Narrative and Spatial Memory for Jury Viewings in a Reconstructed Virtual Environment

Carolin Reichherzer, Andrew Cunningham, James Walsh, Mark Kohler, Mark Billinghurst and Bruce H. Thomas

Fig. 1. Virtual copy of an office for a simulated crime scene scenario.

Abstract—This paper showcases one way of how virtual reconstruction can be used in a courtroom. The results of a pilot study on narrative and spatial memory are presented in the context of viewing real and virtual copies of a simulated crime scene. Based on current court procedures, three different viewing options were compared: photographs, a real life visit, and a 3D virtual reconstruction of the scene viewed in a Virtual Reality headset. Participants were also given a written narrative that included the spatial locations of stolen goods and were measured on their ability to recall and understand these spatial relationships of those stolen items. The results suggest that Virtual Reality is more reliable for spatial memory compared to photographs and that Virtual Reality provides a compromise for when physical viewing of crime scenes are not possible. We conclude that Virtual Reality is a promising medium for the court.

Index Terms— Virtual Reality, virtual environments, narrative memory, spatial memory, crime scene viewing

1 Introduction

This paper explores the use of a reconstructed 3D model of a crime scene presented in Virtual Reality (VR) to firstly, improve narrative and spatial memory for presented evidence in a courtroom and secondly, provide an alternative to crime scene viewings. We are investigating the comparison of two currently employed methods used in court, photographs and a real world visitation, to VR embedded in a narrative crime scenario. In particular, we are interested in the ability of these three evidence presentation methods to support narrative and spatial memory for users. The results of an initial pilot study comparing VR, photographs and real world visitations is presented.

Traditional evidence presentation methods include oral presentations, sketches, photographs, and videos for when site visitation cannot be carried out. More modern technology, such as the use of tablets and computer-generated images [1], have also been trialled recently for courts in Australia [2]. This paper proposes that VR technologies could overcome some of the limitations of current evidence presentation and crime scene visitations.

This paper is part of an ongoing research project with Australian law enforcement, involving a series of discussions with law enforcement officers, forensic experts for 3D reconstruction, former prosecutors, defence lawyers, and South Australian Police officers. These experts have expressed the view that VR has the potential to improve current courtroom and investigation processes from effectiveness, efficiency, and cost perspectives.

This paper is the first investigation of a larger project to determine where commercially available VR technology stands in comparison to the status quo of evidence presentation and processing events during a trial. This is envisioned as a long-term series of experiments, in which new cues and information will be incorporated into the VR condition to address identified shortcomings for future versions. The additional information has the potential to improve on current evidence presentation techniques by improving the understanding of all presented facts, such as evidence and witness statements. Jury visits to the crime scene are the current gold standard in providing a realistic impression to the jury during their fact-finding process. Within the courtroom, however, current evidence presentation uses a two-dimensional medium, and there is

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currently no substitute for a jury actually visiting the crime scene in terms of understanding the case timeline and spatial relationships between evidence.

Currently, the trial process does not provide a natural way for the jury to make sense of evidence. According to the *Story Model* [3], the information presented to a jury member is cognitively pieced together to form a cohesive story with a causal structure that aids their understanding. The individual pieces of information have to be structured to make sense within the whole case. In general, people tend to organise this information in a story format.

However, evidence inside a courtroom is typically presented in a disconnected fashion, out of any chronological or spatial order, and each individual jury member has to has to create their own mental representation of what they believe happened. This can delay the time they need to reach a mutual decision for a verdict [4]. The average attention span of a jury member is estimated to be less than seven minutes at a time [5], and the presentation of complex facts typically presented during a trial can leave them feeling overwhelmed and frustrated [6]. In contrast, presenting the evidence within a temporal context reduces this mental overhead, allowing users to more easily assimilate individual pieces of evidence into their own version of the narrative [7]. Jury site visits allow the jurors to investigate the site independently [8], which provides a possibility for the jurors to make sense of the information that has been viewed in court at their own pace and allow them to structure a mental model that fits their needs.

Previous research has shown that immersive VR can create a realistic illusion of physically being present in a virtual location, a phenomenon referred to as *Presence* [9]. This effect can be useful in not only viewing a scene but also experiencing what it was like to be there [8]. Furthermore, VR can be used to show crime scene evidence that supports the mental creation of a narrative with the spatial aspects of a scene, and showcase alternative scenarios of what could have happened from different viewpoints [10]. VR technology has the potential to provide a deeper understanding of the events that have occurred if presented in a narrative format that the jurors can follow, and VR may offer advantages that surpass other visualisation media [11].

We are investigating the use of VR technology as an effective tool for accurately recalling the information presented in a trial and supporting the creation of a correct mental representation of the events described in court. Moreover, a virtual representation can include evidence and other information that has been removed by the time a jury viewing can occur and exclude information that the jury should not see [12]. This could potentially help the jury reach a verdict faster and more accurately.

To achieve this overall goal, we are interested in answering the following research questions:

R1: Does VR improve narrative memory compared to viewing photographs?

R2: Does VR improve remembering objects and locations compared to photographs (spatial recall)?

As previously mentioned, this research is the beginning of a series of experiments designed to support the fact finding process of a juror in court. One of the long-term research questions is: *How VR can be improved to be offered as a substitute for jury viewings?*

This paper's primary contributions are: 1) Providing a quantitative measurement of combined narrative and spatial recall in a VR environment; 2) Presenting results from an initial pilot study comparing photographs, room-scale VR and real life scenery for the purpose of viewing a scene for the court; and 3) Demonstration of differing viewing behaviour of a physical scene.

In the remainder of the paper, we first summarize related research and clarify the research gap that we are addressing. Then we present results from an experiment comparing narrative recall in different reviewing conditions. Finally, we discuss these results and present conclusions with directions for future work.

