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Pupillometry and Lie detection: a mock-crime experiment

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ABSTRACT

The detection of deception remains a significant challenge in psychological and forensic research. This study examines the effectiveness of pupillometry (pupil dilation) as a physiological indicator of deception within a mock-crime experiment, aiming to detect pupillary changes associated with lying before an explicit response is given ("the liar's mind-set").

The research aims to determine whether variations in pupil diameter can serve as a reliable indicator to distinguish between guilty and innocent individuals.

To address limitations related to the use of written stimuli, an auditory version of the Ocular-Motor Deception Test was employed in order to minimize interference from language comprehension and visual processing.

Additionally, the analysis focuses on pupillary responses occurring prior to the verbal response, with the goal of identifying physiological markers of deception in its earliest stages.

CHAPTER I

DECEPTION AND LIE DETECTION TECHNIQUES

1.1 Deception

1.1.1 Introduction to Deception

The human brain is naturally inclined towards deception, which explains why societies have shown a consistent interest in the act of lying, and the early appearance of lying in human development.

According to DePaulo and Vrij, people lie for at least two different reasons. First, lying may benefits the liar (self-oriented) or another person (other-person oriented). Second, lying may gain advantages or avoid negative consequences. Individuals are more likely to lie when a cost-benefits analysis suggest they could gain advantages.

From a cognitive point of view, deception is considered cognitively more demanding than honesty, given the several cognitive processes activated during the act of lying: deciding to lie, suppressing the lie, and, if needed, modifying the story while maintaining its consistency.

1.1.2 Cognitive Neuroscience contribute

Zuckerman, DePaulo, and Rosenthal (1981) were the first to highlight the cognitive demand component in deception, identifying four factors: emotion, arousal, Control, and cognitive processing.

Several theories attempt to explain the cognitive demands of deception:

- Gombo’s Theory identifies two key cognitive processes: Control mechanisms for thought and active management. The first contributes to suppressing the truth, the second to analyse and adapt to the listener’s reactions.
- The Activation Decision Construction Action Theory underlies the role of executive processes, theory of mind, motivation and emotions, and lies rehearsal.
- The Working Memory Theoretical Model of Deception suggest that deception involves multitasking in order to stay coherent, interpret listener’s behaviour, and adjust their own behaviour accordingly.
- The Sheffield Model and the Working Model of Deception empathise the need to inhibit the “prepotent truth response”.

Overall, deception requires a higher cognitive burden than honesty.

Neuroscientific evidence supports this affirmation. Brain imaging studies show an increased activation of prefrontal areas during deception, particularly the anterior cingulate cortex (ACC), the dorsolateral prefrontal cortex (DLPFC), the ventromedial prefrontal cortex (VMPFC) and the superior temporal sulcus.

Additional support comes from developmental and clinical studies. Young children, whose prefrontal cortex is not fully developed and individuals with neurological conditions (e.g., autism, Parkinson's disease, essential tremor) generally show a reduced ability to deceive.

1.1.3 Taxonomy of Lies

Different types of lies vary in their cognitive complexity. DePaulo (1996) developed a taxonomy of lies based on how they function in everyday life:

1. Outright lies, where the information provided is entirely false or contradicts the truth.
2. Exaggerations, where facts are overstated to create a misleading impression.
3. Subtle lies, which involves omitting key details or telling literal truths meant to mislead. This category also includes behavioural and nonverbal deception.

Each type of lie implies a different cognitive load. Outright lies generally require supressing the truth and constructing an alternative version, in contrast subtle lies demand significantly more mental resources.

Therefore, as the complexity of a lie increases, so does the cognitive demand, especially when the deception requires anticipating the other person's reactions.

1.1.4 Deception and executive Control processes

Neuroimaging studies implicating the prefrontal cortex and adjacent regions in deception support the idea that lying engages the brain's executive Control system. This system refers to higher-order cognitive processes that allow individuals to adapt their thoughts and behaviour in response to shifting cognitive demands and environmental contexts.

Miyake (2000) proposed that executive Control includes at least three core processes: working memory, task switching, and inhibitory Control. These components are thought to play key roles in deception. Specifically, lying involves: holding the truth in mind while generating a falsehood (working memory), and alternating between truthful and deceptive answers (task switching).

Christ et al. (2009) conducted a meta-analysis to examine how deception engages executive Control processes. By comparing brain activity associated with deception to brain activity associated with working memory, inhibitory Control, and task switching, they found overlapping activity in brain regions such as the bilateral ventrolateral prefrontal cortex (VLPFC), the left dorsolateral prefrontal cortex (DLPFC), the left anterior cingulate cortex (ACC), and the left posterior parietal cortex.

Furthermore, the overlap in activation between deception and executive Control tasks suggests that executive Control functions significantly contribute to the act of deception.

Despite the growing consensus from neuroimaging studies on the brain regions activated during lying, translating these findings to real-world applications remains challenging. Laboratory-based lies often differ significantly from those encountered in everyday situations. For example, participants in experiments are usually instructed to lie about emotionally neutral topics in artificial settings, with little personal relevance. Although some studies employ more valid designs, like mock-crime tasks, these scenarios still fail to capture the complexity of real-life deception.

In real-world situations, lies tend to be emotionally charged and personally significant. fMRI research has shown that emotion can modulate the brain circuits involved in memory, inhibition and cognitive Control, and working memory interference, all of which influence the neural basis of lying. Thus, current neuroimaging research represents only an initial step toward fully understanding the intricate cognitive and emotional dimensions of deception.

1.2 Lie Detection

Deception is a complex psychological process that involves several cognitive functions, translated in behavioural changes during tasks. These behavioural markers, particularly reaction time (RT), are commonly used to infer whether the subject is being deceptive.

Typically, lies are associated with longer RTs because fabricating information is mentally taxing. However, this is not universally true. As outlined earlier (cf. Section 1.1.3, *Taxonomy of Lies*), not all deceptive responses require substantial cognitive effort; for instance, denying a familiar fact or reiterating a rehearsed lie may not substantially affect response latency.

To better distinguish lies from truthful responses, researcher often increase cognitive load during tasks. This helps the amplification of the cognitive strain of lying, making it easier to detect. Methods for increasing cognitive load include: asking unexpected or compound questions, requesting event recall in reverse chronological order, having subjects perform dual tasks, time-stressing the response window (Walczyk et al., 2013).

A range of behaviour-based deception detection tools have been developed; these techniques fall into two main categories:

1. RT-Based Techniques That Require Knowledge of the True Memory: these approaches assume that true information is known and embedded among alternatives.
   Some techniques include: RT-Concealed Information Test (RT-CIT) (Kleinberg & Verschuere, 2015, Autobiographical Implicit Association Test (aIAT) (Sartori et al., 2008), Timed Antagonistic Response Alethiometer (TARA) (Gregg, 2007)
2. RT-Based Techniques That Don't Require Prior Knowledge: these methods allow the detection of lies even without knowing the truth in advance. These methods include: cognitive-load increasing tasks, choice reaction time tests, mouse and keyboard dynamics analysis (Sartori, Orrù, & Monaro, 2016)

1.2.1 The Autobiographical Implicit Association Test

The Autobiographical Implicit Association Test (aIAT) was developed by Sartori and colleagues in 2008, as an extension of the Implicit Association Test (IAT) introduced by Greenwald, McGhee, and Schwartz (1998), which is commonly used in social psychology to assess implicit attitudes.

The fundamental principle is that individuals respond more quickly when categories that are mentally associated are assigned to the same response key. Conversely, when unrelated or conflicting categories are paired under a single key, response times increase due to cognitive interference. The aIAT uses this principle to detect autobiographical memories encoded in the brain. This method has proven effective in various forensic contexts, including lie detection and identifying malingering.

The structure of the aIAT

During the aIAT, people are asked to sort sentences on a computer screen into two groups. There are two kinds of sentences:

1. Objectively true or false statements (e.g., “I am in front of a computer” vs. “I am climbing a mountain”) based on the participant’s current situation.
2. Statements related to autobiographical memories, representing two alternative versions of the same event (e.g., “I went to Paris for Christmas” vs. “I went to London for Christmas”), of which only one is factually true for the individual.

Participants respond to each statement using two response keys (e.g., A and L), with category labels displayed on the top left and right of the screen. Stimuli are presented individually at the centre of the screen.

While the aIAT typically involves visually presented written stimuli and our study (further explained) employs auditory stimuli, the underlying logic remains the same: examining how individuals' responses vary depending on the familiarity or subjective truthfulness of the presented information.

1.2.2 Concealed Identity Information Test

Concealed information refers to knowledge intentionally hidden from others, ranging from minor personal opinions to serious crime-related details such as a tool used in a crime, dates, or names of the individuals involved. Detecting such hidden knowledge has long been a central aim in forensic science, as it could significantly enhance the ability to solve crimes and accurately establish guilt or innocence.

