Measuring Pupil Dilation in a Concealed Information Test Using Rapid Serial Visual Presentation

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Abstract

In combination with rapid serial visual presentation (RSVP), pupillometry has been proposed as a useful measure during concealed information testing. Indeed, past research proved that RSVP streams counter the deception methods applied by deceivers. Previous studies successfully used electroencephalography (EEG) to detect concealed identity information in RSVP streams. Yet pupillometry offers a more affordable and practical solution since a dilated pupil indicates recognition and salience. In the current study, we investigated whether concealed identity information can be detected with pupillometry during RSVP. More specifically, we asked 36 participants to look for a fake name and ignore their real name or to look for their real name in an RSVP task while their pupil sizes were tracked. We predicted that participants will not be able to prevent their pupils from dilating upon seeing a familiar stimulus, even when asked to do so. The results showed that the pupil response was larger for the fake name and real name when compared to the control names, yet not significant for the time window we chose upon a previous study's recommendation (320ms – 1,120ms). The exploratory analysis yielded significant results for a smaller time frame (640ms – 920ms) when comparing the real and control name conditions. We conclude that there is no significant positive relationship between concealed identity information and pupil dilation from 320ms to 1,120ms. This study opens avenues for further research into predicting the right time frame for the effect to occur.

Keywords: criminal investigations, concealed information testing, rapid serial visual presentation, pupillometry

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Concealed information testing plays a significant role in criminal investigations. Generally, concealed information can be any piece of knowledge someone intends to keep hidden from the outside world. While in some instances the content can be innocent, in others it can be incriminating evidence like the type of murder weapon, a crime location or the victim's name. In case of guilty knowledge, the investigators need to focus on covert behaviours to measure criminal culpability, like autonomic bodily responses, instead of relying on investigative techniques based on the cooperation of the suspect. The concealed information test (CIT) has been developed by forensic scientists for this purpose (Dodia et al., 2020; Elaad, 2010; Gamer et al., 2008; Lancry-Dayan et al., 2018). During a CIT run, crime-relevant information is shown to the individual while also presenting neutral stimuli (Meijer et al., 2014; Otsuka et al., 2019; Rosenzweig & Bonneh, 2020). The underlying assumption is that if someone taking the test committed or abetted the crime, they will exhibit autonomic bodily responses to the crime-relevant stimuli whereas innocent participants will not show any reaction (Elaad, 2010; Gamer et al., 2008). CITs must be resistant to countermeasures like voluntary suppression or distortion since some of the people that undergo these tests will want to deceive to evade culpability (Bowman et al., 2014; Gronau et al., 2015; Millen & Hancock, 2019). The threshold for a CIT to be admitted in practice is high since the immoral adverse effect of someone innocent being found guilty must be avoided at all costs.

Understanding how priming works is important for understanding the mechanisms of CIT. Individuals can be primed by stimuli they have recently encountered (repetition priming) or by stimuli, one expects to be exposed to (Reisberg, 1997). Posner and Snyder (1975) conducted an experiment measuring how fast participants could indicate whether the two letters in a pair of letters (array) are the same or not after having seen one letter (prime) on the screen shortly before. In some trials, the prime consisted of the same letter as the array or not. Their data confirmed their prior hypothesis that participants who are in the congruent priming condition would respond correctly faster, indicating that the theory of expectation driven priming holds true (Posner & Snyder, 1975). Hence, a guilty suspect will already be primed based on expectation driven priming when being interrogated for a crime they committed, while someone innocent would not be.

One of the currently most promising CIT techniques is measuring event-related brain potentials (ERP) in electroencephalograms (EEG), more specifically, the P300 signal that is connected to the memory consolidation (Bergström et al., 2013; Hu et al., 2015). To prevent participants from suppressing their bodily reactions to the stimuli this method is combined with rapid serial visual presentation (RSVP). During RSVP the stimuli are presented briefly so that they are perceived at the fringe of awareness (Zimmermann et al., 2019). Zimmermann et al. (2019) conducted an experiment where the participants were presented with images of a familiar celebrity at 6 Hz, allowing only one fixation per face. Here, EEG proved to be a suitable biological marker for fast and automatic recognition of familiar faces as the measurements showed a significant difference between recognising famous vs. unfamiliar faces. Yet, this difference was only found on a group level, not an individual level, indicating that the P300 wave detects familiar face identity for one specific individual above chance but not 100%. The results of Bergström et al.'s (2013) mock crime experiment, however, raise the question of whether EEG can also detect automatic recognition when there is an intent to deceive. Participants succeeded in intentionally suppressing the ERPs when they were instructed to completely stop any memories of the crime from coming to mind after seeing crime-relevant information. Hence, getting no elevated ERP signal can be explained in four ways. First, the signal used to determine concealed information is too noisy. Second, the person being questioned has no recollection of a certain event because they were not present.

