task to follow.

After exposure, each participant was guided in the actual physical room where they completed an object arrangement task. The physical room was identical to the virtual room in terms of layout and furniture, however, there were no objects scattered around the room as in the simulated room. The set of objects mentioned above laid at one side of the room on the floor. Before the arrangement task started each participant was instructed to physically place the objects in the exact locations seen in the simulation. Every assignment of an object at a chosen location was accompanied by placement of two stickers on each object. One sticker incorporated a self-report of awareness states for every recognition. There were four choices: Remember, Know, Familiar or Guess.The second sticker was used to record confidence ratings. These ratings related to how confidenct participants were that the object was located at each particular position. There were five choices: No confidence, Low confidence, Moderate confidence, Confident, Certain.

The participants were required to place each object at their chosen location in the physical room starting with the positions they were most confident that they remembered (Figure 3). Prior to the object placement task, awareness states were explained to the participants in the following terms:

- REMEMBER means that you can visualise clearly the object in the room in your head, in that particular location. You virtually 'see' again elements of the room in your mind.
- KNOW means that you just 'know' the correct answer and the alternative you have selected just 'stood out' from the choices available. In this case you can't visualise the specific image or information in your mind.
- FAMILIAR means that you did not remember a specific instance, nor do you know the answer. It may seem or feel more familiar than any of the other alternatives.
- GUESS means that you may not have remembered, known, or felt that the choice you selected have been familiar. You may have made a guess, possibly an informed guess, e.g. you have selected the one that looks least unlikely.

Fig. 3. Arrangement task in the physical room (left) after training in the synthetic room (right)

Table 1: Dependent measures of presented experimental framework

Memory performance	Count of correct placements of objects in the physical room in relation to object positions in the synthetic scene. Also, count of correct placements in the physical room a week after the initial training.
Prior probabilities	Calculation of proportion of correct placements associated with each of the remember, know, familiar and guess awareness states during the initial study as well as during the retention test as week after the initial training.
Posterior probabilities	Calculation of probabilities that correct placements associated with each of the remember, know, familiar and guess awareness states are correct, during the initial study as well as during the retention test as week after the initial training.
Confidence scores	Global confidence scores for correct placements during the initial study as well as during the retention test as week after the initial training.
Idle time	Idle time is defined as the time during which the view direction does not change. Comparison of idle time across viewing conditions.
Memory performance of consistent/inconsistent objects	The scene comprised of consistent objects (objects which can be found in an office) and inconsistent objects. Of exploratory nature for this study.

2.5 Measures

Memory performance was measured by counting the number of correct placements of objects in the physical room, compared to the simulation. A count of correct placements in the physical room a week after the initial training was also conducted in order to investigate memory over time. Table 1 presents a summary of dependent measures utilized in the studies presented. For the purpose of this study each memory recall question included a 5-scale confidence scale and a choice between 'remember', 'know', 'familiar' as well as 'guess' awareness states. The goal of this strategy was to identify the distributions of awareness states responses across conditions focusing on visually induced recollections. This could reveal cognitive variations that could not be investigated by focusing on memory performance only.

Awareness state data was considered in terms of both *prior* and *posterior* probabilities. Prior probabilities reflect on the following: Given that the response of a participant is correct (correct placement of object), what is the probability that the participant has chosen a particular awareness state? Posterior probabilities, on the other hand, pose the following question: Given that a response of a participant was assigned to one of the four memory awareness response categories, what is the probability that the response (correct placement of object) is correct?

Koriat & Goldsmith (1994) have drawn an important distinction between the amount or quantity remembered compared to the accuracy or quality of what is remembered. In the quantity analysis memory awareness states data were represented as *a priori* or *prior* probabilities. Although this notation does not follow the Bayesian probability theory principles for 'prior' probabilities, it was adopted as such in this paper following the notation of earlier memory research (Koriat & Goldsmith, 1994, Conway et al. 1997). Prior probabilities were obtained by calculating the proportions of correct answers falling in each of the four memory awareness categories for each participant. In the accuracy analysis, correct recall scores were represented as *posteriori* or *posterior probabilities*. In order to calculate posterior probabilities, the proportion of correct answers from the total of answers given in each memory awareness category were computed for each participant.

