# Bringing the Jury to the Scene of the Crime: Memory and Decision-Making in a Simulated Crime Scene


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## ABSTRACT

This paper investigates the use of immersive virtual reconstructions as an aid for jurors during a courtroom trial. The findings of a between-participant user study on memory and decision-making are presented in the context of viewing a simulated hit-run-death scenario. Participants listened to the opening statement of a prosecutor and a defence attorney before viewing the crime scene in Virtual Reality (VR) or as still images. We compare the effects on cognition and usability of using VR over images presented on a screen. We found several significant improvements, including that VR led to more consistent decision-making among participants. This shows that VR could provide a promising solution for the court to present crime scenes when site visitations are not possible.



## CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Virtual reality**.

## KEYWORDS

Virtual Reality, 3D Reconstruction, crime scene, jury, interactive virtual environment, spatial memory

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## 1 INTRODUCTION

This paper explores the use of Virtual Reality (VR) for crime scene presentation. We aim to support the recall of both the crime scene narrative and evidence presented to support jury decision-making. Two viewing methods are compared, still images (representing a traditional form of evidence presentation), and VR. We are interested in examining if viewers are better able to piece together what may have occurred when given the chance to explore a crime scene virtually, and how this may impact the jury verdict decision. Findings of a user study are presented where users inspected an ambiguous crime scene scenario.

After a crime occurs, documentation of the crime scene is fundamental for investigation as to reconstruct what unfolded as closely as possible [21]. Recording the crime scene traditionally involves photographs, videos, handwritten notes, or sketches [17, 21]. These documents later make their way into the courtroom to aid the jury in their understanding of the crime along with a description of events [28, 51]. However, these two-dimensional methods of presenting space are bound to introduce some level of distortion regarding the spatial relationships [2]. This two–dimensional information has to be then translated into a three-dimensional mental map by the jurors to understand better the situation, which may impede a correct interpretation of space and evidence [55]. We propose that VR can facilitate understanding of complex environments and the overall event by engaging with the information presented in a manner that allows for a better sense of depth and space.

This project is the result of a series of discussions about the potential of using VR in a court of law in aiding trial proceedings and reducing the costs involved in taking the jury to the original scene of the crime. Contributors to this research are an interdisciplinary group of people consisting of legal professionals, law enforcement, and forensic scientists who have provided their opinions and expertise. Researchers have explored the potential of commercially available VR for virtual site visitations of the jury in a simplified crime scene, and they have deemed it a promising tool to substitute site visitations when a physical visitation is not feasible [48]. Currently, site visitations are considered the gold standard in aiding the jury in their process of finding the truth. However, these viewings come at a significant expense for the court and may occur several months after the crime occurred.

For example, in 2017, the jury of a violent assault case was sent to the scene of the crime in a remote area one year after the alleged assault [36, 38, 45]. Naturally, the conditions of the environment had changed, and all evidence had been removed. As each juror inspected the scene, they had to piece together the environment with the information they had heard or were about to hear in court.

Current trial proceedings and the way information is put forward presents an additional challenge for the individuals serving as jurors. Evidence presentation follows the rules of the court, which may lack a chronological and logical order. As a consequence, jurors face a large amount of complex information that is presented in a disconnected manner, which they have to subsequently piece together as a sequence of events they can agree on [34, 59]. This, in turn, can increase the time necessary to reach a verdict [40]. This is further exacerbated as these procedural rules place a large amount of mental effort on the juror, which may leave them bored and frustrated [25] in a context where absorbing information is critical to forming a well-informed decision.

In an attempt to make sense of the information that is presented to them, jurors actively process information by forming a coherent narrative that incorporates the facts of the case and is consistent with their existing knowledge [44]. They finally base their verdict decision on the explanation derived from the narrative [19]. Overlapping information likely leads the jurors to arrive at the same verdict [41]. One way of supporting the juror in forming a mental representation of what occurred is viewing a crime scene independently at their own pace [13], thus allowing the individual to piece together information that aids their mental model. As interactive technology is slowly being introduced into the courtroom, it will be important to build technology that supports the sense-making process of the individual, and that can be easily used by non-experts. It is particularly important that the technology can be can be easily used by non-experts as the juror demographic spans a wide range regarding age and computer experience that needs to be considered when building interactive tools. These tools must undergo a careful evaluation as poorly introduced technology could lead to a miscarriage of justice [11, 12].

The aim of this work is to contribute to existing research [48] by providing a more complex crime scene with exploratory elements that may offer a more vivid and comprehensive understanding of the crime. This, in turn, may allow the individual to recall better the evidence presented, support recall of the narrative as they are able to put the information in the context of the crime scene, and lastly, reach a more consistent conclusion within the group as they generate more overlapping information. The scenario of a hit and run was discussed with forensics experts and attorneys as a potential use case for VR in its ability to place the viewer in the driver's seat. Three-dimensional reconstructions are already being utilised in cases of vehicle accidents [4, 46].

We are interested in knowing if VR can help improve recall of the narrative and the scene itself, and if the information presented allows participants to arrive at the same decision. The following research questions are being addressed:

- RQ1: Can VR improve narrative recall compared to still images?
- RQ2: Can VR improve spatial recall of presented evidence compared to still images?
- RQ3: Does viewing the environment in VR influence the consistency of verdicts?
- RQ4: Is a higher narrative memory score predictive of the verdict?

VR could potentially amplify the benefits of 3D reconstructions already being utilised by investigators and during a trial by presenting the scene as if the juror was physically there. Jurors have voiced concerns in providing sound decisions due to not being shown enough evidence [19]. In VR, the scene could be inspected within the context of the evidence presented, potentially aiding to the understanding of what unfolded as they build the construction of a narrative. Furthermore, VR provides the benefit of being able to view the crime scene in a court controlled manner, where elements can be excluded that should not be viewed by the jury [28].

This research makes three primary contributions to the field of VR for use in legal proceedings: 1) Providing an empirical evaluation of how people interact with VR technology to support jury understanding in a context where obtaining well-informed answers is critical, 2) A comparative study of using VR to still images for critical spatial understanding, and 3) Identification of the limitations of using VR for court proceedings and future research opportunities to address these limitations. While the idea of VR systems in the legal context has been introduced before, the main novelty of the work is the exploration of VR and its effects on cognition in an adversarial context. In addition, it shows how user studies of this nature could be conducted by future researchers. This is one of the first experiments in this area in an attempt to work towards providing a sufficient scientific basis to satisfy the requirements for the court in the future.