Third, they have forgotten about the event. Fourth, they successfully make an effort to disguise information regarding the event in question (Bergström et al., 2013). Hu et al. (2015) corroborated these results as they found that top-down suppression of autobiographical memory in a mock crime scenario can attenuate the automated cognitive response as measured by the P300 signal of the EEG. The participants were instructed to directly disrupt and suppress the retrieval process by focussing on the crime relevant cue as it appeared on-screen rather than its meaning (Benoit & Anderson, 2012). On top of the P300, the researchers also measured the late posterior negativity (LPN), another ERP that is known to reveal response-monitoring processes (Johansson & Mecklinger, 2003). The results showed that the LPN successfully detected guilty respondents that were top-down suppressing their automated autobiographical recollection process (Hu et al., 2015). In summary, the EEG method is not immune to countermeasures, such as direct suppression or induced forgetting and the P300 potential cannot be used as clear evidence for certain knowledge to never have been in someone's brain. Yet, an increased LPN signal gives reason to believe the individual being questioned finds themselves in a response conflict and is not telling the whole truth.

Bowman et al. (2013) first introduced RSVP to CITs using EEG to counter the top-down cognitive interference of the participant. Their study tested for concealed identity information using faces as the stimuli. In one of the three countermeasure conditions, participants were told to concentrate on not seeing their real names in the stream. In another condition, the participants had to count the number of times two recurring irrelevant names were shown and in the last condition, they had to identify at least one of the recurring irrelevant names and then pretend it was their real name (Bowman et al., 2013). The data proved that participants were not able to voluntarily withdraw salience from their own name or impose it on unknown names. Using the same paradigm, Chen et al. conducted a study on countermeasure resistant identity detection but used names instead of faces as stimuli and pupillometry instead of EEG as the measurement. During the experiment, RSVP streams were presented that contained several unknown names and one critical name. Per trial, one critical name was shown which was either an unknown control name, their name or a chosen fake name. The participants were only instructed to indicate whether they had seen the fake name they picked, while their pupil dilation to their periodically shown real name was measured. They found that responses to the participants' own as well as chosen and thus salient fake names both significantly differed from the responses to the control names qualitatively but not on an individual level. Past research on the implications of pupil dilation has found a positive relationship between pupil size and the episodic recognition (Dobbins, 2021) as well as pupil size and the salience of the presented stimuli (Fietz et al., 2022). Hence, dilated pupils during a CIT reliably indicate hidden knowledge. Our study will integrate concepts of Bowman et al. (2013) and Chen et al. (2021), such as using the RSVP method to counter deception attempts during a CIT. Moreover, we will measure responses to the real, fake and control name stimuli using pupillometry, as seen in the research by Chen et al. (2021).

As mentioned at the outset of the thesis, RSVP streams reliably counter deception tactics during CITs. Yet, when choosing the measurement technique, pupillometry is as reliable as EEG but less invasive, technically challenging and costly (Chen et al., 2021; Fietz et al., 2022). An early experiment on pupillary response to task difficulty by Hess and Polt (1964) revealed that the more difficult the task, the higher the information processing load and thus the larger the pupil size. More recent studies have focussed on eye responses during RSVP-based concealed information testing. The key concept of RSVP is to show a series of stimuli, where each stimulus is shown for only about 100ms. As a result, only the salient and known stimuli (e.g. a participant's first name) will elicit a measurable autonomic response that can be used to differentiate between deceivers and non-deceivers (Alsufyani et al., 2019; Bowman et al., 2013; Harris et al., 2021; Rosenzweig & Bonneh, 2020). The non-salient stimuli, however, will not produce a bodily reaction that stands out from the baseline value. Similar to Bowman et al. (2013), Alsufyani et al. (2019) studied whether face familiarity can be detected using an ERP-based RSVP paradigm. One trial consisted of one familiar and 17 unfamiliar face stimuli, presented 133ms after another. Their data revealed that salient stimuli create a significantly higher electrical response than unfamiliar faces. Millen and Hancock (2019) looked at familiar face recognition by examining eye fixation duration and patterns in a mock crime setting. Their results yielded that fixation patterns can barely be influenced by the participants and attempts to hide recognition were unsuccessful as the eyes of familiar faces naturally grab one's attention. In a mock terror experiment by Rosenzweig and Bonneh (2020) involuntary eye movement and face familiarity were investigated. The crime targets were given information on the perpetrator and were then instructed to watch a video showing barely visible and brief presentations of said information. The researchers were able to identify 100% of the terror targets and 95% of the innocents. Overall, research on RSVP-based CITs examining eye responses has shown promising results. They are particularly suitable for widespread application, as they are relatively non-invasive and have low task difficulty. The latter is important because high task difficulty can lead to dilated pupils and thus to someone being flagged as suspicious (Hess & Polt, 1964).

In summary, pupillometry is a more practical and affordable measurement technique when compared to EEG during a CIT. Based on the reviewed literature, our study addresses the following research question: Is concealed information detectable using pupillometry in an RSVP task? In doing so we follow the same paradigm as Chen et al. (2021). More specifically, we also use names as the stimuli in an RSVP CIT. Moreover, a fake name has to be chosen by the participant at the beginning of the experiment and looked out for throughout. The real name is shown in the streams as well and constitutes the concealed information. Furthermore, we added two manipulations in line with suggestions by Chen et al. (2021). The second half of their trials showed a decreasing significant difference between the real name condition and control condition. Chen et al. (2021) hypothesized, that this is due to habituation and increasing fatigue, hence long testing sessions are redundant. Since we are only interested in the interaction effect, our first manipulation will be reducing the number of trials from 180 to 96. For our second manipulation, we will introduce another condition in which the neutral control name changes with every trial to prevent the participants from picking up on it. We expect both, the real and fake name conditions, to elicit a significantly larger pupil response than the control condition.

