The Effect of Visual and Interaction Fidelity on Spatial Cognition in Immersive Virtual Environments

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Abstract

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 and interaction fidelity of immersive Virtual Environments on memory awareness states. A between groups experiment was carried out to explore the effect of rendering quality on location-based recognition memory for objects and associated states of awareness. The experimental space, consisting of two interconnected rooms was rendered either flat-shaded or using radiosity rendering. The computer graphics simulations were displayed on a stereo head-tracked Head Mounted Display. Participants completed a recognition memory task after exposure to the experimental space and reported one of four states of awareness following object recognition. These reflected the level of visual mental imagery involved during retrieval, the familiarity of the recollection and also included guesses. Experimental results revealed variations in the distribution of participants' awareness states across conditions while memory performance failed to reveal any. Interestingly, results revealed a higher proportion of recollections associated with *mental imagery in the flat-shaded condition. These findings comply with similar effects revealed in two earlier studies summarized here, which demonstrated that the less 'naturalistic' interaction interface or interface of low interaction fidelity provoked a higher proportion of recognitions based on visual mental images.*

Keywords: I.3.3 [Computer Graphics]: Three-Dimensional Graphics and Realism, Virtual Reality. I.3.6 Methodology and Techniques, Interaction techniques.

1 Introduction

1.1 Fidelity

It is not computationally feasible to be immersed into an interactive artificial environment which exactly mimics the panoply and complexity of sensory experiences associated with a real world scene. For a start, it is technologically challenging to control all of the sensory modalities to render the exactly equivalent sensory array as that produced by real world interaction. The mapping from the real world environment to a computer graphics environment is mediated by *environmental* or *visual* fidelity [33]. The term *visual fidelity* refers to the degree to which visual features in the Virtual Environment (VE) conform to visual features in the real environment. Within this area, one can distinguish between *physical* realism, in which the synthetic scene is an accurate point-by-point representation of the spectral radiance values of the real scene; *photorealism*, in which the synthetic scene produces the same visual response as the real scene even if the physical energy depicted from the image is different compared to the real scene; and finally *functional realism*, in which the same information is transmitted in real and synthetic scenes while users perform visual tasks targeting transfer of training in the real world [12]. Since a VE is, by its very nature interactive, the question also arises about how "real" the interactive qualities of the VE might be. *Interface or interaction* *fidelity* refers to the degree to which the simulator technology (visual and motor) is perceived by a human participant to simulate the operational equipment and the actual real world task situation. It is argued that training for instance, in a VE with maximum fidelity would result in transfer of training similar to real-world training as the two environments would be impossible to differentiate [33].

Visual and interaction fidelity relate to system, rendering or display characteristics. There is always a trade-off between visual/interaction fidelity and computational complexity. With today's technology, when visual (or interaction) fidelity is increased, the system responsiveness decreases resulting in reduced frame rate and added visual/tracking latency [23]. Robust metrics are therefore essential in order to assess the fidelity of VE systems comprising of computer graphics imagery, display technologies and 3D interaction metaphors across a range of application fields. Apart from optimization of technological characteristics such as resolution, Field-of-View (FoV), latency, etc., one common belief is that task performance should serve as a fidelity metric for VE systems that mainly target transfer of training into a real world environment [3]. Training in a flight simulator should result in positive transfer of training in the real-world. The challenge is to identify the minimum system characteristics related to computational power and cost in order to achieve this goal.