For participant n,

X_{in} is the number of correct answers for the i awareness state,

x'_{in} is the number of incorrect answers for the *i* awareness state,

i = {remember, know, familiar, guess} = {1,2,3,4}

then,

P_{in} is the prior probability for awareness state *i* related to participant ***n***,

$$P_{in} = \frac{x_{in}}{\sum_{i=1}^{4} x_{in}}$$

P'_{in} is the posterior probability for awareness state *i* related to participant ***n,***

$$P'_{in} = \frac{x_{in}}{x_{in} + x'_{in}}$$

Whilst neither the Brewer & Treyens experiment nor this research included systems necessary to track eye movement, a record of each test participant's head movement was monitored through software as exposure time may affect memory encoding. Whilst this information is not at a high enough resolution to be useful in determining the time spent looking at each object, the amount and location of participants' idle time was monitored so as to ascertain that it was similar across conditions. Idle time is defined as the time during which participants' viewpoint or view direction doesn't change. Such measurements were significant in order to meaningfully compare memory recognition scores and confidence ratings across conditions because participants might not have distributed exposure time evenly while observing the experimental scene. Participants who, for instance, spent 120 seconds of exposure time observing just one wall of the room were excluded from the statistical analysis. Therefore, the goal of monitoring idle time was to ensure that idle time of participants across conditions as well as idle time for each participant observing sections of the room would be similar. A measurement was taken once every 4 frames, providing 3 measurements every second across all conditions.

Table 2. Means and Standard deviations for accurate object-location arrangement and confidence scores as a function of viewing condition (n = total number of participants per condition).

	Viewing condition	
	Flat -shaded (n=12)	**Radiosity (n=12)**
Task scores for initial test (out of 24)	11.91(3.57)	10.25 (2.95)
Task scores for retest (out of 24)	12.33 (2.53)	11.50 (4.14)
Confidence scores (out of 5) for initial test	3.74 (0.65)	3.38 (0.69)
Confidence scores (out of 5) for retest	2.93 (0.66)	2.67 (0.70)

Table 3. Prior/posterior probabilities and standard deviations as a function of viewing condition (n = total number of participants per condition).

	Viewing condition - Main task		**Viewing condition - Retest**	
	Flat-shaded (n=12)	**Radiosity (n=12)**	**Flat-shaded (n=12)**	**Radiosity (n=12)**
Prior (Remember)	0.72 (.19)	0.40 (.22)	0.56 (.22)	0.42 (.25)
Prior (Know)	0.13 (.12)	0.30 (.22)	0.15 (.12)	0.29 (.22)
Prior (Familiar)	0.09 (.10)	0.14 (.091)	0.20 (.15)	0.14 (.10)
Prior (Guess)	0.05 (.05)	0.13 (.07)	0.08 (.07)	0.13 (.12)
Posterior (Remember)	0.96 (.09)	0.87(.29)	0.94 (.08)	0.92 (.16)
Posterior (Know)	0.48 (.42)	0.89 (.29)	0.61 (.42)	0.73 (.44)
Posterior (Familiar)	0.55 (.45)	0.61 (.41)	0.67 (.32)	0.53 (.34)
Posterior (Guess)	0.35 (.38)	0.66 (.33)	0.43 (.41)	0.41 (40)

Table 4. The overall object's ranking in terms of mean confidence rating across all object categories. Note: PCon (Present Consistent), Pin (Present Inconsistent), ACon (Absent Consistent), Ain (Absent Inconsistent).

Ranking	Object	Category	Mean Confidence
1	Electric Guitar	PIn	4.458
2	Poster	PCon	3.708
3	Fire extinguisher	PIn	3.417
4	Magazine	PIn	3.125
5	Pliers	PIn	3.125
6	Desk lamp	PCon	2.833
7	Tennis ball	PIn	2.708
8	Frisbee	PIn	2.542
9	Monitor	PCon	2.208
10	Hammer	PIn	2.125
11	Screw driver	PIn	1.960
12	Year planner	PCon	1.792
13	Stapler	PCon	1.750
14	Mug	PCon	1.583
15	Picture frame	PCon	1.458
16	CPU	PCon	1.333
17	Keyboard	ACon	1.208
18	Plant	ACon	1.208
19	Bowl	PIn	1.167
20	Books	ACon	0.708

3 RESULTS

The participants completed the object arrangement task in the physical room after exposure. The confidence ratings and recognition memory scores were analyzed using analysis of variance (ANOVA). Memory performance scores in conjunction with reported awareness states lead to the calculation of prior and posterior probabilities associated with each awareness state. Confidence scores linked with correct recollections were globally assessed across viewing conditions as well as statistically correlated with the number of correct responses related to each awareness state. A retention memory test took place a week after the initial training.

The total number of objects that were correctly located in the physical room was calculated for each participant after completion of the initial task as well as after the retention test a week after. The memory performance measures were subjected to a 2 (viewing condition: high-quality vs. low-quality) x 2 (testing session: test vs retest) mixed ANOVA with viewing condition as a between-subjects factor and testing session as a

within-subjects factor, with number of correct responses as the dependent variable. Table 2 shows the mean accurate recognition scores and standard deviations (in parenthesis) as a function of viewing condition and test/retest session. All effects were evaluated at a p-level of 0.05 to determine statistical significance. There was a significant main effect for testing session, $F(1,22)=5.01$, $p<0.05$, revealing that objects were more likely to be arranged correctly a week after exposure to the simulated room, (Respective Ms 11.08 vs 11.9, test vs retest) but not for viewing condition, $F(1,22)=0.89$, $p>0.05$. The interaction between testing session and viewing condition was not significant, $F(1,22)=1.25$, $p>0.05$. Respective performance means for test/retest are quite similar.

