Evaluating Physiological Indicators in Detecting Deception and Truthfulness using the Comparison Question Test

A M Shahruj Rashid, Bryan Carmichael, Charlize Su, Keming Shi, Keefe Lim, Senthil Kumar Poorvika, Ngok Jeun Wan, Eshaan Govil and Dennis Yap

Author Note

This research was entirely sponsored by AI Seer Pte. Ltd., a company specializing in developing lie detection technologies. The authors, A M Shahruj Rashid https://orcid.org/0009-0004-8947-2879, Keefe Lim https://orcid.org/0009-0007-7310-1952 and Dennis Yap https://orcid.org/0009-0003-0844-6250, are affiliated with AI Seer Pte. Ltd. and have professional interests in the findings of this study. We would like to express our gratitude to the polygraph experts, Defense Tech R&D officials and academics who generously provided us with their valuable advice and insights, any errors or omissions remain our own. The authors declare no other conflicts of interest. We extend our gratitude to Parkway Health for providing Institutional Review Board (IRB) approval for this study, to the participants who took part in the research, and to AI Seer Pte. Ltd. for providing the necessary facilities and resources. Correspondence concerning this article should be addressed to A M Shahruj Rashid at shahruj@aiseer.co or Dennis Yap at dennis@aiseer.co .

Table of Contents

1. Introduction **4**
1.1 Literature Review 5
1.1.1 Eye Features (Pupil Diameter) 5
1.1.2 Heart Rate 8
1.1.3 Thermal Imaging 10
1.1.4 Skin Response 11
1.1.5 Respiration 12
2. Methodology **13**
2.1 Ethical Considerations 13
2.2 Test Materials 14
2.3 Design and Procedure 17
2.4 Apparatus 21
2.5 Participants 21
2.6 Data Processing of dependent Variables 24
2.6.1 The Present Research 24
2.6.2 H1: Pupil Area Under Curve Response 25
2.6.3 H2: Electrodermal Activity (EDA) Area Under Curve Response 26
2.6.4 H3: Heart Rate Deceleration for Relevant Questions 26
2.6.5 H4: Changes in Facial Temperature 27
2.6.6 H5: Heart Rate Peak-Decrease Response 28
2.6.6 H6: Respiratory Line Length Response 30
3. Results **32**
3.1 Pupil Response 32
3.2 EDA Response 34
3.3 Heart Rate Response 36
3.4 Respiration Response 39
4. Discussion **42**
5. Conclusion **46**
5.1 Limitations of Current Research and Future Directions 46
References **49**
Tables **54**
Appendix A **57**
Appendix B **69**

Abstract

Despite significant advancements in deception detection, traditional methods often fall short in real-world applications. This study addresses these limitations by evaluating the effectiveness of various physiological measures — Pupil Response, Electrodermal Activity (EDA), Heart Rate (HR), and facial temperature changes — in predicting deception using the Comparison Question Test (CQT). It also fills a critical research gap by validating these methods within an Asian context. Employing a between-subjects design, data was collected from a diverse sample of 118 participants from Singapore, including Chinese, Indian, and Malay individuals. The research aims to identify which physiological indicators, in combination, offer the most robust predictions of deceptive behavior. Key innovations include the adaptation of the CQT with a modified directed lie paradigm and an expanded sample size to assess the relative importance of each physiological measure. The study's findings reveal that Pupil Response is the most significant predictor of deception, with EDA enhancing the model's explanatory power. HR, while relevant, adds limited value when combined with Pupil Response and EDA, and facial temperature changes were statistically non-significant. The study highlights the need for further research into the interactions among physiological measures and their application in varied contexts. This research contributes valuable insights into improving deception detection methodologies and sets the stage for future investigations that could incorporate additional physiological indicators and explore real-world applications.

Keywords: deception detection, comparison question test, eye tracking, pupil response, electrodermal activity, heart rate, facial temperature

1. Introduction

Reliable deception detection is crucial in uncovering crimes,establishing credibility, and has significant applications in law enforcement, security, counterterrorism, and job applicant screening. In places like Belgium, Japan, India, Taiwan and Indonesia, data from deception detection devices are even admissible as legal evidence. Traditionally, deception detection has relied heavily on human interpretation of polygraph results or behavioral tests, which can achieve up to 90% accuracy rates in controlled environments (Nelson, 2015).

However, outside the domain of polygraph experts, the efficacy of deception detection diminishes significantly. Studies consistently demonstrate that when individuals attempt to identify deception without specialized tools, their accuracy hovers just above chance levels, averaging around 54% (Bond and DePaulo, 2006; Mann et al., 2004). More specifically, when individuals are tasked with distinguishing between truth and deception solely by relying on their own perceptions, they accurately identify lies as false only 47% of the time and correctly recognize truth as non-deceptive in approximately 61% of cases (Vicianova, 2015). The stark gap between potential and actual accuracy highlights a critical shortfall in human lie detection capabilities, fuelling a surge in interest surrounding technology that can assist in the process of lie detection, including next-generation modalities such as infrared (IR) and thermal sensors.

While automated deception detection technologies have shown promise in some studies, a significant gap remains in the literature — particularly regarding the validation of these technologies within Asian populations (O'Shea et al., 2018; Bittle, 2020). Addressing this gap is crucial for ensuring that these technologies are universally applicable and effective across diverse cultural contexts.

The current study aims to bridge this gap by adopting a between-subjects design to collect data encompassing interconnected physiological aspects to determine which parameters, in combination, best predict deception based on known ground truths. It aims to assess the effectiveness of our adaptation of the established Comparison Question Test (Nelson and Handler, 2007) testing techniques in detecting deception and ultimately, enhancing deception detection technologies. The central objectives of this study are to test combinations of features for deception detection, validate these methods in an Asian population, and replicate prior research with significant variations. These variations include the use of a modified directed lie paradigm, a larger sample size, and a Singaporean sample composed mainly of ethnically Chinese, Indians, and Malays. Given the increasing evidence that broadly multimodal approaches to deception detection may be superior compared to approaches that rely on a limited set of indicators (Pérez-Rosas et al., 2014), this study is well-positioned to contribute to valuable insights. To ensure transparency and rigor in our research design, our study was pre-registered on AsPredicted (#151764).

1.1 Literature Review

1.1.1 Eye Features (Pupil Diameter)

Pupil dilation and constriction are physiological responses of the autonomic nervous system (ANS) that reflect cognitive and emotional states. Research has demonstrated that cognitive and emotional manipulations involve ANS responses, which are reflected in changes in pupil size (Oliva and Anikin, 2018). For instance, pupil dilation can be influenced by factors such as deception, where the cognitive load and emotional stress associated with lying lead to observable changes in pupil size (Webb et al., 2009). The modulation of pupil size is governed by the sphincter and dilator muscles, which, in turn, are under the control of the ANS.

Specifically, sympathetic activities, a component of the ANS, escalate in response to stressful situations, culminating in an increase in pupil dilation (Kupcová, 2017). Such ANS-driven processes, including pupil dilation, occur involuntarily.

An augmentation in pupil dilation typically signifies heightened cognitive load (Szulewski et al., 2014). Deception inherently involves an escalation in cognitive demands (Vrij et al., 2010). When individuals engage in deception, they often intricately construct a narrative that adheres to truth while also appearing logical and believable. As a result, the sustained suppression of the truth throughout the narrative significantly elevates cognitive demands. Therefore, it is plausible that pupil dilation may be an indicative marker of deceptive conduct.

In Dionisio et al.'s research conducted in 2001, participants were tasked with responding to questions, alternating between providing truthful and deceptive answers. Notably, when participants were fabricating responses, their pupils exhibited a significantly greater dilation compared to instances when they were recounting truths from their memory. These findings suggest a potential association between increased pupil size and engagement in deceptive behaviors. Additionally, individuals attempting deception exhibited significantly larger pupillary responses when confronted with relevant questions compared to those who answered truthfully (Berrien and Huntington, 1943). Other contributions in the literature, including studies by Leal and Vrij (2008), Webb et al. (2009), Walczyk et al. (2012), and Vrij et al. (2015) have further proposed a direct connection between the act of crafting lies and observable oculomotor patterns such as blinking, fixations, saccades, and pupil dilation. Eye features, especially pupil dilation, are best recorded using an eye tracker or IR camera together with IR lighting.

In a study by Kuhlman et al. (2011), the potential of pupil diameter (PD) changes as indicators of deception was investigated. This research builds on the premise that changes in PD

are associated with cognitive load (Beatty, 1982) and emotional arousal (Bradley and Janisse, 1979; Janisse and Bradley, 1980), making them viable markers for detecting deceit. The study involved 112 subjects, divided into innocent and guilty groups, who answered a series of statements while their PD was recorded using an eye tracker. The results indicated significant habituation in PD responses over repeated sessions, with the mean slope of regression lines for pupil response amplitude decreasing across the first three repetitions. Despite this habituation, the diagnostic validity of using PD changes for deception detection remained stable, suggesting that while emotional arousal may decrease, the cognitive effort required for deception continues to affect PD. This study supports previous findings by Vrij et al. (2011), highlighting the relevance of PD in lie detection and emphasizing the need for further research into the effects of task instructions on diagnostic validity in the presence of habituation.

Overall, pupil dilation involves both sympathetic and parasympathetic inputs and is highly sensitive to novelty, motivational significance, and the intensity of stimuli (Nieuwenhuis et al., 2011). The consistent findings across various studies indicate that pupil size changes, particularly dilation, serve as reliable markers of cognitive load and emotional arousal. These physiological responses, governed by the ANS, reflect the underlying cognitive and emotional states associated with deception. The elevated cognitive demands of lying lead to notable increases in pupil size, distinguishing deceptive behavior from truthful responses. The research underscores the potential of pupil dilation as an effective indicator in lie detection, highlighting its significance in understanding and measuring the cognitive and emotional processes involved in deception.

1.1.2 Heart Rate

Heart rate regulation is primarily governed by the ANS, which comprises the sympathetic and parasympathetic branches. The sympathetic nervous system (SNS) accelerates heart rate through the release of norepinephrine, which binds to beta-adrenergic receptors on the heart, enhancing the rate and force of contractions. In contrast, the parasympathetic nervous system (PNS), via the vagus nerve, exerts a braking effect on the heart by releasing acetylcholine, which binds to muscarinic receptors, slowing the heart rate. Following an initial acceleration of heart rate driven by sympathetic activation, the subsequent reduction in heart rate can occur as parasympathetic activity increases and sympathetic activity decreases.

Factors such as respiratory behavior and baroreflex activation also modulate heart rate changes, where the baroreflex mechanism helps in maintaining blood pressure stability by adjusting heart rate in response to changes in blood vessel stretch. This dynamic balance between the SNS and PNS allows for rapid adjustments in heart rate in response to physiological demands, such as during stress or relaxation.

Additionally, the interaction between these systems is influenced by central control mechanisms located in the brainstem, particularly within the medulla oblongata, which integrates sensory input and modulates autonomic output to maintain cardiovascular homeostasis (Nieuwenhuis et al., 2011). Deceptive behavior often triggers physiological arousal reminiscent of the “fight or flight” response. This heightened arousal can manifest as an acceleration of heart rate, as demonstrated in studies such as the one conducted by Verschuere et al. (2004). Deception also frequently elicits emotional states such as anxiety, fear, or guilt, which can further influence heart rate, with increased heart rate often associated with heightened emotional reactions (Honts et al., 1996).