1.2 Memory for Virtual Places

The utility of certain VEs for training 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 they require spatial knowledge of an environment [3], [4], [5], [11], [21], [26]. 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 correspond to real world conditions [23]. Previous research has examined the variables that communicate transfer of spatial knowledge and discuss the form and development of spatial representation in VE training in relation to either real-world training or training with maps, photographs and blueprints [29], [3], [5]. The suitability of VE systems as effective training mediums is examined and concluded to be as effective as map or blueprint training [29], [5]. Configurational knowledge acquisition based on estimation of absolute distances and directions between known points could yield similar effects to training with photographs and real world training [3]. Moreover, the effects of tactile, olfactory, audio and visual sensory cues on participants' memory recall of a building were investigated [10]. Two levels of visual detail were considered reducing texture resolution with or without ambient auditory stimulation, olfactory stimulation and tactile stimulation. No significant main effect was revealed on spatial layout recall. Accurate recall of objects' locations was significantly higher when tactile cues and olfactory cues were incorporated into the environment. Generally, experimental post exposure methodologies for spatial recall investigations across conditions of varied visual or interaction fidelity range from questionnaires [11] to drawing sketches of a space after exposure [4] or applying spatial knowledge acquired so as to navigate effectively the real world space represented [29], [3], [5]. Relevant research often aims to identify the minimum system characteristics relevant to rendering computations and interaction interfaces that would yield the maximum performance of a task or the maximum sense of presence. However, there is still the need for an overt task which is capable of being learned and assessed in a quantitative manner. What if the fidelity of a system should be assessed across a range of applications? Here, the questions may become:

Can we interrogate human cognitive systems which are activated by interacting with a given VE scene, to see if the same cognitive responses can be evoked under varied levels of scene fidelity? How can we match the capabilities of the VE system related to visual and interaction fidelity to the requirements of the human perceptual and motor systems?

Because of the wide-range of VE applications and differences in participants across their background, ability and method of processing information, an understanding of *how* tasks are undertaken within a VE complementing *what* is achieved is significant. Common strategies could therefore be revealed across a range of applications and tasks. The investigation presented in this paper focuses on the effect of rendering quality, e.g. perception of objects in a flat-shaded computer graphics rendering setting versus perception of the same space rendered using radiosity rendering, on observers' attributions regarding object-location memory recognition. The framework to be presented has been drawn from traditional memory research adjusted to form an experimental procedure. The main premise is that accuracy of performance per se is an imperfect reflection of the cognitive activity that underlies performance in memory tasks [6], [8], [13], [31], [28]. Accurate memory performance 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. The sense of knowing can be further divided into two. Firstly, whether the correct answer is just known without the associated recollection of contextual detail (knowing). Secondly, the answer feels more familiar than a simple guess but cannot be considered as being known (familiarity) [8]. According to this theoretical framework, performance accuracy is **supplemented** by self-report of these states of awareness during recognition. It could be possible that varied distribution of awareness states is going to be revealed even when overall memory performance remains the same across viewing conditions [24], [25].

The experimental scene utilized in the study presented in this paper consisted of two interconnected rooms. Central to this work is identifying whether the radiosity rendering (high fidelity - shadows) is associated with stronger visually induced recollections linked with the 'remember' awareness state compared to the flat-shaded scene (low fidelity - no shadows) displayed on a stereo head-tracked Head Mounted Display (HMD). Participants could describe how they achieved their spatial recollections after exposure to the environment by selecting one of four awareness states, e.g. 'remember', 'know', 'familiar' or 'guess'. These judgments reflect the ability to recall associated mental images and feelings of familiarity. Interestingly, previous studies adopting a similar methodology have demonstrated that low interaction fidelity interfaces such as the mouse compared to head tracking [23] as well as displays such as the HMD compared to the real-world task situation [24] provoked a higher proportion of visually induced recollections based on the recall of specific details, while there was no effect of condition upon memory recognition. Desirable variations of awareness states for specific application purposes, therefore, could be ultimately identified and generalized. It could be true, for instance, that for flight simulation applications it is crucial for trainees to achieve a high level of conscious recollections associated with mental images relating to instruments as opposed to recollections that are confident but not accompanied by the recall of visual images or memories of events. Results to date show that interfaces of low *interaction* fidelity induce a higher amount of recollections based on mental imagery than high fidelity interaction interfaces. In the study presented here, we explore the effect of *visual* fidelity on the distribution of memory awareness states and we endeavor to explain the consistent pattern of results mentioned above [24], [25], in addition to findings in this paper.