In the remainder of the paper, we first present an overview of related research, followed by the description of the VR reconstructed crime scene we developed. Using this system, we present results from a user study comparing memory and decision-making in two different conditions. We then discuss the findings and offer possible avenues for future research.

## 2 RELATED WORK

While the courtroom has remained a largely traditional environment, opportunities for the HCI community have started to arise as potential courtroom technologies are being evaluated [20, 60]. This section provides an overview of several aspects relevant for consideration, such as VR, cognitive psychology, and legal proceedings that pertain to our investigation. Finally, an overview is provided on how jurors make decisions during a trial and how crime scenes are presented in court.

## 2.1 Presenting Crime Scenes in Court

A trial is a unique challenge to an individual, as they are part of proceedings they are unfamiliar with and may be presented with a large amount of complex information they have no expertise in [18]. Visual aids enable jurors to absorb information faster and more accurately than long oral descriptions [54]. Some of the common ways of documenting and later presenting crime scenes are via photographs, videos, sketches, and maps [1, 17] along with descriptions about what happened to outline the positions of people and objects [15]. Serious crimes, such as traffic accidents that resulted in the loss of human life or homicides, in particular, require in-depth information about the spatial relationships and dimensions [17]. However, traditional crime scene presentation can be problematic as they may present complex three-dimensional information one-dimensionally [55] and some techniques (e.g. photographs) may introduce some level of distortion of the spatial information [2]. 3D reconstruction techniques have been successfully used to aid the investigation process and later serve as visual aids during a trial [3, 8, 37]. These aim to alleviate some of the concerns by preserving spatial relationships. However, while considered widely useful, it remains impossible for the viewer to experience depth and space with these aids [46].

To better present spatial relationships and dimensions, judicial discretion allows the jury to visit the scene of the crime to aid them in their understanding [47]. These viewings are carried out despite the significant cost to the court of transporting the parties, legal assistants, jurors, and the judge separately to the scene [23]. The need for spatial understanding is considered so important that a site visitation may be requested even in cases where the scene has undergone significant changes. Often the viewer has to cognitively piece together how the original scene may have looked like. This may present an opportunity for VR to take advantage of modern 3D reconstruction techniques, currently being used by law enforcement, and show a virtual copy of the original environment to the viewer, enabling them to perceive depth and space easily.

## 2.2 Spatial Knowledge Transfer

VR has been previously assessed and used to visualise complex spatial information [31, 35]. The literature suggests that spatial knowledge gained in virtual environments can be translated into real-world knowledge [24, 63]. Evaluations carried out for training purposes have identified that tasks rehearsed in virtual environments can help build an abstract spatial representation [6, 57]. Mania and Chalmers assessed knowledge transfer of spatial memory in a seminar learning task from a virtual to physical environment [32]. In this study, the task was carried out in one of four conditions: Real-world, a desktop showing the virtual environment, the virtual environment using a VR headset, and audio-only condition. The VR condition did not differ from the real world condition in terms of accuracy, and participants showed higher confidence in VR compared to the real world. The researchers conducted a subsequent study on spatial recollection focused on remembering the position and shapes of objects in a room and compared VR to the real world [33]. Participants viewed the environment either in the real world, or a photorealistic virtual environment in either a monocular head-mounted display (HMD), a stereoscopic HMD with head-tracking, a monocular HMD with mouse navigation, and a traditional display. Their findings showed no significant results between the physical world and virtual worlds, which may indicate a similar level of spatial recall as if the person was physically present. In a similar vein, it has been shown that motor activity supports navigation tasks. Ruddle and Lessels conducted a study where participants performed a navigation task on a desktop, an HMD with a tracked space for active walking, and another HMD condition which did not permit walking. Participants who could explore the scene by walking achieved the highest performance [49]. Motor activity is associated with improved episodic memory, which may explain the higher performance [50].

## 2.3 Jury Decision-Making

Several models exist that attempt to explain the decision-making process of individual jurors. While in a real trial, the verdict is selected collectively, most theoretic models focus on the individual juror [29]. One of the most influential models of how jurors organise information during a trial and make decisions is the *Story Model* [19]. Researchers have identified that jurors naturally construct a narrative in their attempt to make sense of evidence presented and aid in their assessment [44]. The story is constructed by a combination of evidence presented and existing knowledge of the individual. Jurors may generate several narratives as the trial progresses and ultimately choose one that they deem most plausible [41]. Important elements for the acceptance of the story are the plausible incorporation of all evidence presented that accounts for a full timeline with no ambiguities [42]. Missing information will likely be inferred by the juror [44] and evidence may be disregarded if it is perceived as not fitting the narrative [41]. Often, jurors who arrived at the same verdict had constructed similar stories [43]. This indicated that the more elements of a story overlap, the more likely it is for a jury to arrive at the same decision [41]. On the other hand, if jurors had arrived at different conclusions, it was likely due to misunderstandings combined with a poor memory for important pieces of evidence [34].

## 2.4 Visualising Crime Scenes in VR

Interactive virtual environments have the potential to facilitate the comprehension of complex information [52] and the use of VR for crime scene presentations is currently being explored by forensic scientists, researchers, and law enforcement [9, 46, 61]. An early example of a mock trial exploring the use of VR is Courtroom 21. A study assessed the reliability of a witness statement by showing mock jurors in VR what the witness could have seen [26]. The virtual simulation was able to discredit the claims of the defence as the statement of the witness could not have been possible [27]. Ebert et al. created a low-cost prototype system using a VR headset for the reconstruction of crime scenes [7]. They reconstructed a shooting incident that took place in an internet cafe and used a virtual scene to visualize the bullet trajectories. The scene could be interactively explored, which allowed the viewer to inspect the scene from different viewpoints. This prototype was further developed by Süncksen et al. to create, direct, and watch a presentation in court [58]. A person using a VR headset is guided through the presentation by a moderator, who could explain the findings to the viewer or alter the scene. VR has also been used in a real court case. The Bavarian State criminal office in Germany made use of VR to aid the prosecution during a war trial. The Auschwitz concentration camp was reconstructed and presented in VR to visualize what a camp guard could have seen [5].