Firstly, we hypothesise that participants who are instructed to look for their chosen fake name will have a significantly larger pupil size whenever the fake name appears compared to the changing control names. Secondly, we hypothesise that the participants who are instructed to look for the fake name will have a significantly larger pupil size whenever their real name is shown compared to the changing control names. A significant result would suggest that using pupillometry in an RSVP-based CIT serves as a reliable physiological detection mechanism in criminal investigations.

Methods

Participants

The study consisted of a sample of 36 participants, which were all first-year Psychology students at the University of Groningen. Before the experiment, every participant gave informed consent. All participants had normal or corrected to normal vision. The average age of all 36 participants (9 male, 27 female) was 20.2 (*SD* = 1.4). Participants received study points for participation, which is part of the requirements to pass a course. One participant was excluded due to their glasses hindering calibration and one was excluded due to the experiment software malfunctioning. Four participants were not present.

Apparatus and stimuli

The experiment took place in a lab located in the Social and Behavioural Sciences faculty building of the University of Groningen. The lab consisted of a desk with a 27" LCD Iiyama PL2773H monitor where an EyeLink 1000 eye-tracker using Pygaze was placed in front (Dalmaijer et al., 2014). Pupil size was recorded at 1,000 Hz and downsampled to 50 Hz offline. The eye-tracker was set at a distance of approximately 60 cm to the participant, measuring the pupil size throughout the whole procedure. Participants sat behind the monitor with their heads placed comfortably on a chin rest pointed towards the middle of the screen. On the monitor, each participant was presented with 96 trials of a randomly selected series of names through RSVP. All names started with a capital letter and had the same monospaced font (Courrier), size (21 pixels) and luminance. The names on the screen were shown sequentially in the centre of the screen with the same length. The difference in name lengths was evened out using hashtags and plus signs randomly before and after the names to ensure that every string consisted of eleven characters. As a result, the visual angle for each stimulus was 0.61°, whereas the whole screen consisted of a rectangle of 52.97° by 31.31°. The experiment was designed and carried out using Open Sesame 3.2.8 running on Windows 10 Enterprise.

We used the same set of names as Chen et al. (2021), consisting of 533 names, 281 of which are female and 252 of which are male. Those names were taken from the database by the Meertens Institute for Dutch language and culture research. Chen et al. (2021) first selected the first 100 top Dutch names of each year between 1975 and 2014 and then selected all names that are 10 characters or shorter. From that set of names, several subsets of 15 names were randomly selected to be presented to the participant in each trial. The fake name was picked by the participant from one of these subsets of unfamiliar names. The remaining distractor names to put before and after the fake, real and control names were selected randomly from the set of 533 names. Control names are randomly picked names from the name pool of Chen et al. (2021). Names with more than two identical consecutive letters were not allowed to be next to each other in one trial.

Procedure

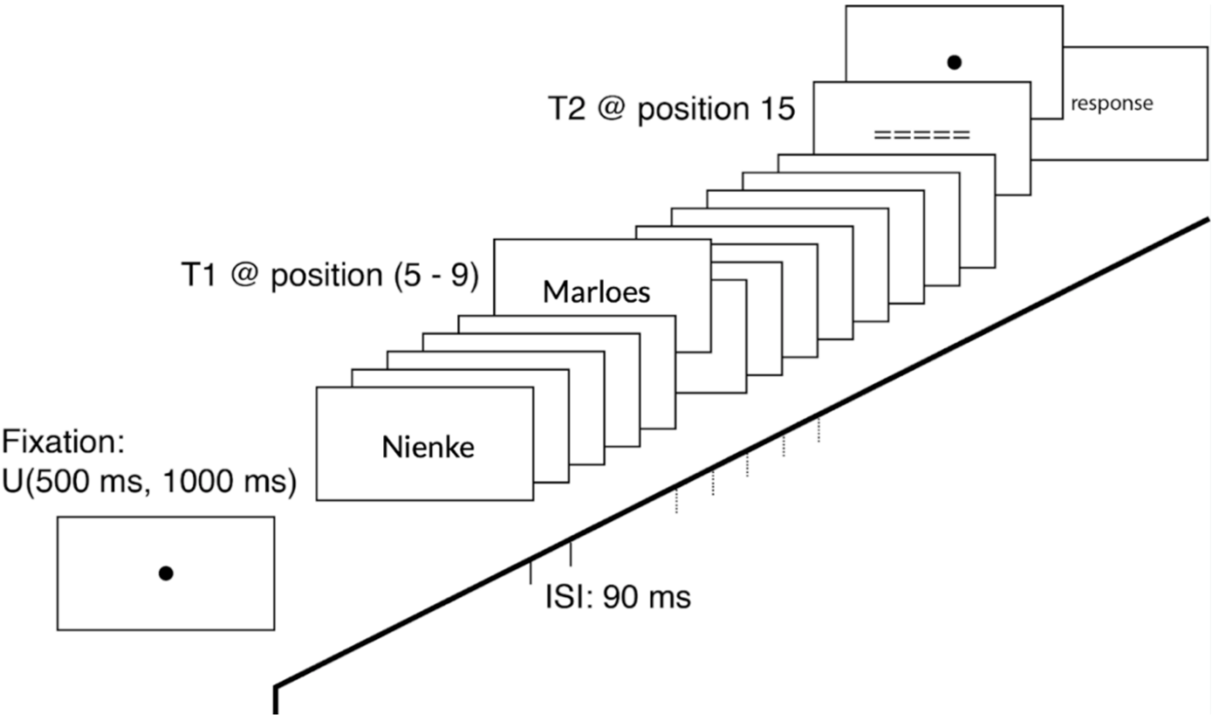
First, the eye-tracking camera was calibrated and the chin rest was adjusted. Then, the program asked for demographic details such as age, dominant hand, and real name. Before the first trial, half of the participants were asked to select an unknown fake name out of a randomly selected subset with 15 names of their indicated sex. In each trial sequence, the participants were presented with 15 randomly selected names that appeared for 100 milliseconds each in the middle of the screen. Depending on the condition, in each stream, the participant is presented with either the real name, fake name or control name. Those three options of names are called *critical names*. In each trial, the critical name could be shown at one of the positions between positions 5 to 9 (see Figure 1). The names in positions prior and after functioned as distractors. After the names, dashes or equal signs were shown for 100ms and the participants had to indicate which one they saw to assure they paid attention until the end of the RSVP. Participants were asked to indicate whether they saw their target name by pressing “M” on a QWERTY keyboard when they did not see the target and “C” when they did see it. The order of the response keys was counterbalanced between participants. When responses to the first question were correct participants would earn 5 points or lose 5 points when the answer was wrong. For the response whether the participants saw the critical name 10 points were added when correct or subtracted when incorrect, meaning responses to the critical name were emphasised. The eye-tracker measured and recorded the participants’ pupil sizes throughout every trial. Every trial started with a one-point drift-correction procedure.

