Reading the criminal mind

Exploring novel methods of memory detection

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Publication date
2023

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Memory detection in virtual reality: The effect of scene modifications

The study presented in this chapter is currently being replicated using a larger participant sample. The results of that study will be written up and submitted along with the results outlined in the present chapter.

Abstract

Can your eyes give away your deepest secrets? In the current preregistered study, we examined whether eye movements toward modified areas of a crime scene allow to detect crime knowledge. After committing either a mock crime or an unrelated task, guilty (n = 12) and innocent (n = 21) participants viewed the crime scene in virtual reality to which several salient modifications were made. Guilty participants looked more (d = 0.88) and earlier (d = 1.00) at these modifications as compared to innocent participants. It was possible to significantly distinguish guilty participants from innocent ones based on their eye movements toward the modified areas (AUC = 0.75). While awaiting replication, we argue that this approach has several important advantages in comparison to traditional memory detection.

When we visually observe the world around us, our eyes are constantly moving. We make rapid, jerky movements called "saccades" interspersed with brief pauses called "fixations" (Yarbus, 1967). During these fixations, our eyes take in information, which is then processed in our brains to form a coherent visual representation of what we are looking at. This way, our eye movements allow us to learn more about the world. Interestingly, this can also be applied the other way around. *When* a person is looking *where* can say a lot about what is going on in that person's mind. This way, eye movements also allow us to learn more about a person.

Several studies have already shown that eye movements are not only influenced by features of the stimuli, but also by features of the observers themselves. Even when the visual stimulus is exactly the same, different individuals can generate completely different scanning patterns (Lancry-Dayan et al., 2018; Mehoudar et al., 2014; Tatler et al., 2011). In particular, memory has been shown to have a strong influence on oculomotor behavior. In a series of studies, Neil Cohen and colleagues showed that familiar faces are scanned with a smaller number of fixations and fewer regions sampled as compared to faces that are unfamiliar to the observer (e.g., Althoff & Cohen, 1999). This memory-guided gaze dynamic also occurs for recently learned faces (Heisz & Shore, 2008), as well as complex scenes (Ryan et al., 2000). The effects can occur very rapidly, obligatorily, and even in the absence of conscious awareness (Hannula et al., 2010).

This link between memory and eye movements is highly relevant for memory detection. Memory detection is a technique to detect whether a suspect of a crime has critical crime knowledge that only the perpetrator should know (e.g., what the murder weapon was, or where it was hidden; Lykken, 1959; for a review see Verschuere et al., 2011). To examine whether an examinee recognizes crime-related information, critical crime information is presented within a series of similar, crime-unrelated information. If the examinee responds differently to the crime information than to the crime-unrelated information, recognition is inferred. Measured responses are usually skin conductance, heart rate, and breathing rate but other responses like reaction times and brain activity have also proven to be effective (Meijer et al., 2016). More recently, it has been shown that under specific conditions, eye movements can also be used to detect concealed knowledge (Lancry-Dayan et al., 2018, 2021, 2022). However, this method requires multiple crime-related items, and for each crime-related item, several equally plausible alternatives (for example, in the studies by Lancry-Dayan et al., 2018, 2021, for each crime-related item, 7 control items were used). Finding sufficient crime-related items and formulating enough appropriate control items is often stated as a major challenge of memory detection (Iacono, 2011). As a result, this method may often be difficult to apply in practice.

Previous studies showed that when people observe an image they have seen before, they tend to look more at regions in the image where a modification occurred (e.g., Ryan et al., 2000). The idea that recognition can also be detected by examining eye movements toward a modified version of a known item was applied to a forensic setting by Derrick et al. (2011). In their study, 11 participants had to try to pass a screening station. Before the screening interview, half of them had assembled a realistic bomb. In the screening interview, the participants had to answer some questions and were shown three images while their eye movements were tracked. Critically, one of the pictures was a modified version of the bomb. The authors found that the bomb-making group fixated more on the manipulated part of the bomb image than the innocent group. One advantage of this method is that only a picture of the crime related item is needed and no control items have to be formulated. While the exploratory findings of Derrick are promising, they await confirmation. Moreover, recent technological advances make it possible to enhance recognition by presenting the crime scene in virtual reality (Norman et al., 2020).