The Concealed Information Test (CIT), developed by Lykken (1959), has received significant attention. The CIT involves presenting individuals with stimuli related to crime-relevant information (i.e. information only known to the perpetrator), alongside neutral alternatives. It is based on the assumption that people will exhibit implicit responses, physiological or cognitive, in front of meaningful stimuli compared to unknow, or neutral ones.

In earlier studies, research (Bowman et al.,2014) used EEG with the rapid serial visual presentation (RSVP) method to detect concealed information. These studies found that brain signals could reveal when someone recognize hidden, crime-related information. This made EEG a powerful tool, especially because it seemed resistant to countermeasures (deliberate strategies used by participants to hide their knowledge). However, despite its accuracy, EEG is not practical for everyday use: EEG facilities are not common outside university laboratories, making it hard to use outside of research settings. To find a more accessible solution that still resists countermeasures, researchers have begun exploring eye-tracking.

Aims and research question

Eye movements are known to reflect attentional and Control processes. Among various eye-based measures, pupil dilation has received attention due to its strong association with emotional and cognitive processes. According to Nieuwenhuis et al. (2022), pupil responses origin in the locus coeruleus-norepinephrine (LC-NE) system, which is activated by motivationally significant stimuli (Koss,1986; Murphy et al.,2011; Nieuwenhuis et al.,2005; Samuels & Szabadi, 2008).

Previous CIT studies have successfully used pupil dilation to distinguish between Guilty and Innocent participants. For instance, Lubow and Fein (1996) reported that differences in pupil responses to crime-relevant versus irrelevant stimuli could correctly identify 50-70% of the Guilty and 100% of the Innocent participants. Furthermore, Seymour et al. (2013) achieved a higher accuracy, reaching 92% with zero false positives.

In summary, findings suggests that pupil size is a reliable indicator of concealed information.

However, all these studies utilized visual stimuli, thus impacting pupil dilation response. Here we aim to study the cognitive components of pupil dilation signal by using auditory stimuli, thus enhancing endogenous as compared to exogenous mechanisms shaping pupil dilation. Furthermore, we aim to study pupil dilation not during the production of a behavioural explicit response but before its production, thus testing the possibility to identify the so-called “liar mindset”.

In summary, our study represents a preliminary attempt to investigate the use of pupillometry as a non-invasive, accessible, and countermeasure-resistant method for detecting concealed identity information.

CHAPTER II

THEORY

2.1 The pupil

2.1.1 Anatomy

The pupil is a transparent opening in the centre of the eye. Light passes through the surface of the lens that is exposed by the pupil and is focused onto the retina in the back of the eye. The diameter of the human pupil varies between roughly 2 and 8 mm. The coloured area around the pupil is the iris, and it contains the muscles that control pupil size. The white tissue around the iris is called the sclera. The transparent tissue that covers the iris and the pupil is the cornea.

Neural pathways

Pupil size is controlled by two pathways: the parasympathetic constriction pathway and the sympathetic dilation pathway.

Pupil constriction is controlled by the iris sphincter muscle. It is composed of smooth muscle cells arranged concentrically around the pupil; under the control of the parasympathetic division of the autonomic nervous system (ANS), this muscle constricts the pupil. The connection between pupil constriction and the parasympathetic nervous system explains why pupils are smaller at rest.

Pupil dilation is controlled by the iris dilator muscle; it consists of radially arranged smooth muscle cells, extending peripherally across the iris. It is controlled by the sympathetic division of the ANS to dilate the pupil. The connection between pupil dilation and the sympathetic nervous system explains why pupils are larger when someone is aroused.

2.1.2 The pupil light response (PLR)

The pupil light response (PLR), or pupil light reflex, consists in the constriction of the pupil in response to brightness, and its dilation in response to darkness. When exposed to bright light, parasympathetic innervation induces sphincter pupillae contraction, reducing pupil diameter. In contrast, low light levels activate sympathetic stimulation, causing pupillary dilation.

A typical PLR pattern unfolds as follows:

Light On:

0-0.2s: This is the latency phase, where the pupil does not react yet. The duration of this period varies based on factors such as stimulus intensity (brighter leads to faster responses) and age (older individuals tend to have slower reactions) (Ellis,1981).

0.2-1.5s: The pupil constricts reaching its minimum size.

1.5-10s: The pupil remains constricted while the light is on, though in some cases, it slightly re-dilates in a process called pupil escape. This escape response depends on the light's colour: blue light maintains stronger constriction, whereas red light allows partial dilation. This occurs due to differences in photoreceptors responding to blue and red light.

Light Off:

10-30s: Once the light is turned off, the pupil gradually returns to its original size. However, dilation takes longer than constriction. Recovery speed also depends on light colour: red light leads to quicker dilation, whereas blue light results in a prolonged constricted state. After exposure to intense blue light, the pupil may stay slightly constricted for several minutes, a phenomenon known as the post-illumination pupil response (PIPR).

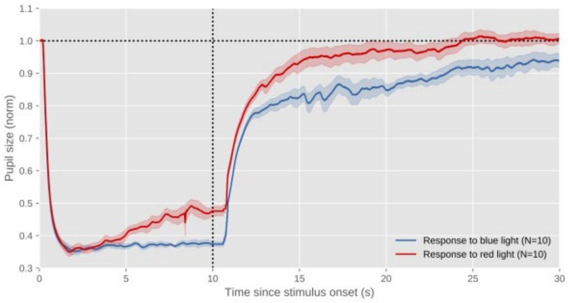


Figure 1. *Pupil response to red and blue light. Normalised pupil size over time following red or blue full-screen stimuli (N=10 per condition). Shaded areas show standard error. Mathôt, S. (2018). Pupillometry: Psychology, Physiology, and Function. Journal of Cognition, 1(1): 16, pp. 1–23.* *https://doi.org/10.5334/joc.18*

Photoreceptors

The PLR is controlled by rods, cones and intrinsically photosensitive retinal ganglion cells (ipRGCs) (Kardon, 2005; Markwell et al., 2010; McDougal & Gamlin, 2008).

Cones are sensitive to colour. There are three types, allowing us to be sensitive to different wavelengths of light. Cones are densely packed in the fovea (the centre of the visual field) and function best under bright light, making them dominant in daytime vision.

Rods, on the other hand, are not sensitive to colour. Rods respond most strongly to a blueish green wavelength and therefore cannot differentiate colours. They are mostly located in the peripheral retina and are highly sensitive to weak light, making them essential for night and peripheral vision.

ipRGCs are the third type of photoreceptors (ganglion cells); they contain their own photopigment, melanopsin (Berson, Dunn, & Takao, 2002). They respond to light more slowly, especially blue light. ipRGCs play a key role in non-image-forming vision that do not require conscious perception, such as regulating pupil sized in response to light and maintaining the circadian rhythm (the body's internal day-night rhythm) (Markwell et al., 2010).

Rods and cones initiate the early phase of the PLR, triggering rapid constriction within approximately 0.2 to 1.5 seconds. However, this initial input desensitizes quickly; if the PLR relied solely on these photoreceptors, the pupil would unconstrict even when the light remained on. Instead, ipRGCs sustain the constriction once rods and cones input decreases (Gamlin et al., 2007). Figure 1 shows ipRGC involvement, evident from 1.5 to 10 seconds observed under blue light compared to red light. This explains why pupil constriction lasts longer under blue light, to which ipRGCs are more sensitive. In summary, rods and cones drive rapid onset of pupil constriction, while ipRGCs ensure that the pupil remains constricted under continuous light exposure (Gooley et al., 2012; Wong, 2012).

All three photoreceptors send their signal to the pretectal olivary nucleus (PON), which initiates the neural pathway responsible for constricting the pupil.

Mental Imagery and word meaning

Although pupil responses are typically triggered by actual visual stimuli, research suggests that mental imagery alone can also influence pupil size. Consequentially, pupils can constrict in response to internally generated images, even when no actual visual input is present.

In a study by Laeng & Sulutvedt (2014), participants were shown a plain grey screen and asked to visualize themselves in particular environments. The results demonstrated that when participants imagine being outdoors on a sunny day, their pupils became smaller, on the contrary when they pictured themselves being indoors in a dark room, their pupils remained larger.

This suggests that the brain processes imagined brightness in a similar way to real light, adjusting pupil size even when the stimulus is purely mental.

2.1.3 The Pupil Near Response (PNR)

The PNR is part of the near triad, a set of three eye movements:

- PNR: the pupil constricts when focusing on a near object, improving depth of field.
- Vergence: the eyes rotate inward to focus on a close object and rotate outward to focus on an object far away.
- Accommodation: the lens becomes more curved to sharpen focus on a near object and flattens to focus on a further one.

