Detecting Subliminal Salient Face Familiarity with Pupillometry

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Abstract

Most people have engaged in lying or information concealment at some point in their lives. Especially in crime-related settings, guilty individuals go to great lengths to appear truthful and innocent. To detect if someone is lying or hiding familiarity with certain knowledge, different methods have been adopted to measure their physiological responses (e.g., fMRI or EEG measurements). Countermeasures – taken by individuals to confound the results – can be prevented by using rapid serial visual presentation (RSVP), where stimuli are presented very briefly and thereby inhibiting the examinees to influence their bodily response. A previous study showed that familiar faces presented in RSVP can break into awareness, detected by a difference in EEG response. Another study, using RSVP and pupillometry, showed that measuring the pupil size is successful to detect recognition of target and familiar names. Our study investigated whether a combination of these methods (RSVP with face stimuli and pupillometry), is also effective. Specifically, whether a familiar face would break into awareness, detected by a difference in pupil size. 53 participants were asked to focus on a previously unfamiliar face and find it in an RSVP stream. This target face became salient and a significant difference in pupil size was detected. In some trials, a familiar face (Barack Obama) was present. This probe was not linked to a specific task, and thus subliminal. Against our expectations, we were unable to detect a significant difference between pupil size in the probe condition and pupil size in the no target condition. Our findings support the use of face stimuli in RSVP, where physiological responses are measured by pupillometry, but there is more need for research that links this to subliminal salience or concealed information.

Keywords: RSVP, pupillometry, face stimuli, familiarity, (subliminal) salience

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In everyday life, people frequently conceal their thoughts, knowledge, or information. Hidden information can range from personal opinions to specific knowledge that you may not want to share with others. Most people keep information hidden in order to avoid difficult or unpleasant situations. However, for perpetrators who go to great lengths to conceal crime-related information, or rather, knowledge, this process is critical. Their primary goal is to appear innocent and prevent revealing information that could implicate them in a crime. It is vital to develop methods for accurately detecting guilty people and distinguishing them from innocents.

A universally known technique to detect lies is the use of a lie detector (Marston, 1938). Using a device such as this relies on physiological response patterns that accompany lying, thereby distinguishing these from responses accompanied by truth-telling. Furthermore, a guilty individual will present an involuntary bodily response to stimuli which are related to this crime (Lykken, 1959). Following this notion, Lykken (1959) developed the guilty knowledge test (GKT), nowadays also known as the concealed information test (CIT). The main idea is that individuals are exposed to crime-relevant information and their physical reaction is measured. Several techniques have been suggested to measure these physiological responses, especially to infer whether someone is guilty or not. These techniques could be neuroimaging techniques, like functional magnetic resonance imaging (fMRI, Kozel et al., 2005), or EEG-measures, like event-related brain potentials (ERPs, Farwell & Donchin, 1991). Kozel et al. (2005) were able to correctly distinguish truthful responses from deceptive responses in 90% of the participants receiving a mock-crime setup. They were the first to use fMRI and show that specific brain regions were activated during deception on an individual level. Farwell and Donchin (1991), using ERPs, found that experimenter-designated targets elicited a large P300 effect in all subjects. Furthermore, probe conditions associated with certain scenarios were included in the method, which elicited a P300 effect in individuals who participated in that scenario, and thereby possessed guilty knowledge.

The CIT's vulnerability to the application of countermeasures by guilty or deceitful examinees is one of its most fundamental flaws (Verschuere, 2011). Countermeasures are deliberate strategies that suspects may use to change their physiological responses, such as either attempting to block or stimulate responses to the relevant or neutral items. Examples include influencing specific thoughts or inflicting pain upon themselves to spike measurements. To limit the mental and physical countermeasures that guilty people may employ, Bowman et al. (2013) presented stimuli too fast for the examinee to alter one’s physiological response. This method is called rapid serial visual presentation (RSVP) and consists of a series of stimuli that are presented on the fringe of awareness; for about 100 milliseconds each. It was shown that particularly salient stimuli (e.g., a target or probe) break through into awareness, resulting in a physiological response. Because this response still occurs, even in fleeting stimuli presentation, this method provides detection of familiarity that is resistant to countermeasures.