2 Background

This interdisciplinary work draws on existing research from the fields of VR, legal proceedings, and cognitive psychology. In this section, we present the use of visual evidence in court, followed by the Story Model, the memory and the cognitive processes that jurors use to make sense of the evidence, and we conclude with a review of current applications of VR use in court and investigation.

2.1 Visual Evidence in Court

During a trial, members of the jury have to absorb and make sense of complex evidence presented to them to recreate the events that unfolded. Visual aids are shown to support faster and more accurate understanding than oral presentations [13] and have made their way into court in the form of sketches, diagrams, photographs, videos and animations [12]. For example, photography is commonly used to show the crime scene to the jury during a trial [14].

However, current visual aids cannot entirely recreate the impression of the real crime scene, such as clearly expressing the spatial relationship between objects. For serious crimes, the jury takes part in "viewings", in which they are sent to the location where the crime occurred in order to put evidence seen previously in court into context. Viewings can provide a strong sense of space, distance, and spatial relationships.

Despite the benefits, viewings have several drawbacks. Carrying out viewings is an expensive process for the court, and in some cases may be impossible. Juries, Judges, and assistants have to be transported separately to the scene of the crime which may be in remote locations. While the court has full control of how evidence is presented during the trial in a courtroom, it has very little control over the physical movements of a juror at a crime scene, potentially skewing each juror's perception by experiencing something slightly different. In some cases, the crime scene has been altered, demolished, or is inaccessible after the crime, which makes a viewing impossible. For example, in a car crash, the evidence is short-lived and susceptible to weather conditions. Important traces, such as skid marks, start to disappear as soon as they cool down. Thus, there is an opportunity for technology to improve the viewing process and alleviate some of these problems.

2.1.1 Presenting Spatial Information

A key aspect in the viewing of an unknown scene is the perception and understanding of the location [15]. Pieces of information and their relationships have to be understood and later recalled, new data extracted and knowledge of events put into context to create a mental representation.

Complex spatial and temporal information may be presented in court via long descriptions of events, supported by sketches, photographs or maps, demonstrating where people and objects were located [16]. However, each of these methods has shortcomings. For example, photos and maps are two-dimensional representations of three-dimensional space and will inherently produce some level of distortion of the spatial relationships found in the scene [17]. The jurors have to translate the presented two-dimensional information and its context into a mental image for understanding the situation.

During a criminal investigation, the spatial information of the crime scene is captured with a set of sketches made by the investigators, to show the relationships of objects in the scene, the layout, and orientation. These sketches can differ in fidelity and will later assist investigators and the jury in understanding the dimensions and limitations of a scene. The effort used to recreate the spatial dimensions of a crime will differ depending on the type of crime. For example, in-depth information will be required for severe crimes such as homicides or traffic accidents that result in death, where the spatial relationships of evidence are vital [18].

2.2 Story Model

During a trial, the evidence being presented is subject to procedural rules and can be introduced without temporal or logical order and missing information in the recollection of events. This means that the jury can be confronted with a large amount of disconnected information, which they have to mentally form into a sequence of events that they can make sense of and agree on [19-21].

A natural way in which the jury makes sense of this information is to develop a narrative in their mind which is then filled with further information as the trial progresses [3, 20]. Arranging the elements into a story provides a framework for temporal and relational organisation, and the basis for inferring causality [22].

Pennington and Hastie proposed the *Story Model* that explains how jurors tie the information they are presented with into a narrative in order to understand evidence and reach an individual decision [4, 7, 23, 24]. During the process of constructing a narrative, the juror can create more than one possible story looking for a mental model that makes the most sense to them, where the evidence presented is placed within the story they are constructing. That model is influenced by the jurors' expectation, the people involved and prior knowledge of similar situations. If an element deemed important to create a narrative is missing as evidence, the juror will likely infer the gap in information [7, 14].

The Story Model facilitates understanding the evidence by attempting to give the big picture of what happened from start to finish, and can have a significant impact on the jury verdict [7]. In a study conducted by Pennington and Hastie [19], mock jurors were presented with evidence in different order. If the prosecution was presented in a story order, but the defence was not, the jury was more likely to convict. Similarly, when the situation was reversed, the jury was more likely to acquit and agree with the defence when the story order was presented by the defence [4, 19]. In another study, the mock jurors explained that their understanding of events depended on which facts they remembered from the case. They had selected the facts that made a coherent story, but almost half of the elements they accepted were inferences due to gaps in their story being filled by what they believed could have happened [19].

To date, the Story Model is the most widely accepted and comprehensive decision-making model of jurors, supported by strong empirical support. It facilitates understanding the evidence by giving a big picture of what happened from start to finish [7].

2.3 Narrative Memory

Due to the confidential nature of jury deliberation in a trial, there is little knowledge about real juror memory. However, studies involving mock jurors, have indicated that jurors forget critical information or recall it incorrectly. This can have an impact on the verdict when important evidence is forgotten [23, 25]. Whereas note taking is seen as beneficial for recall of trial information in some countries, such as Australia, it is up to the judge to permit the juror to take notes [25].

For the jury to reach a just verdict, it is of importance that key evidence presented during the trial is remembered fully and accurately. The memory of a single juror can be unreliable, forgetting critical information of a trial or recalling it incorrectly [23, 26]. In contrast, the collective memory of a jury has been argued to counteract deficiencies of the individual jurors' memory by correcting errors and sharing their trial memories, the latter being an effect known as memory pooling [7, 27]. However, results of collective memory being accurate and resolving erroneous memories have been inconclusive. Jury members with the highest confidence in their memory appear to be the drivers for the verdict, which is no guarantee for correct recall and potentially results in a decision based on inaccurate or incomplete information [26].

2.4 Spatial Recall in Virtual Reality

Spatial knowledge has been evaluated in VR environments. Research using VR for training purposes suggests that spatial information acquired in a virtual environment translates well into the real world. In one study, users who were trained in VR performed the same as users trained in the real world and significantly better than users with no training [28].