2. Memory Awareness States

Memory, in the sense of 'information' for subsequent analysis, plays an important role in perceptual systems such as the visual, auditory, haptic and kinesthetic systems [2]. Remembering and knowing are two subjective states of awareness associated with memory. Some elements of a learning experience or of a visual space may be 'remembered' and hence be linked to a specific recollection event or mental image. Alternatively, they could just pop-out without any specific recollections associated with them and thus, could be just 'known'. In this context, remembering therefore refers to experiences of the past in which previous events are recreated with the awareness of reliving those events and experiences mentally. Knowing refers to experiences in which there is no awareness in reliving particular events or experiences. Tulving [31] was the first to suggest the dissociation between 'remembering' and 'knowing' as an important means of differentiation in the quality of the experience participants have following recognition memory. He provided the first demonstration that these responses can be made in a memory test. Across several experiments participants were instructed to report their states of awareness at the time they recalled or recognized words they had previously encountered in a study list. If they remembered what they experienced at the time they encountered the word, they made a 'remember' response. If they were aware they had encountered the word in the study list but did not remember anything they experienced at that time, they expressed a 'know' response. The results indicated that participants could quite easily distinguish between both experiences of remembering and knowing.

There have been two major approaches that have attempted to explain the remember-know paradigm; the systems approach and the process approach. The systems approach has focused on attributing different memory systems to remember and know responses, and was advocated by Tulving [32]. In contrast, the process approach suggests that remember and know responses reflect different processing strategies. Despite the tensions between these two theoretical approaches it has been conceded that 'they can be used without commitment to any theory, but simply to provide information on how various phenomena, including memory disorders, are characterised experientially' [13]. As one cannot make assumptions on what participants experience mentally from only their performance, the subjective report of states of awareness provides a valuable research tool. Subsequent research to [32], summarised in [13] indicated that the two states of awareness are functionally independent as they are influenced differently, in systematic ways by different experimental manipulations. There is also some preliminary evidence that the distinction between 'remembering' and 'knowing' reflects a difference in brain activity at the time of encoding [29]. Additionally, remembering and knowing do not correspond to a number of other dichotomies including the distinction between explicit and implicit memory and the distinction between conceptual and perceptual processes [13].

There is further evidence showing that know responses can be differentiated into 'know' responses and 'familiar responses. A 'familiar' response can be based on transient feelings of familiarity that can thus be differentiated from 'know' responses [8]. 'Familiarity' can be defined as the feeling that something has been encountered or experienced recently, although nothing about this recent occurrence can be remembered [8]. 'Know' responses, on the other hand, represent highly familiar memory items that may come to mind without recollecting any particular encounter or any feeling of a recent encounter and cannot be placed. Earlier research has demonstrated that these finer grained judgments could be dissociated from each other, just as different source memory judgments can [8], [16]. Both 'familiar' and 'know' responses were therefore used in the current study.

Lately, there has been some argument that rather than capturing system or process differences in memory function, remember and know responses simply reflect the varying levels of confidence with which particular responses are made [17]. This model postulates that remember responses reflect stronger memory traces and are made using a conservative response criterion. On the other hand, know responses reflect weaker memory traces and are made using a more lenient response criterion. However, a number of studies have shown that there is no necessary relationship between confidence levels and states of subjective experience [8], [14], [15]. In a study comparing a real-world task situation and VEs of varied interaction fidelity, positive correlations were identified between remember/know and confidence scores and negative correlations between familiar/guess and confidence scores, however, these results were not consistent and could not differentiate between remember and know or between familiar and guess responses [25]. A confidence scale, therefore, cannot communicate or predict the types of awareness states associated with memory performance. Gardiner, 2000, concludes: '… psychology of memory should take on board subjective reports of conscious states and not just rely on more conventional measures of performance. This evidence has established that the essential subjectivity of remembering and knowing does not make reports of these states of awareness intractable to science' [13].

