THE EFFECT OF TRACKING DELAY ON AWARENESS STATES IN IMMERSIVE VIRTUAL ENVIRONMENTS: AN INITIAL EXPLORATION

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Abstract

This paper presents an experimental methodology exploring the effect of tracking latency on object recognition after exposure to an immersive VE, in terms of both scene context and associated awareness states. System latency (time delay) and its visible consequences are fundamental Virtual Environment (VE) deficiencies that can hamper spatial awareness and memory. The immersive simulation consisted of a radiosity-rendered space divided in three zones including a kitchen/dining area, an office area and a lounge area. The space was populated by objects consistent as well as inconsistent with each zone's context. The simulation was displayed on a stereo head-tracked Head Mounted Display. Participants across two conditions of varying latency (system minimum latency vs added latency condition) were exposed to the VE and completed an object-based memory recognition task. Participants also reported one of three states of awareness following each recognition response which reflected either the recollection of contextual detail, the sense of familiarity unaccompanied by contextual information or even informed guesses. Preliminary results from initial pilot studies reveal better memory performance of objects in the low latency condition. A disproportionately large proportion of guess responses for consistent objects viewed with high latency is also observed and correspondingly a disproportionately low proportion of remember responses for consistent objects in the same latency condition.

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1. Introduction

Spatial awareness and memory is crucial for human performance efficiency of any task that entails perception of space. Awareness states accompany the retrieval of spaces after exposure. Memory of spaces may also be influenced by the context of the environment.

Spatial memory tasks are fundamental and are often incorporated in benchmarking processes when assessing fidelity of a VE simulation targeting training efficiency of any task [Bliss et al. 1997; Mania et al. 2006; Waller et al. 1998]. System latency (time delay) and its visible consequences are fundamental Virtual Environment (VE) deficiencies that can hamper training performance. How an immersive scene which may suffer from tracking latency due to limited computational power or system complexity is cognitively encoded and how recognition and memory of such scenes 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 the subjective experience associated with memory retrieval is significant. 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].

End-to-end latency in a Virtual Environment (VE) is defined as the time lag between a user's action in the VE and the system's response to this action. VE lag comprises of four different types; user-input device lag, application-dependent processing lag, rendering lag and synchronization lag. Excessive system latency is a well-known defect of VE and tele-operation systems [Ellis et al. 2004]. It is particularly troublesome for head-tracked systems since delays in head orientation measurement give rise to errors in presented visual direction. Perceptible latency that is experienced by its visual consequences on a display is one of the most notable problems facing current VE applications [Ellis et al. 1999], [Garret et al. 2002], [Stanney et al. 1998]. High end-to-end latency can severely degrade users' performance in a VE [Ellis et al. 1997], [Ellis et al. 2002]. The RMS (Root Mean Square) tracking errors, which are an objective measure of user's performance, are caused mostly by visual latency, rather than spatial sensor distortion or low update rates [Ellis et al. 1999]. Latency also affects users' performance on 3D object placement tasks [Liu et al. 1993], [Watson et al. 1997]. Latency in a VE can also cause lack of accuracy during tracking tasks, motion sickness, and loss of immersion on users, as well as disorientation, discomfort, and even nausea [Kennedy et al. 1992], [Stanney et al. 1998]. While users can exhibit sensorimotor adaptation that might improve manual performance when time delays exist in situations where task preview is available [Cunningham et al. 2001a], [Cunningham et al. 2001b], the presence of delay has been shown to hinder operator adaptation to other display distortions such as static displacement offset [Held et al. 1966].

