# The Effect of Stereo and Context on Memory and Awareness States in Immersive Virtual Environments


Adam Bennett
University of Sussex
Dept. of Informatics
binnetti@gmail.com

Matthew Coxon
York St John University
Dept. of Psychology
M.Coxon@yorksj.ac.uk

Katerina Mania
Technical University of Crete
Dept. of Electronic and Computer Eng.
k.mania@ced.tuc.gr



## Abstract

Spatial awareness is crucial for human performance efficiency of any task that entails perception of space. Memory of spaces is an imperfect reflection of the cognitive activity (awareness states) that underlies performance in such environments. Furthermore, performance on these tasks may also be influenced by the context of the environment. This research investigates the effect of stereo viewing on object recognition after exposure to an immersive VE, in terms of both scene context and associated awareness states. The immersive simulation consisted of a radiosity-rendered room that was either populated by objects consistent with an office setting or by primitive objects located in similar positions. The simulation was displayed on a stereo head-tracked Head Mounted Display. Twenty-four participants across two visual conditions of varying depth cues (absence vs presence of stereo cues) were exposed to the VE and completed an object-based memory recognition task. Participants also reported one of four states of awareness following each recognition response which reflected whether visual mental imagery was induced during retrieval. Results revealed better memory of objects that were consistent with the environment context and associated with vivid memorial experiences when the space was viewed in stereo.



**CR Categories:** I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction Techniques J.4 [Computer Applications]: Social and Behavioral Sciences—Psychology

**Keywords:** Perceptual Fidelity, Spatial Awareness, Simulations


## 1 Introduction

With the arrival and excitement about 3D cinema, stereoscopic display technologies and integrated real-world and graphic scenes, it is valuable to observe how humans mentally represent an interactive computer graphics scene viewed in stereo and how their recognition and memory of synthetic worlds correspond to their real-world counterparts. Depth perception may enhance task performance in simulated worlds or in some cases, may only result in aesthetically pleasing imagery.

In VEs, stereoscopic displays are designed to simulate disparity that occurs when natural scenes are viewed [Patterson and Martin, 1992; Stanney et al. 2006].



APGV 2010, Los Angeles, California, July 23 – 24, 2010.
© 2010 ACM 978-1-4503-0248-7/10/0007 $10.00


Effects of stereoscopic rendering on objective measurements of task performance as well as subjective notions of presence or perceived ‘sense of being there’ while immersed in a simulation have showcased contradictory results. In some cases there has been no significant difference of stereo viewing on object recognition and presence [Bastanlar et al. 2007], nor on distance perception tasks suggesting that the limitations on the presentation of stereo imagery that are inherent in Head Mounted Displays (HMDs) are likely not the source of commonly reported distance underestimation occurring within scenes viewed on a HMD [Willemsen et al. 2008]. 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 et al. 2007]. In other cases, stereoscopic vision displays combined with 3-dimensional echocardiography improved the visualization of 3-dimensional echocardiography ultrasound images, decreased the time required for surgical task completion and increased the precision of instrument navigation, potentially improving the safety of beating-heart intracardiac surgical interventions [Vasilyev et al. 2008]. Moreover, manipulations of the visual parameters of stereo, scene motion, and observer-based motion on participants' presence evaluations within edited sections of a stereoscopic film provided support for theories predicting that the extent of sensory information available to a participant is one of the factors determining presence [Freeman et al. 1997].

It is apparent that the inherent benefit of depth cues provided by stereo rendering may vary depending on the task performed. The utility of VEs for any applications for which they are being proposed is predicated upon the accuracy of the spatial representation formed in the VE [Bliss et al. 1997; Mania et al. 2006]. Spatial memory tasks are fundamental and are often incorporated in benchmarking processes when assessing fidelity of a VE simulation, since spatial awareness is crucial for human performance efficiency of any task that entails awareness of space [Waller et al. 1998]. How a stereo-rendered synthetic scene is cognitively encoded and how recognition and memory of such worlds transfer to real world conditions is of interest [Mania et al. 2003, 2010, Mania et al. 2004, Fink et al. 2007]. 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 complements spatial memory performance. Common strategies may be revealed across a range of applications and tasks. Moreover, previous real-world experiments suggested that when participants are exposed to large amounts of information in a scene, schemata are used to guide retrieval of information from memory and consistent items may be better recalled e.g. items that are likely to be found in a given environment [Brewer and Treyens 1981].