3. Materials and Methods

3.1 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 3 degrees of freedom tracker was utilized for 360 degrees rotational movement. As regards translational movement, a simple wireless device was custom-made (Figure 3). This device consisted of a small perspex box housing simple push buttons allowing for forward (green button) and backward (red button) navigation relative to the users view direction as detected by the head tracker. The computational overhead of using this device was negligible because it emulated and replaced the USB keyboard. The application ran on a standard PC. Despite the difference in polygon count between the flat-shaded and the radiosity environment the frame rate was retained constant across conditions at 22 frames per second.

3.2 Visual Content

According to the group they were assigned to, participants completed the same memory recognition task in one of the following two viewing conditions:

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

The experimental space consisted of two interconnected rooms including primitive objects (boxes, spheres or pyramids) scattered around each room in various locations (Figure 1,2). One room included a door and the other a window. Each environment varied considerably with regard to shadows. The flat-shaded environment did not include any. Radiosity algorithms, however, display view-independent diffuse interreflections in a scene assuming the conservation of light energy in a closed environment (Figure 1). All energy emitted or reflected by every surface is accounted for by its reflection from or absorption by other surfaces. The surfaces of a scene are subsequently broken up into a finite number of *n* discrete patches, each of which is assumed to be of finite size, emitting and reflecting light uniformly over its entire area. The Lightscape radiosity renderer was used and the result of the radiosity solution was an interactive three-dimensional representation of light energy in the environment allowing for soft shadows and colour bleeding that contributed towards a near-photorealistic image without any specular reflections. The final ~40,000 polygon scene was rendered with one incandescent light source in each room (Figure 1). The luminance level of the scenes was maintained similar; luminance readings were taken in various locations for both viewing conditions using a standard luminance meter.

3.3 Participants

30 participants were recruited from the University of Sussex, UK postgraduate population. A between subjects design was used. The 30 participants were therefore separated into 2 groups of 15 corresponding to two fidelity conditions (flat-shaded vs. radiosity). 80% of the participants in each group were male and all used computers a great deal in their daily activities. Groups were also balanced for age (respective mean 26, std 5) and gender. Participants in all conditions were naive as to the purpose of the experiment. All participants had normal or corrected to normal vision and no reported neuromotor impairment.

3.4 Procedure

The interpupilary distance (IPD) was measured for each participant with a common ruler before exposure and the stereo application's parallax was set accordingly to reduce possible visual stress during exposure. Participants were seated on a swivel chair for the whole duration of exposure to the VE wearing the HMD. They could move around 360 degrees.