More recently interest has been directed towards the subjective impact of latency on the users' reported sense of presence. Latency, as well as update rate, is considered as a factor affecting the operator's sense of presence in the environment [Welch et al. 1996], [Uno, Slater 1997]. Lower latencies were associated with a higher self-reported sense of presence and a statistically higher change in heart rate while exposed to a stress-inducing (fear of heights), photorealistically rendered VE, involving walking around a narrow pit [Meehan et al. 2003]. The role of VE scene content and resultant relative object motion on latency detection has been examined by presenting observers in a head-tracked, stereoscopic Head Mounted Display (HMD) with environments having differing levels of complexity ranging from simple geometrical objects to a radiosity-rendered scene representing a hypothetical real-world setting [Mania et al. 2004]. In this study, a radiosity-rendered scene of two interconnected rooms was employed. Latency discrimination observed was compared with a previous study in which only simple geometrical objects, without radiosity rendering or a 'real-world' setting, were used employing formal psychophysical techniques. Results revealed that the Just Noticeable Difference (JND) for latency discrimination by trained observers averages ~15 ms or less, independent of scene complexity and real-world meaning. Such knowledge will help understand latency perception mechanisms and, in turn, guide VE designers in the development of latency countermeasures.

The experimental methodology presented in this paper focuses upon exploring the effect of tracking latency (minimum system latency vs added tracking latency) on object-location recognition memory and its associated awareness states while immersed in a radiosity-rendered synthetic simulation of a complex scene. The radiosity-rendered space was divided in three zones including a kitchen/dining area, an office area and a lounge area. The space was populated by objects consistent as well as inconsistent with each zone's context, 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 proposing an experimental methodology to be adopted for full-scale experimentation. Preliminary results derived from initial pilot studies are reported involving a small number of participants.

The paper is organized as follows. Section 2 of the paper analyzes background research related to memory awareness states and schemata. Section 3 presents the Materials and Methods related to the pilot studies conducted. Section 4 reports preliminary results derived from the pilot studies.

2 Memory Awareness States and Schemata

In the process of acquiring a new knowledge domain, visual or non-visual, information retained is open to a number of different states. 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'. Tulving [Tul92] provided the first demonstration that these responses can be made in a memory test, item by item out of a set of memory recall questions, to report awareness states as well. He reported illustrative experiments in which 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 experiences of remembering and knowing. 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.

Whilst researchers may be interested in measuring differences between the memorial experiences of remembering and knowing, there is recent evidence to suggest that how this is implemented in a practical sense can influence the accuracy of our measures of these. Specifically, the instructions and terminology influence the accuracy of participants' remember-know judgements (McCabe & Geraci, 2009). In the past, there have been concerns raised about the use of the terms 'remember' and 'know' because the meaning that participants attach to these terms may be slightly different to those intended by the researchers. In clinical populations this has been a particular concern, and several researchers have replaced the terms 'remember' and 'know' with those of 'type a' and 'type b' (e.g. Levine et al., 1998; Wheeler & Stuss, 2003). Recent evidence has suggested that these changes are also beneficial when measuring 'remember' and 'know' judgments in non-clinical populations (McCabe & Geraci, 2009). Participants are generally more accurate, in that there are less false-alarms, when 'remember' and 'know' are replaced with the terms 'type a' and 'type b' in any instructions given. This procedure was therefore followed here.

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 & Anderson'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 [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 experimental 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 experimental framework presented here and tested through limited pilot studies aims to investigate the specific effects of tracking delay on both the accuracy and the phenomenological aspects of object memories acquired in a VE. When adopted for full-scale experimentation, it is of interest to identify whether the presence of added tracking latency applied to a system of minimum tracking latency 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

Participants of the pilot studies were recruited from the postgraduate population of the Technical University of Crete through the use of electronic adverts. Participants were separated into 2 groups of 4 participants corresponding to two levels of tracking latency (minimum system latency vs. added latency of approx. 400 ms). The groups were 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.