Prior probabilities indicate the proportion of correct answers under each memory awareness state (Table 3). The prior probabilities for the main task were subjected to a 2 (viewing condition: flat-shaded vs. radiosity) x 4 (awareness state: remember vs know vs familiar vs guess) mixed ANOVA with viewing condition as a between-subjects factor and awareness state as a within-subjects factor. There was a significant effect of awareness state, $F(3,66) =37.44$, $p<0.05$. . The interaction between awareness states and viewing condition was also significant, $F(3,66) = 9.102$, $p<0.05$. Subsequent one-way ANOVA analyses were conducted on responses in each of the awareness states separately with viewing condition as the grouping factor. There was a significant main effect of condition upon the 'remember' awareness state, $F(1,22) = 13.39$ $p<0.01$ (Respective Ms .72 vs .40, flat-shaded vs radiosity), the 'know' awareness state, $F(1, 22) = 5.50$, $p<0.05$ (Respective Ms. .13 vs. .30, flat-shaded vs. radiosity) and the 'guess' awareness state, $F(1,22) = 10.28$, $p<0.01$ (Respective Ms .05 vs .13, flat-shaded vs radiosity). The proportion of correct answers associated with the 'remember' awareness state was significantly higher after training in the low fidelity condition compared to the radiosity scene. The proportion of correct answers associated with the 'know' awareness state was significantly higher in the high fidelity scene compared to the flat-shaded one. Moreover, the proportion of correct recollections associated with the 'guess' awareness state was significantly higher in the radiosity condition compared to the flat-shaded scene.

Posterior probabilities represent the probability that a memory recall response assigned to each of the memory awareness states is accurate (Table 3). The posterior probabilities for the main task were subjected to a 2 (viewing condition: flat-shaded vs. radiosity) x 4 (awareness state: remember vs know vs familiar vs guess) mixed ANOVA with viewing condition as a between-subjects factor awareness state as a within-subjects factor. There was a significant effect of awareness state, $F(3,66)=6.17$, $p<0.05$. There was

also a significant effect of viewing condition, $F(1,22) = 5.793$, $p<0.05$. The interaction between awareness state and viewing condition was not significant. One-way ANOVA analyses were conducted on responses in each of the awareness states separately with viewing condition as the grouping factor. Interestingly, there was a significant effect of condition upon the 'know' awareness state, $F(1,22)=7.67$, $p<0.05$ (Respective Ms. .48 vs. .89, flat-shaded vs radiosity) and upon the 'guess' awareness state, $F(1,22)=4.64$, $p<0.05$ (Respective Ms .35 vs .66, flat-shaded vs radiosity). Observers who reported the 'know' awareness state were associated with a higher posterior probability or probability that their response was correct when exposed to the radiosity condition compared to the flat-shaded condition. Observers who reported the 'guess' awareness state were associated with a higher posterior probability or probability that their response was correct when exposed to the radiosity condition compared to the flat-shaded condition.

Confidence scores were analysed using a *t*-test with viewing condition as the grouping factor and participant's confidence scores as the dependent value. Confidence scores associated with the flat-shaded condition were significantly higher than the ones associated with the radiosity condition, $t(22)=21.60$, $p<.05$ (Respective Ms 3.74 vs 3.38, flat-shaded vs radiosity). Correlation analysis between the prior probabilities derived from the awareness states results and confidence scores as well as memory recognition scores revealed a varied pattern of significant correlations (Pearson's, n=24). There was a significant positive correlation between confidence scores and correct 'remember' responses for the flat shaded condition, $r = 0.60$, $p<0.05$ but also for the radiosity condition, $r = 0.61$, $p<0.05$. Moreover, there was significant positive correlation between confidence scores and correct 'know' responses for the flat-shaded condition, $r = 0.754$, $p<0.01$.

The prior probabilities for the retest were subjected to a 2 (viewing condition: flat-shaded vs. radiosity) x 4 (awareness state: remember vs know vs familiar vs guess) mixed ANOVA with viewing condition as a between-subjects factor and awareness state as a within-subjects factor (Table 3). There was a significant effect of awareness state, $F(3,66) =17.43$, $p<0.05$. The interaction between awareness states and viewing condition was not significant, $F(3,66)=2.17$ $p>0.05$. The posterior probabilities for the retest were subjected to a 2 (viewing condition: flat-shaded vs. radiosity) x 4 (awareness state: remember vs know vs familiar vs guess) mixed ANOVA with viewing condition as a between-subjects factor and awareness state as a within-subjects factor. There was a

significant effect of awareness state, $F(3,66) = 9.02$, $p<0.05$. The interaction between awareness states and viewing condition was not significant, $F(3,66)=.56$ $p>0.05$.