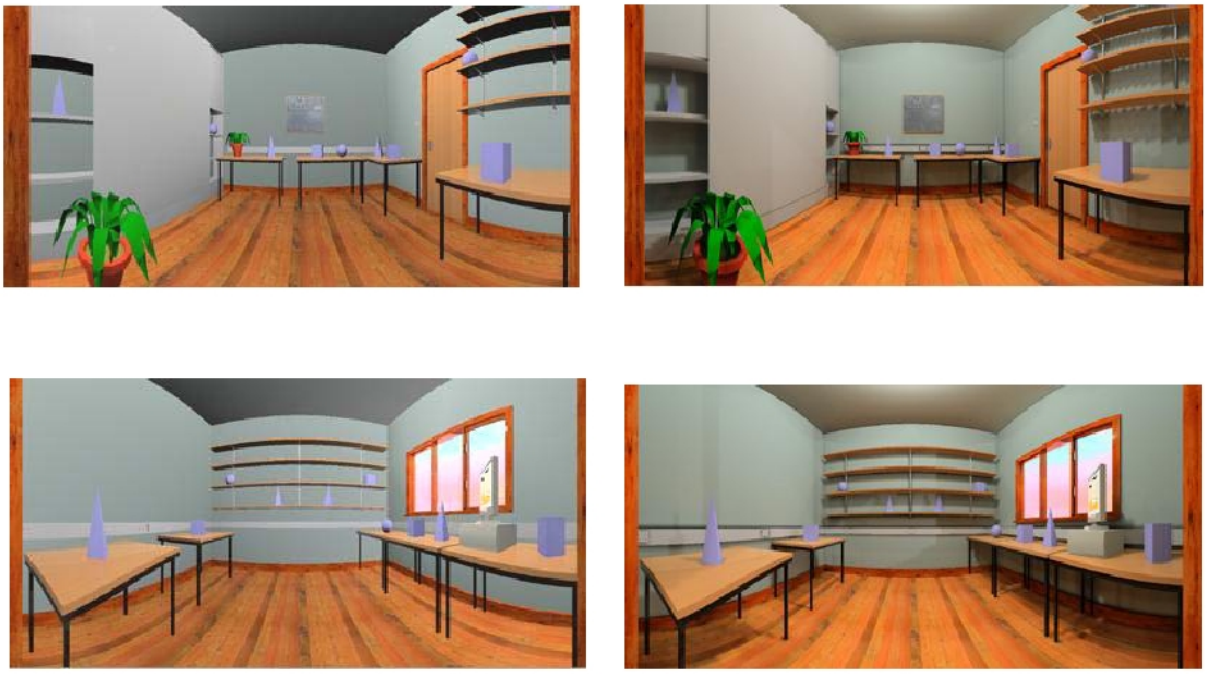

Figure 1. Flat-shaded rendering (first column), radiosity rendering (second column) of the experimental space consisting of two interconnected rooms.

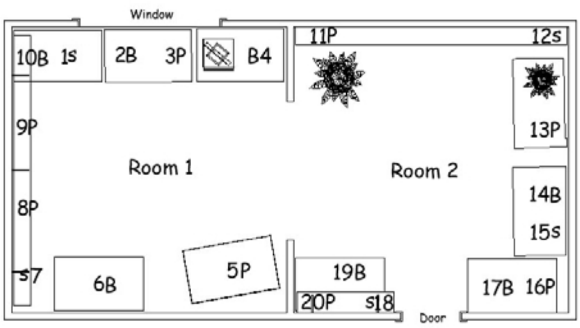

Figure 2. Stylistic plan view of the experimental space as given to participants after exposure (excluding the letters P,S,B signifying the presence of either a pyramid, a sphere or a box in those locations).

Figure 3. Custom-made navigation device.

They held the wireless device allowing for backward/forward translational movement in the direction of the head-tracked movement. Restrictions of navigation applied were based on collision detection and boundaries of head movements. The exposure time was 120 seconds. Idle time, direction of idle time as well as navigation routes were monitored through software during exposure.

Participants were instructed to look around the room but were not explicitly informed about the nature of the task. After 120 seconds exposure to the VE, they were asked to complete the experimental task. The memory recognition questionnaire was designed to test the participants' memory recognition of the geometric shape of the 20 objects in the experimental space. This was followed by self-report of memory awareness states. Stylistic spatial diagrams were administered together with the task questionnaire that consisted of 20 multiple-choice questions representing the 20 objects in the scene (Figure 2). Every question included three possible answers, e.g. box, sphere or pyramid and a confidence scale with five possible states: No confidence, Low confidence, Moderate confidence, Confident, Certain. The letters P, B and S in Figure 2 indicate the location of a Pyramid (P), Box (B) or Sphere (S) at the numbered positions and were not included in the diagram administered. Every question also incorporated an awareness states report for every recognition based on the memory awareness methodology offering four choices: Remember, Know, Familiar or Guess. The participants were required to report on the shape of the object in each numbered position on the diagram starting with the positions they were more confident they remembered. The memory recognition questionnaire did not force participants to start from a specified position in the room offering the capability to report, initially, their most confident recollections. A pilot study was conducted in order to determine the number of objects in the scene in relation to the exposure time so as to avoid possible floor or ceiling effects e.g. the task being too easy or too hard. Prior to filling out the core of the task questionnaire (sample question, Appendix), participants were given instructions designed to explain what the memory awareness states depicted as follows:

- 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.