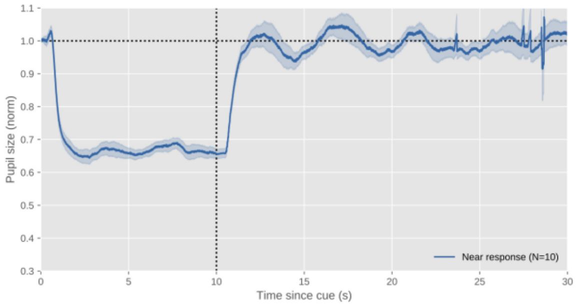


***Figure* 2. Pupil response during gaze shifts.** *Normalized pupil size while shifting gaze from a distant to a nearby point (0 s) and back again (10 s; N = 10 trials). The x-axis shows time since the auditory cue; the y-axis shows pupil size relative to pre-stimulus baseline. Shaded areas indicate standard error. Mathôt (2018). Journal of Cognition, 1(1), 16. https://doi.org/10.5334/joc.18*

2.1.4 The Psychosensory Pupil Response (PPR)

"Man may either blush or turn pale when emotionally agitated, but his pupils always dilatate" (Loewenfeld (1958))

The pupil dilates in reaction to arousing stimuli, thoughts or emotions. This response, also known as reflex dilation, arousal-related dilation or effort-related dilation, occurs due to both sensory and psychological influences.

Types of Psychosensory Pupil Responses

Anything that engages or increases cognitive load causes pupil dilation (Beatty, 1982). A key distinction can be made between responses.

Orienting Response

Sudden and unexpected events, such as sounds, sudden movements, or painful stimuli, can trigger an orienting response (Lynn, 1966; Sokolov, 1963). This response prepares the body for action: head and eye movement toward the stimulus, tensing of muscle and increase in alertness, and a pupil dilation. The orienting response is most evident when stimuli are both "unexpected" (Friedman et al., 1973) and "salient" (C. Wang & Munoz, 2014; C. Wang et al., 2014), reflecting the body's sensitivity to cues that signal potential danger.

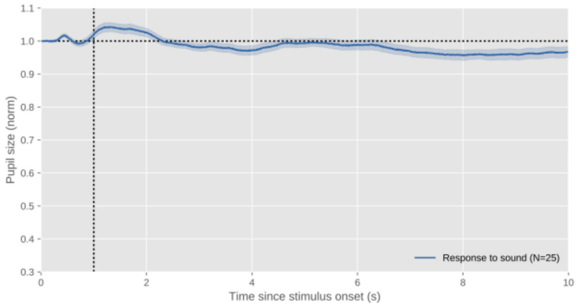


***Figure* 3**. *Pupil response to auditory white noise. Normalised pupil size following a 1 second brust of white noise. The y-axis scales illustrate the small effect. Mathôt (2018). Journal of Cognition, 1(1), 16. https://doi.org/10.5334/joc.18*

Compared to the rapid and strong pupil constriction triggered by PLR, this dilation is smaller in size and delayed time. Figure 3 shows the orienting-related pupil dilation beings rapidly but reaches its peak between 0.5 and 1 second after stimulus onset and then fades quickly (Mathôt et al., 2014b; C. Wang & Munoz, 2014). Often, a second, slower phase of dilation follows, typically visible around 1-2 seconds after the stimulus, which is thought to reflect a more general arousal response.

Mental effort and arousal response

A slower, sustained pupil response linked to mental effort and arousal. Various research (Hess, 1960; Polt, 1964) demonstrated that pupil dilation correlates with mental workload.

Hess & Polt (1964): Participants solved math problems of varying difficulty. More challenging problems caused greater pupil dilation, reflecting increased mental effort.

Kahneman & Beatty (1966): Participants memorized different numbers of digits. The more digits they held in memory, the more their pupils dilated.

Ahern & Beatty (1979): Participants with lower cognitive test scores exhibited stronger pupil dilation when solving complex problems.

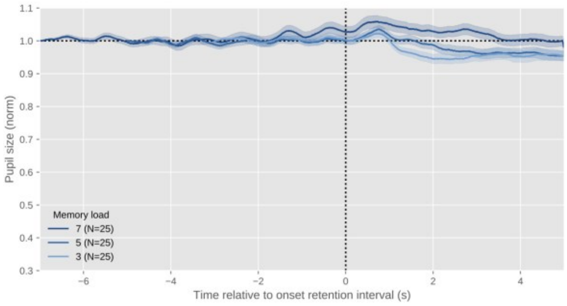


***Figure* 4**. *Pupil response during working-memory maintenance. Normalized pupil size during a 5-second retention interval following auditory presentation of 3, 5, or 7 digits (N = 25 trials per condition). The y-axis scale matches previous figures to highlight effect size. Shaded areas indicate standard error. Mathôt (2018). Journal of Cognition, 1(1), 16. https://doi.org/10.5334/joc.18*

Neural Basis of PPR

The PPR follows the pupil dilation pathway, which involves the Superior Colliculus (iSC), mediating fast, orienting responses (C. Wang & Munoz, 2014; C. Wang et al., 2014); the Locus Coerules (LC) , mediating phasic activation (Nieuwenhuis, De Geus, & Aston-Jones, 2011); The Hypothalamus and LC Connection, which regulates arousal and mental-efforted-related pupil dilation (Aston-Jones & Cohen, 2005; Joshi et al., 2016)..

Functions

The function of the PPR remains unclear. Some researchers (Mathot & Van der Stigchel, 2015) suggest that pupil dilation enhances visual processing in high-arousal situations. Pupil dilation allows increased sensitivity, enhanced detection of threats and an adaptive trade-off between sensitivity and acuity.

Increased sensitivity: larger pupils to let in more light, improving visibility in low-light conditions.

Enhanced detection of threats: in a high-arousal state, dilation may help detect subtle movements, increasing survival chances.

Adaptive trade-off between sensitivity and acuity: during a calm, focused state pupil constriction improves visual acuity for reading and detailed tasks, in this state, the brain prioritizes acuity over sensitivity, leading to pupil constriction, meanwhile during an alert, exploratory state (e.g. when searching for threats or important cues) pupil dilation enhances light sensitivity, making it easier to detect subtle movements or changes. This adaptation supports survival behaviours.

Thus, PPR is not an isolated response but rather a modulation of the more basic pupil reflexes (PLR and PNR) by higher cognitive processes.

Spontaneous Pupil Size Fluctuations

Even in the absence of external stimuli, pupil size naturally fluctuates. These involuntary changes, known as hippus or pupillary unrest, occur in cycles ranging from a few seconds to a minute. "*Hippus is generally used to describe periodic fluctuations, whereas pupillary unrestis a more general term that refers to any kind of spontaneous fluctuation.*"

Lowenstein et al. (1963): found that alert individuals had stable, enlarged pupils. As fatigue increased, pupils became smaller and fluctuated more.

Bouma & Baghuis (1971): pupillary unrest was most evident when participants were left idle, without a specific task. Engaging in a cognitive task reduced these fluctuations, suggesting a link between arousal and task engagement.

More recently (Mathôt et al., 2015a; see also Marzouki, Dusaucy, Chanceaux, & Mathôt, 2017), it was found a link between pupil size fluctuations and eye-movement behaviour: when pupils were small, people were more likely to focus on visually striking elements (e.g., bright colours, sharp edges). When pupils were large, attention was guided by task relevance, rather than visual saliency.

These findings indicate that pupil size fluctuations may reflect shifts in cognitive engagement and arousal levels.

2.2 Pupillometry for the Detection of Deception: where are we?

2.2.1 The ODT

The Ocular-Motor Deception Test (ODT) was created based on findings that reading behaviour and cognitive load affect pupil size. Researchers, including John Kircher and Doug Hacker, explored whether eye movements and pupil responses could indicate deception during a computerized test.

The ODT is a computer-based psychophysiological test designed to detect deception. Its effectiveness relies on four core assumptions: deception is cognitively demanding, deception triggers emotional arousal, deception requires self-regulation, and deception relies on self-motivation.

Deception is Cognitively Demanding

Being deceptive is more cognitively demanding than telling the truth (Johnson et al., 2005; Kircher, 1981; Lubow & Fein, 1996; Raskin, 1979; Seymour et al., 2000; Vendemia et al., 2005; Vrij, 2008; Vrij et al., 2007, 2009; Walczyk et al., 2003, 2009). When responding deceptively a person must understand the statement, evaluate the truth and inhibit it, construct a plausible falsehood that aligns with the deception, memorise and maintain consistency to avoid contradictions, manage potential consequences of being caught.

These processes increase cognitive load, consequentially causing greater pupil dilation, a key indicator used in the ODT. In contrast, truthful responses involve fewer cognitive demands, leading to smaller pupil changes.

Deception triggers emotional arousal

Lying is often associated with fear of being caught, which leads to increased emotional arousal. Studies (Dionisio et al., 2001) have shown that, compared to truthful individuals, deceptive individuals are typically more anxious about failing a deception test, this anxiety contributes to pupil enlargement. However, the pupil enlargement cause by emotion is often confused with dilation caused by cognitive effort.

Although cognitive load and emotional arousal both influence pupil size, their overlap strengthens the ODT's reliability, as deception involves both cognitive strain and emotional activation.