There is a need to demonstrate that the underlying "break-through" into awareness phenomenon can be elicited and detected using a variety of stimulus types. Recently, to ensure a broader applicability of this method, Alsufyani et al. (2018) aimed to replicate the findings from Bowman et al. (2013). However, instead of presenting the participants with words (i.e., names), they opted for different stimuli. They considered whether face images could be used in RSVP and if famous, and thus familiar faces would also break into awareness. Data from their EEG study showed that within an independently identified time window, 71% of the participants demonstrated a significant difference between the mean amplitude of the probe and irrelevant stimulus. This study increased and clarified the potential for the use of non-word stimuli, for instance, faces, in RSVP-based tests. This would be especially relevant in a crime-based setting, where, for example, prosecutors might seek to distinguish suspects, accomplices, or perpetrators by face familiarity.

However, measuring the physiological responses of a CIT with either fMRI or EGG in combination with RSVP, is difficult outside of the laboratory. As a result, Chen et al. (2021) used a different, more accessible design to investigate physiological response. In their study, participants' pupil sizes were recorded during the CIT, an approach also known as pupillometry. They used the methods of Bowman et al. (2013), with the fake name as the target and the participant's own (familiar) name as probe. Participants were asked to choose a fake, unfamiliar name, and focus on this name during the experiment (target). Sometimes, however, the participant's own name would appear in the RSVP stream (probe). From the set of 15 unfamiliar names that was presented to the participant before the experiment, a control name was randomly selected. Results showed that, on a group-level, the pupil size was significantly larger in the task-relevant fake-name condition compared to the control condition. Furthermore, the pupil also increased in size, relative to the control condition, when the task-irrelevant real name (probe) was presented in RSVP. As a result, they could conclude that the pupil size is a promising measure for detecting concealed information. However, it remains unclear if knowledge of, or familiarity with different stimuli (e.g., images or faces), can be detected by pupillometry.

To investigate the question whether face familiarity can be detected by pupillometry, we conduct a research experiment consisting of the combination of RSVP, face stimuli and pupillometry. Our research has two main goals. First, to replicate the findings of Alsufyani et al. (2018) in which familiar faces (salient stimuli) reached consciousness when rapidly presented and which elicited a physiological response. Furthermore, we want to replicate the findings of Chen et al. (2021), who found that the pupil size increased in response to familiar (but subliminal salient), task-irrelevant names. We will combine these two studies to test whether using pupillometry may also suffice as a measure to detect if familiar faces break into consciousness. Similar to Alsufyani (2018), we will not instruct participants to actively conceal (or lie about) the famous face. As they will not be informed of a famous face appearing in the trials, the probe will not be linked to an explicit task. Therefore, our study focuses more on subliminal salience rather than concealed information. At the end of the experiment, the participants will be asked whether they noticed the presence of a famous person, to allow us to interpret the results. We expect to see an increase in pupil size – compared to the condition where no target is present – when the salient target face is presented to the participants. Furthermore, we also expect to see an increase in pupil size for the famous face (the probe), regardless of its task-irrelevance, compared to the control condition. If these effects occur, the results would suggest that the use of pupillometry in RSVP studies with face stimuli has a promising future. Moreover, it may entail that subliminal salient, familiar faces are able to become salient in RSVP trials.

Methods

Participants

53 English-speaking individuals took part in the experiment. All of them were first-year Psychology students (37 female and 15 male) at the University of Groningen in the age group of 18-24 (M = 19.62, SD = 1.25). Participants had normal or corrected to normal vision. Prior to the experiment, participants were instructed to avoid wearing dark eye make-up.

Ethics

This study was conducted following the guidelines of the World Medical Association Declaration of Helsinki (2013) and approved by the ethics committee of the Psychology Department of the University of Groningen (approval number: PSY-2122-S-0168). Informed consent was obtained digitally from all participants before participation, and they were allowed to take a picture of this screen. Oral debriefing was provided to all participants after participation.

Apparatus

Participants were instructed to place their heads on a chin rest with an adjustable height. The distance between them and a 27’’ LCD Liyama PL2773H monitor was 60cm. The display resolution was 1280x720 pixels and had a refresh rate of 1000 Hz. RSVP was presented with OpenSesame (Mathôt et al., 2012) running on Windows. Participants used a QWERTY keyboard to indicate their responses. The size of participants’ pupils was recorded in arbitrary units by an EyeLink 1000 (SR Research, Canada) during each trial using PyGaze (Dalmaijer, E., et al. 2014). Analyses were performed in JASP (2022) and RStudio (2022).