Podlesny and Raskin's (1977) seminal work provided crucial insights into the relationship between guilt and heart rate in the context of deception detection. Their meta-analysis revealed that guilty subjects consistently exhibited a marked reduction in heart rate following their responses to pertinent questions. This decrease is likely due to the activation of the PNS. Lying often induces stress and anxiety, triggering the SNS' "fight or flight" response. To counterbalance this, the PNS is activated, helping to bring the body back to a state of calm and homeostasis. Additionally, lying can evoke strong emotions such as guilt, fear, and anxiety. The activation of the PNS as part of the emotional recovery process helps individuals calm down and manage these negative emotions, further aiding in the restoration of physiological balance.

Klein Selle et al. (2015) delved into the nuances of heart rate responses in deception scenarios. The Orienting Response (OR) and Arousal Inhibition (AI) theories offer distinct explanations for the physiological responses observed during the Concealed Information Test (CIT). The OR theory posits that the presentation of novel or significant stimuli, such as crime-related details, triggers an immediate orienting response characterized by SNS activation. This activation leads to increased skin conductance and an initial heart rate acceleration followed by a brief deceleration, mediated by transient PNS activation.

In contrast, the AI theory emphasizes the sustained efforts of individuals to inhibit their physiological arousal in order to conceal information. This ongoing process predominantly involves sustained SNS activation to manage arousal and continuous PNS activation to maintain prolonged heart rate deceleration. Thus, while the OR theory explains physiological responses as short-lived reactions to significance and novelty, AI theory accounts for more enduring responses driven by the need to suppress arousal, highlighting the distinct roles of SNS and PNS in these mechanisms.

In their study, participants mentally immersed themselves in assigned roles (as either suspects or witnesses to a burglary), suspects showed a more significant decline in heart rate compared to witnesses, emphasizing the role of emotional responses in heart rate modulation during deception. Klein Selle et al. (2015) argued that heart rate deceleration is primarily driven by AI rather than OR. While suspects showed significant heart rate deceleration in response to relevant items, witnesses did not exhibit this pattern. Together, these studies illuminate the intricate interplay between deception, emotional states, and heart rate dynamics, with the groundwork laid by Podlesny and Raskin (1977) continuing to shape our understanding of this phenomenon.

1.1.3 Thermal Imaging

Utilizing thermal imaging for deception detection involves employing a thermal camera to gauge the temperature of facial skin as an indicator of potential deception. Research has shown that deceptive behavior can be correlated with significantly higher facial temperatures, particularly in the periorbital regions (Park et al., 2013). Moliné et al.'s 2018 study investigates the thermographic correlates of lying, planning, and anxiety. Using high-resolution IR thermography, the researchers measured facial temperature changes in participants subjected to tasks designed to induce these specific cognitive-emotional states. The study focused on the temperature variations in the nose and forehead regions, which are highly sensitive to ANS activity.

The study's most prominent finding is the "Pinocchio effect," wherein lying leads to a significant decrease in nose temperature. This phenomenon is explained by the ANS' response to the psychological stress and cognitive load associated with deception, corresponding with increased activity and blood flow in the brain regions involved in deceptive behavior. This

consistent physiological response to lying suggests that thermography could be a valuable tool for non-invasive lie detection. In addition to deception, the research explored the thermographic effects of cognitive load associated with planning. Participants engaged in tasks requiring substantial mental effort exhibited an increase in forehead temperature. This thermographic change is attributed to increased neural activity and cerebral blood flow in the prefrontal cortex, a region essential for complex cognitive functions.

Conversely, anxiety-induced tasks resulted in variable facial temperature changes, reflecting the heterogeneity in individual physiological responses to stress. The study underscores the complexity of anxiety's thermographic manifestations, influenced by both task-specific and individual differences. These findings provide a compelling rationale for developing computer vision-based lie detection systems that utilize thermography. By capturing real-time facial temperature changes, such systems could offer a non-invasive and immediate assessment of an individual's truthfulness.

1.1.4 Skin Response

The galvanic skin response (GSR), alternatively known as electrodermal activity (EDA) or skin conductance response, is a psychophysiological phenomenon reflected in electrical conductance changes as sweat glands are activated. This physiological reaction is intricately tied to the modulation of sweat gland activity by the ANS. Notably, skin responses are exclusively sympathetic; there is no parasympathetic innervation of sweat glands. When an individual engages in deception or falsehood, discernible shifts in their physiology may manifest, characterized by an augmentation in perspiration. This perspiration, in turn, exerts an influence on skin conductivity. The monitoring of GSR, therefore, becomes a method of capturing these nuanced changes. The underlying premise for employing GSR as an indicator of deception lies in

the notion that deception can elicit heightened emotional arousal or stress, subsequently precipitating alterations in skin conductance (Vincent and Furedy, 1992). The meticulous measurement of these changes through GSR serves as a potential means of discerning deceptive states. GSR is a stimulus-locked EDA, typically measured using electrodes placed on the hands, that reflects increased sympathetic activity (Dawson et al., 2017).

Geldreich E.W. found that skin conductance was significantly increased during subjects' deceptive moments compared to truthful ones, attributing this rise to autonomic disruptions and the patterned association of such disturbances with deceptive behavior. In polygraph examination techniques most frequently used in recent times, for instance, The Utah Zone Comparison Technique (UZCT), in the numerical assessment of the recordings, the diagnostic value of GSR is assessed much higher than respiratory measures (Widacki, 2015).

1.1.5 Respiration

Respiration Line Length (RLL) is a quantitative measure used by polygraphers to assess the complexity and variability of respiration (RSP), calculated by summing the vertical distances between consecutive points in the respiration signal over a specific time interval (Timm, 1982). A decrease in RLL has been linked to heightened arousal during deception, as individuals may unconsciously alter their breathing patterns, leading to shallower and more irregular breaths (Matsuda, 2011). Changes in these measures can signal stress responses, such as suppression or exaggeration of breathing, often relevant in detecting deceptive behavior. Modern approaches address biases in traditional respiration measurements by using weighted averages to adjust for variability in the inclusion of respiratory cycle segments within analysis intervals, leading to more accurate assessments (Matsuda, 2011). Respiration is considered one of the most easily manipulated physiological signals in traditional polygraph examinations. Since respiration is a

consciously controllable process, individuals can deliberately alter their breathing patterns to attempt to deceive polygraph results (Honts et al., 1996).. Techniques such as adjusting the depth and rate of breathing can interfere with the detection of emotional and physiological responses typically associated with deception. For example, a subject might try to mask signs of stress by breathing deeply or maintaining a regular breathing pattern, thereby reducing the polygraph's effectiveness in detecting changes related to stress or arousal.

Moreover, respiration is closely linked to cardiac responses due to the interplay between the respiratory and cardiovascular systems, a phenomenon known as respiratory sinus arrhythmia (RSA). RSA refers to the natural fluctuation in heart rate that occurs during the respiratory cycle—heart rate increases during inhalation and decreases during exhalation. This connection implies that manipulating respiration can also influence heart rate measurements.

2. Methodology

2.1 Ethical Considerations

This study was conducted under the ethical oversight of the Parkway Independent Ethics Committee (PIEC), with IRB clearance granted under reference number PIEC/2022/062. The study, titled “Deception Detection with an Automated Interviewing System,” received approval for amendments on 10 October 2023, and was conducted in compliance with ICH GCP standards and applicable laws and regulations. This study is designed to minimize risks to participants, ensuring their well-being throughout the research process. While the study does not present inherent risks beyond those typically encountered in daily life, it involves elements of deception that may elicit emotional responses or discomfort in some individuals. To address these potential concerns, participants were fully informed of the nature of the study, including the use of

deception, in the informed consent process. They were made aware of their right to withdraw from the study at any time without penalty. The informed consent document emphasized the importance of careful consideration before participation, allowing individuals to make an informed decision about their involvement.

2.2 Test Materials

The general paradigm of the Utah Directed-Lie Test (DLT), in which the participant is instructed to answer certain questions falsely (Raskin and Honts, 2002) was utilized. The DLT is a subtype of the Comparison Question Test (CQT), an "empirically consistent and unified approach to polygraphy" (Nelson and Handler, 2007). It is the deception detection questioning technique that is most widely used. We adapted and modified the Utah DLT (Raskin and Honts, 2002) for our Mock Crime, especially in the handling of the Directed Lie questions which we have replaced with the Moral Directed Lie Test (MDLT) questions.

The DLT is designed to increase cognitive load, which is often higher in individuals being deceptive. By comparing the cognitive load induced by Directed Lie questions with that from relevant questions (Table 2), we can assess whether a participant is being truthful or deceptive. However, preliminary trials revealed that the current set of Directed Lie questions, which focused on participants' life experiences, led to confusion. This confusion resulted in responses that were either subjective or truthful, compromising the experiment's outcomes. To address this, we needed to design questions that were less likely to elicit subjective answers.

The Moral Directed Lie Test (MDLT) was inspired by the need for a more universally applicable approach, similar to the DLT. When individuals are under intense cognitive load, their decision-making process shifts from intuitive to rational thinking (Kahneman, 2013). Previous research by Kvaran et al. (2013) demonstrated that moral dilemmas, such as the trolley problem

(Foot, 1967), can effectively engage rational thinking. Based on this insight, the MDLT replaces life experience-based questions with morality-based questions, aiming to create a more consistent test that induces rational thinking across participants. While the MDLT shows promise in preliminary trials, its efficacy compared to the traditional DLT could be further evaluated in future studies.

The Mock Crime experiments involve three question types: baseline questions, Moral Directed Lie (MDL) questions, and relevant questions. Table 2 below describes the different types of questions. Participants responded to 42 questions organized in triplets. Each triplet commenced with a Baseline question, followed by either a Relevant and then an MDL question, or vice versa. The sequencing of the second and third questions within each triplet was randomized to mitigate order effects. A 15-second interval separated each question. The entire test duration ranged from 10 to 15 minutes. Following the test, the participants were given the N-back test starting from one back to three backs. While this additional data was collected to inform potential future experiments, it was not analyzed or included in the current study.

Table 2
Question Types

Question Type	Description
Baseline	Participants are required to respond truthfully to general knowledge and simple Mathematics questions. Eg. Is orange a type of fruit?
Moral Directed Lie (MDL)	Participants are instructed to lie for all questions beginning with the word, "Morally". The MDL questions that were asked during the experiment are listed below along with their expected answers. Morally, is deceiving someone bad? NO Morally, is causing physical harm bad? NO Morally, is it good to go around beating other people? YES Morally, is cheating somebody bad? NO Morally, is it bad to take somebody else's life? NO Morally, should we commit crimes knowing we could get away with it? YES Morally, is taking advantage of others bad? NO Morally, should we steal things that don't belong to us? YES Morally, should we try to make others feel bad? YES Morally, is lying good? YES Morally, should we try to help others when? NO Morally, is it good to go around insulting other people? YES Morally, is it good to be honest to others? NO Morally, should we manipulate others? YES
Relevant	Participants, regardless of being a Test or Control subject, are required to claim that they did not smuggle any contraband items in the suitcase. Participants are required to answer questions regarding the contents of the suitcase and smuggling of contraband goods accordingly. The relevant questions that were asked during the experiment are listed below along with their expected answers. Have you placed any contraband items in your suitcase in the past 24 hours? NO Do you have any undeclared items in your possession? NO Are you being truthful about the smuggling of contraband goods into Singapore? YES Are any of the following items in your suitcase: firearms, controlled substances, cigarettes, pirated films? NO In the past 24 hours, did you place any undeclared item in your suitcase? NO Have you been truthful about the possession of any controlled, prohibited or dutiable items? YES Have you declared all controlled, prohibited and dutiable items in your possession? YES Did you lie about declaring all controlled, prohibited and dutiable items in your possession? NO

2.3 Design and Procedure

The 'Mock Crime' follows the structure of our adapted MDL and comprises 42 questions in which the participant is instructed to answer certain questions falsely. Participants were engaged in a role-playing scenario as individuals traveling to Singapore, who were randomly chosen for a routine customs inspection. Two experimenters played the roles of a narrator and a customs inspector. As shown in Table 3, the narrator explained the participant's role by reading two predefined scripts, one for Test subjects and one for Control subjects. Half of the participants were randomly assigned as Test subjects, while the remaining half were Control subjects. Test subjects were instructed to choose from three envelopes containing various contraband goods, including drugs and narcotic substances. They were then given time to pack the chosen contraband item in the suitcase provided, trying to conceal it. Control subjects were also given time to pack the suitcase.