Perceived presence assessments were obtained after acquiring recognition scores employing the questionnaire reported by Slater et al. in [28] followed by simulator sickness reports utilizing the

Simulator Sickness Questionnaire (SSQ) reported by Kennedy et al. in [18]. Simulator sickness reports were also acquired prior to exposure to the VE. Moreover, participants' navigation patterns were monitored resulting in measures of idle time during exposure across conditions.

3.5 Statistical Analysis

Awareness state data were represented as *prior* and *posterior* probabilities. Prior probabilities reflect on the following: Given that the response of a participant is correct, what is the probability that the participant has chosen a particular state on that question? 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 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 are represented as *a priori* or *prior* probabilities [19]. Although this notation does not follow the Bayesian probability theory principles for 'prior' probabilities, it is going to be adopted as such in this paper following the notation of earlier memory research [8], [19]. Prior probabilities are 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 are 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 is 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*,**

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

4. Results

The participants completed the memory task including self-report of confidence and awareness states across the two conditions (flat-shaded and radiosity). The recognition memory scores, the confidence scores, the presence assessments and idle time measures as well as the prior and posterior probabilities derived from the memory awareness states dataset were analysed using t-tests and **AN**alysis of **VA**riance (ANOVA) [9].

The total number of objects that were correctly located was counted for each participant (Table 1). The recognition scores were analysed using a t-test with viewing condition as the between subjects factor and participants' object-location recognition scores as the dependent variable. This analysis did not reveal a significant effect of viewing condition, t (28)= .68, $p>0.05$.

Confidence reports (No confidence, Low confidence, Moderate confidence, Confident, Certain) were converted to numerical values ranging from 1 assigned to 'No confidence' and 5 assigned to 'Certain'. The mean confidence scores were analysed using a t-test with viewing condition as the between subjects factor and participants' confidence scores as the dependent variable (Table 1). This analysis did not reveal a significant effect of viewing condition, t (28) =.01, $p>0.05$.

Prior probabilities indicate the proportion of correct answers under each memory awareness state (Table 2). The prior probabilities 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, $F(3,84)=3.69$, $p<0.05$. The interaction between awareness state and viewing condition was significant, $F(3,84)=6.29$, $p<0.05$. Subsequent one-way ANOVA analysis was 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, $F(1,28)=27.28$, $p<0.01$ (Respective Ms. .49 vs. .19, flat-shaded vs radiosity). The proportion of correct answers associated with the 'remember' 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). A participant could have assigned very few responses to a particular response category but these could have been always correct. Such a participant would have a low quantity (proportion) of responses under this specific awareness state, which, however, were highly accurate. There were participants that did not assign any responses to certain awareness states resulting in posterior probabilities being calculated reliably for 23 participants. The posterior probabilities were subjected to a 2 (viewing condition: flat-shaded vs. radiosity) x 3 (awareness state: remember 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, $F(3,63)=7.23$, $p<0.05$. The analysis did not produce a significant effect of viewing condition, $F(1,21)=.26$, $p>0.05$. The interaction between awareness state and viewing condition was also not significant, $F(3,63)=1.9$, $p>0.05$.

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=30):

- There was a significant positive correlation between confidence scores and correct 'know' responses for the flat shaded condition, $r = 0.70$, $p<0.05$
- There was a significant positive correlation between confidence scores, $r = 0.69$, $p<0.05$ and correct 'remember' responses for the radiosity condition.

The flat-shaded environment provoked more correct recollections linked with mental images communicated via the high proportion of correct 'remember' responses although interestingly, confidence scores positively correlated with correct 'know' responses.