In the current study, we will examine whether crime knowledge can be detected based on eye movements toward modified scene parts, presented in virtual reality. To that end, participants were randomly assigned to either the guilty condition (who had to commit a mock crime) or the innocent condition (who had to do an unrelated task). Upon return, all participants were informed that there had been a crime on campus and that they were suspected of committing this crime. Then, all participants viewed the crime scene in virtual reality to which we made several salient modifications as compared to the original crime scene. Based on Derrick et al. (2011), we hypothesized that the eyes of guilty participants would be drawn toward these modifications, while innocent participants would deploy fewer fixations to the modified parts of the crime scene.

Method

This study was approved by the ethical committee of the Faculty of Social Sciences of the Hebrew University of Jerusalem and registered as number 2022-02132. The study was preregistered (https://osf.io/ybg4q), and no deviations were made to the preregistration. Materials and data can be found at https://osf.io/pr79y/.

Participants

Participants were recruited through the online recruitment system of the Hebrew University of Jerusalem and received 2 research credits or 20 shekels for participation. As described in our preregistration, we first opened up the experiment to 40 participants. Then, after applying our preregistered exclusion criteria (see below), we ran a Bayesian one-sided independent samples *t*-test in JASP (version 0.16.2; using JASP's default Cauchy scale of 0.707) with the gaze duration proportion as the dependent variable and condition (guilty vs. innocent) as the independent variable. The decision to stop collecting data was based on the Bayes Factor (BF_{10}) of this test. BF_{10} expresses how likely the data are under the alternative hypothesis (larger proportion of gaze duration in the guilty compared to the innocent condition on the modified items) as compared to the null hypothesis (there is no difference between the two groups). We stated that if we would reach substantial evidence for either the alternative hypothesis (i.e., BF_{10} larger than 5) or the null hypothesis (i.e., BF_{10} smaller than 1/5), we would stop testing, if not, we would open up the experiment for another 20 participants. We would repeat this procedure until we would have reached substantial evidence (i.e., $BF_{10} > 5$ or $< 1/5$) or until we would have tested N = 100. After our first batch of 40 participants, we reached a BF_{10} of 5.67, so data collection was stopped.

Based on the preregistered exclusion criteria, 7 guilty participants were excluded because they did not commit the crime properly (i.e., they could not give the jewels and credit card back at the end of the experiment). The final sample consisted of 33 participants, of which 12 were guilty and 21 innocent. Sixty-seven percent of the sample was female, 30% was male, and 3% defined themselves as another gender or non-binary. They had a mean age of 24 years (*SD* = 2 years, range 19-29 years).

Procedure

The study consisted of 3 parts: A mock crime/control task, a virtual reality task, and a questionnaire.

In the first part of the experiment, participants were randomly assigned to either the guilty condition or the innocent condition. To this end, the experimenter gave the first of a stack of 10 shuffled envelopes (5 envelopes for guilty and 5 for innocent) which contained condition-specific instructions. This way, the experimenter could remain blind to the condition of the participant. Participants who received guilty instructions were instructed to steal some jewels and a credit card from a professor’s lab on campus. Participants who received innocent instructions were instructed to read some posters on campus for 10 min.

Instructions can be found in full at https://osf.io/gpkdb. Upon return, all participants were informed that there had been a crime on campus and that they were suspects of this crime.

In the second part of the experiment, participants did a virtual reality task. Participants were told that they would see two rooms in virtual reality and that they had to try to remember as much as possible from each room because there would be a memory task afterward. Critically, one of the two rooms was a modified version of the crime scene (the professor's lab; see Figure 1). Six modifications were made to the crime scene: two omissions (a folder and a dartboard were removed), two additions (a lamp and a gift were added), and two changes (an envelope and a backpack were changed to a different envelope and backpack). From each category (omission, addition, and change), one modification was central to the crime, and one was peripheral. Participants saw the crime scene and control room for 30 seconds each. The order of the rooms (first the crime scene or first the control room) was counterbalanced among participants.