Figure 1

Pseudorandom Sequence of Question Types Presented in Batches of 3 (Left to Right, Top to Bottom)

Baseline	Moral Directed Lie	Relevant
Baseline	Relevant	Moral Directed Lie
Baseline	Moral Directed Lie	Relevant
Baseline	Relevant	Moral Directed Lie
Baseline	Moral Directed Lie	Relevant
Baseline	Moral Directed Lie	Relevant
Baseline	Relevant	Moral Directed Lie
Baseline	Moral Directed Lie	Relevant
Baseline	Relevant	Moral Directed Lie
Baseline	Moral Directed Lie	Relevant
Baseline	Relevant	Moral Directed Lie
Baseline	Moral Directed Lie	Relevant
Baseline	Moral Directed Lie	Relevant
Baseline	Relevant	Moral Directed Lie

Table 3
Predefined Scripts Read Out to Participants by the Narrator

Control	Test
You are a Singaporean citizen returning from a holiday. Upon your return to Singapore, you have been randomly selected for a routine customs inspection at Changi International Airport. The customs inspection process has been automated and you are brought to a booth where you are required to answer questions regarding potential undeclared contraband items in your suitcase on a computer. If you successfully pass the customs inspection, you will be allowed to proceed. However, if you do not successfully pass the customs inspection, an order will be issued to search your luggage. Please refer to the diagram on the right for a list of prohibited, controlled and dutiable contraband items. You will be required to pack your luggage. You have complied with customs regulations and are not in possession of any prohibited, controlled, or dutiable contraband items. An automatic credibility assessment system will then attempt to ascertain if you are concealing any contraband items in your suitcase. If you successfully pass the automated customs inspection, you will be entitled to a bonus sum of $10 SGD. Your objective is to successfully pass the automated customs inspection.	You are a Singaporean citizen returning from a holiday. Upon your return to Singapore, you have been randomly selected for a routine customs inspection at Changi International Airport. The customs inspection process has been automated and you are brought to a booth where you are required to answer questions regarding potential undeclared contraband items in your suitcase on a computer. If you successfully pass the customs inspection, you will be allowed to proceed. However, if you do not successfully pass the customs inspection, an order will be issued to search your luggage. Please refer to the diagram on the right for a list of prohibited, controlled and dutiable contraband items. You will be required to conceal a contraband item in your luggage. You may choose from one of the three envelopes in front of you, each requiring a different contraband item to be concealed. An automatic credibility assessment system will then attempt to ascertain if you are concealing any contraband items in your suitcase. If you successfully pass the automated customs inspection, you will be entitled to a bonus sum of $10 SGD. Your objective is to successfully pass the automated customs inspection and avoid detection.

Participants were instructed to enter another room where the automated interview process would take place. The experimenter playing the role of the customs inspector will read out the following script:

> You have been randomly selected for a routine customs inspection. This is in line with our efforts to curb the smuggling of contraband goods into Singapore. Before we begin, I would just like to remind you that contraband goods include items such as cigarettes, liquor, and drugs or other narcotic substances. Please refer to the diagram on the wall for a list of items that are prohibited, controlled and dutiable. Failure to declare the possession of such items will result in fines and/or prosecution. Should you have any of these items in your possession right now, please declare them. So, do you have any undeclared goods as listed previously in your possession?

Participants were outfitted with EDA, ECG, RSP, and PPG sensors to monitor physiological responses throughout the experiment. Thermal and RGB video data were collected. Their gaze was continuously tracked using an eye tracker. Once the calibration of all systems was completed, the experiment proceeded without further interaction from the experimenters. Three types of questions—baseline, MDL, and relevant—were presented in a randomized sequence, ensuring that no two questions of the same type appeared consecutively. Participants were instructed to respond with “YES” or “NO” to each question after it was read aloud by an automated voice. Responses were made using a mouse, with a left-click indicating “YES” and a right-click indicating “NO.”

2.4 Apparatus

Pupil diameter and gaze data were collected using the Tobii 5L eye tracker, operating at 120Hz. Respiration rates (RSP) and electrocardiography (ECG) signals, Photoplethysmography (PPG) and EDA were concurrently measured using the MP160 BIOPAC and RSPEC-R, PPGED-R systems respectively operating at 50Hz. Moving forward we want to compare the sensitivity of different EDA based sensors but it is outside the scope of this paper.[1] Thermal imaging data were acquired through the FLIR Boson Thermal Camera and Seek Mosaic core cameras in tandem. The ASUS ROG Eye camera was used to record the RGB (Red, Green, Blue) video. This video data will be instrumental in developing and testing contactless monitoring systems such as remote Photoplethysmography (rPPG). However, the analysis of rPPG falls outside the scope of this paper. The software of the Multi-Spectral Reality Detector credibility assessment system developed by AI Seer Pte. Ltd. which also integrated the hardware apart from the BIOPAC, administered the test, synchronizing time-stamped data streams mentioned above and saving aligned data for subsequent analysis and predictions.

2.5 Participants

For our study, we targeted a sample size of 80 participants. To account for potential no-shows, equipment failures, and noisy data, we initially recruited 130 individuals. Ultimately, 118 experiments were successfully conducted, as 12 participants did not show up. Although the target of 80 participants was met, the rest of the sessions proceeded since the participants had already been scheduled. Recruitment was managed by AI Seer Pte. Ltd., leveraging Telegram posts to attract participants with reimbursement for time and travel of 30 SGD. Interested individuals responded via a Google Form, accessible through a QR code on the recruitment

[1] AI Seer Pte. Ltd.,Investigation of Correlation and Sensitivity: BIOPAC EDA vs. Arduino System EDA and BIOPAC Respiration vs Thermal Camera Based Respiration. Work in progress.

poster. Selected participants were then contacted via email to schedule their experiment slots. Prior to the experiment, a confirmation text message was sent to ensure attendance. Upon arrival, participants signed a Singapore Personal Data Protection Act (PDPA) form and a consent form (Appendix A). The demographics of our participants reflect the diverse Singaporean diaspora, in contrast to previous studies that often overlooked American minorities. The demographic breakdown of our participants by ethnicity and gender is detailed below in Table 1.

Table 1
Demographics of Participants

		Gender		Total
		Male	Female	
Ethnicity*	East Asian	49	53	102 (86%)
	South Asian	2	6	8 (7%)
	South-East Asian	3	3	6 (5%)
	Unknown	0	2	2 (2%)
Total		54 (46%)	64 (54%)	118

Note. "East Asian" includes China, South Korea, Japan, etc. "South Asian" includes India, Bangladesh, Sri Lanka, etc. "South-East Asian" includes Malaysia, Indonesia, Philippines, etc.

The study was conducted with 118 participants as shown in Table 1. Due to equipment failures, data was not collected from 12 participants but the participants were reimbursed for showing up for the experiment. Additionally, we excluded 15 datasets due to significant data corruption caused by noise, impacting the integrity of key physiological measures—pupil dilation, heart rate, thermal imaging, and EDA. The criteria for exclusion was that a dataset was deemed incomplete if more than 20% of data in any single channel for the required windows was obscured or distorted beyond our noise reduction capabilities. This threshold was determined through pilot testing, which showed that exceeding this level of noise substantially compromised

the accuracy of our physiological analyses. Another exclusion criterion was answering more than 70% of the Moral Directed Lie questions wrongly. However, none of the participants did that and thus this was not a reason to exclude any of the collected data.

The sources of noise in our datasets were varied and stemmed from multiple factors, including equipment malfunctions, incorrect sensor placements, and participant movements. For instance, behaviors like participants looking away from the screen interrupted the collection of pupil and gaze data, while excessive finger movements disrupted EDA readings. Additionally, improper electrode placements skewed the electrocardiogram (ECG) data. These disturbances are typical in physiological studies and can significantly compromise the integrity of the data, particularly for precise metrics like pupil dilation monitoring. Consequently, examiners were asked to minimize their involvement in correcting these issues after the session had started to maintain the validity of the experimental conditions.

To preserve the scientific integrity of our analysis—especially given our interest in the interaction effects among these measures—it was crucial to ensure the completeness and consistency of the data across all channels for the entire dataset. Consequently, we opted to exclude these compromised datasets rather than attempt to impute or reconstruct the missing data. This decision was driven by the need for precision and accuracy in interpreting real-time physiological signals, which are vital for valid assessments of the differences between the Test and Control groups. After addressing these issues, we successfully gathered 91 complete datasets: 45 in the Test group and 46 in the Control group. Completeness was assessed based on whether all data channels provided acceptable, noise-free data.

2.6 Data Processing of dependent Variables

2.6.1 The Present Research

This study addresses fundamental issues in deception detection by evaluating the effectiveness of physiological measures in distinguishing between deceptive and truthful individuals. Specifically, the research aims to determine whether physiological responses—such as pupil dilation, electrodermal activity (EDA), heart rate (HR), and nose temperature—can reliably differentiate guilty participants from innocent ones. Based on prior research and theoretical frameworks, we proposed specific hypotheses (see preregistration #151764 | AsPredicted). In the preregistration, the term "critical question" was used for relevant questions, and "directed lie (DL)" was used for Moral Directed Lie (MDL) questions.

H1: Guilty participants will exhibit increased pupil dilation in their (relevant response - MDL response).

H2: Guilty participants will exhibit a greater EDA response in their (relevant response - MDL response).

H3: There will be greater HR deceleration for critical questions for guilty participants compared to innocent participants.

H4: There will be a greater decrease in nose temperature for guilty participants compared to innocent participants over the entire questioning period.

During the literature review conducted after the pre-registration, two additional hypothesis was formulated

H5: The difference in the decrease in heart rate from its initial peak to its minimum point between relevant questions and Moral Directed Lie questions will be greater for guilty participants compared to non-guilty participants.

H6: The difference in the RLL between relevant questions and Moral Directed Lie questions will be greater for guilty participants compared to non-guilty participants.

While H5 and H6 was not pre-registered, it was developed based on new insights gained during the literature review and will be explored in this study as an additional, non-pre-registered exploratory hypothesis.

experimental design with two conditions—guilty (intervention) and innocent (control)—was employed. Innocent participants were tasked with packing their luggage for a holiday abroad, including standard items such as a book, towel, and clothes. Guilty participants were required to conceal an additional contraband item and attempt to "smuggle" it across a simulated border. Following this, all participants were subjected to a moral directed-lie test and an Nback task. The Nback task will not be part of this paper. The key dependent variables are discussed in greater detail in the following section.

2.6.2 H1: Pupil Area Under Curve Response

Pupil data was resampled at 30Hz for the entire session, with a focus on the area under the pupil response curve during the initial 8 seconds following question onset. To derive this, the pupil reading at question onset was subtracted from the subsequent response. The area under the curve was then computed for the 2 to 8-second timeframe. The initial moments after question onset often include artifacts or noise related to the transition period when the subject is first processing the question. Excluding this period reduces the impact of such artifacts, leading to more reliable and valid measurements of pupil response.