Design

The participants started with 10 practice trials to get familiar with the procedure. In total, the experiment consisted of 96 trials. Even participants were told to look for their real name (Truth condition). Uneven participants were instructed to search for the fake name they had to choose prior to the trials (Lie condition). For this study, an experiment with a 4 x 2 design was used. There were four conditions (T1) for the Lie and Truth conditions respectively: Target, Secret Target, Control and No Target. Participants had to indicate whether they saw the target, the chosen fake name, in the Lie condition while in the Truth condition they searched for their real name. In the Lie-Secret Target condition, the real name was shown and in the Lie-Control condition, the reaction to a randomly chosen distractor name that was the same for every control trial was recorded. Finally, in the Lie-No Target condition, a different randomly chosen distractor was shown. For the Truth-Target condition, the real name was shown, while in the Truth-Secret Target and Truth-Control condition the same randomly chosen distractor was presented. For both Truth and Lie conditions, in each trial, a different name was chosen for the No Target condition. An example of one trial in the Lie-Secret Target condition is shown in Figure 1.

Figure 1

Example of one trial in the Lie-Secret Target Condition



Note. In this trial, random names are shown before and after position 6. T1 is presented at position 6 and it is the participant's real name Marloes. T2 consists of equal signs and is presented at position 15. After another fixation point, participants responded to the questions regarding T1 and T2.

Data Processing and Analysis

All data and analysis scripts are publicly accessible in the Open Science Framework (https://osf.io/aq8pm/). Raw data is accessible on reasonable request.

For data analysis R was used with lme4 (v1.1-26; Bates et al., 2015). First, we analysed how accurate participants responded to questions one and two. Question one *(Did you see ------ or ====?)* indicates how well participants maintained their attention on the screen during the RSVP trials. Question two *(Did you see your (fake) name?)* was used to assess how well participants were able to detect their (fake) name and to get an indication of task difficulty.

Regarding our hypotheses, we did the analysis solely on the data of participants that were in the Lie condition. The first hypothesis of our experiment is that participants in the Lie condition had a significantly larger pupil size whenever their fake name (Target) appeared on screen compared to control names that changed with every trial (No Target). Our second hypothesis is that participants who were in the Lie condition would have a significantly larger pupil whenever their real name (Secret Target) came up compared to only control names that changed with every trial (No Target). Mean pupil sizes within the window of 320-1,120ms were calculated for each trial. Pupil size was then time-locked and baselined by subtracting mean pupil size during a period of 300ms leading up to the presentation of T1 from the rest of the pupil trace.

To test these hypotheses, we estimated linear mixed-effects regression (LMER) models on a group level to investigate the difference in pupil size between the No Target reference conditions and the Secret Target, Target and Control conditions respectively. With the LMER we test if the variance between mean pupil sizes can be explained by the T1 conditions. Next, we used Bayes Factors to find evidence for or against the absence of the effect the T1 condition has on pupil size. Pupil size was used as a dependent continuous variable, and T1 was considered a categorical independent variable. Participant was used as a random factor. After that, we did a post-hoc contrasts analysis. This included a Tukey correction for multiple comparisons. Only No Target and Target were compared, as well as No Target and Secret Target. Lastly, we did an exploratory analysis where we visualised a linear mixed-effects regression on each time point to find out the critical time points at which Target Secret was significantly larger than No Target. In other words, we are looking for a time window when the p-value for pairwise comparison of Secret Target vs No Target is smaller than .05 and thus significant.