Deception requires self-regulation

Lying requires active self-monitoring and Control over thoughts and emotions. Self-regulation involves: tracking inconsistencies in fabricated stories, suppressing natural emotional responses to deception, and adjusting behaviour to appear credible. (Zimmerman, 2008).

This process adds cognitive load, further increasing pupil dilation. However, excessive cognitive strain can overwhelm working memory, leading to noticeable inconsistencies in deception.

Deception requires self-motivation

Successfully maintaining a deception requires strong self-motivation, as lying is an active, effortful process. A deceptive person must believe in their ability to lie, expect success, and stay committed to appearing truthful (Zimmerman & Moylan,2009). This effort involves monitoring their responses, suppressing truthful reactions, and managing emotions, all of which add to cognitive load. Increased cognitive strain leads to longer response times, greater pupil dilation, and altered reading behaviours, making deception detectable. Since the ODT measures cognitive effort rather than stress, it remains effective even when individuals try to Control their emotional responses or use countermeasures.

2.2.2 How the ODT works

The ODT is a computer-based deception detection tool designed for screening scenarios. The test presents true/false statements to an examinee, who must respond quickly and accurately while an eye-tracking device continuously records pupil diameter and eye movements.

Testing Procedure:

1. Examinees sit before a computer screen with an integrated eye tracker.
2. They are presented with true/false statements about illicit activities.
3. The test measures their response time, accuracy, pupil dilation, and reading behaviours.
4. A logistic regression model analyses these data points to classify individuals as either truthful or deceptive.

Types of Statements Used in the ODT

There were used three types of statements. Relevant Statements, directly related to the topic of deception (e.g., “I have never stolen money from an employer”). Control Statements, unrelated statements used as a comparison baseline (e.g., “I am reading this statement on a weekday”). Neutral Statements, low-cognitive-load statements included to allow recovery between test items.

Findings and Accuracy

Studies (Anne E. Cook et al. 2024) have demonstrated that the ODT achieves an accuracy rate 85.5%: 83.3% for innocent participants and 86.6% for guilty participants. The results also suggests that deceptive individuals exhibit greater pupil dilation, longer response times, and distinct reading behaviours compared to truthful individuals.

2.2.3 The ODT and Countermeasures

A countermeasure refers to any strategy an individual uses to manipulate their physiological or cognitive responses to pass a deception test. These strategies can be physical, mental, or knowledge-based, but research suggests that the ODT remains highly resistant to them.

Physical Countermeasures: actions like biting the tongue, pressing toes to the floor, or controlled breathing are commonly used in polygraph deception tests to alter physiological responses. However, research by Twyman et al. (2013) found that these techniques do not significantly affect pupil dilation, making them ineffective against the ODT.

Mental Countermeasures: strategies such as mentally distracting oneself (e.g., counting backward) or recalling emotional memories are meant to alter cognitive load. Some individuals try to rehearse their lies in advance so that deception becomes "lie recall" rather than "lie construction," reducing cognitive effort. Research by Peth et al. (2016) showed that mental countermeasures can slightly reduce deception indicators, but pupil dilation and cognitive strain still expose deception.

Knowledge-Based Countermeasures: providing individuals with detailed information about how the ODT works does not significantly improve their ability to defeat it. A study at Masaryk University tested whether people who were given instructions on countermeasures could manipulate the ODT, but they were unable to consistently deceive the test.

2.3 Limitations of the ODT and Proposed Advancements

The ODT has achieved notable success in resisting countermeasures and producing reliable results; however, it is not exempt from certain limitations.

One key concern is that the reading component of the test may influence the results, adding noise unrelated to deceptive behaviour, such as reading speed, comprehension, and visual processing. All these components can independently affect pupil size.

A poor comprehension of ODT items, for example, may reduce the impact of their content on pupillary responses. Prior research (e.g., Rayner et al., 2012; Wei, 2019) indicated that eye fixation patterns during reading differ significantly between skilled and unskilled readers, and these differences may become more pronounced in the context of a cognitive demanding task such as the ODT.

Additionally, most ODT focus on responses during or after statement processing, potentially overlooking valuable cues that occur before a participant explicitly responds.

To address these gaps, our study proposes two main innovations. First, we introduced an auditory version of the ODT, eliminating the possible influence of reading-related cognitive load. Second, we explored whether pupil dynamics prior to an explicit response (overt response) can reveal the cognitive “mind-set” of a deceiver. By focusing on early, pre-decisional stages of processing, we aim to detect deception even before a conscious answer is provided, potentially enhancing the sensitivity and interpretability of pupillometric deception detection.

CHAPTER III

OUR STUDY

3.1 Purpose

This study aims to investigate the cognitive and physiological markers of deception by examining pupil dilation during instances of lying. Specifically, it explores whether pupil dilation can differentiate between truthful and deceptive cognitive processing, particularly during the critical pre-response phase.

We hypothesize that participants required to lie (Guilty group) will exhibit greater pupil dilation compared to truthful participants (Innocent group) when getting ready to respond to Target questions. This anticipatory physiological response is expected to reflect the increased cognitive load and emotional arousal associated with maintaining a deceptive mindset.

By focusing on the early stages of cognitive processing rather than solely on overt responses, this study seeks to advance the sensitivity and temporal precision of pupillometric deception detection.

3.1.1 Participants

Sixty-three participants between 18 years old and 33 years old took part in the experiment (mean=22,63; SD=2,93; females=46). Participants were randomly assigned to either the Guilty group or Innocent group.

No incentives, such as monetary compensation or university credits, were provided for participation. Recruitment was carried out through flyers and announcements posted on Facebook; the study flyer was also shared via various faculty WhatsApp groups.

All participants were informed about the general procedure of the experiment and provided written informed consent after reading an information sheet. The study was approved by the Ethics Committee of the School of Psychology at Università degli Studi di Padova and was conducted in accordance with the principles outlined in the Declaration of Helsinki.

3.1.2 The mock crime

The study consisted of two sessions, each lasting approximately 20 minutes and held one week apart (with a time deviation ranging from a minimum of 6 days and maximum of 8 days).

Both sessions took place at the laboratories of the Department of General Psychology of Università degli Studi di Padova, specifically in room C-12 – Laboratory for Subject Testing and Eye Movements.

Procedure

A double-blind procedure was employed to minimize expectancy effects and experimenter bias, which are critical concerns in deception-based experimental designs such as mock-crime paradigms. The separation of roles, further explained in the next paragraph, was designed to preserve the integrity of the blind and ensure that any interaction with participants during data collection could not be influenced by prior knowledge of group assignment.

First Session

At the beginning of the first session, participants were given an envelope containing a map of the floor -1 (Appendix 2), a laboratory access badge, and a letter corresponding to their assigned experimental condition (Appendix 1). In addition, participants assigned in the Guilty group also received a set of keys inside the envelope. The envelope was handed to all participants in front of the elevators in the Psychology 1 building.

Participants assigned to the Innocent group were instructed to follow the map, enter the laboratory, and find the twentieth word on page 1142 of the red dictionary placed on top of a cabinet (the word was 'menzogna' 'deception'). They were then asked to report the word to the experimenter.

Participants in the Guilty group followed the same path as the Innocent group. However, their main task was to use the keys to open a safe hidden inside the cabinet and steal the money stored within. To conceal their true actions, they were instructed to fabricate an alibi: like the Innocent participants, they had to find the twentieth word on page 1142 of the dictionary and report it to the experimenter.

__Figure 8.__ First session of the mock crime

Midweek Assignment

Midway through the week between the two sessions, each participant was sent three self-report questionnaires, taking approximately 10 minutes to complete in total:

- NEO-FFI: Costa, P. T. & McCrae, R. R. NEO PI/FFI Manual Supplement for Use with the NEO Personality Inventory and the NEO Five-Factor Inventory. Odessa, FL.: Psychological Assessment Resources (1989).
- DASS: Lovibond, P. F. & Lovibond, S. H. The structure of negative emotional states: comparison of the Depression Anxiety Stress Scales (DASS) with the Beck Depression and Anxiety Inventories. Behav. Res. Ther. 33, 335–343 (1995).
- BIS-BAS: Carver, C. S. & White, T. L. Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS Scales. J. Pers. Soc. Psychol. 67, 319–333 (1994).

Each participant was assigned a unique numerical ID, which they were required to enter on the questionnaires.

The decision to administer personality questionnaires was driven by the aim of examining whether specific personality traits are associated with deceptive behaviour. However, the data collected through these questionnaires will not be analysed as part of this thesis.

Second Session

For the second session, participants were again accompanied to the C-12 laboratory. They were asked previously to not wear any kind of makeup, to minimize noise during the pupil tracking measurements. Those in the Guilty group were escorted by the same experimenter who had originally delivered their envelope. During the walk to the lab, acting as an accomplice to the theft, the experimenter reminded them not to get "caught" by the eye tracker and to remember their alibi carefully.

Upon entering the lab, participants were greeted by a second experimenter who had not been present during the first session. The experimenter informed them that a theft had occurred the previous week and explained that the purpose of the session was to determine who was responsible.