Stimuli

We selected faces for the experiment from the *10K faces database* (Bainbridge et al., 2013). More specifically, the total number of faces included in the RSVP was 1127. Prior to the experiment one of these faces was randomly selected for each participant to be the target stimulus. As the probe stimulus, a photo of Barack Obama (Figure 1a, Souza, 2012) was placed in the stream. Irrelevant distractor faces in each trial were selected randomly from our overall list of faces. A control face was also randomly selected for each participant before the experiment to check whether there would be no difference with the no target condition. This was done to ensure that a random face – equal in presentation frequency to the probe and target – would not become familiar and elicit a pupil dilation. Pictures were all monochrome and did not represent any body part of the person besides the face. All faces were presented in the center of a gray-colored screen inside a fixed oval shape (140 x 200 pixels), as shown in

Figure 1a-b. The visual angle for each picture was 11.42° in height and 6.82° in width. Using custom Matlab scripts the photo of Obama was processed to appear similar to the unfamiliar faces in, for instance, contrast and brightness.

Figure 1a-b. *Examples of stimuli*

Note. Figure 1a shows the face of Barack Obama (Souza, 2012). Figure 1b shows a face used as a stimulus (Bainbridge, 2013).

Procedure

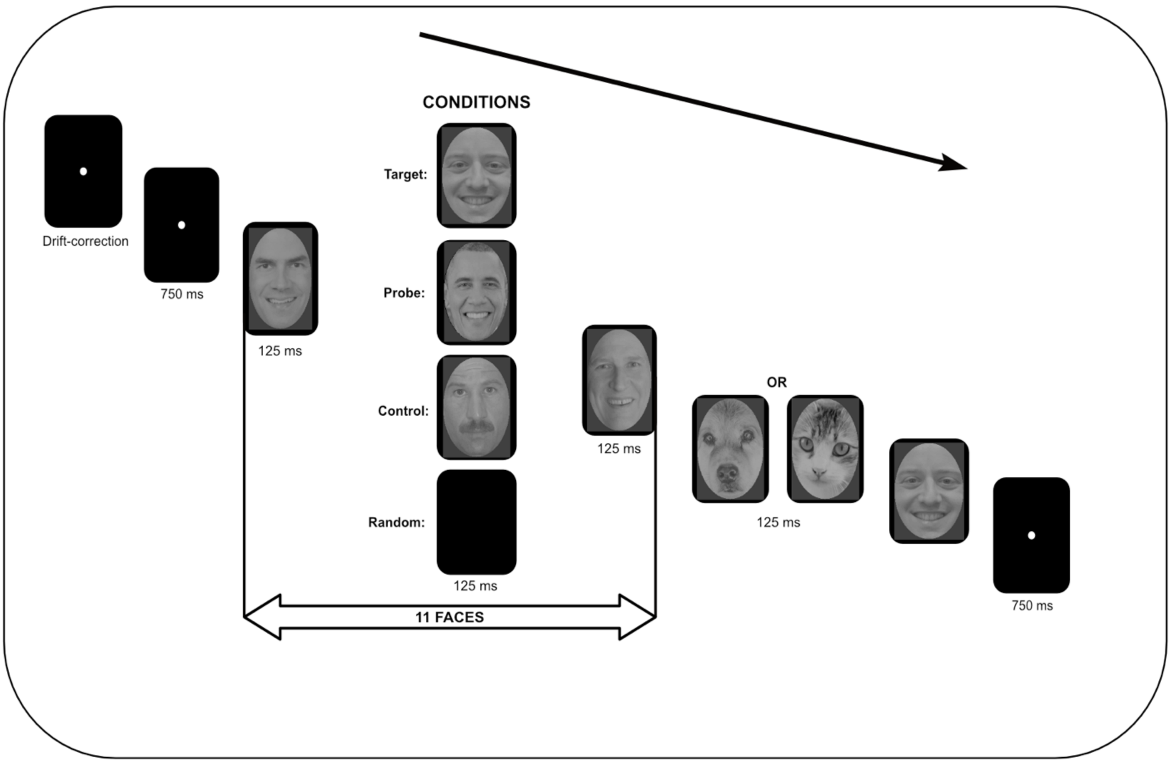
After inspecting the pupil traces, we decided on a cut-off value of five or more removed trials in the processed data due to blinks. We calculated it by removing any participant who had exceeded three median absolute deviations from the median (*Mdn* = 1, *MAD* = 1). As a result, the data of 10 out of 53 participants was deleted, leading to a final inclusion of 43 participants.