Reichherzer et al. conducted a user study comparing site visitations in VR to a physical visit and viewing the scene as photographs [48]. In this study, participants viewed a simulated burglary scene and the impact of viewing methods on memory was assessed. Their findings suggest that spatial memory in VR is more reliable than viewing photographs and concluded that VR may be a suitable compromise if a real visitation is not possible.

As this previous work shows, VR could potentially combine the benefits of acquiring spatial understanding comparable to a real site-visitation while simultaneously allowing the prospective juror to view the scene in the same state as it was when the police arrived. However, there have been few formal studies conducted comparing VR to more traditional techniques for presenting information in court that investigate its impact on cognition. Our research is one of the first that compares juror comprehension from a VR environment to that from still images. In the next section, we describe the crime scene reconstruction system for VR that we developed, and then a user study with the system.

# 3 SYSTEM OVERVIEW

We developed a prototype system to present evidence and a VR reconstruction of a crime scene to a potential juror. The system replicates a situation where the individual would be able to visit the scene kept in the same state as it was after the crime occurred. The scene features a parking lot where an argument ensued between two students, and one student was killed. The system offers two viewing conditions: First, an interactive VR mode and second, a Baseline mode showing only still images on a screen of the 3D reconstruction.

Photographs of the scene were also taken and added to both conditions. In a real court case, a reconstruction would coexist together with traditional media to best convey a realistic impression of the environment. Some material cannot be reliably captured, such as reflective surfaces. The system contains evidence items with reflective surfaces to assess further if they impact the user.

## 3.1 3D Reconstruction

A reconstruction of the simulated crime scene was created using a laser scanner, similar to those which are presently used in law enforcement. Several elements were scanned separately: the parking lot, the items representing evidence, the body of the victim and a car. A stationary and a handheld FARO laser scanner were used for gathering the data [10]. The handheld FARO Freestyle laser scanner captured the smaller evidence items, as it allows for higher accuracy and mobility to move around the small items to capture them from different angles. The stationary Faro Focus S70 laser scanner captured the environment and the body of the victim. The car was provided in e57 format by a supporting forensic institute. The scans were further processed and manually combined, ultimately consisting of 133 million individual points. See Figure 1 for a comparison of the original car park and its transformation into a hit-run scenario. The car was positioned where the eyewitness reported seeing it.

**Figure 1: The original car park without crime scene elements (top) and the same car park as a point cloud with added evidence items, car and victim.**

## 3.2 Implementation

Our prototype was developed using the Unity game engine (version 2019.2.6f1) on a PC (Intel i7 processor, 64GB RAM, NVIDIA GeForce 1080 TI GPU) running Windows 10. Two forms of visualisations were set up, one for each viewing condition. A second VR environment was set up which served as a training session for participants in the VR session to get accustomed to the controls, which featured a simple scene with tooltips explaining how to use the controls. To import the point cloud data into Unity, the data was transformed into the Potree file format. Potree is a point cloud renderer based on WebGL designed for very large point clouds [53] for which a Unity framework exists [16]. In Unity, orange crime scene markers were added to the scene, which showed the user locations where there was an evidence item. The reconstruction was supplemented by photographs in both conditions as per expert advice. Both conditions allowed the user to listen to an eyewitness statement, which was an audio file that automatically played when a relevant action was performed.

*3.2.1 VR Mode.* The VR condition was designed for the VIVE Pro Eye headset with a combined resolution of 2880 x 1600 and a refresh rate of 90Hz. In VR, users can move in the virtual space both by regular walking or by using a standard VR teleportation method. For teleportation, users point and pull the trigger on the VR controller to cast a target on the ground to teleport to that location. Releasing the trigger will teleport the user to that location. The system supports *hotspots* which featured a graphical user interface that showed two photographs of the evidence: A close-up shot of the item and a second shot showing the evidence in the context of the scene. The user could also view two specific viewpoints of the driver and the eyewitness — these were predefined locations that the teleport target would snap to when pointed nearby (see Figure 2). The viewpoint of the driver was unique to the VR condition as this would not be possible with traditional media. In this condition, the audio of the eyewitness statement was triggered when the user teleported to their viewpoint.


**Figure 2: Interface in VR: A graphical user interface to view evidence (top) and pre-defined teleportation locations to take on specific viewpoints (bottom).**

*3.2.2 Baseline Mode.* The system can present the data in a "Baseline" mode, that presents evidence as an interactive slideshow and could be navigated using the arrow keys on the keyboard. The interactive slideshow consisted of one image per slide which would show either a screenshot of the reconstruction or a photograph of the evidence. The photographs used were the same as for the VR mode. The slideshow consisted in total of 32 images, with the first 14 presenting the reconstructed crime scene from different viewpoints, the remainder presenting photographs of the evidence items. The very last image showed the perspective of the eyewitness, which was identical to what participants in the VR mode would see when they first teleported to that location. See Figure 3 for two examples of the interface for the Baseline condition. The interface featured a breadcrumb trail track to orientate the user where they are at within the slideshow. The audio file of the eyewitness was played when the user reached the slide of the eyewitness.

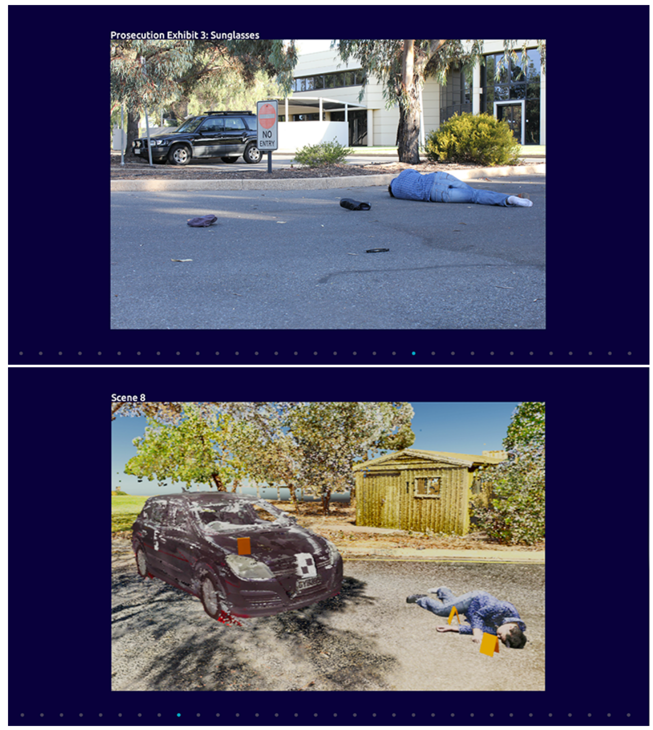


**Figure 3: Examples of the images shown to the participants in the Baseline condition.**

## 4 USER STUDY

We conducted a user study to evaluate how people perceive a simulated crime scene compared to viewing it on a screen to answer our research questions after listening to an adversarial view of the case. Due to the complexity of a real trial, this study focuses on simplified aspects of viewing a crime scene. This section describes our experimental design, viewing conditions, measures, and procedure of the study.