Mania and Chalmers [29] gave participants a seminar learning task using a desktop display with a 3D environment, a physical real life condition, a Head Mounted Display (HMD) condition with audio paired with a 3D environment, and audio on its own. They took measurements of facts presented in the seminar as well as spatial memory. Participants that used the HMD had a significantly higher confidence in the accuracy of their responses than those exposed to the reality condition. Moreover, the sense of Presence did not appear to have an effect on the accuracy of spatial recall.

A further study compared remembering objects in space in a real-world environment or in a virtual copy of the environment viewed with an HMD [30]. There were four conditions in total: Real world, Monocular HMD with mouse navigation, monocular HMD with head-tracking, stereo HMD with head-tracking. No significant difference was found in accuracy between all conditions, indicating that VR works as well as the real world for memorising spatial locations and objects. However, participants reported a higher vividness in memory for conditions that had a lower level of fidelity (the mouse condition). These findings suggest that information acquired in VR offers a good understanding of the space.

2.5 Virtual Reality in Court

Commercial crime scene reconstruction has been available since 2004. Virtual reconstructions have been used to assist police investigation and the jury [31-33]. They can help resolve ambiguities and facilitate visualisation of complex situations. For example, Buck et al. developed a virtual reconstruction for a real police investigation of a car crash where it was unclear whether an accident or a homicide had occurred. The visualisation revealed the driver had intentionally reversed and killed the victim, a result that could not have been proven without the reconstruction [32]. DeltaSphere is an early example of a commercial crime scene reconstruction system [34].

In order to address the limitations of traditional methods, researchers have begun to explore how VR can be used to present crime scenes. For example, the *Forensic Holodeck [35]* reconstructed a shooting scenario that occurred inside an internet cafe to analyse the bullet trajectories. The reconstruction was created with a laser scanner and the 3D model later imported into the Unity3D game engine and presented in VR. The scene itself was static, but the user was able to move around using the Oculus Rift VR HMD.

Experiencing information in three dimensions like this provides a sense of spatial awareness that is hard to reproduce in a two-dimensional medium, such as with photographs or traditional computer monitors The interactive element has also been shown to hold the attention longer of the person viewing the environment [36]. The immersive graphical display can also help jury members to retain important information longer. Studies have shown that juries in traditional courtrooms retain 85% of what they see and only 15% of what they hear [12, 36]. Finally, VR can be used to show information not otherwise visible, such as seeing bullet paths in a shooting, or car paths in a car crash.

In summary, VR reconstruction provides the advantage of viewing the scene from multiple viewpoints and assessing alternative possibilities if new information becomes available. The addition of VR and the perception of being at the scene could make remembering and understanding the scene as intuitive as if the person had actually been there.

3 Experiment

In order to answer the research questions outlined in the introduction, we conducted an experiment comparing three viewing conditions: VR, photographs, and physical viewing of the crime scene. Jury viewings of the physical crime scene are usually carried out for homicides or traffic accidents that resulted in bodily harm. These are highly complex scenarios with a strong component of spatial relevance, where the jury is exposed to the scene for a set amount of time during a visitation. Due to the complexity and ethical concerns, we decided on a scenario which simplifies the crime scene and number of variables involved while maintaining the relevance of spatiality and relationship of items. In this section, we describe the experiment in detail.

3.1 Experimental Design

We used a between-subjects experiment design, where each participant experienced one of three viewing conditions. The experiment required each participant to read a narrative of the crime, and then to immediately recall what they had read. This was followed up by the participant being exposed to one of the viewing conditions which was either a set of photographs (PHOTO), Real Life (RL) or Virtual Reality (VR). After this, they had to recall the spatial locations of evidence and the narrative a second time.

Thirty participants (eleven female) participated in the experiment, 10 participants for each of the three conditions. Students and University personnel were recruited, along with people from the general public. Gender was balanced throughout all three conditions and participants were aged between 19 and 56 years old *(M=30.60, SD=10.27)*.

To be eligible for the experiment participants needed to be over 18 years old and a native speaker of the English language. They were compensated with a $25 gift card for their time.

3.2 Experimental Setup

A 6.0 × 5.0m office on campus was chosen for a simulated burglary crime scene (see Figure 3). The actual walkable area in the area was approximately 2.3 × 2.5m. Chairs were knocked over and drawers left open to create the impression of someone having broken in. Inside the scene, the locations where relevant objects were taken away or left behind were marked with an orange marker (see Figure 1). The marker was designed with the 3D software Blender [37], and 3D printed for the RL, and by extension the PHOTO, condition. All markers were approximately 60 mm tall by 30 mm wide, with no unique identification on them. South Australian courts employ markers without identification markings for their jury viewings.

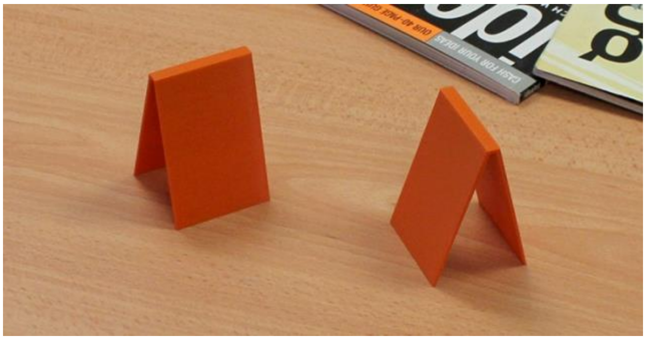

Figure 2: The physical markers used for all conditions. The VR condition used the model that was digitally created.

3.2.1 Environment Reconstruction

The reconstruction of the office was created using the Matterport Pro3D (MC200) camera based capture system that consists of three depth and three RGB cameras [38]. A total of 41 360° room scans (point cloud and image) were captured, which were combined into a single detailed representation of the scene consisting of 293,811 polygons (see Figure 2). The computation of the final mesh was performed via the Matterport cloud based service. The mesh was then imported into Unity3D 5.6 for the VR condition. Figure 2 shows the final VR scene generated from the Matterport system. For comparison, Figures 3 and 4 show the quality of the reconstruction compared to a photograph of the real environment. A separate scan was made that included the markers. The scanned markers were not of high quality due to its small size, so a 3D computer generated models were inserted as a reference at the locations of the physical markers into the VR mesh.