Prior to the start of the experiment, participants were shown the target face and were required to finish ten practice trials to get familiar with the task. The experiment consisted of three consecutive blocks and each block of trials consisted of 32 trials resulting in a total of 96 trials. As shown in Figure 2, before each trial a fixation dot was shown for approximately

500-1000 milliseconds to capture the attention of the participant and to enable a baseline pupil size. The participants were then shown 11 faces concluding the trial with either a cat or a dog in an RSVP stream, each for 125 ms. During the stream, four conditions were possible. Participants were either shown the target face, the probe, a control face or no target face, which was presented randomly on position 5, 6 or 7 for every trial. After the sequence of faces, either a dog or a cat was shown to keep the participant's attention fixed throughout the entire stream. Finally, another fixation dot was presented. Overall, the RSVP trial duration was 3000 ms counting from the first to the last fixation dot.

Figure 2.

Visual Representation of a Singular Trial Sequence



Tasks

After each RSVP, the participants were initially asked to indicate whether a picture of a dog or a cat was shown. This was done to ensure the participant remained focused during the whole trial. They were instructed to press '*m*' to indicate if they saw a dog and press '*c*' if they saw a cat. After this first task, the target face was shown once more and the participants were asked *"Did you see this face?*". When they did not, they had to press '*c*' and when they did, they had to press '*m*'. The order of response buttons was counterbalanced over participants. After each response, the participant was shown whether they were correct or incorrect. The answer to the first question would either lead to an increase or decrease of the total score by five points. The answer to the second task, of whether they had seen the target face, resulted in either 10 points increase or 10 points decrease.

At the end of the experiment, the participants were given two questions. These were *"Did you notice the face of a famous person was shown sometimes?"* and *"If you had to guess which famous person we showed, who would it be?",* respectively. The latter, which was an open question, was added to ensure that participants who selected '*yes*' on the former question did, in fact, see Obama.

Design

In the RSVP sequence, 11 faces were shown. There were four conditions, one where the target face was present, one where the probe (Obama) was present, a condition where no target was present and a condition where a control face was presented. This control face was randomly selected from the database and served as a baseline that was similar in presentation frequency to the target and the probe. Each condition was shown either on position 5, 6 or 7. The four conditions in combination with three possible positions, and two possible animals resulted in 24 different combinations. Each possible combination was presented four times which resulted in 96 trials.

Data processing and analysis

To determine to what extent participants were able to sustain their attention during the trials, we first analyzed the accuracy of the responses to the question of whether they saw a dog or a cat at the end of each trial. We then baselined the pupil sizes by taking the average size from the first three samples in each trial after the T1 presentation and subtracting this baseline value from all other samples in that trial. The window that has been chosen for the analysis is based on the study from Göl, Jansen and Rasztar (2022), where it was found that the biggest difference in pupil response occurs between 640 ms and 920 ms after the T1 presentation.

As an exploratory analysis, we used a Shapiro-Wilk test for the normality assumption. Afterwards, we used two nonparametric Mann-Whitney U tests on the group level to check for differences that may exist in the pupil size. In more detail, we used the means of the baseline-corrected pupil size [during the analysis window] as a dependent measure and condition as a fixed effect, to find if a difference exists between the pupil sizes when comparing target with no target, probe with no target and control with no target.

Results

In our study, we had two predictions. First we checked whether the pupil size would be larger after the target face was presented, in comparison to when no target was presented. This would indicate that the task-relevant stimulus, the face that the participant had to actively look for, elicited a reaction which can be detected by using pupillometry in an RSVP. The second prediction was related to the detection of the famous face. If the pupil size in the probe condition would be larger than in the no target condition, then it would entail that the task-irrelevant, familiar face (even if subliminal) had elicited a physiological reaction. Supported by the results of the experiment, this prediction could provide support for the use of pupil size and RSVP in order to detect subliminal salience, or even concealed information.