### 4.1 Experimental Design

A user study was conducted as a between-participants design. Each participant experienced one of two display methods: VR or viewing images on a screen. First, they were introduced to the case by listening to three audio files outlining what happened. After the introduction, the participants viewed the crime scene either in Baseline or VR mode. Following the viewing, participants had to retell the narrative, marking the spatial location of evidence items and make a verdict decision.

## 4.2 Materials and Apparatus

The user study was conducted in one room that allowed for room-scale VR. The room was approximately 4.70m x 4.0m in size with the walkable area being approximately 1.70m x 2.80m. We used our prototype system described in section 3 as the apparatus for displaying the two conditions (VR and Baseline mode).

Participants wore headphones as they listened to three different statements as the case is introduced on a 13" Macbook Pro. The word length of the prosecution and defence statement was of similar length to not unfavourably bias one side. The statements contained 361 and 331 words, respectively, and were written by an attorney. Three professional voice actors were hired for the role of the prosecutor, defence attorney, and eyewitness using an online platform [62]. The requested style of acting was set to "Articulate" and "Slow-Paced". The role of the neutral party was recorded by one of the investigators.

## 4.3 Measures

We captured the following objective and subjective measures in each condition: 1) Narrative Recall, 2) Spatial Recall, 3) Verdict Decision, 4) Emotional Arousal, 5) Cognitive Load, and 6) Perceived Usability.

For Narrative Recall, thirty-two elements from all statements that were deemed significant were pre-identified by the investigators for recall by the participants. During narrative recall, participants would be asked to verbally recall as much as they could from the presented narratives (referred to as *FR: Free Recall*). After their retelling, elements that were missed would be prompted by the investigator, with a question, e.g. "What did the accused do when he got into the car?" (referred to as *CR: Cued Recall*). Narrative Recall was grouped into four different categories: General, Prosecution, Defence, and Overall. *General* refers to elements relevant to the entire case, such as names and locations. The categories *Prosecution* and *Defence* refers to elements taken directly from each respective statement and consisted of an equal number of points to be recalled. *Overall* refers to the combined total of each individual category.

Spatial Recall was measured by providing participants with a map of the scene to indicate the location of each evidence item they remembered. They were asked to point to the location with a marker and write down the name of the evidence. The responses were categorised as *Hits* (correct item in a correct location), *Commissions* (location or object is incorrect) and *Omissions*.

The verdict of the participant was measured through a questionnaire and included questions on their confidence of the verdict and a question on the perceived strength of the case of prosecution and defence. A 5-point Likert scale was used for confidence (1 = *Low confidence*, 5 = *High confidence*) and how strong the case of prosecution or defence was (1 = *Not at all*, 5 = *Very*). Regarding the verdict, participants were given three options: *"Death by dangerous driving"*, *"Death by driving without due care"*, and *"Not guilty"*. Descriptions of these verdicts were provided to the participants.

Emotional Arousal was measured via Galvanic Skin Response (GSR). GSR measures the changes of conductivity in the skin, which serves as an indicator of emotional arousal. This measure was introduced due to common concerns voiced by legal professionals that viewing a crime scene in VR may cause a strong emotional reaction and is, therefore, a potential source of bias. For this reason, participants wore a GSR sensor on their wrist, with two electrodes attached to the palm of the hand in two different locations. The GSR sensor used was a Shimmer3 GSR+[56] and conductivity measured at 125 Hz.

Lastly, cognitive load was measured as subjective effort rating with the Paas scale [39] and Perceived Usability was measured with the UMUX-Lite Questionnaire [30], which serves as a shorter version of the Usability Metric for User Experience (UMUX). The questionnaire was designed to be consistent with the System Usability Score (SUS) [14].

Recall (narrative and spatial) and usability were predicted to be significantly higher in the VR condition relative to the Baseline condition. In contrast, the VR condition was expected to require significantly lower mental effort. It was not expected for VR to be at risk of evoking a significantly higher emotional response. Another prediction was that significant differences in the consistency of verdict choices would be revealed across conditions. The hypotheses addressed are as follows:

- *H1: VR will be better than Baseline mode for narrative memory,*
- *H2: VR will lead to a more consistent verdict decision compared to screen viewing,*
- *H3: Spatial elements will be more accurately remembered in VR,*
- *H4: There will be no measurable difference in emotional arousal as measured via Galvanic Skin Response,*
- *H5: VR will evoke lower cognitive load compared to Baseline mode, and*
- *H6: VR will provide a more intuitive user experience compared to Baseline mode.*

## 4.4 Participants

Thirty adults (twelve female) were recruited from the general public, student pool, and staff of the University, resulting in fifteen participants per condition. Participants were aged between 18 and 58 years old ($M = 28.9, SD = 9.67$). Age and gender were balanced in both conditions. An AUD$20 honorarium was provided to every participant for their time upon completion of the experiment. Participants had to fulfil inclusion criteria that were strictly enforced, such as not having been a victim of a violent crime, being a native English speaker, and not suffering from post-traumatic stress disorder.

## 4.5 Procedure

The user study consisted of several phases: 1) Preparatory, 2) Introduction to the case, 3) Viewing of the scene, 4) Recall and Verdict. In the *Preparatory* phase, participants were briefed on the study and signed a consent form once they were comfortable participating. Participants put on the GSR sensor, and a baseline reading was recorded as they listened to the briefing of the study. In this phase, participants also completed two pre-experiment tasks on memory using the Automated Neuropsychological Assessment Metrics

(ANAM) [22], which took approximately five minutes to complete. This was done to assess if the memory ability of the participant pool was within the population average.