	Viewing condition	
	Flat -shaded (n=15)	Radiosity (n=15)
Task scores (out of 20)	11.2 (4.2)	10.06 (3.39)
Confidence scores (out of 5)	2.93 (0.66)	2.67 (0.70)

Table 1. Means and Standard deviations for accurate object-location recognition and confidence scores as a function of viewing condition (n = total number of participants per condition).

	Viewing condition	
	Flat-shaded (n=15)	**Radiosity (n=15)**
Prior Remember	.49(.17)	.19(.12)
Prior Know	.13(.14)	.24(.21)
Prior Familiar	.13(.14)	.24(.21)
Prior Guess	.24(.16)	.30(.25)

Table 2. Prior probabilities and standard deviations as a function of viewing condition (n = total number of participants per condition).

	Viewing Condition	
	Flat-shaded (n=11)	**Radiosity (n=12)**
Posterior Remember	.89(.18)	.67(.37)
Posterior Know	.59(.36)	.72(.39)
Posterior Familiar	.32(.37)	.50(.32)
Posterior Guess	.40(.40)	.48(.22)

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

Moreover, confidence scores positively correlated with correct 'remember' responses for the photorealistic, radiosity condition, although the proportion of correct 'remember' responses assigned to this viewing condition was lower compared to the flat-shaded condition. Statistical correlation does not indicate causality and based on memory literature and previous studies in synthetic environments [24], [25] there is no consistent pattern of correlations identified between confidence scores and awareness states.

Navigation routes and idle times were recorded. Total idle time in each of the two rooms of the experimental space across conditions, was subjected to a 2 (viewing condition: flat-shaded vs.

radiosity) x 2 (time spent in each room: room1 vs room2) mixed ANOVA, with viewing condition as a between-subjects factor and time spent in each room as a within-subjects factor. In the flat-shaded condition, the mean time spent in room one was 39 seconds and 81 secs in room two. In the radiosity condition, the mean time spent in room one was 54 secs and 66 in room two. There was a significant effect of time spent in each room, $F(1,28)=5.80$, $p<0.05$. The interaction between the time spent in each room and viewing condition was not significant, $F(1,28)=1.89$, $p>0.05$. The validity of the memory recall results reported above is enhanced, given that participant groups spent comparable amounts of time in each room across conditions. Memory performance is a function of looking time [7] therefore participants' navigational tendencies could affect memory recognition after exposure. In the future, similar investigations should also yield the amount of time spent looking at particular object locations in the experimental space.

There was no effect of viewing condition upon the presence dataset, $t=.44$, $p>0.05$, as measured by a questionnaire [28] (Respective Ms. 3.45 vs. 3.80, flat-shaded vs radiosity). The measuring device either did not pick up any effect or there was not an effect across conditions as assessed by the questionnaire. How the degree of 'reality' of the motor response or rendering quality relates to presence assessments, if at all, remains an open research question [30]. Simulator sickness data acquired before and after exposure were not significantly different, $t=.32$, $p>0.05$. Simulator sickness symptomatology ratings before and after exposure were extremely low for all participants.