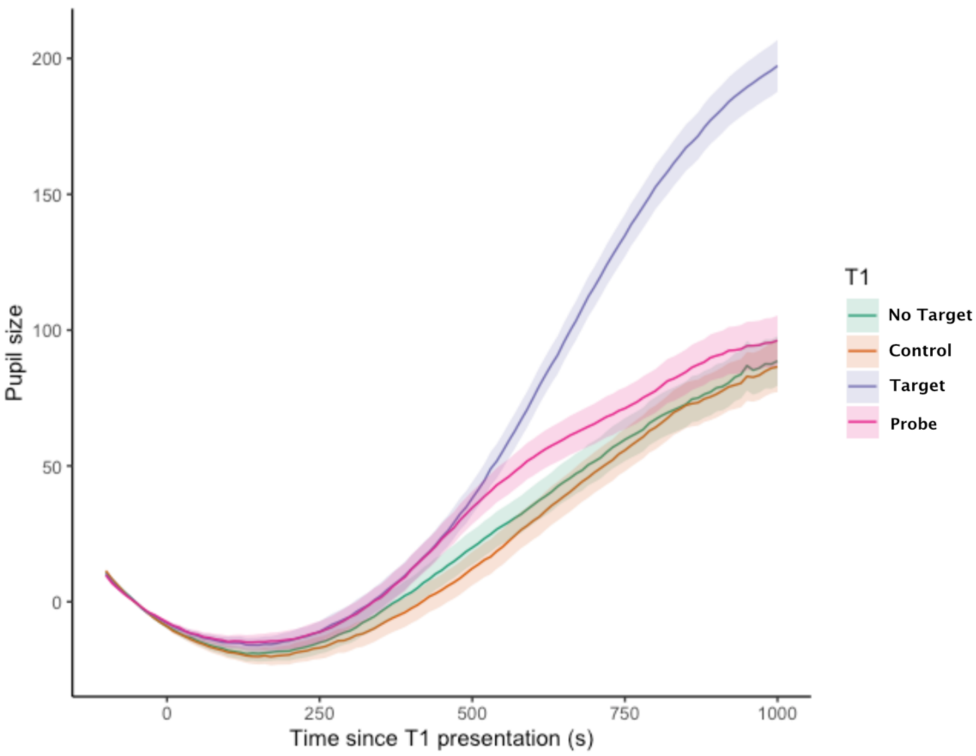
Task Performance

On average participants were able to respond well above the guessing rate in both tasks. Regarding the first task (question: "*Did you see a cat or a dog?*") participants were able to indicate with an accuracy of 99% whether a picture of cat or a dog was shown at the end of the RSVP. When we inspected the performance on the second task (question: "*Did you see this face?*" accompanied with the target face). Participants responded correctly to the presence of the target in 57% of the cases and to the absence in 95% percent of the cases. To the two end questions *"Did you notice the face of a famous person was shown sometimes?*" and *"If you had to guess which famous person we showed, who would it be?*", of the 43 participants 38 gave an answer (79%) and of these 38 participants 45% indicated that they saw Obama.

Pupil traces

Pupil traces in response to the presentation of T1 are shown in Figure 3. Visual inspection of the pupil size after the presentation of the target face shows a difference starting from approximately 500ms and showing an upwards trend until 1000ms. Likewise, the pupil response to the presentation of the probe diverged from no target after approximately 500 ms. This effect, however, is not as large compared to the target condition. Inspecting the Control and the no target condition does not show a big difference.