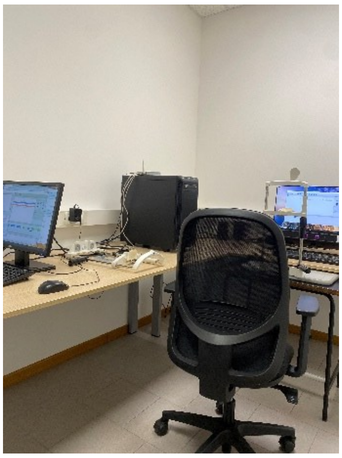
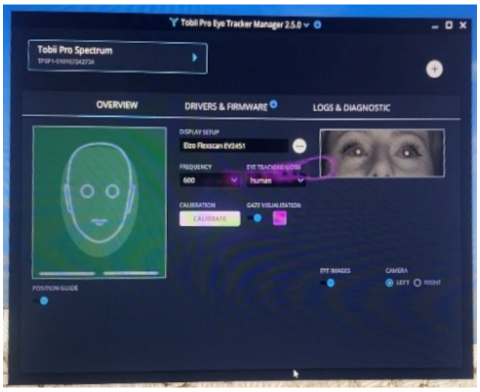


Figure 9. *Laboratory C12, Department of General Psychology, Padova (IT).*

All participants were seated in front of the eye tracker and provided with headphones. A calibration procedure was conducted to track eye movements accurately. The room was kept completely dark during the session.



DISPLAY SETUP: Eizo Flexscan EV2451
FREQUENCY: 600
EYE TRACKING MODE: human

Figure 10. *Pre-calibration phase in the Tobii Pro Eye Tracke. The image shows the Tobii Pro Eye Tracker Manager interface during the pre-calibration stage. At this point, the system has detected the participant's eyes, visible in the upper right corner, but the calibration process has not yet started. The face outline and position guide (left side) indicate that the participant is properly aligned with the eye tracker. The selected eye tracking mode is set to "human," with a sampling frequency of 600 Hz.*

After a brief reading of the instructions, the experiment began. The questions were presented auditorily through headphones, while the screen displayed only a fixation cross. Participants were asked to respond to true/false statements by pressing one of two keys: 'A' for *yes*, and 'L' for *no*. The questions were divided into four blocks:

- Target Yes (5 items)
- Target No (5 items)
- Control Yes (20 items)
- Control No (20 items)

All questions were presented twice in a randomized order, resulting in a total of 100 questions (Appendix 3). Participants could only respond after hearing a beep.

3.1.3 Tools

Pupil dilation data were recorded using a Tobii Spectrum Pro 600 Eye Tracker, with a sampling frequency of 600 Hz. On average, the experimental session lasted approximately 14 minutes. The task was programmed using PsychoPy (v.2022.2.5).

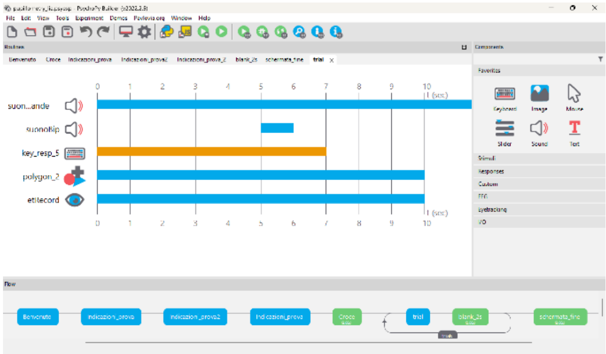


Figure 12. *PsychoPy (v.2022.2.5) experiment trial*

For both groups, consistency between the questions and responses was expected. The key difference between Guilty and Innocent participants was expected to emerge prior to their overt response, specifically during the cognitive processing phase (i.e., the “liar’s mindset”) preceding answers to Target No questions. These were truthful for the Innocent group but required deception from the Guilty group, who had been explicitly instructed to lie and avoid detection by the eye tracker.

3.2 Study’s Hypothesis

The hypothesis underlying our study was that we would observe significant differences in pupil dilation across three distinct conditions.

Hypothesis 1: General effect of question type on pupil dilation.

We expect that, regardless of group membership (Guilty or Innocent), Target questions will elicit significantly greater pupil dilation compared to Control questions. This effect is attributed to the increased cognitive load required for the retrieval of past events (from the previous week e.g., “Did you steal the money?”), as opposed to responding to simple, contextual questions (e.g., "Are you in Padova right now?").

Hypothesis 2: Within-group effect of question type.

Within each group (Guilty and Innocent), we hypothesize that pupil dilation will differ significantly between Target and Control questions. Specifically, we predict an increase in pupil dilation in response to Target questions, confirming that even in the absence of deceptive motive (Innocent group), the type of question influences cognitive load.

Hypothesis 3: Between-group effect on the size of the pupillary response.

We expect the difference in pupil dilation between Target and Control questions to be significantly greater in the Guilty group compared to the Innocent group. This effect could be interpreted as evidence of stronger cognitive and emotional involvement in the Guilty group, who may "enter the mindset of the liar" even before the response onset, showing anticipatory activation related to the attempt to deceive or Control information.

3.3 Data analysis

3.3.1 Preprocessing of pupil signal

Pupil size is a continuous signal that reflects changes over time, typically represented as a time series. In early pupillometry research (Kahneman and Beatty, 1966), pupil size was expressed in absolute values, as in millimetres of pupil diameter. However, using absolute values presents a key limitation: pupil size is subject to slow, random fluctuations that create noise into the data. This noise can reduce statistical power and makes it more difficult to detect effects of interest.

To deal with the impact of these fluctuations, researchers employed baseline correction.

Baseline correction is part of preprocessing, the process of cleaning raw eye-tracking data. It is usually performed at the end of the preprocessing process, after taking care of other sources of noise.

1. **Eye Blink**

   Missing data in pupillometry most commonly occur when video-based eye trackers fail to detect the pupil in the camera image, most often caused by eye blinks. Blinks typically present as a rapid decrease in recorded pupil size, followed by a brief period of missing data, followed by a rapid increase in pupil size once the eye reopens. While the missing segment itself can be managed through various strategies, the preceding and following distortions can significantly impact the data. Therefore, it is essential to correct not only the missing data but also the distortions around it.

   A widely used method for addressing the issue is cubic-spline interpolation. This technique involves identifying four key points around the blink:

- Point B is placed just before the onset of the blink,
- Point C just after the blink offset
- Point A before point B
- Point D after point C

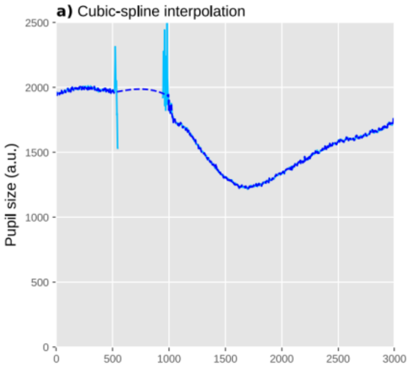


Figure 13. *Example of cubic-spline interpolation. Mathôt, S., & Vilotijević, A. (2022). Methods in cognitive pupillometry: Design, preprocessing, and statistical analysis. Behavior Research Methods, 55(6), 3055–3077. https://doi.org/10.3758/s13428-022-0*

These points are equally spaced so that the intervals between A-B, B-C, and C-D are consistent. A smooth cubic spine line is then draw though these points, replacing the missing and distorted data between B and C with interpolated values. This approach allows a realistic reconstruction of the pupil size trajectory.

2. **Downsampling**

   After correcting the missing data due to eye blink and interpolating them, the pupil-size signal was downsampled to reduce the noise. Given that pupil responses are slow physiological signals, high sampling is not necessary and may introduce additional and irrelevant noise. Therefore, downsampling was applied prior to baseline correction in order to preserve the overall shape of the signal. This step reduced the size of the data, making the analysis more manageable without compromising the quality.

3. **Baseline Correction**

   The procedure involves comparing pupil size during the trial to the pupil size during a baseline period, which typically is the onset of the trial (for our experiment the baseline period was defined as the interval preceding the onset of the auditory stimuli). By focusing on changes in pupil size relative to the baseline, rather than absolute measurements, researcher can individuate pre-existing differences in pupil diameter. This reduces the influence of noise and enhances the sensitivity of the analysis.

Verification of Gaze Centralization

Before analysing pupil dilation, participants' gaze fixation was verified. Both written and oral instructions were given, asking participants to maintain their gaze fixed on the central fixation cross to avoid data noise caused by peripheral gaze or excessive eye movements.