An immersive simulation system which improves upon current latency measurement and minimization techniques was developed [Papadakis et al. 2011]. Hardware used for latency measurements and minimization was assembled by low-cost and portable equipment, most of them commonly found in an academic facility without reduction in accuracy of measurements. A custom-made mechanism of measuring and minimizing end-to-end head tracking latency in an immersive VE was constructed. The mechanism was based on an oscilloscope comparing two signals. One was generated by the head-tracker movement and reported by a shaft encoder attached on a servo motor moving the tracker. The other was generated by the visual consequences of this movement in the VE and reported by a photodiode attached to the computer monitor. Visualization and application-level control of latency in the VE was implemented using the XVR platform. Minimization processes resulted in almost 50% reduction of initial measured latency at around 60 ms. The description of the mechanism by which VE latency is measured and minimized will be essential to guide system countermeasures such as predictive compensation.

The ability to add a constant amount of latency in order to conduct experiments of variable latency conditions was added to the system using a circular buffer for storing tracker positions and reporting them to the rendering thread on a later frame. This addition did not affect frame or tracking rate.

3.2 Visual Content

The original scene was photorealistically illuminated using pre-computed radiosity textures and stereoscopically rendered, using XVR's side-by-side stereoscopic rendering feature. The VE represented a room as shown in Figure 1. The radiosity-rendered space was divided in three zones including a kitchen/dining area, an office area and a lounge area. The space was populated by objects consistent as well as inconsistent with each zone's context. Four consistent objects and four inconsistent objects populated each zone resulting in 24 objects located in the scene overall, 8 in each zone. The polygon count of the scene was ~140,000 polygons.

The between-subjects factor was 'Minimum System Latency' vs '400 ms added to minimum system latency' and the within-subjects factor was Context specific vs Inconsistent objects. According to the training group that they were assigned to, participants completed a memory recognition task including self-report of spatial awareness states and confidence rating for each recognition after exposure to one out of the two experimental conditions.

- Minimum System Latency, referred as 'Low Latency': A stereo-rendered radiosity simulation of a scene displayed on a stereo head-tracked HMD including consistent as well as inconsistent objects in each zone. The tracking latency utilized was the minimum system latency of around 50 ms.
- 400 ms latency added to Minimum System Latency, referred as 'Hi Latency': A stereo-rendered radiosity simulation of a scene displayed on a stereo head-tracked HMD including consistent as well as inconsistent objects in each zone. The tracking latency utilized was the minimum system latency of around 50 ms with added latency of approx. 400 ms.

The office scene in all visual conditions consisted of the so-called 'Room frame' objects: walls, floor, ceiling and doors. It also included standard objects such as desks, dining table, chairs, shelves etc. The scene was populated by four consistent objects in each zone as well as four inconsistent objects for each zone. The list of objects was assembled based on an initial pilot study which explored which objects were expected to be found in each area and which were not [Zotos et al. 2009]. According to this study, 25 participants ranked the objects on the list. The consistency of each

Figure 1. *The experimental scene (top-view).*

Figure 2. *Testing blueprint.*

item was rated on a scale from 1 to 6 according to whether each object was expected to be found in each area or not, with 6 being the most expected, and 1 being the least. Based on these ratings, consistent objects were selected from the high end of the scale, and the inconsistent ones from the low end.

The objects were distributed over locations indicated in a testing blueprint similar to the one presented in Figure 2. Participants were required to select from a recognition list provided which object was present in each location.

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 170 seconds in each condition. The exposure time was defined after a series of pilot studies which aimed to identify the exposure time while ensuring that no floor or ceiling effects were observed, e.g. the task being too easy or too difficult. The final pilot studies reported in this paper aimed to finalize the experimental design and provide preliminary insight.

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, a top view of the bare environment was provided including 24 numbered vacant object positions in which an object had been present (Figure 2). A memory recognition test was administered, in which participants were required to select which object they considered they saw during exposure in each numbered position, selecting objects from an object recognition list as well as one out of 5 levels of confidence: No confidence, Low confidence, Moderate confidence, Confident, Certain, and three choices of awareness states: Remember, Know and Guess. A recognition list was devised including a list of objects per scene zone. Each zone included in alphabetical order the eight present objects as well as eight absent objects (four inconsistent and four consistent) in each zone. The list included a total of 48 objects.