5. Discussion

In previous studies [24] [25] a display such as the HMD coupled with low fidelity motor input such as mouse navigation when compared to head-tracking appeared to have prevented participants from employing non-visually induced recollections and resulted in a larger distribution of correct responses assigned to the 'remember' awareness state [24], [25]. A similar result was identified in the study presented here associated to rendering quality rather than to the interaction interface. By decreasing the degree of 'reality' (interaction fidelity) of the motor response utilizing a mouse or of the rendering (visual fidelity) being exposed to a flat shaded environment, participants -paradoxically- were more aware of the visual identity of the recognized object based on mental images. Something less 'real' or of low interaction/visual fidelity and therefore, less computationally expensive maybe more attentionally demanding because of its novelty or variation from 'real'. The additional attentional demands that the low fidelity environment places on the cognitive system may therefore enhance the memorial experiences associated with it. This would be consistent with previous research that has indicated that 'remember' responses require more attentional processing in the first instance than those based on familiarity [27], [6]. Consistent with our assumptions, this investigation showed that viewing conditions had no impact on the overall accuracy of observers' recognition scores. However, the viewing condition had an impact on the proportion of correct responses associated to a specific mental image. Participants' self report of their own states of awareness could, in general, complement task performance. Such information could be desirable for specific training applications when cognitive processes complementing behavioural task-related metrics are considered to be essential for training. Achieving high fidelity could incorporate the need for similar awareness states between a real-world task situation and its computer graphics simulation, depending on application goals.

The apparently surprising but consistent results of [24], [25] complemented by the results presented here could also be discussed in relation to mental representations by examining the effect of global illumination algorithms on spatial awareness. Radiosity takes into account all diffuse inter-reflections in the scene excluding specular reflections. Taking input from mental representation theories, Plato thought that memories were based on images. According to his theory, memories are carved into the mind much like pictures can be carved on a wax tablet. Plato even took account of individual differences in terms, for instance, of the 'purity' of the wax and in the ease of carving figures into it. Moreover, mental imagery is significant since this is a means by which information is learned, stored and retrieved. Consider how one decides what is the best route to get to work at rush hour in the morning or if a piece of furniture would fit in one's home. In both cases, imagery is used to carry out a kind of 'mental simulation' [10]. Is this internal mental simulation 'photorealistic' or is it cartoon-like, retaining contours of objects rather than colours and shadows? If the latter is true, then certainly, the flat-shaded condition is closer to participants' mental representations, a fact that may allow more attention to be allocated to the content of the representation rather than the generation of an appropriate representation in the first instance. A major bottleneck in using mental imagery could be the capacity of working memory; this capacity hinges on properties of a passive store and properties of active imagery operations. Within contemporary models of memory [22] and those of mental imagery [20], these limitations have been associated with attentional processes.

In this paper we do not suggest that flat-shaded rendering or low visual or interaction fidelity is adequate for spatial awareness. Global illumination algorithms provide valuable depth cues by computing sophisticated shadows and diffuse or specular effects which could aid in object recognition and navigation. Interaction interfaces such as head tracking are intuitive. The research presented endeavors to comprehend the simulation of cognitive processes rather than simulation of physics or behavioural simulations and indicates 'how' memory retrieval is communicated from a process or memory system point of view. The degree to which an environment recruits attention is likely to be extremely important.

The blue primary shapes in these experiments, although selected for their similar size and diffuse colour, are not typical of a real-world scene and lack contextual meaning. Recent work on memory recognition of schema consistent and inconsistent objects in an academic's office has provided preliminary suggestions that recollections induced by mental imagery were also associated to low fidelity viewing conditions for objects which are more intricate [2]. Further work should also explore the effect of visual detail such as specularity or texture resolution on object recognition.

Generally, current distinctions between differences in visual/spatial representations emerging from research in cognitive science and neuroscience may apply to mental images as well, with or without immediate sensory input [10]. Indeed, visual imagery, visual representation and memory are unlikely to be a unitary concept [22]. They comprise of distinguishable subsystems specialized for performing particular aspects of cognitive tasks. Distinctions among subsystems of imagery specialized for particular tasks will become increasingly sophisticated as researchers come to understand better the varieties of visual representation, in real and synthetic (simulation) worlds. A significant direction for future research on fidelity of VE simulations will be to develop metrics that will integrate or separate visual and interaction fidelity into a coherent framework.

6. References

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Appendix

Sample memory awareness states question

1 *Object Location Number:* Box Sphere Pyramid

Confidence:	No conf.	Low conf.	Moderate conf.	Confident	Certain
Awareness:	Remember	Know	Familiar	Guess	