The study presented in this paper focuses upon the effect of depth cues (stereo rendering vs monocular viewing) on object-location recognition memory and its associated awareness states while immersed in a radiosity-rendered synthetic simulation of an office scene. The office scene is populated either with objects which are consistent with the office context (books, computer, etc.) or with primitive objects in similar locations displayed on a head-tracked, stereo-capable HMD. The main premise of this work is that memory performance is an imperfect reflection of the cognitive activity that underlies performance on memory tasks.

## 2 Memory awareness states and schemata

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); strong familiarity rather than a un-informed guess (familiar); and guesses. 'Remembering' has been further defined as 'personal experiences of the past' that are recreated mentally [Gardiner and Richardson-Klavehn 1997]. Meanwhile 'knowing' refers to 'other experiences of the past but without the sense of reliving it mentally'. The work of [Tulving 1992] first suggested that this mental re-living (remembering) and general 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. These distinctions provide researchers a unique window into the different subjective experiences an individual has of their memories.

Measures of the accuracy of memory can therefore be enhanced by self-report of states of awareness such as 'remember', 'know', 'familiar' and 'guess' during recognition [Conway et al. 1997; Brandt et al. 2006]. Object recognition studies in VE simulations have demonstrated that *low* interaction fidelity interfaces, such as the use of a mouse compared to head tracking, as well as *low* visual fidelity, such as flat-shaded rendering compared to radiosity rendering, resulted in a higher proportion of correct memories that are associated with those vivid visual experiences of a 'remember' awareness state [Mania et al. 2003; 2006; 2010]. As a result of these studies, a tentative claim was made that those immersive environments that are distinctive because of their variation from 'real' representing low interaction or visual fidelity 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, leading to more vivid mental experiences. The present research builds upon this pattern of results and its possible explanations.

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. In terms of real world scenes, schemas represent the general context of a scene such as 'office', 'theatre' etc. and facilitates memory for the objects in a given context according to their general association with that schema in place. 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 and Treyens 1981].

[Pichet's & Anderon's 1966] schema model predicts better memory performance for schema consistent items, e.g. 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] suggests that schema-inconsistent information for a recently-encountered episodic event will be easily accessible and, therefore, leads to better memory performance. Previous VE experiments revealed that schema consistent elements of VE scenes were more likely to be recognized than inconsistent information [Mourkoussis et al. 2010; Mania et al. 2005], supporting the broad theoretical position of [Pichet & Anderson 1966]. Such information has led to the development of a selective rendering framework. In this framework, scene elements which are expected to be found in a VE scene may be rendered in lower quality, in terms of polygon count thereby reducing computational complexity without affecting object memory [Zotos et al. 2009].

The work presented here aims to investigate the specific effects of stereo cues, or absence of them, on both the accuracy and the phenomenological aspects of object memories acquired in a VE. It is of interest to identify whether the absence of stereo cues is associated with the stronger vivid visually induced recollections that have previously been demonstrated with lower interaction or visual fidelity [Mania et al. 2010]. A secondary goal is to investigate the potentially positive effect of schemas on object recognition tasks post-VE exposure.

## 3 Materials and Methods

### 3.1 Participants and Apparatus

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. The 24 participants were separated into 2 groups of 12 corresponding to two visual conditions (stereo vs. non-stereo). The groups were also balanced for age and gender and 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 or stereovision impairment. The test VE was set up in a studio on campus, which was darkened to remove any periphery disturbance during the exposure.

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.

### 3.2 Visual Content

The between-subjects factor was Binocular Stereo vs Mono and the within-subjects factor was Context specific vs Primitive objects. According to the training group that they were assigned to, 24 participants completed two memory recognition tasks after exposure to two out of four simulation counterparts in counterbalanced order:
- *Stereo schema condition:* A stereo-rendered radiosity simulation of an office displayed on a stereo head-tracked HMD including objects one would normally find in an office (Figure 1).
- *Stereo primitive condition:* A stereo-rendered radiosity simulation of an office displayed on a stereo head-tracked HMD including primitive objects (Figure 2).