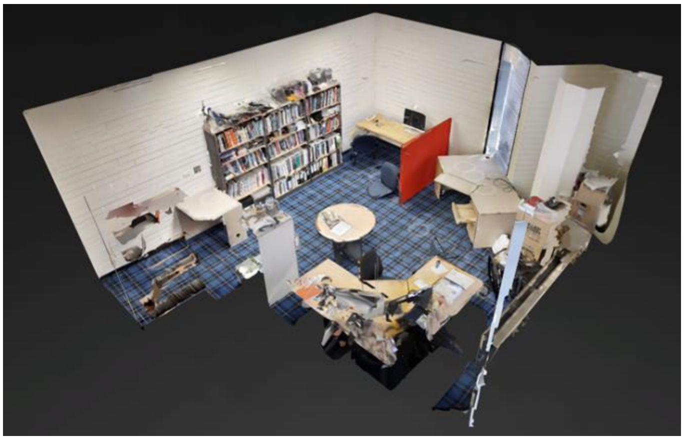

Figure 3: The mesh of the reconstructed office.

Figure 4: Photograph of the office taken with a scan.

Figure 5: The virtual copy of the office scan shown in Figure 4.

3.2.2 Viewing Conditions

In a courtroom printed photographs are a common way to present evidence to a jury [39]. In our case, participants sat at a table and were given a set of fifteen individually A4 printed photographs taken from different angles with close-ups of the locations with the markers. See Figure 5 for example photographs.

Figure 6: Examples of images presented to participants for the PHOTO condition. Viewpoints were fixed in this condition due to the nature of the format.

In the RL condition, the participants entered the real office described in the narrative. An HTC Vive Tracker [40] attached to a head strap was worn on the participant's head to track their movements through the office (see Figure 6). As participants entered the office, the entrance area (as highlighted in Figure 7) was used to attach the head tracker and receive the final instructions. Participants were instructioned to ignore the entrance area. They faced the entrance door while the tracker was being attached, preventing inadvertent exposure to the scene.

Figure 7: The headband used to track the movement.

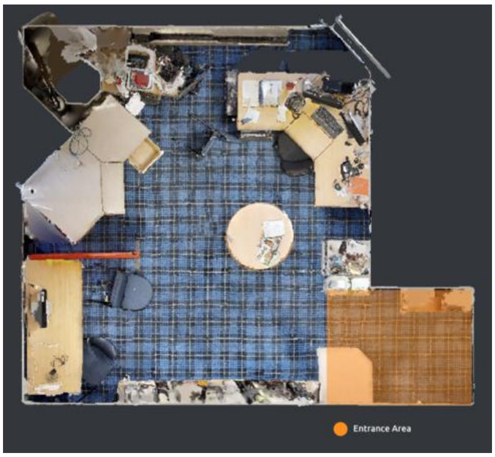

Figure 8: Floor plan of the office with the entrance area used to attach the headband.

In the VR condition, we used an HTC Vive headset [41] with a resolution of 1080 × 1200 pixels per eye and a 90 Hz refresh rate. The Vive Lighthouse room scale tracking allowed participants to freely walk around and explore the area. The approximate measurements of the walking area in the real office were used to calibrate the room-scale setup in the VR condition (2.2 × 2.5 m). Before participants viewed the virtual scene, their inter-pupillary distance (IPD) was measured, and the HMD calibrated accordingly for the viewing. The participants were asked to stand on a marked location which was the same starting point as for the participants in the RL condition.

3.3 Task and Procedure

The experiment was performed in four phases: 1) Preparatory, 2) Immediate Narrative Recall, 3) Exposure to the Viewing Condition, and 4) Delayed Recall. Three rooms were employed: 1) a preparatory room for the PHOTO and RL conditions, which also served as a viewing room for the PHOTO condition 2) an RL condition viewing room (the crime scene), and 3) a VR laboratory for both preparatory and viewing of the VR condition.

Preparatory

Participants were met at a separate office where most of the experiment took place for the PHOTO and RL conditions. Users for the VR condition were greeted at and stayed in the location with the VR setup for the entirety of the study. In the preparatory room, the participants were given an information sheet to read and asked to sign a consent form approved by the University ethics committee.

Immediate Narrative Recall

The main study task consisted of reading the narrative of a simulated burglary scenario that occurred in the office. This was performed in the preparatory room. The scenario was provided by a former South Australian state prosecutor and adapted by adding spatial locations of the items taken from the developed crime scene. A copy of the written scenario given to the participants is provided in Appendix 1.

Participants were encouraged to take as much time as they required to read through the narrative. When the participants felt they understood the narrative and were ready for the experiment, they told the experimenter to start the next phase. In addition to the written text, they were given photographs of the items that they were told have been taken or left behind. The evidence items were photographed on a neutral background (see Figure 8). They were then asked to tell the narrative from memory again, a Free Recall (FR). If relevant points of the story were missed, the experimenter followed up with Cued Recall (CR) questions, such as "*Who was assigned to the investigation?*"

Figure 9: Example image of the stolen goods that was given during the Immediate Recall phase.

Exposure to the Viewing Condition

Following the recall, participants had four minutes to view the scene as per their assigned condition. The time constraint was chosen in proportion to a real jury view, where jurors have on average twenty minutes to view a scene. Our initial tests studies (before the presented pilot study) indicated that four minutes was sufficient amount of time to obtain an understanding of the scene, but not enough to memorize every detail. Participants in the PHOTO condition were given a set of images, whereas participants in the RL or VR scenario were led to the actual office or given a virtual reality headset respectively. All of the participants were asked to stay engaged within the scene until the time was up. They were then led to a laptop to answer a questionnaire on their perception of being present in the scene.