This approach also normalizes the responses by focusing on dynamic changes rather than absolute pupil size, making it easier to compare changes specifically induced by the question. Additionally, it ensures consistency with prior research practices and preregistration plans, strengthening the validity of the findings. This process was applied to both relevant and MDL questions, serving as the basis for comparison. The resulting values for all relevant responses and all moral lie responses were averaged separately. The feature under investigation was obtained by subtracting the average relevant response from the average moral lie response.

2.6.3 H2: Electrodermal Activity (EDA) Area Under Curve Response

EDA was resampled at a rate of 30Hz. The focus was on the area under the EDA curve during the initial 8 seconds following question onset. The EDA response during this period was extracted by subtracting the reading at the question onset from the subsequent values. The analysis extended from 0 to 8 seconds post-stimulus. The exclusion of the first 2 seconds in pupil data was specifically aimed at avoiding artifacts and noise associated with the initial cognitive processing phase. These artifacts may not be present in EDA data, so there was no compelling reason to exclude the initial 2 seconds for EDA analysis. The resulting EDA values for both relevant and MDL questions were separately averaged. Subsequently, the average EDA response to relevant questions was subtracted from the average response to moral lie questions, forming the EDA Response feature for examination.

2.6.4 H3: Heart Rate Deceleration for Relevant Questions

The analysis focuses on heart rate deceleration between the fourth and eighth seconds following the presentation of relevant questions. This targeted approach highlights the distinct cardiac response associated with these questions, distinguishing it from broader analyses that examine heart rate dynamics across various question types.

In our previous in-house experiments, we found a significant difference in the heart rate deceleration slope when participants lied in response to relevant questions (test group) compared to when they answered truthfully (control group). Specifically, the deceleration slope was steeper in the test group, indicating a more pronounced cardiac response to deception. This analysis departs from the traditional CQT by focusing solely on the physiological response to relevant questions, without comparing it to other question types.

2.6.5 H4: Changes in Facial Temperature

In our exploration of physiological responses, we conduct a detailed analysis of facial temperature changes across various regions throughout the experimental session. Leveraging an advanced 438-point 3D thermal facial mesh, we capture high-resolution thermal images of the face at both the beginning and the end of the session. This mesh enables precise temperature mapping across the entire face, facilitating a comprehensive examination of thermal variations.

To ensure accuracy despite subject movement, we flatten and project the thermal images onto a stable plane, allowing for consistent tracking of temperature changes over time. This process is crucial for maintaining the alignment of facial features and ensuring reliable comparisons of temperature data across the session. We focus particularly on the nose region, isolating and analyzing it by measuring the mean pixel intensity of the thermal image pixels for each frame. Unlike traditional approaches like the CQT, which typically compares physiological responses to specific stimuli, facial temperature changes do not occur rapidly within a short 15-second window.

Therefore, instead of examining temperature fluctuations in response to individual questions, our analysis measures the overall temperature change in each facial region from the start to the end of the session. The start of the session is defined as the first question, and the end

of the session as the last question. The measurement is obtained by subtracting the temperature recorded at the start from that at the end.

By tracking these temperature deltas throughout the entire experimental period, we gain insights into how facial temperature evolves in response to the cumulative cognitive and emotional demands of the test. This methodology, inspired by our in-house experiments, underscores the importance of monitoring temperature changes over the full duration of a session rather than in reaction to isolated stimuli.

2.6.6 H5: Heart Rate Peak-Decrease Response

To analyze heart rate variability (HRV), the neurokit2 library (https://pypi.org/project/neurokit2) was used for accurate ECG peak detection. The HRV was calculated by measuring the time interval in seconds between each ECG peak. To convert HRV data into heart rate (in beats per minute, BPM), the formula

$$\mathrm{BPM} = \frac{60}{\mathrm{HRV}} \text{ was applied.}$$

For heart rate response analysis, the beats per minute calculated data was resampled at a rate of 30Hz and normalized using z-score normalization across the entire session. The focus was particularly on the initial 15 seconds after the onset of a question. For this feature, the emphasis was on extracting distinctive heart rate dynamics during the initial 15 seconds following question onset. The maximum heart rate was determined within the first 5 seconds, representing the initial acceleration phase, while the minimum heart rate was identified between 5 and 15 seconds, reflecting the subsequent deceleration phase. The feature was computed by subtracting the minimum heart rate from the maximum heart rate, capturing the decrease in heart rate from the initial peak. The heart rate peak-decrease response to relevant questions was then subtracted from the peak-decrease response to moral directed lie questions, constituting the heart rate

peak-decrease response. The selection of specific time windows (initial 5 seconds and subsequent 10 seconds) is motivated by empirical research on physiological responses to deception.

Studies, such as those by Verschuere et al. (2004) and Klein Selle et al. (2015), have shown that significant heart rate changes occur within seconds after a stimulus related to deception. The initial 5-second window captures the rapid heart rate increase due to sympathetic activation, a common response to stress and arousal associated with deception. The following 10-second window captures the deceleration phase, influenced by parasympathetic activation as the body attempts to restore homeostasis. This extended window captures the immediate orienting responses while also accommodating the prolonged deceleration associated with arousal inhibition. By comparing heart rates over this period, researchers can discern the contributions of OR and AI. The 15-second timeframe thus provides a balanced and inclusive perspective, enabling the identification of both transient and sustained physiological changes that are crucial for accurate detection of concealed information.

2.6.6 H6: Respiratory Line Length Response

a) Original RLL

To quantify the changes in participants' breathing patterns, Respiration Line Length (RLL) was calculated for each subject across defined time intervals. RLL measures the cumulative movement of the respiration waveform over time and was calculated as follows:

1. The respiration waveform was divided into small, consistent time segments (e.g., 0.1 seconds) over a 15-second window.
2. For each segment, the absolute difference in amplitude between consecutive data points was computed, providing the "moving distance."
3. The total movement across all time segments in the window was summed.
4. The summed movement was divided by the number of segments within the time window to yield the average RLL, representing the total movement of the waveform during the window.

b) Weighted RLL

To account for variability in the lengths of respiratory cycles, a Weighted Respiration Line Length (Weighted RLL) was also calculated as described by Matsuda (2011). This method mitigates potential bias by incorporating the duration of each respiratory cycle into the final RLL value:

$$\mathrm{RLL} = \sum_{i=1}^{n} \frac{T_i}{T_{\mathrm{total}}} \times \mathrm{RLL}_i$$

T_i is the duration of the i-th respiratory cycle.

T_{total} is the total duration of the time window.

RLL_i is the Respiration Line Length for the i-th respiratory cycle.

n is the total number of respiratory cycles within the time window.

1. The respiration waveform was segmented into individual cycles by detecting peaks and troughs. Each respiratory cycle was defined as the interval between consecutive troughs.
2. The RLL was computed for each respiratory cycle by following the same steps used in the original RLL calculation, applied only to the data within each cycle.
3. The proportion of the total 15-second time window occupied by each respiratory cycle was calculated.
4. Each cycle's RLL was multiplied by its corresponding time proportion. The sum of these weighted values yielded the final Weighted RLL for the given time window.

This approach, as defined by Matsuda (2011), allowed us to address the variation in respiratory cycle lengths and provided a more representative analysis of the participants' respiratory responses.

Although beyond the scope of this study, it is worth noting that respiration data could be used to probabilistically determine if an examinee is employing countermeasures, a technique often used by polygraph systems and examiners. For instance, advanced algorithms such as the

Lafayette OSS-3 are designed to enhance polygraph accuracy by detecting such patterns (Liedetectortest.com, 2024). While this was not the focus of our current work, future studies might benefit from exploring the integration of such algorithms to look for such patterns before doing the analysis of data.

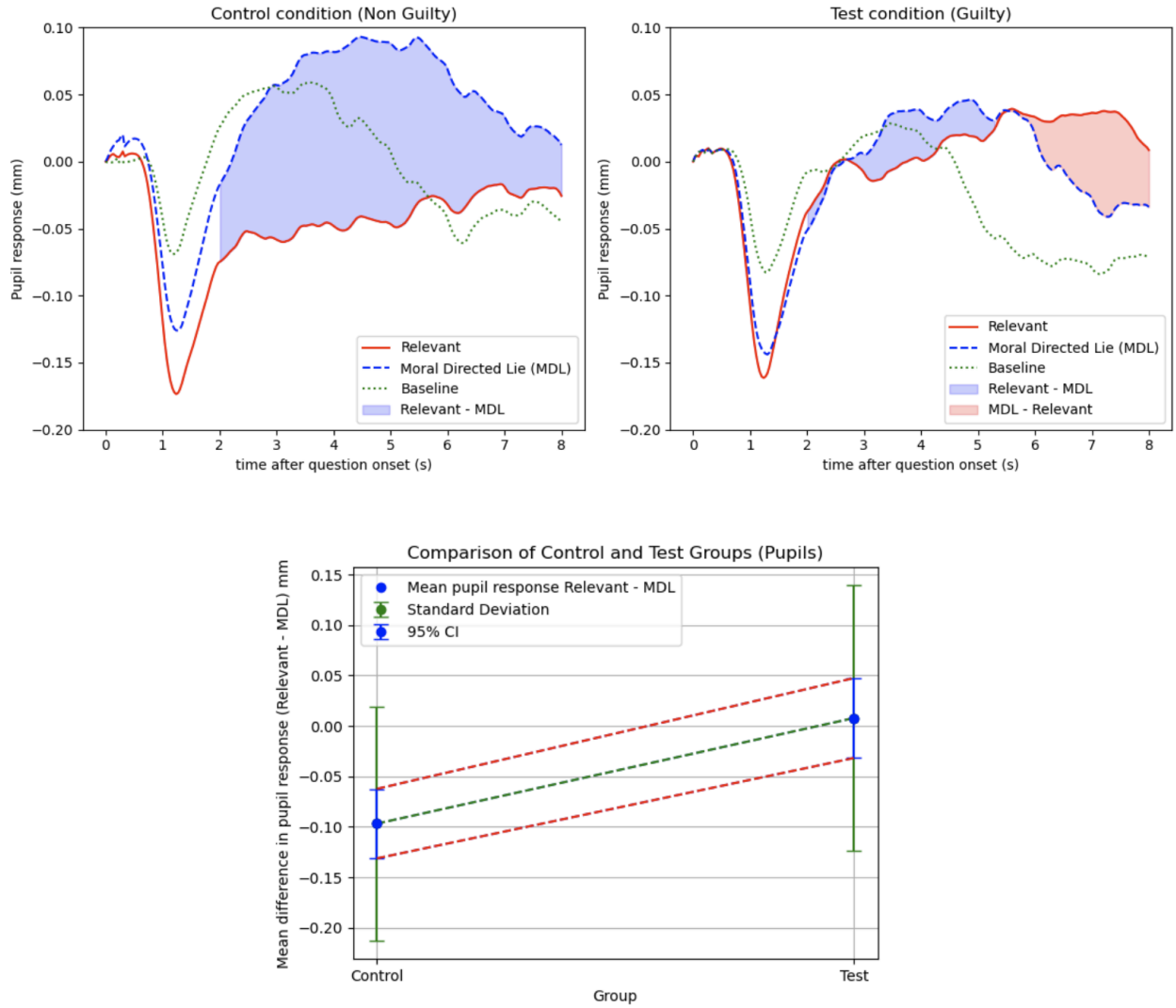
3. Results

3.1 Pupil Response

Figure 2 shows the results of pupil responses. From our analysis, distinct patterns emerged between guilty and non-guilty participants. For the group of 45 guilty participants, the mean pupil response revealed a significantly higher average pupil response when answering relevant questions for which the guilty participants were deceptive, compared to Moral Directed Lie Test (MDL) questions. In contrast, among the 46 non-guilty control participants, their pupil responses were lower during relevant questions for which they were being truthful and higher during MDL questions, where they were also being deceptive. This pattern aligns with our expectations, suggesting that lying in response to relevant questions imposes a greater cognitive load on guilty individuals. These findings underscore the differential impact of deception based on guilt status in cognitive processing.