- *Non-Stereo schema condition:* A stereo-rendered radiosity simulation of an office displayed on a stereo head-tracked HMD including objects one would normally find in an office.
- *Non-stereo primitive condition:* A stereo-rendered radiosity simulation of an office displayed on a stereo head-tracked HMD including primitive objects.

The office scene in all visual conditions consisted of the so-called ‘Room frame’ objects: walls, floor, ceiling, door, ceiling light, doorknob and light switch. It also included standard objects such as desks, chairs, shelves, rug, year-planner. The scene comprising of office specific objects included six additional objects, included in the memory recognition questionnaire, repeated across the room in specific locations: computer, potted plant, coffee mug, phone, open book, boxfile. These six objects were evaluated as office consistent objects in [Brewer and Treyens 1981]. For the purposes of this experiment, the typewriter included in the [Brewer and Treyens 1981] experiment was replaced by a computer.

Figure 1. Office consistent experimental scene

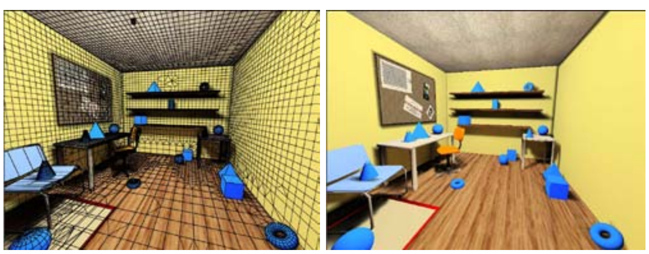

Figure 2. Experimental scene populated by primitive objects

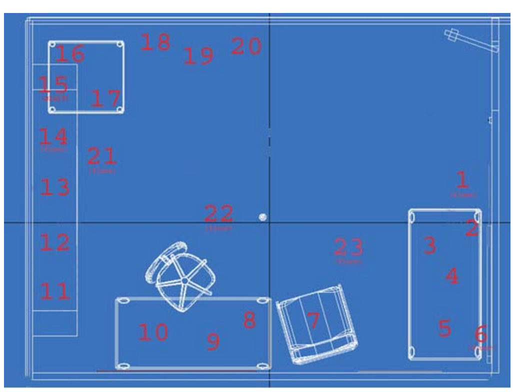


Figure 3. Testing blueprint

A similar office scene was constructed which contained the same frame and standard office objects and was identical to the first model. The six office-related objects mentioned above were substituted with primitive blue objects which were of roughly the same size relatively to the office-related objects above: Box, Sphere, Pyramid, Cone, Cylinder, Torus. The blue primitive objects were distributed over the same locations occupied by the objects in the first room. Included objects were optimized so as to reduce the overall polygon count, keeping the polygon count of each environment down to around 30,000 individual polygons.

The radiosity scenes produces colour-bleeding effects from one surface to another, shades inside the shadow area and creates soft-edge shadow with penumbrae along shadow boundaries. Computed geometry meshes of lighting data for a given surface were converted to textures. In order to maintain a constant update speed in each environment either rendered in stereo or non-stereo, a control script was added which ran in every frame calculating the interval between this frame and the last and restricting the update to a given frequency. This control script was run by the simulation once every frame, capping it at a constant 16 fps for both environments. Stereoscopic effects were realized by employing a dual channel video subsystem.

Whilst neither the [Brewer & Treyens 1981] 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.

### 3.3 Experimental Procedure

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. They were told that final adjustments were made indicating this may take some time to complete before the main experiment run. Participants were not informed that they would subsequently complete a memory task. The questionnaires were administered within 1 minute after VE exposure.

After the exposure to the simulation, a blueprint of the bare environment was provided including 23 numbered vacant positions on a top view of the scene in which an object had been present as well as an object recognition questionnaire (Figure 3). A memory recognition test was administered, in which each question had 6 possible answers representing the 6 objects which were located in these positions (either primitive or context consistent) as well as 5 levels of confidence: No confidence, Low confidence, Moderate confidence, Confident, Certain, and four choices of awareness states: Remember, Know, Familiar or Guess. Prior to the memory recognition task, awareness states were explained to the participants in the following terms:
- REMEMBER means that you can visualize 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 visualize 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.