Prior to the memory recognition task, awareness states were explained to the participants in the following terms:

- TYPE A means that you can recall specific details. For example, 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, or you recollect other specific information about when you saw it.
- TYPE B 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.
- 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 of Pilot Studies

The accuracy of memory was measured by counting the number of correct positions of objects (out of a possible 24). 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 three 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).

	No latency (n=4)		Hi latency (n=4)	
	Consistent	**Inconsistent**	**Consistent**	**Inconsistent**
Total correct (out of 24)	7.00 (3.92)	6.75 (3.40)	5.75 (1.71)	5.50 (3.70)

Table 1. Number of correct responses and standard deviations as a function of viewing condition (no latency, hi latency) and schema consistency (consistent, inconsistent).

Trends in the data indicate that, of these participants, more items were being correctly recalled in the correct location with no latency (M= 6.88) than with hi latency (M= 5.63). This seemingly does not depend upon whether the objects are consistent or inconsistent. These pilot data are based on a small number of participants (n=4) and are at this stage inappropriate for further parametric statistical analysis. The reliability of this trend will be verified using a 2x2 mixed analysis of variance (ANOVA) with viewing condition (no latency, hi latency) entered as a between subjects variable and the context consistency of the objects (consistent, inconsistent) entered as a within subjects variable in the main experiment.

	No Latency (n=4)		Hi Latency (n=4)	
	Consistent	**Inconsistent**	**Consistent**	**Inconsistent**
Confidence (5-point scale)	3.52 (.58)	3.56 (.50)	2.27 (.46)	3.35 (.71)

Table 2. Mean confidence rating and standard deviation as a function of viewing condition (Hi latency, No latency) and context consistency (consistent, inconsistent).

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.

Trends in the data indicate that, of these participants, confidence ratings were slightly higher for responses to inconsistent objects (M=3.46) than consistent objects (M=2.90), and that confidence ratings were slightly higher in the no latency condition (M=3.54) than the hi latency condition (M=2.81). Importantly, there are suggestions of an interaction, with confidence ratings generally lower in the hi latency condition for consistent objects (M=2.27) than any other.

As per the above section, these pilot data are based on a small number of participants (n=4) and are at this stage inappropriate for further parametric statistical analysis.

Awareness states

The proportion of correct responses assigned to each awareness state are displayed in Table 3.

	No latency (n=4)		Hi latency (n=4)	
	Consistent	**Inconsistent**	**Consistent**	**Inconsistent**
TYPE A	0.55 (.46)	.67 (.34)	.24 (.17)	.77 (.30)
TYPE B	0.10 (.21)	.33 (.34)	.14 (.10)	.19 (.32)
Guess	0.34 (.45)	.00 (.00)	.63 (.38)	.04 (.07)

Table 3. Proportion of correct responses and standard deviations as a function of viewing condition (Hi latency, No latency), context consistency (consistent, inconsistent) and reported awareness state (Type A, Type B, Guess).

Trends in the data indicate that, of these participants, more inconsistent objects were associated with a remember response (M= 0.72) than consistent objects (M=0.39), and a similar pattern is found for 'know' responses (M=.26 vs. M=0.12). Naturally, consistent objects were therefore associated mainly with guess responses (M=0.48) compared to guess responses for inconsistent objects (M=0.02).

In general there are no indications in this data set that the proportion of remember responses differ greatly between the no latency condition (M=0.55) and the hi latency condition (M=0.49), with similar indications with the proportion of know responses in the no latency condition (M=0.10) and the hi latency condition (M=0.12), as well as the proportion of guess responses in the no latency condition (M=0.34) and the hi latency condition (M=0.38).

However, there appears to be the first signs of an interaction between the latency condition (no latency, hi latency) and the object consistency (consistent, inconsistent) across the three reported awareness states. In particular, there are a disproportionately large proportion of guess responses for consistent objects in the hi latency condition (M=0.63), and correspondingly a disproportionately low proportion of remember responses for consistent objects in the same latency condition (M=0.24).