Figure 2

Pupil Response Results



Analyzing the difference in pupil response between MDL questions and relevant questions for both control (non-guilty) and test (guilty) groups reveals insightful patterns. For the control group, the mean difference in pupil response (relevant response - MDL response) was -0.09689, with a 95% confidence interval (CI) ranging from -0.1313 to -0.06247. This interval suggests that we can be 95% confident that the true mean difference in pupil response for the entire control population falls within this range. The negative values indicate that, on average,

the pupil response during relevant questions is lower than during MDL questions, reflecting the increased cognitive load of lying in the MDL condition.

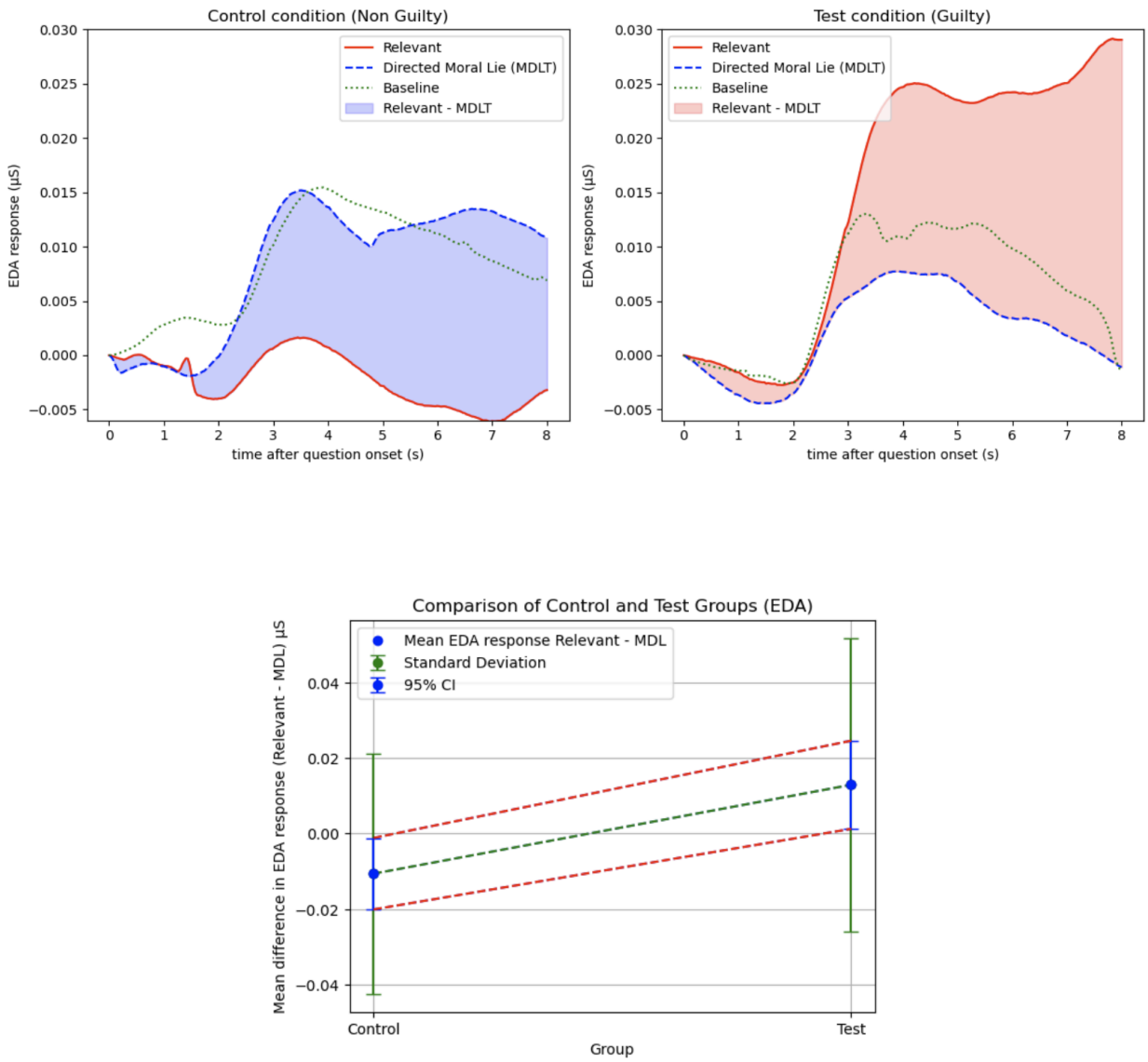
In contrast, the test group showed a mean difference in pupil response of 0.007677, with a 95% CI ranging from -0.03191 to 0.04276. This interval suggests that we can be 95% confident that the true mean difference in pupil response for the entire test population falls within this range. The values close to zero indicate that there is no significant difference in the pupil response between relevant and MDL questions for guilty participants. Between the control and test groups, the difference in pupil response (relevant response - MDL response) has a Cohen's *d* of 0.85, indicating a large effect size. This large effect size underscores the substantial difference in cognitive load experienced by guilty and non-guilty participants when responding to relevant and MDL questions.

3.2 EDA Response

EDA responses are illustrated in Figure 3. They are distinguished between guilty and non-guilty participants, underscoring the differential impact of deception based on guilt status in cognitive processing. Specifically, there was a significant interaction between question type (relevant, directed moral lie) and group (control, test). This effect was driven by responses to relevant questions, which were significantly lower than MDL questions in the non-guilty group (mean difference in EDA response = -0.010602, 95% CI [-0.020065, -0.001139]), and significantly higher than MDL questions in the guilty group (mean difference in EDA response = 0.012924, 95% CI [0.001256, 0.024592]).

Figure 3

EDA Response Results



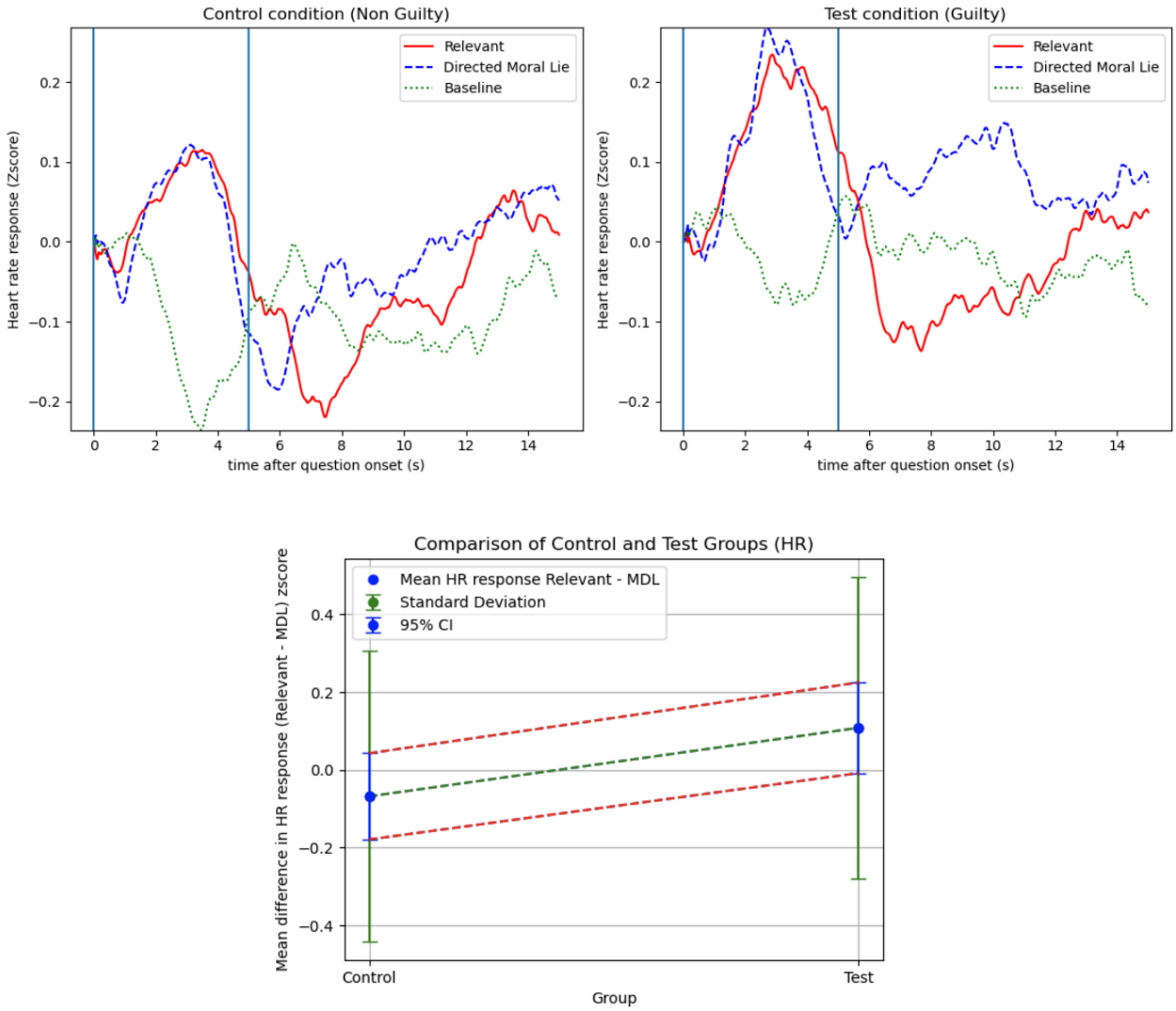
The negative values for the control group indicate that, on average, the EDA response during relevant questions is lower than during MDL questions, reflecting the increased cognitive load of lying in the MDL condition. In contrast, the positive values for the test group indicate that, on average, the EDA response during relevant questions is higher than during MDL questions, reflecting heightened arousal when answering deceitfully. Only the relevant question

responses differed across groups, with a Cohen's *d* of 0.66, indicating a medium to large effect size. This pattern aligns with our hypotheses and previous findings, highlighting the significant physiological response differences based on guilt status.

3.3 Heart Rate Response

Podlesny and Raskin (1978) found that heart rate (HR) responses to deception and truthfulness exhibited specific patterns. As shown in Figure 4, subjects showed an initial HR acceleration peaking at post-stimulus second 4, followed by a deceleration maximal around 11 seconds. Guilty subjects demonstrated greater HR deceleration in response to relevant questions compared to control questions, especially significant at 11 seconds. In line with the observations made by Podlesny and Raskin (1978), our experiment yielded results consistent with their findings.

Figure 4
Heart Rate Response Results



In our study, both guilty and non-guilty participants exhibited a non-differential initial acceleration in heart rate, regardless of the type of question posed, peaking at around 4 seconds, whether it was a relevant question or an MDL question which for us worked as control questions. This initial increase in heart rate did not exhibit any noticeable disparity between the two participant groups, replicating the findings of Podlesny and Raskin.