Following the *Preparatory* phase, participants were introduced to the case which was presented as audio files. First, participants listened to a neutral party introducing the location and a brief explanation of the victim. This was followed up by prosecution and defence lawyers making their opening statements. This phase took approximately 5 minutes.

This was followed up the *Viewing of the scene* phase, where participants could explore the scene in their assigned condition (either VR or Baseline) and GSR was recorded a second time. This phase was limited to five minutes. The time limit was chosen after running a pilot study, which indicated that five minutes was enough time to build an understanding of the scene without being able to remember every detail. This is done to approximately replicate a real jury viewing, where participants do not have enough time to memorise the entire scene. Participants were instructed to review every piece of evidence (marked via an orange marker) and listen to the eyewitness statement. If they had not visited the location of the eyewitness by a certain time, they were instructed by the investigator to visit the location to ensure there was enough time left to listen to the statement. Participants in the VR condition were first subjected to a short training session to ensure they are comfortable with the controls during a timed task.

After being exposed to the scene, subjects were asked to retell everything they could remember from the event as outlined to all participants in the *Introduction to the case* phase (FR). Elements missed were cued with a question (CR). Next, participants were presented an overview map of the crime scene, where they were asked to mark down the location of each evidence they remembered. They were also asked to place a coloured sticker on the map representing the Awareness State of their recall: Remember, Guess, and Know. A vivid mental image stood for Remember, whereas Know referred to remembering the answer without having a mental image associated with it. If they could not remember or were not sure, they picked Guess. Once the memory tasks are finished, participants were given a questionnaire to choose their verdict, cognitive load, and usability.

## 5 RESULTS

Participants in both conditions did not differ in performance on the two tasks of general memory ability. We found the following key results: 1) Participants in VR showed higher accuracy in Spatial Recall, 2) Narrative Memory was partially better in VR, 3) Verdict decision differed significantly between conditions, and 4) VR led to a more consistent verdict decision compared to screen viewing.

In this section, we report the results of the experiment with statistical analyses with significance set at $p = 0.05$. The results of directional hypotheses are reported as a one-tailed t-test. We first report the two measures of memory—narrative recall and spatial recall—followed by the results about the verdict decision and emotional arousal. Lastly, the results for cognitive load and usability will be presented.

### 5.1 Narrative Recall

An overall score for narrative recall was calculated as follows: $SCORE_{narrative\_recall} = 2FR + CR$, where FR is the number of items correct from Free Recall and CR the number from Cued Recall.

Scores for each category for narrative recall (General, Prosecution, Defence, and Overall) was analysed using an independent samples t-test between the Baseline and VR conditions (see Figure 4). We found a significant difference in the Narrative Recall scores in the category for *Prosecution* in participants in the VR condition ($M = 52.67, SD = 8.42$) compared to Baseline ($M = 45.67, SD = 12.08$); $t(25.01) = -1.84$, $p < 0.05$, $d = -0.67$. We found no significant differences for *General*, *Defence* and *Overall*. While *Defence* and *Overall* did not show a significant result, moderate effect sizes were observed which are summarised in Table 1.

| Category | t-test statistics |
|---|---|
| Prosecution | $t(25.01) = -1.84$, $p < 0.05$, $d = -0.67$ |
| Defence | $t(27.65) = -1.14$, $p = 0.13$, $d = -0.42$ |
| Overall | $t(27.98)$ - 1.49, $p = 0.07$, $d = -0.54$ |
| General | $t(27.99) = -0.19$, $p = 0.43$, $d = -0.07$ |

**Table 1: Results of the t-test per Narrative Recall category for Baseline and VR condition.**

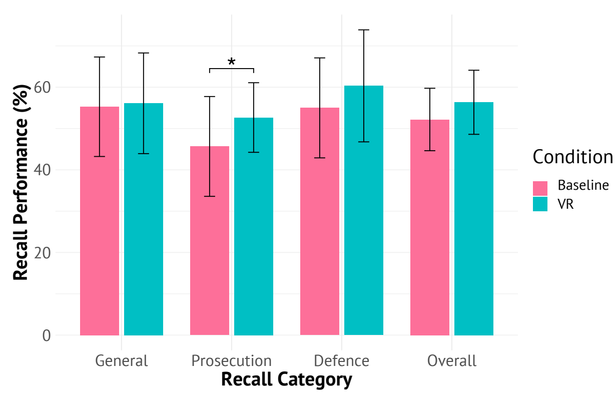


**Figure 4: Mean ratings for Narrative Recall performance. VR showed significantly better narrative recall than Baseline in the Prosecution category.**

### 5.2 Spatial Recall

Spatial Recall was assessed using a template with a tolerance radius of approximately 1.7m around the correct position (see Figure 5). The radius was chosen rather generously as there were few landmarks for participants to reference. The template was overlaid over each participant sheet, and correct objects within the tolerance radius were counted as a Hit. Misplaced items were counted as Commissions, and forgotten items were recorded as Omissions. Each response type was further categorised into the memory awareness state (Remember, Know, and Guess) as indicated by the participant.

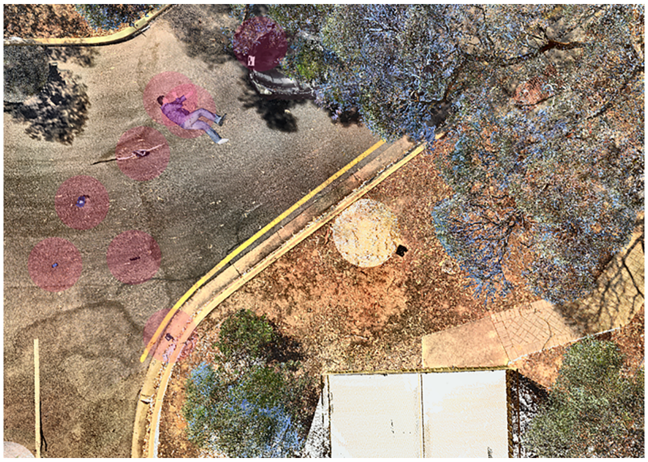

**Figure 5: Template used to assess spatial recall. The red circles represent the valid radius.**

Scores were transformed into percentages and an independent samples t-test was performed. The analysis revealed a significant difference only for Hits in the Remember awareness state between VR ($M$ = 50, $SD$ = 14.94) and the Baseline mode ($M$ = 38.33, $SD$ = 20.30); t(25.72) = -1.793, $p$ < 0.05, $d$ = -0.655. Results showed no significant differences for the remaining two categories and awareness states.