## 4 Results

The accuracy of memory was measured by counting the number of correct positions of objects (out of a possible 23). Awareness state data was considered in terms of prior 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? Prior probabilities were obtained by calculating the proportions of correct answers falling in each of the four memory awareness categories for each participant.

*Total Correct*

The total number of objects that were identified in the correct location was counted for each participant (Table 1).

| | **Mono (n=12)** | | **Stereo (n=12)** | |
|---|---|---|---|---|
| | **Consistent** | **Primitive** | **Consistent** | **Primitive** |
| **Total correct (out of 23)** | 11.75 (3.36) | 8.33 (3.99) | 12.83 (3.38) | 8.42 (3.45) |

Table 1. Number of correct responses and standard deviations as a function of viewing condition (stereo, mono) and schema consistency (consistent, primitive).

These recognition scores were analyzed using a 2x2 mixed analysis of variance (ANOVA) with viewing condition (mono, stereo) entered as a between subjects variable and the context consistency of the objects (consistent, primitive) entered as a within subjects variable. No main effect of viewing condition was found ($F(1,22) = 0.37$, $p>0.05$) indicating that participant's scores did not vary reliably between the mono and stereo viewing conditions. Similarly, no interaction was found between viewing condition and the context consistency of the objects ($F(1,22) = 0.21$, $p>0.05$). However, a main effect of context consistency was found ($F(1,22) = 12.90$, $p<0.05$) indicating that participant's scores varied reliably between schema consistent objects and primitives.

Overall, more objects were recognized in their correct position when they were consistent with the schema (M=12.29, s.d. = 3.34) than when they were inconsistent with the schema (M=8.37, s.d.=3.65).

*Confidence*

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'. Mean values are presented in Table 2.

These confidence ratings were analyzed using a 2x2 mixed analysis of variance (ANOVA) with viewing condition (mono, stereo) entered as a between subjects variable and the context consistency of the objects (consistent, primitive) entered as a within subjects variable.

| | **Mono (n=12)** | | **Stereo (n=12)** | |
|---|---|---|---|---|
| | **Consistent** | **Primitive** | **Consistent** | **Primitive** |
| **Confidence (5-point scale)** | 3.09 (.79) | 2.58 (.91) | 3.17 (.59) | 2.57 (.81) |

Table 2. Mean confidence rating and standard deviation as a function of viewing condition (stereo, mono) and context consistency (consistent, primitive).

No main effect of viewing condition was found ($F(1,22) = 0.017$, $p>0.05$) indicating that participant's ratings did not vary reliably between the mono and stereo viewing conditions. Similarly, no interaction was found between viewing condition and the context consistency of the objects ($F(1,22) = 0.052$, $p>0.05$). However, a main effect of context consistency was found ($F(1,22) = 6.57$, $p<0.05$) indicating that participant's scores varied reliably between context consistent and primitive conditions. Participants provided higher confidence ratings (indicating greater confidence) in context consistent conditions ($M$=3.13, *s.d.* = 0.69) than context inconsistent conditions ($M$=2.57, *s.d.*=0.85).

*Awareness states*

The proportion of correct responses assigned to each awareness state (displayed in Table 3) were analyzed with separate 2x2 mixed ANOVAs for each state. Viewing condition (mono, stereo) was entered as a between subjects variable and the context consistency of the objects (consistent, primitive) was entered as a within subjects variable. An alpha level of .05 was used throughout the analyses to judge a reliable difference.

| | **Mono (n=12)** | | **Stereo (n=12)** | |
|---|---|---|---|---|
| | **Consistent** | **Primitive** | **Consistent** | **Primitive** |
| **Remember** | .38 (.30) | .41 (.40) | .52 (.22) | .23 (.22) |
| **Know** | .18 (.11) | .08 (.14) | .17 (.11) | .15 (.17) |
| **Familiar** | .26 (.22) | .24 (.23) | .20 (.16) | .24 (.17) |
| **Guess** | .18 (.15) | .25 (.31) | .10 (.17) | .37 (.39) |

Table 3. Proportion of correct responses and standard deviations as a function of viewing condition (stereo, mono), context consistency (consistent, primitive) and reported awareness state (remember, know, familiar, guess).