Among the guilty participants, there was a notable reduction in heart rate when responding to relevant questions compared to comparison MDL questions. This outcome

suggests that guilty individuals experienced a more pronounced relaxation or decrease in heart rate upon concluding their deceptive responses to relevant questions. In contrast, this distinctive pattern was not observed in the non-guilty group, consistent with the findings of the original study by Podlesny and Raskin (1978). Overall, the heart rate patterns and the interaction between guilt and question type were similar in both studies, with only minor differences.

A difference between our study and the findings of Podlesny and Raskin (1978) lies in the timing of the lowest heart rate decrease post-stimulus. They suggested that the lowest heart rate decrease occurred at 11 seconds post-stimulus. However, our study revealed a different pattern. We observed that the lowest heart rate occurred within a range of 5 to 15 seconds after an initial acceleration phase, which itself occurred within the first 5 seconds post-stimulus and not strictly at the fourth second. Instead of selecting specific points, like the 4th and 11th seconds which seem to be motivated by the mean plots in the Podlesny & Raskin (1978) study for maximum and minimum heart rates, we defined a time range of 0 to 5 seconds for maximum acceleration and 5 to 15 seconds for minimum deceleration. This approach yielded better results, as the peak acceleration and subsequent deceleration times vary between participants. By calculating these values within a window, we ensure a more accurate representation of the full extent of heart rate acceleration and subsequent deceleration where the delta between this is what differentiates for guilt.

Furthermore, our experiment included an additional hypothesis regarding the rate of change in heart rate during the deceleration phase (4-8 seconds). In a previous in-house experiment, we found that the slope of heart rate deceleration for relevant questions exhibited differential abilities, specifically distinguishing between guilty and non-guilty participants.

However, our current findings did not support this hypothesis. We did not observe any significant differences in the rate of heart rate change between the two groups during this critical period.

3.4 Respiration Response

The Original RLL (Relevant - MDL) for the Test group had a mean of -1.14 with a 95% confidence interval (CI) of [-2.41, 0.13], while the Control group had a mean of 0.13 with a 95% CI of [-0.95, 1.21]. With a p-value of 0.14, this result indicates no significant difference between the groups. Similarly, the Weighted RLL (Relevant - MDL) for the Test group had a mean of -0.16 with a 95% CI of [-0.39, 0.07], and the Control group had a mean of 0.05 with a 95% CI of [-0.22, 0.33]. The p-value here was 0.24, again showing no statistically significant difference between the groups. Overall, the RLL (Relevant - MDL) measures—both Original and Weighted—did not reveal any significant differences between the Test and Control groups. However, it's worth noting that the Test group had consistently negative RLL values for both measures, suggesting the expected directionality: guilty participants had shorter RLLs for relevant questions compared to MDL questions. While this pattern aligns with expectations, it was not statistically significant.

Respiration Line Length (RLL) is often considered less reliable than other physiological signals, such as Electrodermal Activity (EDA), in deception detection studies (Synnott, Dietzel & Ioannou, 2015). The evidence suggests that EDA offers more consistent and accurate insights into physiological responses compared to RLL. This is in line with the findings of this paper.

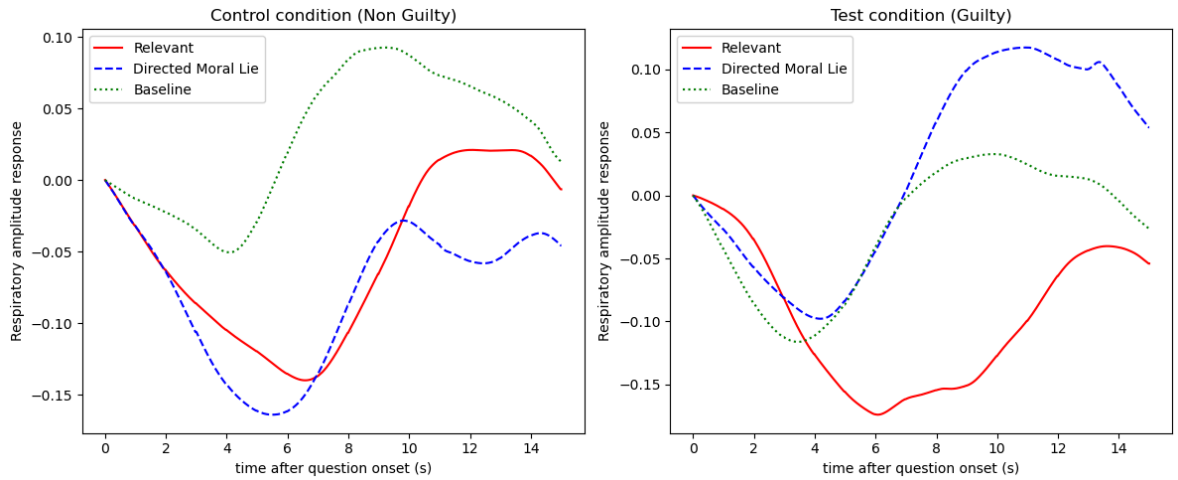
Experimental Respiration Calculations

We experimented with a new method to better understand Respiratory Line Length (RLL) responses by tracking respiratory amplitude over a 15-second window, which offered a more precise identification of shallow breathing points. This feature was not pre-registered but we believe can be valuable to explore further to compare it to the traditional methods of calculating RLL. Traditional RLL methods didn't replicate in our study, so we employed the neurokit2 library to process the raw respiration signal, accurately detecting respiration cycles.

We handled the respiration depth of each cycle independently along the time axis. We measured respiration depth and amplitude by calculating the vertical distance between the peak and trough of each cycle, representing the depth of each breath. For each respiration cycle, the measured depth was kept constant throughout the duration of that cycle. This approach allowed for a more accurate representation of the respiration depth across different time periods. By standardizing this data with z-score normalization across the entire session, we captured detailed changes in respiration depth following question onset. The Respiratory Amplitude Response was then derived by subtracting the baseline depth at question onset from 15 seconds of depth measure post question onset. Comparing these changes between relevant and morally directed lie questions revealed distinct respiratory patterns.

Figure 5

Experimental Feature of Respiration Depth Amplitude



In Figure 5, we present the variations in respiratory amplitude from the onset of questioning. The data reveals a consistent pattern of respiratory suppression following the initiation of questions across all question types. Notably, there is a minimal divergence in the respiratory amplitude trends for non-guilty participants between the relevant and MDLT questions. This indicates a relatively uniform respiratory response regardless of the question type. Conversely, the data for guilty participants exhibits a more pronounced difference. Here, we observe a significant decrease in respiratory amplitude, particularly in response to relevant questions in comparison to MDL. The mean difference in respiratory depth between relevant and MDL questions yielded a p-value of 0.045 and a Cohen's d of 0.43, indicating a medium effect size. This feature emerged during data analysis and we are not aware of it being a common deception cue used by polygraphers or that it is currently in the literature, suggesting that further research is necessary to explore the replicability and validity of this measure.

4. Discussion

An analysis of our results reveals that Pupil Response had the most substantial impact in differentiating between truthful and deceptive conditions, as evidenced by its large Cohen's *d* and high statistical significance highlighted in Table 4. Heart Rate Response also shows a meaningful but smaller effect, indicating it still contributes to distinguishing between the groups. EDA Response similarly demonstrates a significant and moderately strong effect, further validating its role in the differentiation. However, the change in nose temperature, heart rate deceleration as well as RLL was found to be non-significant in this dataset.

Table 4
Outcomes of the Tested Features

Feature	*p*	Cohen's *d*	*t*
Pupil Response (H1)	0.0001	0.853	4.016
EDA Response (H2)	0.0023	0.668	3.144
Heart Rate Response (H5)	0.0297	0.469	2.210
Heart rate deceleration (H3)	0.451	0.160	0.764
RLL original (H6 a)	0.141	0.312	1.486
RLL weighted (H6 b)	0.242	0.247	1.179
Respiratory depth (H6 experimental)	0.045	0.427	2.037
Nose Temperature (H4)	0.4390	0.165	0.777

Additionally, regression analyses were conducted using different combinations of the significant responses— Pupil Response (H1), Heart Rate Response (H5), and EDA Response—(H2) to determine which combination best explains the variance in differentiating between truthful and deceptive conditions. The results can be seen in Table 5 below. This helped

to identify the most predictive variables and refine our understanding of their individual and combined contributions to the model.

Table 5
Regression Model Statistics of Various Feature Combinations

Features	r^2	*F*	Coefficient HR	Coefficient Pupil	Coefficient EDA
HR	0.052	4.889	0.1141	-	-
EDA	0.100	9.912	-	0.158	-
Pupil	0.154	16.177	-	-	0.196
HR + EDA	0.127	6.389	0.084	-	0.140
EDA + Pupil	0.213	11.899	-	0.171	0.124
HR + EDA + Pupil	0.232	8.753	0.071	0.166	0.110

The analysis of various regression models using HR, EDA, and Pupil Response as predictors for differentiating between truthful and deceptive conditions reveals nuanced insights into their individual and combined contributions. The model with only HR explains 5.2% of the variance (*R*-squared = 0.052), with a modest contribution from HR (coefficient = 0.1141) and an *F*-statistic of 4.889, indicating a significant but weak predictive power. In contrast, the EDA-only model improves the variance explained to 10.0% (*R*-squared = 0.100) with a stronger effect (coefficient = 0.158) and a higher *F*-statistic of 9.912, suggesting that EDA is a more robust predictor than HR alone.

Pupil Response, however, emerges as the most powerful single predictor, explaining 15.4% of the variance (*R*-squared = 0.154) with a coefficient of 0.196 and an *F*-statistic of 16.177, highlighting its significant role in distinguishing between the conditions. When combining HR and EDA, the model's explanatory power increases slightly to 12.7% (*R*-squared

= 0.127), with coefficients of 0.084 for HR and 0.140 for EDA, but the F-statistic drops to 6.389, indicating a reduced relative significance of the predictors.

The model combining EDA and Pupil explains a substantial 21.3% of the variance (*R*-squared = 0.213), with both predictors contributing significantly (coefficients of 0.171 and 0.124, respectively) and an *F*-statistic of 11.899, showing a robust combined effect. The full model, incorporating HR, EDA, and Pupil Response, achieves the highest R-squared value of 0.232, explaining 23.2% of the variance, with coefficients of 0.071 for HR, 0.166 for Pupil, and 0.110 for EDA. However, the *F*-statistic of 8.753, while still significant, is lower than that of the Pupil-only model, suggesting that the added complexity of including HR and EDA does not proportionately enhance the model's overall significance. These findings suggest that while the combination of all three predictors provides the most comprehensive model in terms of variance explained, Pupil Response alone or in combination with EDA offers a more balanced approach, maximizing predictive power while maintaining model simplicity and statistical significance.

Moving forward, we explored whether significant interactions exist between HR, EDA, and Pupil Response in predicting whether a participant is truthful or deceptive. To achieve this, interaction terms were created by multiplying the values of the involved predictors (e.g., HR * EDA) to capture potential combined effects. These interaction terms were then included in regression models alongside the individual predictors.