Delayed Recall

Between the Immediate and Delayed Recall of the narrative, there was a minimum of thirty minutes. During this time the participants were asked to take the Automated Neuropsychological Assessment Metrics (ANAM) survey [42], which measured their spatial and memory ability. This was used to make sure all participant's memory ability was within the population average. This was performed in the preparatory room for the PHOTO and RL condition. The VR lab was used for the VR condition.

Following the viewing, the participants were presented with a floor plan of the office and asked to place all the objects they remembered mentioned in the narrative in their correct location. When doing this, they were asked for their Awareness State for each object positioned [43], of which there were three different states: *Remember, Know* and *Guess*. *Remember* stood for visualizing the location in all its detail *and* knowing the right item for that location. *Know* was intended for knowing the right location without any visual memory of the space. *Guess* was if they felt they could not remember and did not know the right answer. The last task was a Delayed Narrative Recall in which the participant had to retell the scenario given to them in the beginning.

The study concluded with final questions on their perceived difficulty of the task and an attention-to-detail question, which asked for how many chairs were fallen over.

3.4 Dependent Variables

The following subjective and objective measures were captured during the experiment: (1) Narrative Memory, (2) Spatial Memory, (3) Movement data of participants in the RL and VR condition, and (4) Sense of Presence.

Narrative Memory was chosen to measure as to whether the context helps to remember the items and locations involved and how people later recall the information. It was measured with an item-by-item checklist, consisting of 30 points that were deemed important from the narrative for Free Recall (FR) and Cued Recall (CR). Items on the list were names, evidence, locations and key points such as observations of the victim. FR was worth two points, whereas CR was worth one point counting towards the score.

Spatial Memory was measured using a picture of the floor plan provided to each participant after the experiment. Participants had to mark on the floor plan where they thought that items were placed, and a score was created counting the correct number of items and location (Hits), and forgotten items (Omissions). Items that were misplaced or recalled incorrectly were counted together as Commission. We also wanted to know the vividness of the memories involved and added a second Awareness State score [44] of Remember, Know or Guess for each item.

The user movement was measured with a VIVE tracker that was attached to a headband. We recorded the current timestamp, position, and orientation of the participant's forehead every 1/100th of a second.

Finally, we wanted to measure whether there was a connection between the sense of Presence and the accuracy of spatial recall. This was measured using the Slater-Usoh-Steed (SUS) Questionnaire [45]. The questionnaire consisted of 6 questions on a 7-point Likert scale about how real the office space felt, plus an additional open question about their subjective experience and what helped them feel as if it was perceived as reality.

4 Results

The ratio of males to females, age, performance on measures of general memory and spatial ability, and perceived task difficulty did not differ between groups. A summary table of these results can be found in Table 4. Overall, we found the following:

1) The viewing behaviour significantly differs between the RL and VR conditions, 2) Spatial Recall appears to be affected by the viewing condition, and 3) Narrative Memory improved equally for all participants in all conditions.

We first present the results of the participant movement, followed by spatial recall, and the outcome of the narrative memory. Presence and attention-to-detail results will then be discussed. Finally, the general observations of participants' behaviour and reactions will be presented last.

4.1 Participant Movement

An independent t-test was conducted to compare the distance travelled in each condition. The distance was measured by calculating the difference between each timestamped position recorded from the head-mounted VIVE tracker; these positions were summed up together. On average, participants in the RL condition moved a longer distance (*M=52.55m, SD=14.22m*) compared to the VR condition *(M=36.83m, SD=12.14m)*, $t(17)= 2.575$, $p=0.02$. The data from one participant who experienced a low level of motion sickness and decided to stand still during the last minute of the experiment was removed for the analysis. See Figure 9 for movement visualisation of the two conditions.

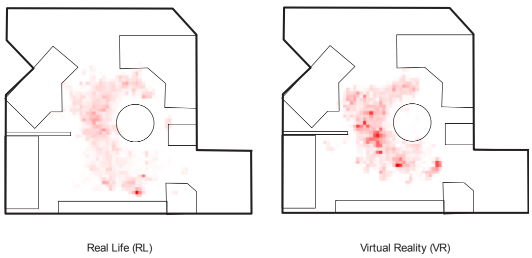

Figure 10: Movement for all participants represented as normalised heatmaps. The hot spots present in the VR condition suggest that participants lingered in specific locations longer than in RL and consequently did not move as much.

4.2 Spatial Recall Task

For the placement task, answers were divided into three different categories: Hits, Commissions, and Omissions (forgotten items). Hits and Commissions were further divided into the awareness states Remember, Know and Guess. To be counted as a Hit, the placement on the floor plan had to be accurate. A floor plan with the locations plus a tolerance radius that corresponds to roughly 30cm was used as a template to locate the Hits (see Figure 10).

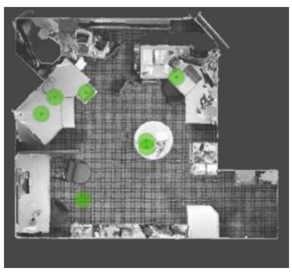

Figure 11: Template used to validate accurate positions. The template was overlaid over each participant map for the assessment.

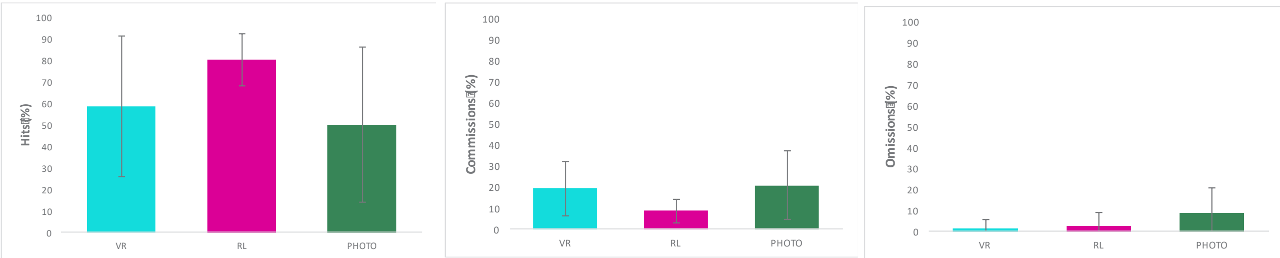

Figure 12: Means for each condition and response types: Hits (left), Commissions (middle) and Omissions (right). The error bars show the big variability in responses for VR and PHOTO.