Figure 1

Pictures of the crime scene during the mock crime (left) and the two rooms presented during the virtual reality task (top right is the control room, bottom right is the modified crime scene).

Mock Crime **Virtual reality task**

In the third part of the experiment, participants had to complete a short questionnaire. Participants were asked to answer eight multiple-choice recognition questions about the rooms they visited in virtual reality, provide their demographics (age and gender) and provide some feedback on their experience with the experiment.

Results

Confirmatory analyses

For our main analyses, we first computed the average proportion of time where gaze was directed at the modified areas, out of the whole viewing time. Afterward, we tested whether this proportion was higher for guilty participants than for innocent participants by running a one-sided independent sample *t*-test (both frequentists and Bayesian) with the gaze duration proportions as dependent variable and condition (guilty vs. innocent) as independent variable. These analyses showed that guilty participants looked significantly more at the modified areas than innocent participants, $t(31) = 2.43$, $p = .011$, $d = 0.88$, 95% CI [0.249; ∞], $BF_{10} = 5.67$

Exploratory analyses

The area under the ROC curve

To test whether guilty individuals could be distinguished from innocent individuals based on the proportions of gaze duration on the modifications, we calculated the area under the ROC curve. The area under the ROC curve is a measure of the diagnostic accuracy of a test. It ranges from 0.5 to 1, where a value of 0.5 indicates a chance level accuracy and suggests no discrimination, while a value of 1 reflects a perfectly accurate test (Mandrekar, 2010). This analysis showed that it was possible to distinguish guilty participants from innocent ones significantly above chance with an area under the ROC curve of 0.75, 95% CI [.57; .94], $p = .018$. To define the optimal cutoff point, the Youden index was calculated. The maximum Youden index was obtained for cutoff point 0.039, $J_{max} = 0.452$. Although this cutoff point corresponded to a high specificity (only 5% false positives), it did also correspond to a low sensitivity (50% false negatives).

Different types of modifications

To explore the influence of the different types of modifications, we ran a 3 (modification type: omission, addition vs. change; within-subjects) by 2 (crime-relatedness: central to the crime vs. peripheral; within-subjects) by 2 (condition: guilty vs. innocent; between-subjects) mixed (Bayesian) ANOVA with gaze duration proportions as dependent variable. The results of interest were the interaction between the condition and modification type and the interaction between condition and crime-relatedness. The interaction between condition and modification type was not significant, $F(2, 62) = 0.74$, $p = .480$, $\eta^2 = 0.01$. The interaction between condition and crime-relatedness was also not significant, $F(1, 31) = 0.01$, $p = .926$, $\eta^2 = 0.00$. The Bayesian ANOVA indicated that the data are 7.68 times more likely under the model that included the two main effects modification type and condition and the interaction between modification type and crime-relatedness, as compared to the null model.

Crime-related areas without modifications

There were two crime-related areas in the virtual reality crime scene to which we made no modifications. There was no evidence that guilty participants looked more at these areas than innocent participants, $t(31) = -0.56$, $p = .711$, $d = -0.20$, 95% CI [-0.80; ∞], $BF_{10} = 0.24$.