Results

Task Performance

Participants responded to the attention question, whether they saw -------- or ======, with an accuracy of 97.34% and to the T1 response question with 94.56% (see Table 1). This implies that the participants were able to detect their fake names during the RSVP trials and maintained attention up to the end of the trials.

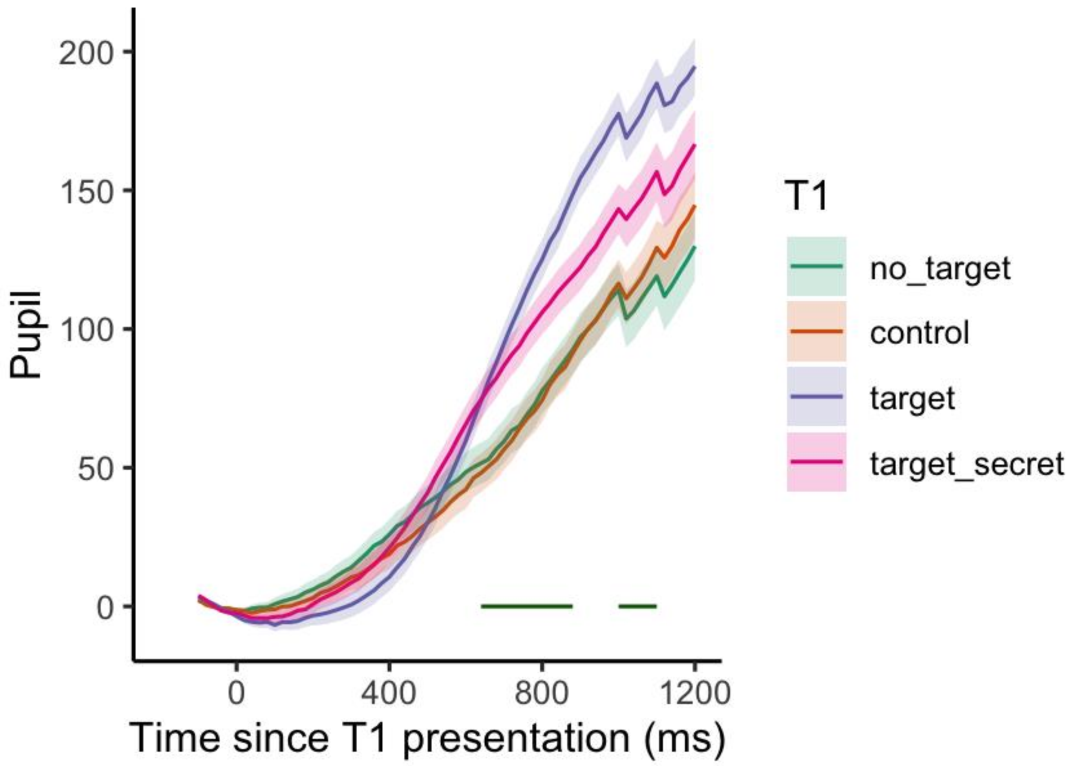
Pupil Data

Chen et al. (2021) mentioned in the discussion that setting a fixed time window for pupil variation observation would be advisable. Their results showed a range (from 320ms to 1,120ms) in which the pupil size was significantly larger when presented with their real name than with a random control name. Our hypotheses, that in the Lie condition pupil size would be significantly larger in the Target and Secret Target condition than in the No Target condition in the range of 320ms to 1,120ms, was not confirmed by our data. For that, we plotted the mean pupil size traces (see Figure 2a).

Figures 2a and 2b

2a) *Mean Pupil Size Traces for all T1-Lie Conditions*

2b) *Green Line that indicates the time point in which the pairwise comparison of Secret Target and No Target is significant*