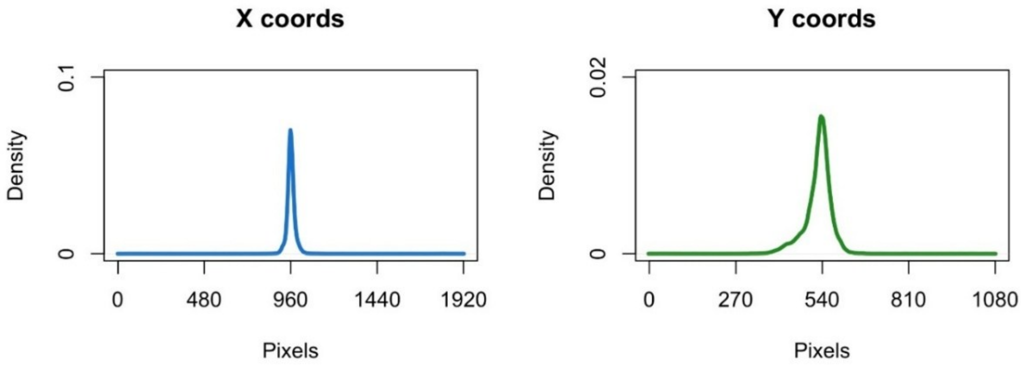


Figure 14. *Spatial distribution of eye movements during the experiment.*

Figure 14 shows the spatial distribution of eye movements (separated by X and Y axis) recorded throughout the experiment. As shown, the density of gaze points is concentrated around the centre of the screen, with X = 960 and Y = 540 (Y corresponding to a screen resolution of 1920 × 1080). This indicates that all participants maintained central fixation for the majority of the time.

This confirms that the pupillometric data were not affected by peripheral gaze or excessive eye movements, thus ensuring the reliability of the pupil diameter measures used in the following analyses.

3.3.2 Results

Before the actual analysis of the results, a data-cleaning process was performed. Bad trials were rejected, where "bad trials" refers to either participant with at least 50% of missing data overall, or participant with at least 50% of missing data in at least 50% of the trials. Using this criterion, two participants were excluded, corresponding on Figure 14 to the highest bands (yellow and black)

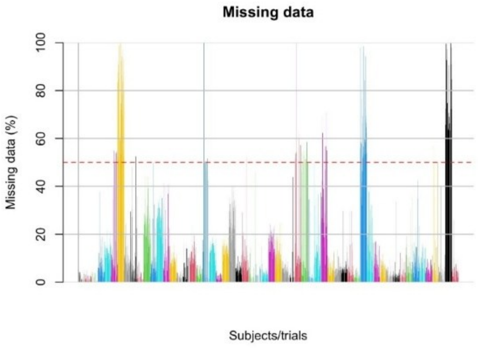


Figure 15. *Display of the proportion of missing data for each participant. The horizontal line represents the 50% missing data cutoff. Participants exceeding this cutoff were excluded from the analysis to ensure the reliability of the results.*

Following the analysis of the collected data, the results confirmed all three hypotheses formulated in our study. In particular, significant differences in pupil dilation emerged for both question type (Target vs. Control) and assigned condition (Guilty vs. Innocent), consistent with our predictions.

A mixed-effects model was used to assess the relationship between pupil dilation and two key predictors: group (Guilty vs. Innocent, as a between-subjects variable), and category (Target vs. Control questions, as a within-subjects variable).

This approach considered both main effects of the predictors and interaction effects, i.e., whether the difference in pupil response between Target and Control questions varied as a function of participant condition.

Main results

- **Between-subjects effect**: not significant. No significant differences in pupil dilation were found between participants in the Guilty and Innocent groups, regardless of question type.
  The chi-square test showed no significant difference: (χ^2 [1] =0.033, p = 0.86).
- **Within-subjects effect**: significant. Pupil dilation was greater in response to Target questions compared to Control questions, confirming the increased cognitive load required to retrieve past events.
  The chi-square test revealed a highly significant effect: (χ^2 [1] =23978.9, $p < 0.001$).

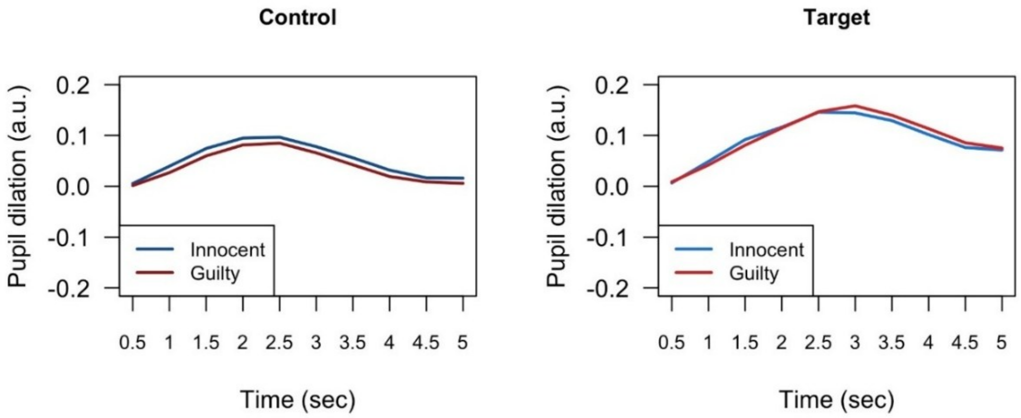


Figure 16. *The difference dilation of the pupil for Control questions and Target questions. The y-axis shows pupil size in arbitrary units as recorded by the Tobii Spectrum Pro 600 Eye Tracker (a.u.). The x-axis shows Time in seconds.*

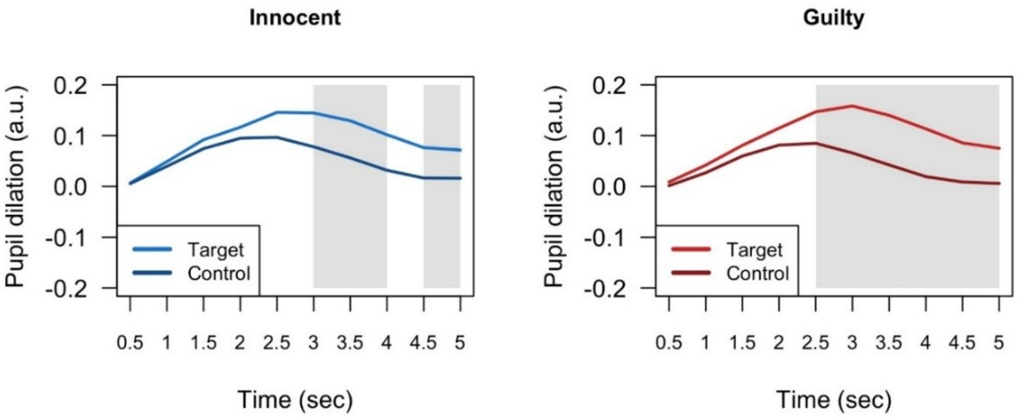


Figure 17*. Pupil dilation for innocent and Guilty groups and time windows. The y-axis shows pupil size in arbitrary units as recorded by the Tobii Spectrum Pro 600 Eye Tracker (a.u.). The x-axis shows Time in seconds.*

The analysis including time windows revealed significant differences in pupil dilation between Control and Target questions for both the Innocent and Guilty groups, starting from approximately 2.5 seconds after question onset, as highlighted by the grey-shaded areas in the figures. This temporal pattern aligns with our initial hypotheses regarding cognitive load differences elicited by the two question types.

- **Group * Category interaction**: significant. Pupil dilation in response to Target questions was significantly greater in the Guilty group compared to the Innocent group. This suggests that Guilty participants entered a cognitive state associated with information Control or suppression even prior to the response onset.
  The chi-square test indicated a significant result, (χ^2 [1] =543.24, $p < 0.001$).

In particular, this last interaction showed:

- A significant difference in pupil dilation between Target and Control questions within the Guilty group ($z=-130.9$; $p<0.001$).
- A significant difference between Target and Control questions within the Innocent group, although this difference was less pronounced than in the Guilty group ($z=-86$; $p<0.001$).
- A significant difference comparing Target questions within the Guilty group and Control questions within Innocent group: pupil dilation was greater for Guilty group than for the Innocent group ($z=2.9$; $p=0.023$).
- No significant difference was found between Target questions for the Innocent group and Control questions for the Guilty group, suggesting that the difference between Target and Control questions is more pronounced in the Guilty group than in the Innocent group.

These results indicate that the effect of question type on pupil dilation is present in both groups but the difference in pupil dilation between Target and Control questions (delta) was significantly greater in the Guilty group compared to the Innocent group, reflecting a greater cognitive load in response to Target questions among Guilty participants (t [167.9] = 2.59, p = 0.01).