Recognition questions

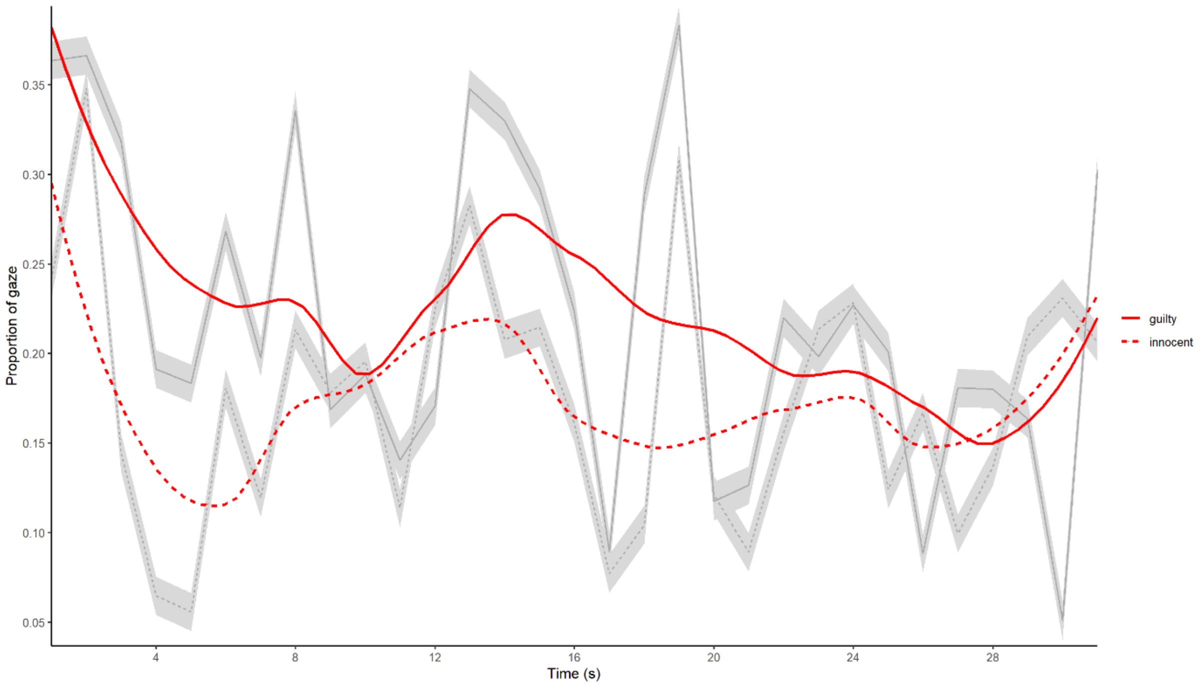
Participants answered on average 6.61 ($SD = 0.86$) out of 8 recognition questions correctly. Guilty participants ($M = 6.67$, $SD = 0.49$) scored slightly better than innocent participants ($M = 6.57$, $SD = 1.03$), but this difference was not significant, $t(31) = 0.30$, $p = .766$, $d = 0.11$, 95% CI [-0.60; 0.82], $BF_{10} = 0.35$.

Other dependent variables

Time to first fixation. We tested whether the time until participants looked at modifications was shorter for guilty participants than for innocent participants. To test this, we ran a (Bayesian) one-sided independent sample t-test with time to first fixation as dependent variable and condition (guilty vs. innocent) as independent variable. This analysis showed that guilty participants looked significantly earlier at the modifications than innocent participants, $t(31) = -2.77$, $p = .005$, $d = -1.00$, 95% CI [-∞; -0.36], $BF_{10} = 10.46$. The time course of when guilty versus innocent participants looked at the modifications is visualized in Figure 1. This figure illustrates that the majority of the increased attention toward modifications occurs within the initial 10 seconds, and then gradually decreases during the next 10 seconds.

Figure 1

Time course of gaze towards modifications by guilty participants and innocent participants.



Note. In grey, the gaze proportions in each time bin with their standard errors are depicted. In red, smoothed trend lines are added for clarity purposes.

Fixation duration. We tested whether the fixation durations on the modifications were longer for guilty than for innocent participants through a (Bayesian) one-sided independent sample t-test with fixation duration as dependent variable and condition (guilty vs. innocent) as independent variable. Guilty participants did not exhibit longer fixations at the modifications than innocent participants, $t(30) = 0.51$, $p = .306$, $d = 0.19$, 95% CI [-0.42; ∞], $BF_{10} = 0.51$.

Discussion

In the current study, we tested whether eye movements toward modified areas of a crime scene presented in virtual reality allow to detect crime knowledge. As predicted, we found that guilty participants looked more at the modified areas than innocent participants.

Furthermore, exploratory analyses showed that it is possible to distinguish guilty participants from innocent ones based on their eye gaze behavior and that guilty participants also looked earlier at the modified areas.