No reliable main effects of viewing condition were found for correct remember responses ($F(1,22) = 1.38$, $p>0.05$), for correct know responses ($F(1,22) = .69$, $p>0.05$), for correct familiar responses ($F(1,22) = .27$, $p>0.05$), nor for correct guesses ($F(1,22) = .040$, $p>0.05$). Differences in viewing condition alone (mono, stereo) had no reliable effect on the proportion of correct responses assigned to each awareness state.

Similarly, reliable main effects of context consistency were not found for correct remember responses, ($F(1,22) = 3.54$, $p>0.05$), correct know responses ($F(1,22) = 2.17$, $p>0.05$), nor correct familiar responses, ($F(1,22) = .058$, $p>0.05$), but were found for correct guess responses ($F(1,22) = 6.06$, $p<0.05$). In terms of guess responses, participants had a higher proportion of guess responses when the objects were context consistent (M= .32, s.d. = .35) than those that were primitive (M= .14, s.d. = .16). Differences in context consistency alone (consistent, primitive) had no reliable effect on the proportion of correct responses assigned to each awareness state, except when guesses were reported. Participants were more likely to make correct guesses when the objects were consistent with the schema of the room.

Finally, no significant interactions were found between viewing condition and schema consistency for correct know responses, ($F(1,22) = 1.02$, $p>0.05$), correct familiar responses ($F(1,22) = .18$, $p>0.05$), nor correct guess responses ($F(1,22) = 1.74$, $p>0.05$).

Importantly, a reliable interaction *was* found between viewing condition and context consistency in terms of correct remember responses (those associated with a vivid experience of remembering) ($F(1,22) = 5.11$, $p<0.05$). Any effect of context consistency therefore differed according to the viewing condition.

This interaction was investigated further through a series of t-tests with Bonferroni corrections. A reliable difference was only found between the proportion of correct responses in schema consistent and primitive object conditions in the stereo viewing condition, $t(11) = -3.77$. In the stereo viewing condition, participants reported a higher proportion of correct remember responses for schema consistent objects (M=.52) than primitive objects (M=.23).

## 5 Discussion

The analyses indicated that stereo cues did not reliably influence either the accuracy of, or phenomenology of, memory for the VE simulation on their own. Although there were no reliable differences between the different viewing conditions these perceptual factors did strongly influence the distribution of awareness states once the interaction with the context consistency of objects (consistent, primitive) was also considered. The proportion of correct responses that had a vivid 'remember' experience were greater in the stereo condition when the objects were consistent with the office context than when they were primitive. This was not true of responses in the mono condition.

Furthermore, in general, more objects were correctly remembered when they were consistent with the office scene, providing further support for the suggestion that schema consistent objects are remembered better in VE simulations [Mourkoussis et al. 2010]. A number of questions arise from these findings, most notably: Why is there an interaction between the presence of perceptual cues and context consistency with vivid recollective experiences?

The results of the present study have revealed a different pattern compared to those past studies which have reported that low visual fidelity environments, or low interactivity, may be more attentionally demanding because of their novelty or variation from 'real' resulting in more vivid remember responses [Mania et al. 2010]. One might assume that a lack of stereo cues may also produce an attentionally demanding low fidelity environment. However, here, the presence of stereo cues led to more correct object placements associated with 'remember' responses for meaningful or context consistent objects. The relationship between visual fidelity and awareness states in associated object recognition tasks, therefore, appears to differ according to the type of low fidelity stimulus considered, either interaction-related or rendering-related; in this case stereo cues. Whilst low fidelity appeared to be beneficial in relation to inducing more 'remember' responses when compared with radiosity rendering, high fidelity appeared to be beneficial in relation to such vivid memories, in terms of stereo cues. Importantly, this difference was only found within an interaction between stereo cues and the context consistency of the objects.

It is also possible that the key to such effects is not in the fidelity of the simulated experience but instead the match between the fidelity of the experience and the objects being remembered. Hence, in previous experiments memory for blue primary shapes (primitives) has been enhanced by less 'real' environments [Mania et al. 2006; Mania et al. 2003]. This could be because they are consistent with each other, in that they are consistently 'unreal'.