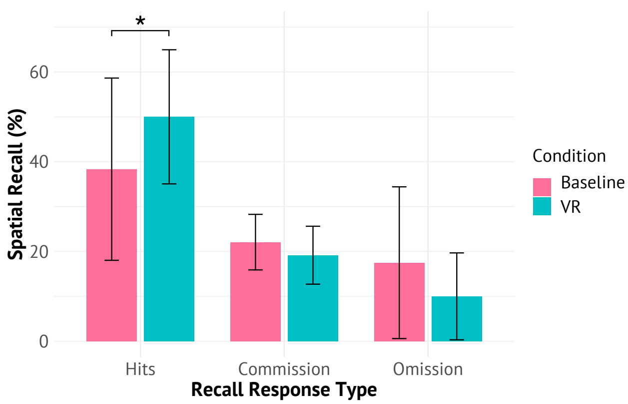


**Figure 6: Mean results for Spatial Recall categories in the Remember awareness state. Recall performance is presented as percentage.**

## 5.3 Verdict Decision

A chi-squared test of independence was performed to assess the relation between verdict decision and display condition. The results were significant, $\chi^2(1) = 5.400$, $p < 0.05$. The effect size, Cramer's V, was 0.424. The verdict *"Death by dangerous driving"* was chosen by 46.67% of the Baseline condition and 86.67% of the VR condition, whereas *"Death by driving without due care"* received 53.33% and 13.33% by the Baseline and VR condition, respectively. Table 2 shows a summary of the results.

| Verdict | VR | Baseline | Overall |
|---|---|---|---|
| Death by driving without due care | 13.33% | 53.33% | 33.33% |
| Death by dangerous driving | 86.67% | 46.67% | 66.67% |

**Table 2: Percentage of verdict decisions.**

To identify the effect of Narrative Recall for Prosecution and display method on the likelihood of choosing a verdict category, a logistic regression was performed. The logistic regression model was statistically significant $\chi^2(27) = 6.29$, $p < 0.05$ in the verdict outcome. However, only the display method was significantly predictive of the verdict. The model explained 26.3% (Nagelkerke $R^2$) of the variance. The verdict *"Death by dangerous driving"* was 9.5 times more likely (using the odds ratio) to be chosen in the VR condition (Wald $\chi^2(1) = 5.15$ $p < 0.05$). Figure 7 shows the verdicts chosen based on scores achieved on the *Prosecution* category representing the choice of individual users.

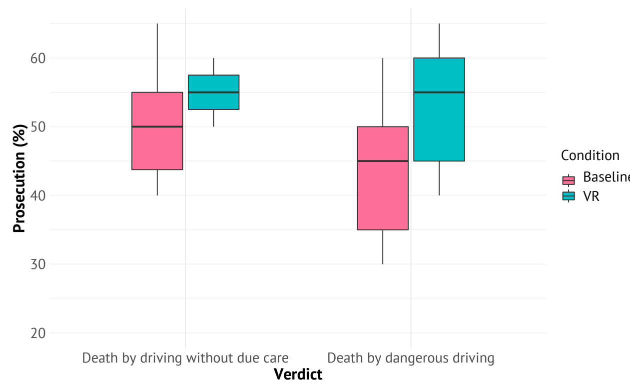


**Figure 7: Narrative Recall performance for the category of Prosecution and choice of verdict for each condition.**

Self-reported confidence in their verdict was similar between both groups. Data were not normally distributed and assessed with a Mann-Whitney test that showed no significant differences, $U$ = 75.0, $p$ = 0.066, $r$ = 0.07. There was also no significant difference on the question if the prosecution ($U$ = 75.5, $p$ = 0.1, $r$ = -0.33) or the defence case ($U$ = 132.5, $p$ = 0.39, $r$ = 0.18) was perceived as the stronger case.

## 5.4 Emotional Arousal

The difference of normalised data captured before and during the experiment was used as a measure of emotional arousal and compared between display types. An independent t-test revealed no significant differences in emotional arousal between conditions, $t(27.94) = -0.42$, $p = 0.68$, $d = -0.15$.

## 5.5 Cognitive Load

Cognitive load was measured with the question *"How much effort did you put into interpreting space in the scene?"*. Participants recorded their response on a nine-point Likert scale (1 = *very, very low mental effort*, 9 = *very, very high mental effort*). Differences in cognitive load were investigated using a Mann-Whitney U test due to data not being normally distributed. We found a significant difference with VR ($Md$ = 2[2; 3]) requiring a lower cognitive load compared to Baseline ($Md$ = 7[6; 7]) ($U$ = 198.500, $p$ < 0.001, $r$ = 0.764).

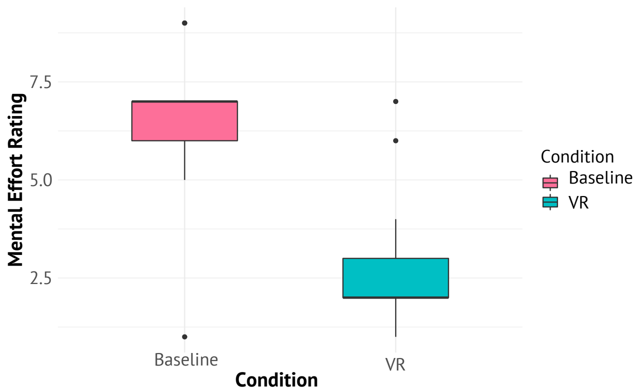


**Figure 8: Participants using Baseline mode rated their mental effort significantly higher than VR users.**

## 5.6 Perceived Usability

The UMUX-Lite questionnaire uses a regression equation to create a score that corresponds with the SUS scores. The result showed an average score of 73.8 ($SD$ = 12.9) for the Baseline condition and 81 ($SD$ = 6.9) for the VR. The results correspond to "Good" and "Excellent", respectively. An independent samples t-test was performed and revealed that VR was perceived as significantly easier to use compared to the Baseline condition, $t(21.45) = -1.91$, $p$ < 0.05, $d$ = -0.70 (see Figure 9).