Figure 3 *Pupil trace visualization for the four conditions*

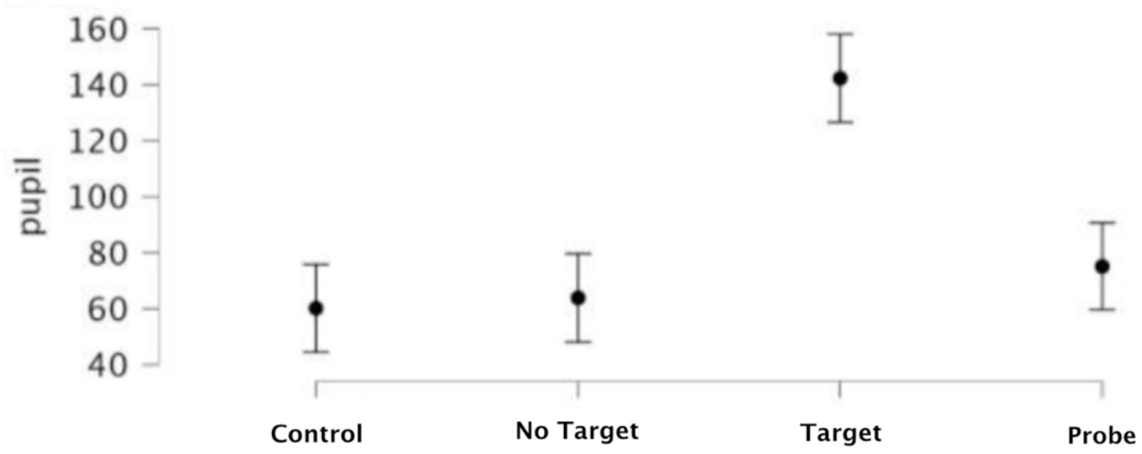


The mean values of participant's pupil sizes in the four different conditions were measured in the time window of 640 to 920 ms. The four conditions and their respective mean values, control (M = 60.15, SD = 253.28), no target (M = 63.88, SD = 255.76), target (M = 142.18, SD = 254.12), probe (M = 75.12, SD = 251.48) can be seen in Figure 4.

As the normality assumptions were violated, for the group level analysis two Mann-Whitney U tests were conducted to investigate differences in pupil size between the target, the probe and the no target condition. According to our first hypothesis, pupil sizes in the target condition would be larger compared to the no target condition. A significant difference between target – no target supported our hypothesis ($U = 412934$, $p < .001$, $d = -0.179$). For the comparison probe – no target a non-significant p-value was found ($U = 490915$, $p = .246$, $d = -0.030$). This result does not support our hypothesis that in the trials in which the probe was presented, a larger pupil than in the no target condition would be observed. Lastly, we tested whether there was a significant difference between the control and the no target condition. A significant difference between these two conditions would indicate that participants became familiar with the control condition as well. This difference, however, was non-significant (U = 496888, p = .584, d = -0.014).

Figure 4.

Mean pupil size during the window of 640 – 920 ms over four conditions



Discussion

In this study, we show that familiarity with a face elicits a distinct pupil response in rapid serial visual presentation (RSVP). More specifically, the size of the pupil increases when a face is presented for which an individual is actively searching. This autonomic, physiological response indicates that recognition is still available at the edge of awareness. Thus, similar to previous findings (Alsufyani et al., 2018), familiar target faces break into conscious awareness when presented in RSVP. New to this field of research was the use of pupillometry in combination with faces shown in RSVP. We have shown that this combination is successful in detecting recognition of salient faces. Furthermore, we also expected to observe a substantial pupil difference (compared to the control condition) for a well-known yet subliminal salient stimulus (that is, Obama's face). Unfortunately, we were unable to do so.

Although the presentation of the target face elicited a significant difference in pupil size, the Target was correctly identified in merely 57% of the trials. This accuracy, which is just above the guessing rate (50% chance to answer correctly), might indicate that the task was too difficult. Faces are complex stimuli that require a lot of information to be processed (Damasio et al., 1990) compared to name stimuli used in studies from, for instance, Chen et al. (2021) and Bowman et al. (2013). A possibility for target recognition just above the guessing rate could be that the processing of this complex information might take more time, resulting in less accuracy when identifying the target in RSVP. Although we increased the presentation time of each stimulus from 100 ms (Chen et al., 2021) to 125 ms, increasing this stimulus onset asynchrony (SOA) even more could potentially improve accuracy.