Mean confidence ratings concerning a subset of individual objects found in the scene are listed in Table 4. Idle time measurements were statistically similar while training in either of the two visual conditions. Participants who demonstrated extreme variations in relation to mean idle time or uneven navigation tendencies, e.g. being idle for most of the time or not having observed large sections of the experimental room, were excluded from the study.

Detailed results concerning recognition memory performance for consistent and inconsistent objects in the scene were not calculated because this investigation was of exploratory nature and out of the main scope of the studies presented here. However, certain observations are included in the Discussion below. Mean objects' confidence ratings across all object categories are included in Table 4.

4 DISCUSSION

The results demonstrated that participants who trained in the low fidelity simulation reported a larger proportion of correct 'remember' responses while conducting the memory recognition task in the real-world situation compared to participants trained in the high fidelity simulation. These results were consistent with previous findings that associated a larger proportion of correct 'remember' responses with *low* visual and interaction fidelity simulations. (Mania, Troscianko, Hawkes & Chalmers 2003; Mania, Woolridge, Coxon & Robinson, 2006). The results observed consistently in previous studies was also observed in this study despite the fact that participants *physically* performed the task in the real-world room after training in its simulated counterpart, an ecologically plausible training scenario.

Recent developments in psychological research have shown that distinctive information or experiences generate more awareness states associated with 'remembering'. For example, participants who are shown typical and distinctive faces are more likely to recognise the distinctive faces in a later memory test with an accompanying experience of 'remembering' (Brandt, Macrae, Schloerscheidt, & Milne 2003). Similar results have also been found using other stimuli such as forenames (Brandt, Gardiner, & Macrae 2006).

In the current context, a low fidelity rendered simulation could be considered as being more distinctive than a high fidelity rendered simulation because of its variation from

'real'. Given that these are immersive environments, distinctiveness in this instance would be judged relative to reality. The less 'real' the environment is, the more distinctive it can be considered. It would be expected that a more distinctive immersive environment (e.g. low fidelity one) would result in more 'remember' responses than a less distinctive immersive environment (e.g. a high fidelity one). It is worth noting that distinctiveness in this sense may not only refer to visual distinctiveness but to motor responses to the environments (Mania, Troscianko, Hawkes & Chalmers 2003). The important variable therefore appears to be differentiation relative to multiple aspects of reality (e.g. visual appearance of, and, motor responses within). Here, higher confidence scores associated with the flat-shaded condition compared to confidence of recollections after training in the radiosity condition further support this suggestion.

Whilst the relationship between distinctiveness and memory may prove useful in explaining these effects it is important to consider what cognitive processes may underlie such a relationship. Previous psychological research has indicated that 'remember' responses require more attentional processing in the first instance than those based on familiarity (Parkin, Gardiner, & Rosser 1995; Brandt et al. 2003). A tentative claim would therefore be: immersive environments that are distinctive recruit more attentional resources. This additional attentional processing may bring about a change in participants' subjective experiences of 'remembering' when they later recall the environment. This change would therefore lead to an increase in the experience of 'remembering'. Interestingly, this effect was not observed during the retest that revealed similar proportions of awareness states distributed across the viewing conditions . It is likely that the fidelity of the training environment only affects awareness states when transfer of training is tested immediately. As time goes by, the enhanced attentional resources associated with low fidelity environments do not influence the long-term memories associated with the training simulation.

Moreover, it is found here that more correct 'know' responses are reported after training in the high fidelity rendered simulation than in the low fidelity rendered simulation. This would suggest a shift from 'remember' responses to 'know' responses. Memories that are accompanied with a feeling of 'remembering' for participants in the low fidelity simulation are only accompanied with a feeling of 'knowing' in the high fidelity simulation. In line with suggestions made above, this could be explained on the basis of reduced attentional processing of these items in the high fidelity simulation.

Finally, there is preliminary support for an inconsistency effect. Better memory performance was observed for inconsistent objects in the scene based on the top 10 spots in the overall confidence ranking. Only 3 out of 10 of these were consistent, present, objects (shown in table 4). Specifically, the electric guitar, one of the most salient objects in an academic's office, induced confident recollections. Certain 'absent' objects were also incorrectly assigned to specific locations. Further investigations should further explore such effects in relation to specific objects assigned to each memory awareness state. We are in the process of investigating the effect of low quality rendering such as wireframe rendering on communicating 'meaning' or schemas of real-world contexts. The degree to which an environment recruits attention is likely to be extremely important in relation to cognitive strategies at play during spatial knowledge acquisition in synthetic scenes.

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