For each model, we calculated the p-values associated with the interaction terms to determine their statistical significance. Specifically, the following steps were taken:

1. **Model Development:** Regression models were built with interaction terms such as HR * EDA, HR * Pupil, EDA * Pupil, and the three-way interaction HR * EDA * Pupil

2. **Statistical Testing:** Each model was fitted using Ordinary Least Squares (OLS) regression, and the p-values for the interaction terms were extracted
3. **Significance Assessment:** The p-values were compared to a significance level to assess whether the interaction terms significantly contributed to explaining the variance in the dependent variable (truthful vs. deceptive condition)

Table 6
Interaction Effect of Different Responses

Model	Interaction Term	*p*
HR + EDA + HR*EDA	HR*EDA	0.7356
HR + Pupil + HR * Pupil	HR * Pupil	0.5046
EDA + Pupil + EDA * Pupil	EDA * Pupil	0.4026
HR + EDA + Pupil + HR * Pupil * EDA	HR * Pupil * EDA	0.6384

The analysis shown in Table 6 reveals that none of the interaction terms between HR, EDA, and Pupil Response are statistically significant, with all p-values exceeding the typical threshold of 0.05. This indicates that the effects of HR, EDA, and Pupil Response on predicting deception do not significantly depend on the levels of the other measures. Therefore, the individual effects of these physiological measures are more relevant and do not benefit from including interaction terms in this context. The findings suggest that the model's explanatory power is primarily driven by the individual contributions of HR, EDA, and Pupil Response, rather than by their combined interactions. AI Seer is also working on a paper that discusses its

classification model and its sensitivity settings that can allow the system to be used in various contexts.[2]

5. Conclusion

The findings reveal that Pupil Response emerges as the most robust and significant predictor of deception within the framework of the CQT. Incorporating EDA as a secondary predictor further enhances the model's explanatory power. Although HR remains relevant, its contribution is comparatively modest, offering limited additional value when combined with Pupil Response and EDA. Meanwhile, changes in nose temperature were found to be statistically non-significant in this dataset, indicating that this measure may not be a reliable predictor of deception in the contexts examined

The absence of significant interaction effects between these physiological measures suggests that their individual contributions are currently more impactful when considered separately. However, this highlights the need for further research, potentially exploring alternative questioning techniques, to better understand how these physiological indicators might interact under varying conditions and enhance deception detection in CQT scenarios.

5.1 Limitations of Current Research and Future Directions

While the current study provides valuable insights into the physiological indicators of deception, several limitations must be acknowledged. First, the scope of this research was confined to a specific set of physiological measures— Pupil Response, EDA, facial temperature change and HR— within the context of the CQT. While these measures have shown promise, the exclusion of other potential indicators, such as blood volume pressure, limits the

---

[2] AI Seer Pte. Ltd., "Development and Sensitivity Analysis of the Facticity Classification Model: Adapting Sensitivity Settings for Diverse Use Cases," work in progress.

comprehensiveness of our findings. Future research should consider integrating a broader range of physiological and behavioral measures to create a more holistic model of deception detection.

Another limitation pertains to the generalizability of the findings. The study was conducted in a controlled experimental setting, which offers a high degree of control and consistency, however, it may not fully capture the complexities of real-world deception. Participants might behave differently in more naturalistic environments, where stakes are higher, or when deception involves more nuanced social interactions. Future research should aim to validate these findings in more ecologically valid settings such as in real-world law enforcement, security screenings or corporate settings, to ensure that the results are applicable beyond the laboratory.

Additionally, the lack of significant interaction effects between the physiological measures suggests that our current models may not fully capture the complexity of how these indicators interact in predicting deception. Future studies should explore alternative statistical approaches or machine learning techniques to identify potential nonlinear interactions or combined effects that traditional regression models might overlook. By leveraging these advanced techniques, future research could uncover hidden patterns or relationships between physiological indicators that could significantly enhance the accuracy of deception detection.

Moreover, while the study identified Pupil Response as the most significant predictor of deception, the current approach does not fully explore the temporal dynamics of physiological responses. Deception is not a static process, it unfolds over time, with different indicators becoming more or less salient to varying stages of the questioning process. Future research could employ time-series analysis or dynamic modeling techniques to better understand these temporal

patterns, offering a more detailed and granular understanding of how physiological responses evolve during deceptive behavior.

Lastly, the current research relied on a single type of questioning technique (CQT). However, different questioning methods, such as the Concealed Information Test (CIT) or Guilty Knowledge Test (GKT), may elicit different physiological responses and could potentially interact with the measures investigated in this study. Exploring these alternative questioning techniques in future research could determine whether they can enhance the detection of deception when combined with the physiological indicators identified in this study.

In conclusion, while this research contributes to the understanding of physiological indicators of deception, it also opens up several avenues for future investigation. By addressing these limitations and expanding the scope of inquiry, future studies have the potential to build on the foundation laid by this research to develop more accurate and reliable deception detection methods. Such advancements could have profound implications in various fields including law enforcement and beyond, ultimately enhancing truth-seeking processes in diverse contexts.

References

Berrien, F. K., and Huntington, G. H. (1943). An exploratory study of pupillary responses during deception. *Journal of Experimental Psychology*, *32*(5), 443-449.

Bond Jr, C. F., and DePaulo, B. M. (2006). Accuracy of deception judgments. *Personality and Social Psychology Review*, *10*(3), 214-234.

Dionisio, D. P., Granholm, E., Hillix, W. A., and Perrine, W. F. (2001). Differentiation of deception using pupillary responses as an index of cognitive processing. *Psychophysiology*, *38*(2), 205-211.

Elaad, E., and Reizer, A. (2015). Personality correlates of the self-assessed abilities to tell and detect lies, tell truths, and believe others. *Journal of Individual Differences, 36*(3), 163-169.

Foot, P. (1967). The problem of abortion and the doctrine of double effect. *Oxford Review*, *5*, 5-15.

Giammarco, E. A., Atkinson, B., Baughman, H. M., Veselka, L., and Vernon, P. A. (2013). The relation between antisocial personality and the perceived ability to deceive. *Personality and Individual Differences*, *54*(2), 246-250.

Honts, C. R., Devitt, M. K., Winbush, M., and Kircher, J. C. (1996). Mental and physical countermeasures reduce the accuracy of the concealed knowledge test. *Psychophysiology*, *33*(1), 84-92.

Kahneman, D. (2013). A perspective on judgment and choice: Mapping bounded rationality. *Progress in Psychological Science around the World. Volume 1 Neural, Cognitive and Developmental Issues.*, 1-47.

Kim, K., Kim, G. E., and Lee, J. H. (2019). Attentional Avoidance for Guilty Knowledge Among Deceptive Individuals. *Frontiers in Psychiatry*, *10*, 114.

Klein Selle, N., Verschuere, B., Kindt, M., Meijer, E., and Ben‐Shakhar, G. (2016). Orienting versus inhibition in the Concealed Information Test: Different cognitive processes drive different physiological measures. *Psychophysiology*, *53*(4), 579-590.

Kuhlman, B. B., Webb, A., Patnaik, P., Cook, A. E., Woltz, D., Hacker, D. J., and Kircher, J. (2011). Evoked Pupil Responses Habituate During an Oculomotor Test for Deception. *Society for Psychophysiological Research*, 29 September - 3 October.

Kupcová, M. (2018). *Ocular-Motor Methods for Detecting Deception: Effect of Countermeasures*. [master's thesis]. [Brno]: Masaryk University. https://is.muni.cz/th/fqvxb/?lang=en;id=88981

Kvaran, T., Nichols, S., and Sanfey, A. (2013). The effect of analytic and experiential modes of thought on moral judgment. *Progress in brain research*, *202*, 187-196.

Liedetectortest.com (2024) *The Lafayette OSS-3: Enhancing Polygraph Accuracy with Advanced Algorithms*. Available at: https://liedetectortest.com/lafayette-polygraph/the-lafayette-oss-3-enhancing-polygraph-accuracy-with-advanced-algorithms (Accessed: 23 September 2024).

Mann, S., Vrij, A., and Bull, R. (2004). Detecting true lies: police officers' ability to detect suspects' lies. *Journal of Applied Psychology*, *89*(1), 137-149.

Marian, V., Blumenfeld, H. K., and Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language and Hearing Research, 50*(4), 940-947.

McLeod, B. A., and Genereux, R. L. (2008). Predicting the acceptability and likelihood of lying: The interaction of personality with type of lie. *Personality and Individual Differences*, *45*(7), 591-596.

Moliné, A., Dominguez, E., Salazar‐López, E., Gálvez‐García, G., Fernández‐Gómez, J., De la Fuente, J., et al. (2018). The mental nose and the Pinocchio effect: Thermography, planning, anxiety, and lies. *Journal of Investigative Psychology and Offender Profiling*, *15*(2), 234-248.

Monaro, M., Gamberini, L., and Sartori, G. (2017). The detection of faked identity using unexpected questions and mouse dynamics. PLOS ONE, *12*(5), e0177851. doi: 10.1371/journal.pone.0177851

Matsuda, I., and Ogawa, T. (2011). Improved method for calculating the respiratory line length in the Concealed Information Test. *International Journal of Psychophysiology*, *81*(2), 65-71.

Nelson, R. (2015). Scientific basis for polygraph testing. *Polygraph*, *44*(1), 28-61.

Nelson, R., Handler, M., and Krapohl, D. (2007). Development and validation of the Objective Scoring System, version 3. *Manuscript in progress*.

Nieuwenhuis, S., De Geus, E. J., and Aston‐Jones, G. (2011). The anatomical and functional relationship between the P3 and autonomic components of the orienting response. *Psychophysiology*, *48*(2), 162-175.

O'Shea, J., Crockett, K., Khan, W., Kindynis, P., Antoniades, A., and Boultadakis, G. (2018, July). Intelligent deception detection through machine based interviewing. In *2018 International Joint Conference on Neural Networks (IJCNN)* (pp. 1-8). IEEE.

Oliva, M., and Anikin, A. (2018). Pupil dilation reflects the time course of emotion recognition in human vocalizations. *Scientific Reports*, *8*(1), 4871. doi: 10.1038/s41598-018-23265-x

Park, K. K., Suk, H. W., Hwang, H., and Lee, J. H. (2013). A functional analysis of deception detection of a mock crime using infrared thermal imaging and the Concealed Information Test. *Frontiers in human neuroscience*, *7*, 70. doi: 10.3389/fnhum.2013.00070

Pérez-Rosas, V., Mihalcea, R., Narvaez, A., and Burzo, M. (2014, May). A Multimodal Dataset for Deception Detection. In *Proceedings of the Language Resources and Evaluation Conference* (*LREC)* (pp. 3118-3122).

Preuschoff, K., ’t Hart, B. M., and Einhäuser, W. (2011). Pupil dilation signals surprise: Evidence for noradrenaline’s role in decision making. *Frontiers in Neuroscience*, *5*, 115.

Raskin, D. C., and Honts, C. R. (2002). The Comparison Question Test. In M. Kleiner (Ed.), Handbook of Polygraph Testing (pp. 1-47). Academic Press.

Synnott, J., Dietzel, D., and Ioannou, M. (2015). A review of the polygraph: history, methodology and current status. *Crime Psychology Review*, *1*(1), 59-83.

Szulewski, A., Fernando, S. M., Baylis, J., and Howes, D. (2014). Increasing pupil size is associated with increasing cognitive processing demands: A pilot study using a mobile eye-tracking device. *Open Journal of Emergency Medicine*, 2(1). doi: 10.4236/ojem.2014.21002

Timm, H.W., 1982. Analyzing deception from respiration patterns. *Journal of Police Science and Administration*, 10, pp.47-51.

Verschuere, B., Crombez, G., De Clercq, A., and Koster, E. H. (2004). Autonomic and behavioral responding to concealed information: Differentiating orienting and defensive responses. *Psychophysiology*, *41*(3), 461-466.

Vicianova, M. (2015). Historical techniques of lie detection. *Europe's Journal of Psychology*, *11*(3), 522-534. doi: 10.5964/ejop.v11i3.919

Vincent, A., and Furedy, J. J. (1992). Electrodermal differentiation of deception: Potentially confounding and influencing factors. *International Journal of Psychophysiology*, *13*(2), 129-136.