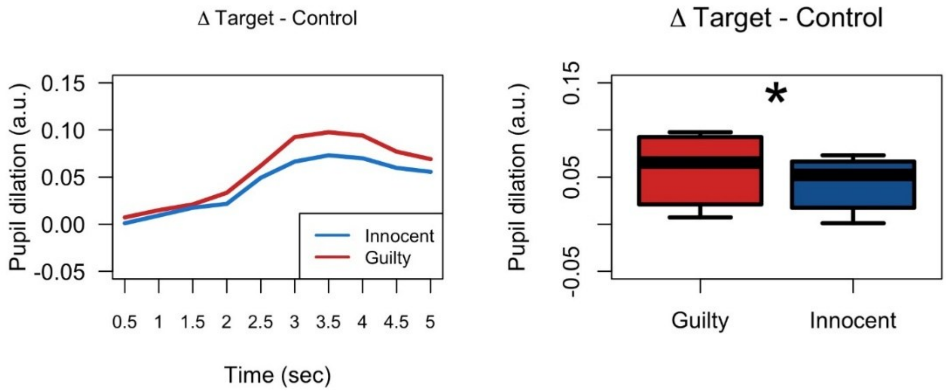


Figure 18. *Pupil dilation for Guilty group is significantly greater. The y-axis shows pupil size in arbitrary units as recorded by the Tobii Spectrum Pro 600 Eye Tracker (a.u.). On the left figure the x-axis shows Time in seconds. On the right figure a boxplot shows the difference of Target and Control questions for each group.*

3.4 Discussion

The present study examined pupil dilation as a physiological marker of cognitive load and confirmed all three hypotheses. Pupil size increased significantly in response to Target questions as compared to Control ones, both across and within groups. This effect supports the notion that memory retrieval, required by Target questions, demands higher cognitive effort than answering simple contextual questions (Haj, M. E., Janssen, S. M. J., Gallouj, K., & Lenoble, Q., 2019).

The interaction between group and question type revealed that the increase in pupil dilation for Target questions was significantly greater in the Guilty group than the Innocent group. This result is consistent with the idea that Guilty individuals engage in more effort-requiring cognitive processes when confronted with incriminating cues, and is in line with the "cognitive load theory" (e.g., Vrij et al., 2006, 2011; Walczyk et al., 2013). In summary, liars must suppress the truthful response, and the effort associated with such inhibition attempts might result in cues such as slower RTs or, as in our case, higher pupil dilation.

In other words, the idea within this framework is that lying is cognitively more demanding than telling the truth. This aligns with the literature on pupil dilation showing that higher pupil diameter is associated with higher cognitive load (Mathôt, 2018).

Moreover, our data is consistent with the known latency of the PPR to cognitive effort (Mathôt, 2018): accordingly, significant differences in pupil dilation emerged after approximately 2.5 seconds.

Furthermore, our results are also in line with the "arousal inhibition theory" (Verschuere et al., 2007), which states that guilty suspects who wish to "seem innocent" will attempt to inhibit their experienced physiological arousal. For instance, in our experiment, a guilty participant might not only process the truthful response to target question (to deliberately choose the deceptive one), but also try to inhibit the physiological arousal. Several studies suggest that this kind of effort causes enhanced, rather than reduced, physiological responses (Dan-Glauser & Gross, 2011; Pennebaker & Chew, 1985), thus supporting our data on higher difference in pupil dilation between target and control questions in guilty as compared to innocent participants.

Taken together, the importance of the preliminary results obtained in the present study lie in providing initial evidence about the possibility to detect the mindset of the liar, specifically, the ability to understand whether a person intends to lie even before the overt response is given.

Deception is defined as *"a deliberate attempt, without forewarning, to create in another a belief which the communicator considers to be untrue"* (Vrij, 2004). According to this definition, deception cannot be reduced to the mere process of producing a deceptive response. Conversely, deception starts with the intention to deceive and the whole deception process should be investigated. Despite focusing on this aspect is critical to study deception, the so-called "liar mindset" or the "intention to deceive" is often neglected in literature. To the best of our knowledge, this is one of the first studies explicitly targeting the prediction of intention to lie prior to an over response. Therefore, our study may become a potential breakthrough in deception detection literature. For this reason, further analysis are required to extend the group-level analysis presented here will also at the individual-level, aiming to enhance the precision and real-world applicability of the method.

Future implications of this research could include the development of portable, non-invasive lie detection systems. Pupil size could be reliably tracked implementing tools on commonly used digital devices combined with advanced algorithms. This opens the possibility for accessible deception detection tools that could be used for example in remote interviews, or online assessments.

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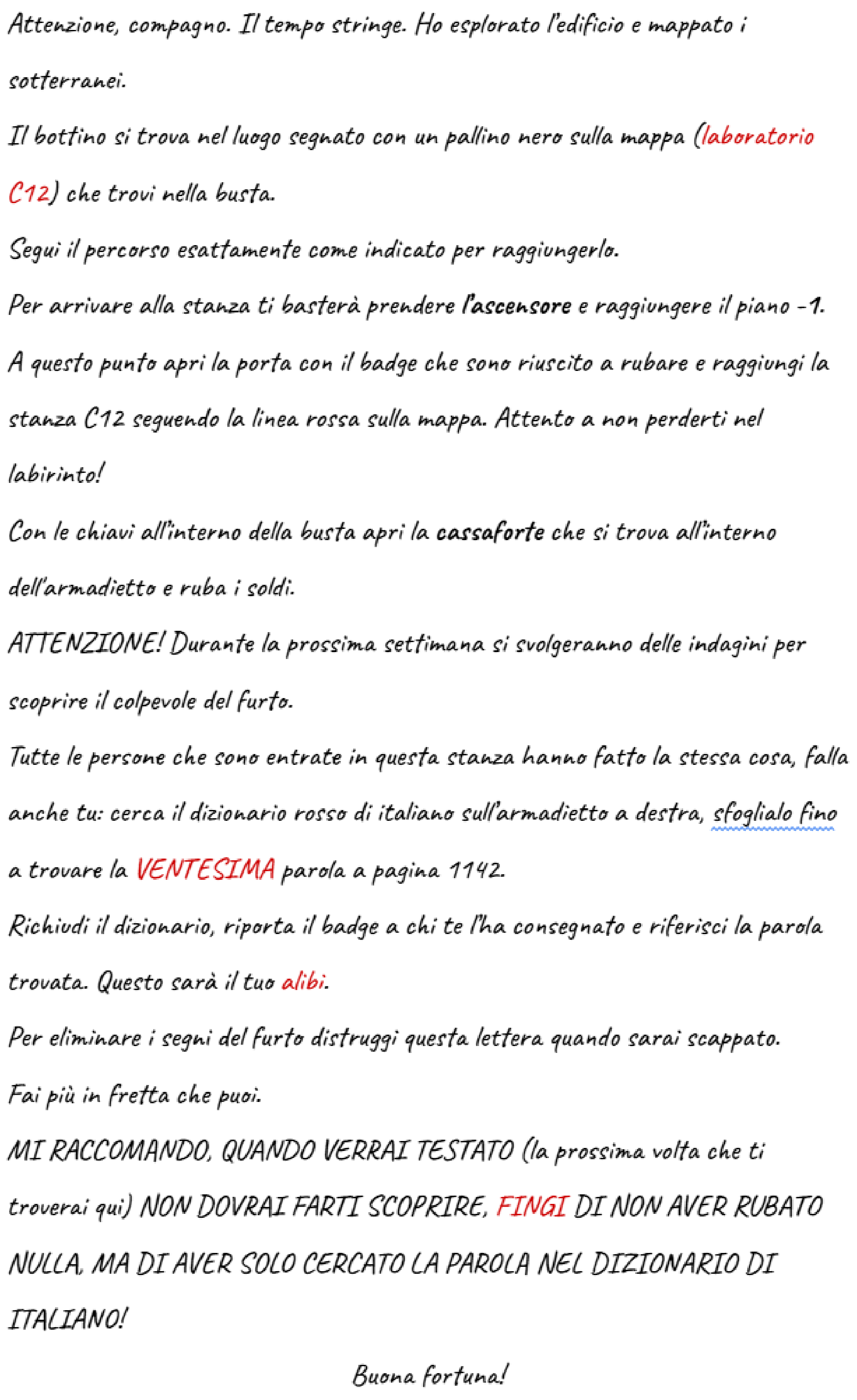
APPENDIX 1



Attenzione, compagno. Il tempo stringe. Ho esplorato l'edificio e mappato i sotterranei.

Il bottino si trova nel luogo segnato con un pallino nero sulla mappa (laboratorio C12) che trovi nella busta.

Segui il percorso esattamente come indicato per raggiungerlo.

Per arrivare alla stanza ti basterà prendere **l'ascensore** e raggiungere il piano -1.

A questo punto apri la porta con il badge che sono riuscito a rubare e raggiungi la stanza C12 seguendo la linea rossa sulla mappa. Attento a non perderti nel labirinto!

Con le chiavi all'interno della busta apri la **cassaforte** che si trova all'interno dell'armadietto e ruba i soldi.

ATTENZIONE! Durante la prossima settimana si svolgeranno delle indagini per scoprire il colpevole del furto.

Tutte le persone che sono entrate in questa stanza hanno fatto la stessa cosa, falla anche tu: cerca il dizionario rosso di italiano sull'armadietto a destra, sfoglialo fino a trovare la VENTESIMA parola a pagina 1142.