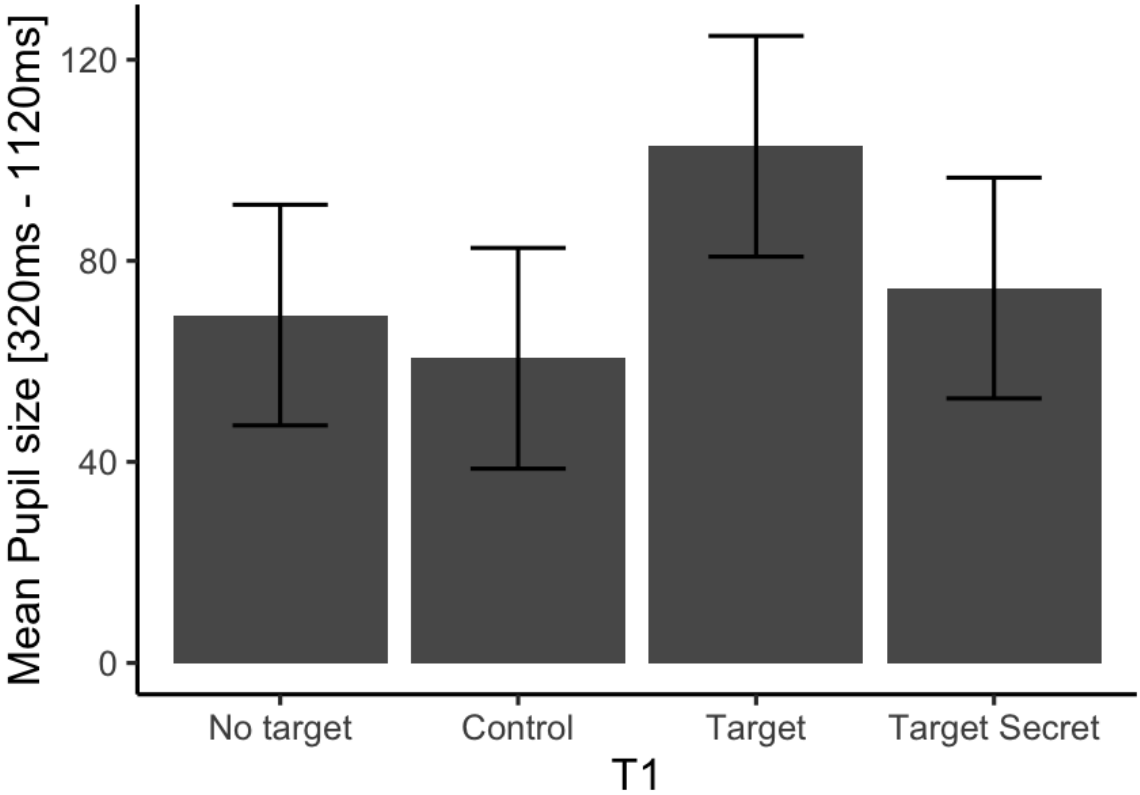


Note. This plot shows the pupil size for each condition in the time window -100 – 1,200ms as well as the corresponding standard errors. The green line indicates the time frames for which the p-value for pairwise comparison of Secret Target vs No Target is smaller than .05, thus indicating a significant difference between Secret Target and No Target.

The average pupil size in the Lie condition is between 320ms and 1,120ms since T1 presentation was calculated (see Figure 3 and Table 2a). The average pupil size in the Target condition is 91.4 (*SE* = 15.8), Secret Target condition: 82.4 (*SE* =15.8), Control is 63.3 (*SE* =15.8), and for the No Target condition 65.8 (*SE* =15.8).

Figure 3

Bar Graph of the Mean Pupil Sizes of all T1-Lie Conditions Including Their Standard Error for Time Points Between 320ms and 1,120ms



We used a linear mixed-effects regression analysis to test whether the variance between mean pupil sizes between 320ms and 1,120ms since T1 presentation can be explained by the T1 condition. Mean pupil sizes within that window were calculated for each trial and were used as dependent variables. Bayes Factor (*BF*) was estimated by comparing a model with the T1 condition as a dependent categorical variable with a model without that variable using Bayes Information Criterion (*BF* > 1,000) (BIC, Wagenmakers, 2007). Next, we did a post-hoc comparison. Post-hoc comparisons revealed that both the differences between No Target - Target (p = .088, z = -2.83) and No Target - Secret Target (p = .594, z = -1.84) were not significant at a 5% significance level (see Table 3). From that information, we can conclude there is no significant evidence for or against either of the two hypotheses in the time window of 320 – 1,120ms.

Finally, we did an exploratory analysis and plotted a linear effects regression on each time point to find the time points at which the differences between the T1 conditions are not equal to 0 (see Figure 2a (or 2b) & Table 4). In our data, we observe *p*-values lower than .05 in the time frame between 640ms to 920ms and 1,000ms to 1,100ms since the T1 presentation. This means that we found a time window that shows a significant difference between the Secret Target and No Target conditions. When comparing *p*-values of the No Target and Target condition we observe values lower than the 5% significance level for the whole time frame -200 – 1,200.

Discussion

The purpose of this study was to gain a better understanding of pupillometry in RSVP-based CITs as well as the relationship between pupil dilation and name saliency. In line with research by Chen et al. (2021), we hypothesized that a chosen fake name and a real name will both elicit a larger pupil response than a control name, while the real name constituted hidden information. Our first hypothesis compared the target to the no target condition, while our second hypothesis compared the secret target with the no target condition. Based on the data, neither of our hypotheses could be rejected, which leads to two key implications. First, as opposed to the findings by Bowman et al. (2013) and Chen et al. (2021) we could not find sufficient evidence in favour of RSVP streams effectively countering deception methods. Second, we could not support the suggestion of Chen et al. (2021) that the pupil size in the Secret Target condition would be significantly larger than in the No Target condition between 320ms and 1,120ms. Yet the exploratory analysis showed that effect for a smaller time window (640ms – 920ms). This implies that for some time the pupil dilated significantly enough to indicate when participants saw their real names even though participants were instructed to hide their identity and only look for their fake names. However, we only observed the real-name effect for that time window on a group level, as we did not conduct an individual analysis of the effect.

Limitations and Future Directions

There are at least four potential limitations concerning these results. A first limitation concerns the low task difficulty and thus low engagement as seen in the high correct answer rates for questions one and two. Future research should increase task difficulty by adding more trials while controlling for habituation and fatigue.

A second limitation is that participants might have seen familiar names during the trials, confounding the results. While this happens infrequently, future researchers may consider two approaches. One option is to instruct participants to manually exclude all familiar names from the name pool. Here, the risk that the participants might recognise names during the experiment solely because they have seen them in the name pool needs to be addressed. Another option is to require the participants to write a list of all salient names (e.g., names of parents) that will be excluded from the experiment. Both approaches are more time- and labour-intensive.