Hits (%)	VR	RL	PHOTO
Mean	58.57	80.00	50.00
SD	32.61	12.05	35.80

Commissions (%)	VR	RL	PHOTO
Mean	19.29	8.57	20.71
SD	13.06	5.64	16.31

Omissions (%)	VR	RL	PHOTO
Mean	1.43	2.86	8.57
SD	4.52	6.03	12.05

Table 1: The values for the Means and Standard Deviation for each of the response types and condition.

Due to the distribution of scores being slightly skewed, comparisons of scores across groups were made using median tests. Differences between groups for Hits and Omissions were not significant (χ^2=2.50, *p*=0.29, and χ^2=2.61, *p*=0.27, respectively). However, an overall significant difference for Commission rate was reported, χ^2=7.50, *p*=0.02. Pairwise comparisons using the Median test revealed that the Commission rate was significantly higher amongst the VR condition compared to the RL condition. Although the Commission rates in the PHOTO group were very similar to the VR group, differences between PHOTO and both VR and RL were not significant. Details of the measurements are presented in Figure 11 and Table 1.

The division of Hits into Remember, Know, and Guess rates did not reveal any significant differences between groups.

4.3 Narrative Memory

Narrative Memory was assessed using a 2 x 3 mixed measures ANOVA. The independent factor was 'Group' and the repeated measure was the two time points. There was a significant improvement across all groups after being exposed to the scene, *F*=7.88 (1, 27), *p*=0.009, however, there was no difference between groups in overall performance, *F*=0.78 (1, 27), *p*=0.468. Similarly, there was no significant interaction between time and condition, *F*=0.26 (1, 27), *p*=0.775. The RL and VR conditions had a very similar outcome, with RL having the steepest effect in remembering the narrative better. Figure 9 shows the increase for each individual condition between Immediate and Delayed Recall.

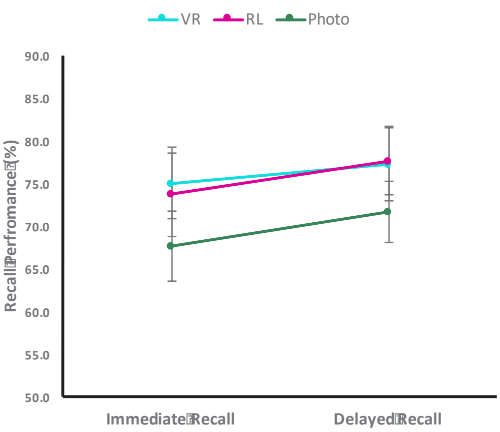

Figure 13: Increase in Narrative Memory scores was similar between all conditions. The graph shows the percentage of the recall performance.

4.4 Attention-to-Detail and Presence

Self-reported attention-to-detail and presence (SUS) scores varied between groups and differences were determined by a one-way ANOVA. The attention-to-detail question was a question at the end of the questionnaire, which asked for the number of fallen over chairs at the scene. A Sidak post hoc test revealed that the results for the attention-to-detail ratings turned out to be larger for VR compared to PHOTO only (p<.05), with no difference between the VR and RL conditions. See Table 2 for the Mean values. The correct answer for that question was two. Self-reported presence (SUS) scores were greater for both RL and VR compared to PHOTO (both p<.001), see Table 3 for the average scores of the survey.

We performed a Spearman RHO analysis between Presence scores and response type to determine if there is a correlation between Presence and spatial memory. Results from Spearman RHO correlations show no significant association between the SUS scores and Hits (r=0.26, *p*=0.16), Omissions (r=-0.15, *p*=0.45), or Commissions (r=-0.17, *p*=0.33).

Chairs	VR	RL	PHOTO
Mean	1.70	1.40	1.10
SD	0.48	0.52	0.32

Table 2: Mean values the attention-to-detail question.

SUS	VR	RL	PHOTO
Mean	5.43	5.85	2.93
SD	1.37	1.25	0.73

Table 3: Mean values for the Presence ratings.

4.5 General Observations

Participants in all conditions were quite invested in trying to put meaning into the scene they were viewing and connect it back to the narrative that they had read. Those who had forgotten spatial locations before the viewing tried to deduce them based on what would make sense for them, which did not always yield the correct answer. For example, in some cases, this resulted placing a bag with money into the drawers instead of on the floor where it should have been. Participants reported the task to be more on the challenging side throughout all conditions *(M=4.56, SD=1.25,* on a Likert scale ranging from 1 to 7, with 7 meaning "*very difficult*").

Several participants in the PHOTO condition struggled to make a realistic mental layout of the scene based on the photographs that were provided and commented on having to force themselves to think logically about the space and where things went. One participant counteracted that by arranging the photographs in a way that would resemble the relative spatial relationships to one another. Another participant commented on struggling to associate the evidence items, which were presented on a neutral background, with their appropriate locations in the scene which was represented with an orange marker in the pictures. They said, *"I feel like I couldn't retrieve the location of particular items as my photographic memory presented them on a white background."*

There were also limitations with the VR condition. In terms of feeling as if they were '…in the office space,' some participants commented that the flaws in the VR reconstruction which reduced the perception of reality. For example, one participant said that the VR scene *"looked like an office from the zombie apocalypse, everything looked frayed and old."* Another user described how the misaligned textures on the carpet and the *"not fully formed shapes"* of objects pulled her back to reality at times. For instance, some of the chairs were missing a leg. However, being able to walk around seemed to counteract this effect to an extent, despite being aware of the cables from the headset.