Richiudi il dizionario, riporta il badge a chi te l'ha consegnato e riferisci la parola trovata. Questo sarà il tuo alibi.

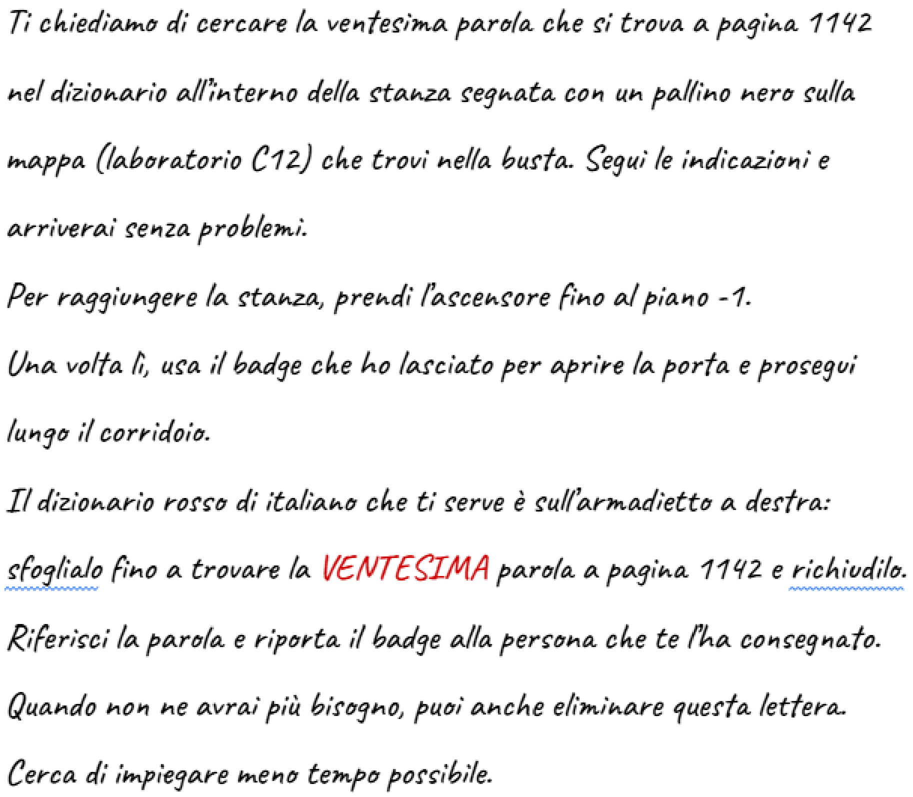
Per eliminare i segni del furto distruggi questa lettera quando sarai scappato.

Fai più in fretta che puoi.

MI RACCOMANDO, QUANDO VERRAI TESTATO (la prossima volta che ti troverai qui) NON DOVRAI FARTI SCOPRIRE, FINGI DI NON AVER RUBATO NULLA, MA DI AVER SOLO CERCATO LA PAROLA NEL DIZIONARIO DI ITALIANO!

Buona fortuna!

Figure 6. *Instructions given to Guilty participants*



Ti chiediamo di cercare la ventesima parola che si trova a pagina 1142 nel dizionario all'interno della stanza segnata con un pallino nero sulla mappa (laboratorio C12) che trovi nella busta. Segui le indicazioni e arriverai senza problemi.

Per raggiungere la stanza, prendi l'ascensore fino al piano -1.

Una volta lì, usa il badge che ho lasciato per aprire la porta e prosegui lungo il corridoio.

Il dizionario rosso di italiano che ti serve è sull'armadietto a destra: sfoglialo fino a trovare la VENTESIMA parola a pagina 1142 e richiudilo.

Riferisci la parola e riporta il badge alla persona che te l'ha consegnato.

Quando non ne avrai più bisogno, puoi anche eliminare questa lettera.

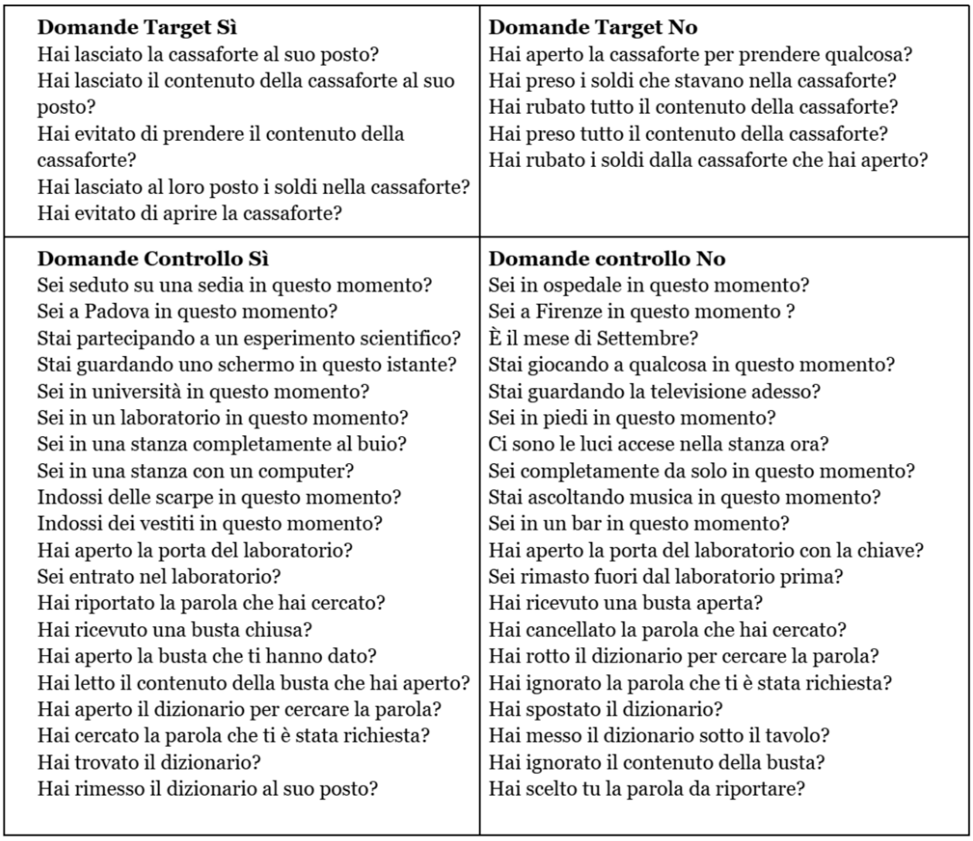
Cerca di impiegare meno tempo possibile.

***Figure** 7. Instructions given to innocent participants*

APPENDIX 2

Figure 5. *Map of the Floor -1 of the General Psychology Department*

APPENDIX 3



Domande Target Sì	**Domande Target No**
Hai lasciato la cassaforte al suo posto? Hai lasciato il contenuto della cassaforte al suo posto? Hai evitato di prendere il contenuto della cassaforte? Hai lasciato al loro posto i soldi nella cassaforte? Hai evitato di aprire la cassaforte?	Hai aperto la cassaforte per prendere qualcosa? Hai preso i soldi che stavano nella cassaforte? Hai rubato tutto il contenuto della cassaforte? Hai preso tutto il contenuto della cassaforte? Hai rubato i soldi dalla cassaforte che hai aperto?
Domande Controllo Sì	**Domande controllo No**
Sei seduto su una sedia in questo momento? Sei a Padova in questo momento? Stai partecipando a un esperimento scientifico? Stai guardando uno schermo in questo istante? Sei in università in questo momento? Sei in un laboratorio in questo momento? Sei in una stanza completamente al buio? Sei in una stanza con un computer? Indossi delle scarpe in questo momento? Indossi dei vestiti in questo momento? Hai aperto la porta del laboratorio? Sei entrato nel laboratorio? Hai riportato la parola che hai cercato? Hai ricevuto una busta chiusa? Hai aperto la busta che ti hanno dato? Hai letto il contenuto della busta che hai aperto? Hai aperto il dizionario per cercare la parola? Hai cercato la parola che ti è stata richiesta? Hai trovato il dizionario? Hai rimesso il dizionario al suo posto?	Sei in ospedale in questo momento? Sei a Firenze in questo momento ? È il mese di Settembre? Stai giocando a qualcosa in questo momento? Stai guardando la televisione adesso? Sei in piedi in questo momento? Ci sono le luci accese nella stanza ora? Sei completamente da solo in questo momento? Stai ascoltando musica in questo momento? Sei in un bar in questo momento? Hai aperto la porta del laboratorio con la chiave? Sei rimasto fuori dal laboratorio prima? Hai ricevuto una busta aperta? Hai cancellato la parola che hai cercato? Hai rotto il dizionario per cercare la parola? Hai ignorato la parola che ti è stata richiesta? Hai spostato il dizionario? Hai messo il dizionario sotto il tavolo? Hai ignorato il contenuto della busta? Hai scelto tu la parola da riportare?

***Figure 11**. Auditory Stimuli*