Third, the Dutch name pool used was not familiar to our international participants. The pupil dilation to the real and fake names' salience might only be attributable to the participant recognizing the only names they have heard before rather than their meaning (Dobbins, 2021). In future research, the name pool should be matched with the participant pool, for example by adding several name pools that are then matched with the participants' nationalities.

The fourth challenge in our research was to find a balance between having more trials for less noise and fewer trials to counter the habituation effect and increasing fatigue as hypothesized by Chen et al. (2021). Since we did not find a significant difference between the

Secret Target and No Target conditions in 96 trials, future research should add more trials while controlling for habituation and fatigue, for example with questionnaires.

In addition to the above-mentioned suggestions, future research could use the time frame as determined by our exploratory analysis as the a-priori time window for the data analysis. By using the window from 640ms to 920ms, researchers could get an insight into whether there is a reliable real-name effect and when it occurs. Moreover, future researchers should develop CITs using stimuli other than words. In some cases, a picture of the murder weapon as it has been retrieved from the crime scene will have more salience than just showing the word describing it on a screen. The challenge is to keep the presented stimuli as similar to each other as possible, hence contrast and brightness needs to be adjusted individually. The study by Alsufyani et al. (2019) exemplifies this. To study familiar face identity, they retrieved images from various databases and manually adjusted the eye-line, background, blurriness, contrast, brightness and tint. This approach is very time consuming but relevant in criminal investigations where the only hint cannot be summarized in one word.

Conclusion

In conclusion, we could not reject either of our hypotheses and the exploratory analysis showed that pupil size is sensitive to concealed identity information during an RSVP paradigm. Further approaches for research that increase the task's sensitivity have been offered. Moreover, our study did not contain a sufficient number of trials to eliminate noise hence the measurements from 1,000ms to 1,120ms should have been excluded from the analysis. For a few participants, the critical stimulus has already been shown after 1,000ms since T1 is presented equally between positions 5 to 9 (see Figure 1). In those instances, the pupil size decreases earlier and jagged lines as seen in Figure 2 emerge. Excluding measurements, at time point 1,000 and higher could have rendered the overall Secret Target –

No Target difference significant. Hence, the time frame and trial number need to be adjusted in future research.

Despite the above-mentioned limitations, the present study has contributed to the general understanding of the relationship between pupil dilation after seeing a familiar and unfamiliar stimulus during RSVP CITs. In a theoretical context, our exploratory results are a promising insight into the concept of pupillometry during RSVP streams in concealed identity detection. Moreover, we can confirm that this approach is affordable, technically straightforward and does not rely on the cooperation of the participant (Chen et al. 2021). In the context of a criminal investigation, this paradigm is a suitable way of handling suspects who intend to deceive to evade criminal culpability.

Conflict of Interest

The Authors declare that they have no conflict of interest.

Compliance with Ethical Standards:

This research involves human participants. All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Tables

Table 1

Mean Traces of all T1 Conditions for Questions One and Two

T1	T1 correct	T2 correct
Target	0.8900463	0.9537037
Target secret	0.9664352	0.9756944
Control	0.9606481	0.9849537
No target	0.9652778	0.9791667

Table 2

Estimate, Standard Error, Degree of Freedom and Upper and Lower Confidence Interval Bounds for Each T1 Condition

T1	Estimate	*SE*	df	95% CI	
				LL	UL
No Target - Lie	65.77509	15.81492	Inf	34.77842	96.77177
Control - Lie	63.29287	15.82414	Inf	32.27813	94.30762
Target - Lie	91.40178	15.81802	Inf	60.39903	122.40454
Secret Target - Lie	82.42912	15.82102	Inf	51.42050	113.43774
No Target - Truth	72.65481	15.85974	Inf	41.57029	103.73934
Control - Truth	57.93543	15.85585	Inf	26.85854	89.01233
Target - Truth	114.18350	15.86591	Inf	83.08689	145.28012
Secret Target - Truth	66.74712	15.86279	Inf	35.65662	97.83762

Note. CI = confidence interval; LL = lower limit; UL = upper limit

Table 3

Contrast Table

Contrast	Estimate	*SE*	df	*z*-ratio	*p*
No target lie – control lie	2.482	9.07	Inf	0.274	1.0000
No target lie – target lie	-25.627	9.06	Inf	-2.829	0.0879
No target lie – target secret lie	16.654	9.06	Inf	-1.837	0.5943
No target lie – no target truth	-6.880	22.40	Inf	-0.307	1.0000
No target lie – control truth	7.840	22.39	Inf	0.350	1.0000
No target lie – target truth	-48.408	22.40	Inf	2.161	0.3757
No target lie – target secret truth	0.972	22.40	Inf	-0.043	1.0000
Control lie – target lie	-28.109	9.07	Inf	-3.097	0.0410
Control lie - target secret lie	19.136	9.08	Inf	-2.108	0.4098
Control lie – no target truth	-9.362	22.40	Inf	-0.418	0.9999