These pilot data are based on a small number of participants (n=4) and are at this stage inappropriate for further parametric statistical analysis. The reliability of these trends will be verified with a series of 2x2 mixed analysis of variance (ANOVA) for each awareness state with viewing condition (no latency, hi latency) entered as a between subjects variable and the context consistency of the objects (consistent, inconsistent) entered as a within subjects variable in the main experiment.

5 Discussion

The preliminary analyses of the pilot data indicated that latency in the VE simulation may influence the accuracy of memory for objects in that environment. The correct objects and their locations may be remembered more accurately when there is no latency than when there is high latency. The pilot data also indicated that object consistency with the visual scene may have an influence too. Interestingly, the proportion of correct responses that had a vivid 'remember' experience were greater when the objects were inconsistent with the environment, than when they were consistent. This appears to potentially interact with latency, with a disproportionate number of correct responses to consistent objects in the hi latency condition being associated with guesses. Confidence scores interacted with latency and object consistency in a similar way, with lower confidence scores for responses to consistent objects in the hi latency condition.

It has been noted previously by some of these authors that pure accuracy measurements are an imperfect measure of the memorial experience in VE simulations. This has to some extent been predicated by consistently high performance on accuracy tasks that is underpinned by differential patterns in actual memorial experience [Mania et al. 2003, 2010, Bennett et al. 2010]. In this initial pilot exploration there are some suggestions that, unlike previous variations, variations in latency may impact upon overall accuracy. This can be explained simply as additional perceptual processing resources that may have been dedicated to interpreting and updating the internal mental scene as a result of the latency can instead be redistributed to processing the objects within it. That is to say, navigating a world in which there is no latency may minimize the perceptual resources needed to cope with this unnatural motion and instead allow these to be re-distributed to other perceptual tasks such as object recognition.

In terms of the memorial experiences that underpin these recollections, past studies have indicated 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]. That is to say that deviation from 'real' may capture attention. This is typified in the current experiment in conditions where the objects are not ones you might expect in the environment (inconsistent objects) for which there are clear indications that this may lead to more vivid 'remember' experiences of seeing them in the VE simulation. Potentially of more interest are the measurements of memorial experiences associated with inconsistent objects when there is a high latency. This combination of conditions is potentially the least consistent with reality in that both the interactivity, the latency, and the objects are inconsistent with reality. Interestingly this combination produced the highest proportion of 'remember' responses in this exploratory data set which is consistent with the attentional hypothesis that has been put forward based upon consistency with reality. More broadly, the suggestion is tentatively supported 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].

Nevertheless, the present data also pose an interesting challenge for interpretation. There are initial indications that participants had particular difficulty with consistent objects in the hi latency condition, with generally lower accuracy, lower confidence ratings and a disproportionate amount of guess responses. One possibility is that interacting with a high latency VE simulation is particularly demanding of perceptual processing resources, such that any remaining resources are devoted to processing and interpreting objects that 'pop-out' by varying from reality at the expense of interpreting those that are consistent. This would suggest at least two stages at which attentional demands may influence processing of objects in similar VE simulations. The first stage may be based upon additional processing demands that arise from the VE environment. If these demands are interactive (e.g. latency) then these make more demands of processing resources than those that are less interactive (e.g. radiosity). The second stage then makes use of the remaining processing resources. Where these are novel aspects of the environment that vary from 'real' may receive more attention than those that are consistent. If sufficient resources are available then both novel and non-novel items may be attended to for processing. This interpretation if of course tentative and rests on a number of assumptions that would require further testing if this result was found with a larger sample size.

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. In any case, the pilot study results presented here stimulate a number of considerations for further testing when the full-scale experiments are conducted with the appropriate number of participants and parametric statistical manipulation of data is possible. There is some indication that a high saliency environment may have a profound effect upon memory for the objects and their locations within it.

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