Eye movements serve as a means of gathering information from the environment to form a coherent visual representation of what we are looking at. In doing so, people look more at objects that are the targets of a search, but also dwell on objects that differ from expectations. These expectations can be based on general knowledge about the context in which they are embedded (e.g., an octopus on a farm; Loftus & Mackworth, 1978), or, as in the current study, on previous viewing history. These expectation-based biases of attention toward areas of interest facilitate efficient processing of the environment (Hannula et al., 2010). They allow us to quickly compare the current input with past experiences in order to update the visual representation, guide decision-making, and navigate through the world (Ryan & Cohen, 2004).

Advantages over classical methods of memory detection

The current results not only demonstrate the potential of memory detection based on eye movements towards modifications, but they also imply that this approach may have some important advantages over classical memory detection methods.

Although the classical method of memory detection has already been validated in many studies and obtains high accuracy rates (Meijer et al., 2014; Verschuere et al., 2011), it has been rarely used in practice (with Japan being the only exception; Hira & Furumitsu, 2002; Osugi, 2011). Some of the most important reasons for its limited use are the information leakage problem and the risk of countermeasures. In the next paragraphs, we argue how the current method might provide a solution to these problems.

First, this method could provide a solution to the leakage problem. The leakage problem refers to the fact that innocent suspects could gain crime knowledge through means other than committing the crime, leading to false positive results (Bradley et al., 2011). If a suspect heard or read about certain items of a crime scene, then using these items could result in false positive outcomes, so they become useless. For example, if it is known to the public that a crime happened in the living room of the suspect, then this item can no longer be used in a classic memory detection test anymore. However, if the investigators would make certain modifications to the particular living room, then innocent suspects who only heard where the crime took place, but have never seen the living room, would not notice the changes while guilty suspects would. So even if information has been leaked, the researchers are in control because they can decide which changes should be made to the critical item that might have been leaked. Furthermore, as in the current study, the test could be used to detect recognition of a crime scene, and leakage of an entire crime scene is highly unlikely in practice.

Second, this method could bypass countermeasures. Countermeasures are techniques that a guilty suspect could use to control their responses in order to beat the test (i.e., to look innocent), leading to false negative results (Ben-Shakhar, 2011). One of the main advantages of using eye movements as a measurement is that it does not give away what is being measured. If participants are not aware of what is being tested, there would be no need for faking. Furthermore, faking under the proposed method is particularly unlikely because suspects may not be explicitly aware of the specific changes in the crime scene. Even if participants would know what is being tested, research has shown that eye movements could be attracted to changes even without awareness of the change (Ryan et al., 2000).

Limitations and future directions

While we lack a direct comparison with established measures, the detection efficiency of the current method seems lower than what is usually found in previous research. A recent review by Lancry-Dayan et al. (2022) showed that autonomic nervous system responses (skin conductance, heart rate, and breathing rate) result on average in areas under the ROC curve of

0.81, neural activity leads to a mean detection efficiency of 0.91, and eye tracking paradigms that include and a simultaneous display elicit a mean detection efficiency of 0.86. These results are all well above the detection accuracy of 0.75 that was found in the current study. However, previous studies primarily used highly familiar items, whereas the present study used newly learned items, which have been shown to have lower detection efficiency (Lancry-Dayan et al., 2021; Millen et al., 2020). Moreover, unlike previous studies, the current study employed only one crime-related item (the crime scene). Future research could investigate whether utilizing multiple 3D pictures could enhance the detection efficiency of the current method.

There are also several questions that remain unanswered. For example, as guilty participants in the current study did the virtual reality task immediately after they performed the mock crime, their memories were strong. Future studies could examine whether the effect lasts over time when information is forgotten. Moreover, it is unknown how well the 3D pictures should match the crime scene to register appropriate responses. For example, in real-life applications, it could be possible that the 3D picture would be taken only weeks or even months after the crime took place and the crime scene may have changed in the meantime. The 3D picture could also be taken from a different point of view from the one the criminal had while committing the crime. Future studies could assess whether the effects are robust to these kinds of variations, and if so, to what extent.

Conclusion

In conclusion, when visiting a modified crime scene in virtual reality, guilty participants looked at the modifications earlier and longer, compared to innocent participants. Based on their eye gaze behavior, it was possible to significantly distinguish the guilty from the innocent participants. This approach has several important advantages in comparison to traditional memory detection, although its detection efficiency seems to be lower.

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