In the experiment presented here, the phenomenology of the memories may have again been enhanced because more 'real' objects were remembered in more 'real' environments, a match in which both objects (office-related) and environment (stereo-rendered) were consistently 'real'. More broadly, the suggestion is that vivid recollective experiences occur more frequently when there is a match between the novelty of the object being remembered and the novelty of the environment it is in. That is, that objects and their environments are processed in an interactive way that is determined by consistency [Davenport & Potter, 2004].

Such an explanation for the observed changes in awareness may not be in-line with psychological research that suggests 'remember' responses rely upon distinctiveness or novelty from a scene's context [Dobbins et al. 1998], rather than consistency. However, this research focuses solely on stimuli out of context and in relatively sterile environments. Our understanding of how such processes work within fully immersive environments, such as those that VEs provide, is only now beginning to be explored and it is possible, indeed likely, that there will be differences between real-world experiences and simulated scenes. Similarly, such an explanation is not entirely in-line with the results presented here. The reported interaction was limited to consistent objects in stereo conditions. 'Unreal' objects (primitives) in the 'unreal' environment (no stereo cues) showed no advantage over 'real' objects (office equipment) in terms of the nature of the recollective experience expressed through awareness states. It is tempting to suggest that this may relate to practical considerations such as effect size, sample size or task characteristics or viewing condition manipulations. Alternatively, it may merely suggest that the above hypothesis is false.

In any case, the results presented here provide an intriguing problem for further investigation. Why do people have richer memorial experiences of objects in VE environments when they are context consistent *and* supported by stereo cues? But not when these cues are removed? What does this mean for how we process information in such environments? And how can this knowledge improve training in a VE simulation? Here, we have testedboth variations of context specific objects and high fidelity in terms of enhanced stereo cues in the same experiment. Some of the paradoxical previous results indicating vivid memorial experiences associated with low fidelity may have occurred because memory was mediated by the mismatch between the 'unreal' objects and the higher fidelity.

## References


BASTANLAR, Y., CANTURK, D., KARAKAN, H. 2007. Effects of Color Multiplex Stereoscopic View on Memory and Navigation. *3DTV conference* 2007, 1-4.

BRANDT, K.R., GARDINER, J.M., & MACRAE, C.N. 2006. The distinctiveness effect in forenames: The role of subjective experiences and recognition memory. *British Journal of Psychology* 269-280.

BREWER, W.F. & TREYENS, J. 1981. Role of Schemata in Memory for Places. Cognitive Psychology, 1981, 13, 207-230.

CONWAY, M. A., et AL. 1997. Changes in Memory Awareness During Learning: The Acquisition of Knowledge by Psychology Undergraduates. *Journal of Experimental Psychology : General*, 126(4), 393 – 413.

DAVENPORT, J.L. & POTTER, M.C. 2004. Scene Consistency in Object and Background Perception. *Psychological Science*, 15(8), pp.559-564

DOBBINS, I.G., KROLl, N.E.A. and QIANG, L. 1998. Confidence-Accuracy Inversions in Scene Recognition: A Remember-Know Analysis. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 24(5), 1306-1315.

FINK, W., FOO, P.S., WARREN, W. 2007. Obstacle avoidance during walking in real and virtual environments, *ACM Transactions on Applied Perception*, 4(1).

FREEMAN J., AVONS S. E., DAVIDOFF J., PEARSON D. E. 1997. Effects of stereo and motion manipulations on measured presence in stereoscopic displays. Perception 26 ECVP Abstract Supplement.

FRENZ, H. LAPPE, M., KOLESNIK, M., BÜHRMANN, T. 2007. Estimation of travel distance from visual motion in virtual environments. *ACM Transactions on Applied Perception*, 4(1).

GARDINER, J. M. AND RICHARDSON-KLAVEHN, A. 1992. Remembering and Knowing. *In*: Tulving, E. and Craik, F. I. M., eds. 1992. *Handbook of Memory*. Oxford: Oxford University Press.

HOLLINGWORTH, A. & HENDERSON, J.M. 1998. Does consistent scene context facilitate object perception? *Journal of Experimental Psychology: General*, 127(4), 398-415.