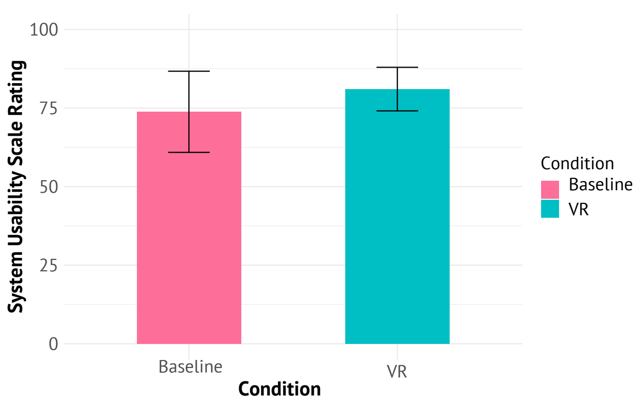


**Figure 9: Mean usability score. Error bars represent standard deviation.**

## 5.7 User Remarks on Verdict

Participants were asked to comment on what influenced their verdict decision as part of the questionnaire at the end of the experiment. The viewpoint of the driver appeared to be highly influential in the decision of the participants in the VR condition. Six people commented on how the driver's viewpoint influenced their decision, particularly addressing the question if the driver would have been able to see the victim. They believed the driver had a very clear view of the scene (*"The driver's perspective gave the most insight into my decision because the driver has a clear view of what was in the car park in front of him"*) and cast doubt on their defence (*"The driver perspective shows his defence of not being able to see the victim upon impact is likely false"*, and *"The witness perspective and the broken headlight confirmed that Sam was hit by the front of the car which backs up the guilty conclusion I got from the driver's view"*). Only one participant explicitly stated that the driver's viewpoint was not taken into consideration.

In contrast, participants in the Baseline condition remained divided on the intent of the driver. Some participants shared the doubts on whether the driver could have seen the victim (*"The damage was to the front of the car. The driver would have had to see Stan in his way"*). Participants choosing the milder sentence believed he hit the victim, however, were not convinced the evidence they viewed was enough to prove intention (*"The defendant did not pay attention to their surroundings however it is difficult to say beyond reasonable doubt that the incident was intentional or they intended to drive dangerously"*).

## 5.8 Observations

During the experiment, the position and orientation of the user were recorded to a log file. The walking patterns of each participant (represented by a different colour) can be viewed in Figure 10. Shapes that resemble a circle show the user and how much they walked, whereas the straight edges show when the teleportation tool was used. The three convergence points show the starting point, the driver's seat and eyewitness location. The teleportation tool appears to have been used easily and widely and allowed the user to view the scene from different angles. Interestingly, the teleportation tool was used even for small distances, despite the fact that it would have been possible to walk. Furthermore, most participants opted to stand stationary as they listened to the eyewitness. This was done even though they were briefed that the audio would not be interrupted. At the eyewitness location, users would assess what she could have seen by peaking around the corner and exploring different viewing angles.

An interesting observation was made once the experiment was finished. All participants in the Baseline condition were offered to view the VR scene upon completion as an appreciation for their time. Anecdotally, at least one participant who had chosen the more lenient verdict of *"Death by driving without due care"* expressed that viewing the scene in VR had changed his opinion and they would have now changed their verdict. Participants who chose *"Death by dangerous driving"*, on the other hand, felt reinforced in their decision. This supports the idea that participants may gather additional information in the VR condition.

## 5.9 Discussion

In this paper, we evaluated narrative and spatial recall within an interactive virtual environment and compared it to viewing images on a screen. The study presented also evaluated the potential impact

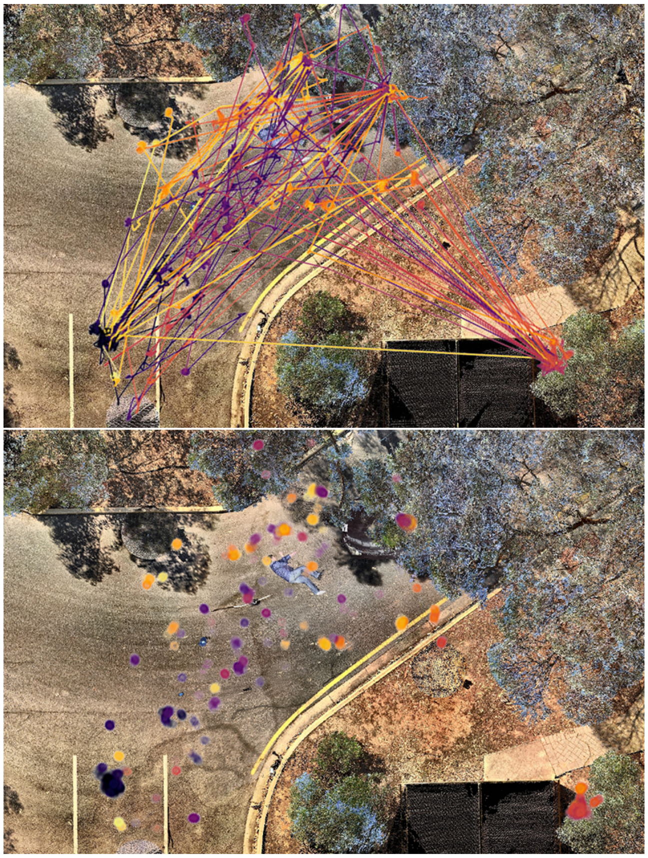

Figure 10: Participants relied mostly on the teleportation tool (straight edges) for navigation and explored little by physical walking (circles). The image on top shows walking and teleportation combined, the image on the bottom shows only walking for better comparison.

on decision-making within a simulated hit and run scenario. The findings on the memory measure showed some interesting insights for VR. Our results showed a significant effect in Narrative Recall only for the category of the Prosecution in favour of VR, partially supporting H1. While not significant, we found a medium-sized effect for the Defence and Overall category where participants scored a higher than average score in VR. This may suggest that the study was underpowered and should be repeated with a larger sample size. VR may have been more memorable for the participant and easier to interpret the case they had heard. The measure of emotional arousal showed no significant differences, indicating that viewing a scene in VR may be more memorable, but in this case, it did not cause a heightened emotional response. This supports H4.