4.5.1 False Memories

An interesting phenomenon was the creation of memories that were false or conflicted with other elements of the narrative. For example, the window referenced in the narrative was the cause for some confusion. Two of the participants reported that the perpetrators left the building by climbing out of the window. Both times this mistake was made during the Delayed Recall only. This was observed in the PHOTO and RL condition, despite the participant being aware of the office being on the first floor (approximately 4 metres above the street level), and being difficult to access through a window. Another participant described the items in the office to be visible through a window, which was confused with the equipment being visible in plain view in the van. One participant in the RL condition and two other participants in the VR condition described the two youths to have been observed running out of the building before getting into the van, observed by a security or police officer. In the VR and PHOTO conditions, some items were placed with moderate (Know) to high (Remember) confidence on a third unrelated desk, indicating a false memory was formed.

4.6 Limitations

There are some limitations with this user pilot study. We were interested in understanding the appropriateness of commercially available VR technologies for their suitability of jury viewing considering the current status quo of evidence presentation in a trial. This required reducing the complexity normally involved in cases where jury views are carried out, which also resulted in the narrative having less of an impact on the spatiality of the scene than for example, a homicide. Another limitation was the size of the study, with 10 participants per condition. Results that showed a large effect size could be strengthened in a larger study. Another limitation was the reconstructed mesh created with Matterport system used for the VR condition. While the 3D meshes did not appear to affect performance, the quality of the 3D mesh was noticeable by most participants. Current 3D reconstruction systems are improving, and they are getting close to a photo-realistic impression of the scene.

5 Discussion

In these results we found a significant difference in the response type for Commissions between the VR and RL condition. Surprisingly to us, there were no differences between the Hits in all conditions. However, there was a large variability in the results for both the VR and PHOTO conditions. The range of responses was consistently larger in the PHOTO condition for all response types compared to both VR and RL, which may explain the lack of differences between the PHOTO condition and the other two groups. The large variability also suggests that the response to photographs is more unreliable than VR, which in turn signals that VR could increase the reliability of court decisions.

Results from this experiment indicate a different viewing behaviour between the RL and VR conditions. The users appear to move more evenly across the area in the RL condition. At the same rate, both conditions showed a significant difference in Commissions, suggesting that participants in the VR condition were more often only "half accurate", confusing either location or item associated with it. The confusion could be explained by the participants not searching enough to encode the environment that helps memory. It also appears that participants in the RL scene inspected the scene more thoroughly. Overall, it seems that for accurate spatial recall, viewing in RL helps form the best representation of the environment.

Confirming a previous study that Presence does not have an effect on spatial memory [29], we also observed that a high sense of being in the place did not have an influence on spatial memory performance. This seems to suggest that the spatial knowledge acquired in the VR environment does not translate as well for the purpose of vividness in memory and accuracy compared to the RL condition. The research focused on navigation for VR suggest that time is needed for a full understanding of a virtual environment to develop, referred to as *Survey Knowledge* [15, 46]. There was likely not enough time in our scenario for this to develop. On the other hand, it could mean that a high sense of Presence is not needed to remember a location well.

Around 60% of the participants in the VR condition had never used the technology before. Yet, everyone was able to walk around and explore the scene while trying to make sense of what they had seen and read before. Participants in the PHOTO condition consistently commented on the difficulties of creating a mental map and that the experience is more difficult by not being able to visit the scene. This could point to a higher mental overhead that has to be used in the PHOTO condition to make sense of the location that could otherwise be used to concentrate on the trial itself.

False memories in the narrative seemed to be independent of the condition. More importantly, the gaps that occurred were due to gaps in the participants understanding of what they believed was plausible to have happened, an effect that has been observed in court [19], and what the Story Model attempts to address. For example, the accused leaving the building by climbing out of a window seemed plausible as a window was mentioned in the narrative and the knowledge that they must have left the building to enter the van in which they were later caught by police. The creation of a false memory in the VR condition is specifically interesting, as a similar effect has been reported before in a study where participants gave false virtual memories the same qualities as real ones [47].

Despite the lack of acquired spatial knowledge, participants did pay attention inside the VR condition to other details in the environment. The number of chairs (attention-to-detail) counted was only vividly recalled for the VR condition. However, this could be attributed to the imperfect model and novelty of the technology that inspired participants to be inquisitive about their environment

Finally, no differences were shown in the Narrative Memory; however, this could be attributed to spatiality not playing as large of a role as it would be in cases where jury visits are deemed specifically important. Despite the simplicity of the case, the task was considered challenging throughout all conditions, suggesting that a lot can be done to improve the process of remembering narrative and spatial locations.

6 Conclusion and Future Work

This paper describes the results of a narrative and spatial memory experiment in the context of viewing real (physical viewing) and virtual copies (VR and photographs) of a simulated crime scene. Our results did not show a difference for narrative memory between VR and the other conditions (R1). We were able to partially answer the question on the effect of VR in spatial memory (R2). Viewing in the

VR condition appears to be more reliable than in the PHOTO condition due to the higher variability in responses in the latter condition. Our findings additionally suggest that VR has the potential to be a good compromise for when a site visitation cannot take place, because overall there was no significant difference in recall and hit performance between the VR and RL condition.

As with any visual medium, the risks of potential visual bias needs to be addressed. This can be reduced by auditing the data thoroughly, to ensure the accuracy of the original and reconstructed data [48]. Currently, laser scanning technology is already being employed by forensic experts. Generally, it is acceptable to the Court to use the same colour and lighting information in the captured scene from the time when the crime scene was first recorded. A real world jury view also offers potential bias, but the jury view is generally considered high enough in probative value to outweigh the risks [12]. A virtual environment however offers the possibility of the court to be in complete control of what is being viewed, but leaving it up to the court to change the viewing conditions, such as taking out items or pieces of the scene they believe could bias the juror. We envision that the forensic process that currently applies to visual media to be applied to virtual reconstruction data to minimise risk.