Contrast	Estimate	*SE*	df	*z*-ratio	*p*
Control lie – control truth	5.357	22.40	Inf	0.239	1.0000
Control lie – target truth	-50.891	22.41	Inf	2.271	0.3097
Control lie – target secret truth	3.454	22.41	Inf	-0.154	1.0000
Target lie – target secret lie	8.973	9.07	Inf	0.989	0.9761
Target lie – no target truth	18.747	22.40	Inf	0.837	0.9910
Target lie – control truth	33.466	22.40	Inf	1.494	0.8109
Target lie – target truth	-22.782	22.40	Inf	1.017	0.9721
Target lie – target secret truth	24.655	22.40	Inf	1.101	0.9569
Target secret lie – no target truth	9.774	22.40	Inf	0.436	0.9999
Target secret lie – control truth	24.494	22.40	Inf	1.094	0.9584
Target secret lie – target truth	31.754	22.41	Inf	-1.417	0.8496
Target secret lie – target secret truth	15.682	22.40	Inf	0.700	0.9970

Contrast	Estimate	*SE*	df	*z*-ratio	*p*
No target truth – control truth	14.719	9.20	Inf	1.600	0.7506
No target truth – target truth	41.529	9.22	Inf	-4.506	0.0002
No target truth – target secret truth	5.908	9.21	Inf	0.641	0.9983
Control truth – target truth	-56.248	9.21	Inf	-6.106	<.0001
Control truth – target secret truth	8.812	9.20	Inf	-0.957	0.9802
Targe truth – target secret truth	47.436	9.22	Inf	5.144	<.0001

Note. Degrees-of-freedom method = asymptotic; number of contrasts = 28; 4 x 2 Design; *p*-value adjustment: Tukey method for comparing a family of 8 estimates

Table 4

P-Values for 71 Observations for Every 20ms comparing Target vs No Target and Secret Target vs No Target

Time in ms	*p* Target vs No Target	*p* Secret Target vs No Target
-200	3.838940e-01*	0.27352378
-180	4.368272e-01*	0.36356238
-160	3.249122e-01*	0.12886363
-140	5.016298e-01*	0.27772775
-120	3.973150e-01*	0.31737751

Time in ms	*p* Target vs No Target	*p* Secret Target vs No Target
-100	4.319924e-01*	0.24659622
-80	4.698054e-01*	0.27729985
-60	1.147252e-01*	0.93621303
-40	9.817355e-01*	0.20933405
-20	2.906907e-01*	0.14699469
0	1.614969e-01*	0.68620829
20	8.370765e-02*	0.52409019
40	4.193294e-02*	0.17391582
60	5.584579e-02*	0.22061577
80	1.235786e-01*	0.29385822
100	3.463594e-02*	0.24452132
120	6.522067e-02*	0.20847705
140	5.687859e-02*	0.26423483
160	6.665998e-02*	0.37210655
180	7.441697e-02*	0.27971378
200	8.866641e-02*	0.41828556
220	7.156204e-02*	0.49275426
240	7.164052e-02*	0.53393724
260	5.212664e-02*	0.46786465
280	4.710359e-02*	0.48850944
300	4.744431e-02*	0.55262912

Time in ms	*p* Target vs No Target	*p* Secret Target vs No Target
320	3.783173e-02*	0.46107308
340	3.494375e-02*	0.50331084
360	2.864253e-02*	0.46341853
380	5.414441e-02*	0.63238500
400	5.530946e-02*	0.70428743
420	7.282703e-02*	0.75500556
440	1.496689e-01*	0.93217098
460	2.559438e-01*	0.99292074
480	3.507858e-01*	0.99290545
500	5.964229e-01*	0.91514767
520	8.585372e-01*	0.67756676
540	9.999829e-01*	0.49819413
560	9.089053e-01*	0.36823574
580	6.198141e-01*	0.19335405
600	3.800130e-01*	0.12648286
620	1.330275e-01*	0.06447917
640	3.207157e-02*	0.03351090*
660	6.228228e-03*	0.01900985*
680	2.975364e-03*	0.02205828*
700	7.749382e-04*	0.01439293*
720	3.167835e-04*	0.01530493*

Time in ms	*p* Target vs No Target	*p* Secret Target vs No Target
740	7.208315e-05*	0.01144135*
760	3.114908e-05*	0.01127933*
780	1.466264e-05*	0.01190484*
800	2.255088e-05*	0.01862819*
820	6.863212e-06*	0.02110851*
840	5.646435e-06*	0.02310384*
860	2.385124e-06*	0.02849537*
880	1.195626e-06*	0.03818725*
900	8.944168e-07*	0.05757398
920	6.826870e-07*	0.04767915*
940	5.233383e-07*	0.05598409
960	5.737148e-07*	0.05353320
980	4.368729e-07*	0.05094060
1,000	3.326033e-07*	0.03967117*
1,020	3.176216e-06*	0.01855278*
1,040	2.654440e-06*	0.01654581*
1,060	4.017606e-06*	0.02091431*
1,080	2.117450e-06*	0.01902652*
1,100	1.515462e-06*	0.01612155*
1,120	6.242735e-05*	0.05905138
1,140	1.363861e-04*	0.07153397

Time in ms	*p* Target vs No Target	*p* Secret Target vs No Target
1,160	1.237123e-04*	0.06144384
1,180	1.706553e-04*	0.06149453
1,200	2.247243e-04*	0.06107930

*p < .05.