There was a significant increase in the Hits response type for Spatial Recall for participants who viewed the scene in VR, supporting H3. Participants who were immersed in the scene and could experience it "as if being there", were more likely to correctly remember the item itself and place it in the correct location. This supports findings reported in an earlier study comparing VR with traditional court media [48]. One possible explanation for this is that participants thoroughly explored the scene in VR with their teleportation tool, and experiencing it from several angles may have helped to encode spatial information. For example, one user reported a heightened sense of spatial awareness in their feedback form *"The use of VR heightened my spatial awareness. I no longer felt like I had to remember a scene, [I felt] as if I was part of it. I felt like the ability to understand the spatial relationships between key items and views was significantly increased compared to photo/text techniques."* Another possible reason for this finding was the mental effort involved in interpreting the space in the scene. The measure of Cognitive Load showed a significant difference, with participants in the Baseline condition reporting a higher required mental effort (supporting H5). One participant commented on the struggle of creating a mental representation of what they were viewing on the screen *"It was hard to visualise from still images"*. This may suggest that participants in VR could focus better on what they were seeing, without any "mental overhead' associated with trying to reconstruct the space. This may have been aided by VR participants perceiving the system as easier to use than Baseline condition (supporting H6).

A striking finding was the different conclusions participants arrived at after viewing the scene. In VR, participants were almost unanimous in their decision, whereas in the Baseline condition they were split in their choice. The verdict *"Death by dangerous driving"* was 9.5 times more likely to be chosen by participants who viewed the scene in VR. A possible explanation for this result may be the amount of information that can be presented in VR. Participants interpreted the information differently depending on the viewing condition. In the Baseline condition, participants believed the victim must have been hit as the driver reversed, whereas participants in the VR condition believed that the victim was hit as the car moved forward. The ability to view the body in relation to the victim in a three-dimensional scene may have aided participants to conclude that this is the most likely outcome. An immersive scene allows large amounts of information to be presented in a way that is manageable, and participants took advantage of the exploration in a way that may have better supported their mental model. As the *Story Model* suggests, the more information overlap between individuals, the more likely they are to reach the same conclusion. Overall, the findings suggest that participants interpreted the content in VR in a similar manner and therefore leading to a conclusion that was consistent within the group, supporting H2.

The introduction of VR into the court of law requires consideration of many aspects. An often addressed concern is the fair introduction of the technology. All legal parties need to agree to the usage of the medium and potential adverse effects need to be considered. The intention of this research is a first step whether this medium could be a useful tool for the jury and building an understanding of VR on the effect on people in court.

## 5.10 Limitations

Although great care was taken to build this scenario with input from many professionals, there are still many aspects that need to be considered and further investigated. First, the scenario remains a fictional scenario. The elements in the scene were discussed with forensic scientists. However, the elements were placed manually, and it is difficult to predict how the scene would have presented itself in a real case. The positioning of the car in this scenario was also placed as per the eyewitness account – however, positioning the car correctly is a difficult task in forensics, and eyewitness accounts continue to be disputed in their reliability [64]. In addition, the study showed only a small portion of what would occur in a real trial. For example, each evidence item would be introduced individually and with context, whereas this scenario only showed items that would have been collected by forensic scientists. It was up to the participant to interpret what they saw. Furthermore, jurors retreat to deliberate on a verdict. Here, participants were required to make an individual choice in a short amount of time. The sample size of the study also poses a limitation, with 15 participants per condition. Results could be strengthened with an increased sample size. Further developments of the study could consider basing their scenarios on real cases with a "ground truth" and adding more complexity to the scenes that further resemble an actual trial, such as the addition of expert statements.

## 6 CONCLUSION AND FUTURE WORK

In this paper, we described an experiment measuring the potential of VR to impact memory and decision-making after viewing a fictional crime scene, compared to viewing images on a screen. We found that participants in VR were significantly more accurate in remembering the correct placement of evidence items (Spatial Recall), therefore answering RQ2,*Can VR improve spatial recall of presented evidence compared to still images?*. Participants also achieved a significantly higher score in one of the categories for Narrative Recall, with VR showing increased recall on average in three of the four categories, partially answering RQ1, *Can VR improve narrative recall compared to still images?*. Participants who viewed the scene in VR reported a significantly lower mental effort compared to participants who did not. Similarly, participants perceived the VR system as easier to use. The reduced mental effort paired with a system that was perceived as easy to use may have contributed to better encoding the scene through a thorough exploration.

Participants who viewed the scene in the Baseline mode were divided in their verdict decision, whereas participants in VR came to an almost unanimous decision. Narrative Recall was not found to be predictive of the verdict, therefore not answering RQ4, *Is a higher narrative memory score predictive of the verdict?*; however, RQ3 was answered, *Does viewing the environment in VR influence the consistency of verdicts?*. Participants who viewed the scene in VR were 9.5 times more likely to choose the verdict *"Death by dangerous driving"*. Despite the stark differences in the verdict, participants did not show a difference in their emotional arousal, indicating that it was not an emotional reaction that may have caused the choice of a more punitive verdict. Our results of consistency in the verdict and improved accuracy in recall suggest that viewing a scene in VR is more memorable and aids interpretation of the narrative provided. This further builds on the ability of VR to tell a story by exploring the environment within the context of what happened, complementing the natural way of how individuals make sense of information. This shows that VR could have the potential to be a more reliable option for viewing crime scenes compared to using still images.

This experiment was developed with the input of forensic professionals but was nonetheless designed to be ambiguous. The goal of this experiment was to identify how participants develop a narrative based on what they were presented and how this further affects their decision-making. Future work could explore a real scenario with a "ground truth" and how different groups perceive the case based on the display method. More detailed statements of forensic scientists could be included further outlining their findings. In future crime scenes, the virtual objects could also be more accurately placed, such as using CCTV to better position a car in a crash scene.

The interesting observation of participants altering their verdict after viewing the VR condition would be good to explore in future experiments. Jurors could be shown a crime scene using a traditional method, with only half of them being subsequently immersed into VR. The experiment could explore if there is a change of verdict after exploring the scene in 3D. Finally, these experiments were conducted with just a single person deliberating over a crime scene. It would be beneficial to also conduct future studies with a full jury group who could deliberate together after visiting crime scenes in VR, the real world, or as still images. This would more accurately simulate the impact of the use of VR crime scene reconstructions in the courtroom.

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