Another limitation that could explain the mediocre percentage of target identification is linked to salience. In our design, we repeated a previously unfamiliar face and asked the individuals to identify this face. We then assumed that this face would be salient for the participants, as they are actively looking for its features and the face is shown again after each trial. The participants have, however, never encountered this face before in real-life. To increase the power, the experimental design could use the faces of people individually familiar, and thus more well-known to the participants, rather than a random face from a database. Regardless, the significant difference in pupil size for the target condition compared to no target shows that the novel combination of pupillometry, RSVP and face stimuli is effective. This manipulation could provide a promising future for more research, especially for subliminal salience or Concealed-Information Testing.

A visual representation and the mean pupil sizes for the probe indicate a dilation compared to no target or control conditions (Figure 3 and 4 respectively). This effect, however, turned out to be non-significant, indicating that there is no substantial difference in pupil size for our subliminally salient probe, relative to conditions where no target or a control face was shown. The task-irrelevant probe was not recognized by approximately 55% of the participants (indicated by the responses to the end question "*If you had to guess, who would the famous person be?*"). Since recognizing a salient face elicits a physiological response (e.g., pupil dilation), not actively seeing the probe for the majority of participants might contribute to the non-significant pupil difference. The familiar face of Obama could possibly not be salient enough (too subliminal) in an RSVP stream. Moreover, the familiarity with Obama is subjective. It is not justifiable to assume everyone knows Obama. A possible way to ensure participants recognize Obama's face, could be to add another end-question. For instance, to show his face in combination with the question *"Do you know this face?".* That way, there is a possibility to compare individuals who saw Obama with individuals who did not due to other factors, while eliminating the possibility of non-familiarity. The results from Alsufyani et al. (2018) suggested that RSVP with face stimuli would be appropriate to determine whether a suspect has knowledge of a particular face, and that long-term familiarity could be useful in crime-related settings where one might be acknowledged with a compatriot. Obama, however, might not elicit a significant difference in our experiment due to a possible lack of long-term familiarity. More research needs to be done – where long-term familiarity is controlled – for the ability to measure whether real-life familiarity and knowledge of a face can break through an RSVP stream into consciousness. As mentioned before, using individually familiar, well-known faces could be a possibility. By increasing the familiarity, in turn, the salience of the probe could be increased.

The previous suggestion, where the absence of significant salience and long-term familiarity of Obama is linked to the mediocre rate of probe recognition (i.e., 45%), can be argued. Since identifying someone is an open question, stating the exact name correctly is not at a guessing rate similar to closed-ended questions (i.e., "*Did you see this face, Yes or No?*" with a guess rate of 50%). Therefore, it could be possible to take this recognition percentage and interpret it as a good measure. This would indicate that non-target, familiar faces can be salient enough to break through into awareness in an RSVP stream. An explanation then for the non-significant pupil difference could be that this recognition is not able to be detected by pupillometry. To rule this out, our experiment could be repeated but with a different tactic to measure physiological response (e.g., a less-available option such as fMRI).

Another reason for the non-significant difference in pupil size could be that the participants are not actively seeking and/or anticipating this face. One might wonder if, when the participants are made aware of concealed information, the difference in pupil size would increase more and become detectable. This could be interesting for future research, where the expectancy of concealed information could be investigated. Furthermore, this design would provide a realistic setting for potential crime-related investigation since guilty individuals would expect to be questioned about concealed crime knowledge. Extending this research by adding a group that is actively trying to hide certain face knowledge might help improve this research field even more.

In conclusion, we have replicated findings from previous studies (Alsufyani et al., 2018) where salient faces can reach consciousness during RSVP. In our study, the participant's physiological response to identifying the target and probe was measured by pupil size. Therefore, we can state that RSVP in combination with pupillometry is an accurate measure for the recognition of face stimuli. We have not, however, been able to show a significant pupil effect for the detection of a subliminally salient face. Several explanations were given. It may be due to the subliminal probe not being salient enough, the subjectiveness of familiarity for Obama, or the fact that the participants are simply not expecting the probe, whereas they are focusing, and thus expecting, the target face. Additionally, some of these explanations may overlap or interact and influence the results. Possible follow-up studies have been suggested that might increase our knowledge on the combination of RSVP, pupillometry and concealed face information. In summary, besides previous EEG studies (e.g., Alsufyani et al., 2018), pupillometry is also effective at an RSVP level in combination with face stimuli, but needs more research regarding concealed information testing.

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