MANIA, K., ADELSTEIN, B., ELLIS, S.R., HILL, M. 2004. Perceptual Sensitivity to Head Tracking Latency in Virtual Environments with Varying Degrees of Scene Complexity. Proc. *ACM Siggraph Symposium on Applied Perception in Graphics and Visualization* 2004, 39-47, ACM Press.

MANIA, K., BADARIAH, S., COXON. M. 2010. Cognitive Transfer of Training from Immersive Virtual Environments to Reality. *ACM Transactions on Applied Perception*, 7(2), 9:1-9:14, 2010, ACM Press.

MANIA, K., ROBINSON, A., BRANDT. K. 2005. The Effect of Memory Schemas on Object Recognition in Virtual Environments. *Presence Teleoperators and Virtual Environments*, 6(1), 73-86, MIT Press.

MANIA, K., TROSCIANKO, T., HAWKES, R., CHALMERS, A. 2003. Fidelity metrics for virtual environment simulations based on spatial memory awareness states. *Presence, Teleoperators and Virtual Environments*, 12(3), 296-310. MIT Press.

MANIA, K., WOOLDRIDGE, D., COXON, M., ROBINSON, A. 2006. The effect of visual and interaction fidelity on spatial cognition in immersive virtual environments. *IEEE Transactions on Visualization and Computer Graphics*, 12(3): 396-404.

MOURKOUSSIS, N., RIVERA, F., TROSCIANKO, T., DIXON, T., HAWKES, R., MANIA, K. In press 2010. Quantifying Fidelity for Virtual Environment simulations employing memory schema assumptions. *ACM Transactions on Applied Perception.*

MINSKY, M. 1975. A framework for representing knowledge. In P.H. Winston (Ed.), The Psychology of Computer Vision. McGraw-Hill.

PATTERSON, R. MARTIN, W. L. 1992. R. Patterson and W.L. Martin, Human stereopsis, *Hum. Factors* 34 (1992) (6), 669–692.

PICHERT, J.W., ANDERSON, R.C. 1966. Taking a different perspectives on a story. *Journal of Educational Psychology* 69, 309-315. SCHANK, R.C. 1999. *Dynamic memory revisited*. Cambridge, UK. Cambridge University Press.

SOLLENBERGER, R.L. AND MILGRAM, P. 1993. Effects of stere oscopic and rotational displays in a three-dimensional path-tracing task, *Hum. Factors* **35** (3), 483–499.

STANNEY, K, KELLY, H. 2006. Effects of low stereo acuity on performance, presence and sickness within a virtual environment. *Applied Ergonomics*, 37(3), 329-339.

TULVING, E. 1992. *Elements of Episodic Memory*, Oxford : Oxford Science Publications.

WALLER, D., HUNT, E., KNAPP. D. 1998. The Transfer of Spatial Knowledge in Virtual Environment Training. *Presence: Teleoperators and Virtual Environments*, 7(2), MIT Press.

VASILYEV, N., NOVOTNY, P.M., MARTINEZ, H. L., SALGO, I. S., HOWE, R. D., DEL NIDO, P.J. 2008. Stereoscopic vision display technology in real-time three-dimensional echocardiography-guided intracardiac beating-heart surgery. J Thorac. *Cardiovasc. Surg.* 135:1334-1341, The Americal Association for Thoracic Surgery.

WILLEMSEN, P. GOOCH, A, THOMPSON, W., CREEM REGEHR, S. 2008. Effects of Stereo Viewing Conditions on Distance Perception in Virtual Environments. *Presence, Teleoperators and Virtual Environments*, 17(1), 91-101. MIT Press.

WILLIAMS, W., NARASIMHAM, G., WESTERMAN, C., RIESER, J. BODENHEIMER, B. 2007. Functional similarities in spatial representations between real and virtual environments. *ACM Transactions on Applied Perception*, 12(4).

ZOTOS, A., MANIA, K., MOURKOUSSIS, N. 2009. A Schema-based Selective Rendering Framework. *ACM Siggraph Symposium on Applied Perception in Graphics and Visualization*, 85-92, Chania, Crete, Greece.