Our future work will focus on several points: 1) increasing the complexity of the scene, 2) tying the spatiality of the crime scene elements more tightly with the narrative, 3) user studies with higher sample sizes, 4) using a different form of capturing technology such as laser scanners, and 5) encouraging exploration so participants can encode relevant information more strongly.

Encouraging exploration could occur through the addition of visual cues or interactive hotspots that can be further explored to help in the sense-making process, aiding the juror by offering options that are not possible during a real site visitation. As with any new technology employed in a court of law, agreement must be obtained from the defense, prosecution, and judge. To avoid bias towards either defense or prosecution only evidence that both parties agree on will be taken into consideration, also known as *agreed facts*. One example of exploring evidence would be the replacement of the markers and including the evidence as selectable 3D objects in the scene, as well as adding photographs taken by the forensic team who first entered the scene. The virtual crime scene could also be extended by adding the viewpoints of witnesses, which can allow the viewer to perceive the narrative from different angles and explore alternate possibilities of what might have happened as additional information becomes available. Such features could be valuable during jury deliberation to revisit the site, a feature that is currently not available for real life visitation. We will also focus on reducing the commission rate within the VR scene and improving overall accuracy for memory tasks. While photographs as a medium cannot be improved further, we can improve VR through identifying limitations to encoding or spatial processing that occurs during VR. Another interesting point of research would be how VR can improve understanding of spatiality and events compared to 3D reconstructions presented on a two-dimensional screen.

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Appendix 1: Narrative

The following is the narrative that was used in the experiment for all three conditions:

Last night, at approximately 10.00p.m., Constable RONA was assigned to investigate a stolen-property complaint from an office in Mawson Lakes.

Const RONA received information that a pair of youths stole electronic equipment including a Sony tablet from a drawer, approximately $500 in cash that was taken out of a bag on the floor, Bose headphones and an Apple MacBook Pro that were left on a now empty desk by the windows from premises at the University of South Australia campus, Mawson Lakes. A Wacom Cintiq tablet was taken from a table across the room. On the round table in the centre of the room the accused left a knife with a partial fingerprint and a baseball cap.

The victim and University employee DELLACOSTA indicated that he saw the accused and his co-accused pull away from the kerb outside the building when he drove in after work.

Const RONA then patrolled the area and observed a white van, license plate SZE 585, proceeding southbound on Fitzroy Road, then followed it and caused the vehicle to pull over.

At approximately 11:00 p.m., Const RONA stopped the van and observed equipment matching the description given by the University employee in plain view in the rear of the van.

Further investigation on the two male occupants of the vehicle established that the accused McKIMMEY was on bail for outstanding charges of common assault and break and enter. These charges, if proved, would put him in breach of a good behaviour order for an earlier trespass.

Both males were then arrested and advised of their rights.

Appendix 2: Results of the ANAM Cognitive Battery

The table below shows the results of the ANAM survey for measuring the participant's spatial and memory ability. The CDS and CCD (*Code Substitution* and *Code Substitution Delayed*, respectively) questions tested memory, whereas M2S (*Match to Sample*), SP (*Spatial Processing*) and MKN (*Manikin*) questions focus on spatial working memory and processing. Individual factors are described in detail in Kane et al. [42].

The abbreviation *RT* stands for reaction time, *Corr* for correct answers, and *Inc* for incorrect answers.

Measure	VR	RL	PHOTO
CDS_MeanRT	1220.15 ± 316.95	1372.62 ± 389.22	1177.02 ± 249.61
CDS_MeanRTCorr	1216.65 ± 319.98	1374.37 ± 389.36	1174.00 ± 250.81
CDS_MeanRTInc	1267 ± 835	583.20 ± 652.49	956.36 ± 777.77
CDS_PercCorr	97.08 ± 1.79	98.61 ± 1.47	96.80 ± 2.62
CCD_MeanRT	1062.45 ± 429.79	1191.78 ± 427.09	948.45 ± 178.18
CCD_MeanRTCorr	1034.37 ± 384.81	1167.56 ± 424.68	941.48 ± 168.57
CCD_MedRTCorr	905.25 ± 317.54	982.10 ± 325.62	829.90 ± 107.29
CCD_MeanRTInc	1053.48 ± 1066.12	1177.05 ± 727.33	415.02 ± 692.76
CCD_PercCorr	95.55 ± 5.00	93.89 ± 4.69	98.06 ± 4.36
M2S_MeanRTCorr	1928.49 ± 828.74	1739.24 ± 631.76	1664.17 ± 291.51
M2S_PercCorr	91.00 ± 13.30	93.00 ± 9.20	86.36 ± 13.00
M2S_MeanRT	1945.92 ± 810.56	1831.57 ± 770.62	1801.94 ± 346.04
M2S_MeanRTInc	1817.37 ± 2442.03	1255.85 ± 2076.81	2249.33 ± 1442.65
SP_MeanRTCorr	2194.71 ± 613.86	2315.11 ± 1009.00	2077.47 ± 673.11
SP_PercCorr	94.00 ± 7.00	98.00 ± 4.83	97.50 ± 3.54
SP_PercInc	5.50 ± 7.25	1.50 ± 3.38	2.00 ± 3.50
SP_MeanRT	2217.00 ± 597.50	2315.90 ± 1020.69	2981.47 ± 670.60
Manikin Mean RT (ms)	2716.16 ± 1101.46	3124.60 ± 1095.97	2345.00 ± 1050.44
MKN_PercCorr	78.12 ± 19.90	74.06 ± 33.60	60.93 ± 20.94
MKN_PercInc	20.94 ± 19.30	25.00 ± 33.85	34.38 ± 17.80
MKN_MeanRT	2711.32 ± 1118.60	3155.74 ± 1131.21	2257.92 ± 975.53

Table 4: Summary results of the ANAM test. See Kane et al. for a description of individual factors [42].

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