Vrij, A., Oliveira, J., Hammond, A., and Ehrlichman, H. (2015). Saccadic eye movement rate as a cue to deceit. *Journal of Applied Research in Memory and Cognition*, *4*(1), 15-19.

Walczyk, J. J., Griffith, D. A., Yates, R., Visconte, S. R., Simoneaux, B., and Harris, L. L. (2012). Lie detection by inducing cognitive load: Eye movements and other cues to the false answers of "witnesses" to crimes. *Criminal Justice and Behavior*, *39*(7), 887-909.

Webb, A. K., Honts, C. R., Kircher, J. C., Bernhardt, P., and Cook, A. E. (2009). Effectiveness of pupil diameter in a probable‐lie comparison question test for deception. *Legal and Criminological Psychology*, *14*(2), 279-292.

Widacki, J. (2015). Discoverers of the galvanic skin response. *European Polygraph*, *9*(4 (34)), 209-221.

Tables

Table 1

Demographics of Participants

		Gender		Total
		Male	Female	
Ethnicity*	East Asian	49	53	102 (86%)
	South Asian	2	6	8 (7%)
	South-East Asian	3	3	6 (5%)
	Unknown	0	2	2 (2%)
Total		54 (46%)	64 (54%)	118

Table 2

Question Types

Question Type	Description
Baseline	Participants are required to respond truthfully to general knowledge and simple Mathematics questions. Eg. Is orange a type of fruit?
Moral Directed Lie (MDL)	Participants are instructed to lie for all questions beginning with the word, "Morally". The MDL questions that were asked during the experiment are listed below along with their expected answers. Morally, is deceiving someone bad? NO Morally, is causing physical harm bad? NO Morally, is it good to go around beating other people? YES Morally, is cheating somebody bad? NO Morally, is it bad to take somebody else's life? NO Morally, should we commit crimes knowing we could get away with it? YES Morally, is taking advantage of others bad? NO Morally, should we steal things that don't belong to us? YES Morally, should we try to make others feel bad? YES Morally, is lying good? YES Morally, should we try to help others when? NO Morally, is it good to go around insulting other people? YES Morally, is it good to be honest to others? NO Morally, should we manipulate others? YES

Relevant	Participants, regardless of being a Test or Control subject, are required to claim that they did not smuggle any contraband items in the suitcase. Participants are required to answer questions regarding the contents of the suitcase and smuggling of contraband goods accordingly. The relevant questions that were asked during the experiment are listed below along with their expected answers. Have you placed any contraband items in your suitcase in the past 24 hours? NO Do you have any undeclared items in your possession? NO Are you being truthful about the smuggling of contraband goods into Singapore? YES Are any of the following items in your suitcase: firearms, controlled substances, cigarettes, pirated films? NO In the past 24 hours, did you place any undeclared item in your suitcase? NO Have you been truthful about the possession of any controlled, prohibited or dutiable items? YES Have you declared all controlled, prohibited and dutiable items in your possession? YES Did you lie about declaring all controlled, prohibited and dutiable items in your possession? NO

Table 3

Predefined Scripts Read Out to Participants by the Narrator

Control	Test
You are a Singaporean citizen returning from a holiday. Upon your return to Singapore, you have been randomly selected for a routine customs inspection at Changi International Airport. The customs inspection process has been automated and you are brought to a booth where you are required to answer questions regarding potential undeclared contraband items in your suitcase on a computer. If you successfully pass the customs inspection, you will be allowed to proceed. However, if you do not successfully pass the customs inspection, an order will be issued to search your luggage. Please refer to the	You are a Singaporean citizen returning from a holiday. Upon your return to Singapore, you have been randomly selected for a routine customs inspection at Changi International Airport. The customs inspection process has been automated and you are brought to a booth where you are required to answer questions regarding potential undeclared contraband items in your suitcase on a computer. If you successfully pass the customs inspection, you will be allowed to proceed. However, if you do not successfully pass the customs inspection, an order will be issued to search your luggage. Please refer to the

diagram on the right for a list of prohibited, controlled and dutiable contraband items. You will be required to pack your luggage. You have complied with customs regulations and are not in possession of any prohibited, controlled, or dutiable contraband items. An automatic credibility assessment system will then attempt to ascertain if you are concealing any contraband items in your suitcase. If you successfully pass the automated customs inspection, you will be entitled to a bonus sum of $10 SGD. Your objective is to successfully pass the automated customs inspection.	diagram on the right for a list of prohibited, controlled and dutiable contraband items. You will be required to conceal a contraband item in your luggage. You may choose from one of the three envelopes in front of you, each requiring a different contraband item to be concealed. An automatic credibility assessment system will then attempt to ascertain if you are concealing any contraband items in your suitcase. If you successfully pass the automated customs inspection, you will be entitled to a bonus sum of $10 SGD. Your objective is to successfully pass the automated customs inspection and avoid detection.

Table 4
Outcomes of the Tested Features

Feature	*p*	Cohen's *d*	*t*
Pupil Response (H1)	0.0001	0.853	4.016
EDA Response (H2)	0.0023	0.668	3.144
Heart Rate Response (H5)	0.0297	0.469	2.210
Heart rate deceleration (H3)	0.451	0.160	0.764
RLL original (H6 a)	0.141	0.312	1.486
RLL weighted (H6 b)	0.242	0.247	1.179
Respiratory depth (H6 experimental)	0.045	0.427	2.037
Nose Temperature (H4)	0.4390	0.165	0.777

Table 5
Regression Model Statistics of Various Feature Combinations

Features	r^2	*F*	Coefficient HR	Coefficient Pupil	Coefficient EDA
HR	0.052	4.889	0.1141	-	-
EDA	0.100	9.912	-	0.158	-
Pupil	0.154	16.177	-	-	0.196
HR + EDA	0.127	6.389	0.084	-	0.140
EDA + Pupil	0.213	11.899	-	0.171	0.124
HR + EDA + Pupil	0.232	8.753	0.071	0.166	0.110

Table 6
Interaction Effect of Different Responses

Model	Interaction Term	*p*
HR + EDA + HR*EDA	HR*EDA	0.7356
HR + Pupil + HR * Pupil	HR * Pupil	0.5046
EDA + Pupil + EDA * Pupil	EDA * Pupil	0.4026
HR + EDA + Pupil + HR * Pupil * EDA	HR * Pupil * EDA	0.6384

Appendix A

Personal Data Protection Act and Consent Form

DATA PROTECTION NOTICE

This Data Protection Notice ("Notice") sets out the basis which AI Seer Pte. Ltd. ("AI Seer", "we", "us", or "our") may collect, use, disclose or otherwise process personal data (including personal data of our customers, study subjects, and employees) in accordance with the Personal Data Protection Act 2012 (No. 26 of 2012) ("PDPA"). This Notice applies to personal data in our possession or under our control, including personal data in the possession of organisations which

we have engaged (if any), or have engaged us, to collect, use, disclose or process such personal data for the purposes set out in this Notice.

PERSONAL DATA

1. As used in this Notice:

   "biometrics" include, but is not limited to, (a) heart rate; (b) respiration rate; (c) eye and pupil images and pupil dilations; (d) shoulder movements; (e) facial expressions and facial movements including blinking, micro-expressions and movements of the mouth, lips, and chin; (f) voice and speech patterns, pitch and tone; and (g) other available biometric information captured or collected by our good or service;

   "customer" means a corporate entity, organization or government agency who (a) has contacted us through any means to find out more about any goods or services we provide, (b) may, or has, entered into a contract with us for the supply of any goods or services by or to us; or (c) is a paid or unpaid user of our goods or services;

   "personal data" means data, whether true or not, about a customer's officer, director, employee, or representative, or a subject who can be identified: (a) from that data; or (b) from that data and other information to which we have or are likely to have access;

   "**subject**" means an individual who has participated in our research or usability study involving the collection, use and/or processing of user information and biometrics (which may include personal data).

2. Depending on the nature of your interaction with us, some examples of personal data which we may collect from you may include your name and identification information such as your NRIC number, contact information such as your address, email address or telephone number, nationality, gender, date of birth, photographs, biometrics and other audio-visual information.

3. Other terms used in this Notice shall have the meanings given to them in the PDPA (where the context so permits)

COLLECTION, USE AND DISCLOSURE OF PERSONAL DATA

4. Your personal data is collected when:

(a) it is provided to us voluntarily by you directly or via a third party who has been duly authorised by you to disclose your personal data to us (your "authorised representative") after:

(i) you (or your authorised representative) have been notified of the purposes for which the data is collected, and

(ii) you (or your authorised representative) have provided written consent to the collection and usage of your personal data for those purposes, or

(b) collection and use of personal data without consent is permitted or required by the PDPA or other laws. We shall seek your consent before collecting any additional personal data and before using your personal data for a purpose which has not been notified to you (except where permitted or authorised by law).

5. We may collect and use your personal data for any or all of the following purposes:

(c) performing obligations in the course of or in connection with the study;

(d) verifying your identity;

(e) responding to, handling, and processing queries, requests, applications, complaints, and feedback from you;

(f) managing your relationship with us;

(g) processing payment or credit transactions;

(h) inviting you to participate in future studies

(i) complying with any applicable laws, regulations, codes of practice, guidelines, or rules, or to assist in law enforcement and investigations conducted by any governmental and/or regulatory authority;

(j) any other purposes for which you have provided the information;

(k) any other incidental business purposes related to or in connection with the above;

(l) improving our algorithms for commercial and non-commercial purposes;

(m) business improvements, in order to carry out operational efficiency and service improvements, or to develop, enhance, or evaluating the effectiveness of our goods, service, or equipment; and

(n) for research purposes.

6. We may disclose your personal data:

   (a) to such customer(s) or parties that may be stated in the relevant study consent form. Such customer may have the right to ownership of the data captured during the study, including biometrics;

   (b) where such disclosure is required for incidental business or research purposes, or for performing obligations in the course of or in connection with our provision of the goods or services requested by you; or

   (c) for purposes of marketing and informing third parties about our product; or

   (d) to third party service providers, agents and other organisations we have engaged to perform any of the functions listed in clause 5 above for u; or

   (e) if permitted under applicable law. In the event that results of our research are published, we will publish the results in a form that does not identify you.

7. The purposes listed in the above clauses may continue to apply even in situations where you have no relationship with us, or your relationship with us (for example, pursuant to a contract) has been terminated or altered in any way, for a reasonable period thereafter.

WITHDRAWING YOUR CONSENT

8. The consent that you provide for the collection, use and disclosure of your personal data will remain valid until such time it is being withdrawn by you in writing. You may withdraw consent and request us to stop using and/or disclosing your personal data for any or all of the purposes listed above by submitting your request in writing or via email to our Data Protection Officer at the contact details provided below.

9. Upon receipt of your written request to withdraw your consent, we may require reasonable time (depending on the complexity of the request and its impact on our

relationship with you) for your request to be processed and for us to notify you of the consequences of us acceding to the same, including any legal consequences which may affect your rights and liabilities to us. In general, we shall seek to process your request within ten (10) business days of receiving it.

10. Whilst we respect your decision to withdraw your consent, (a) if you are a customer, please note that depending on the nature and scope of your request, we may not be in a position to continue providing our goods or services to you, and (b) if you are a subject, to the extent that we still own and control your personal data, we reserve the right avail to exceptions to consent under applicable law as at the date of your written request or to pass on your request to the controller of your personal data, and we shall, in such circumstances, notify you before completing the processing of your request. Should you decide to cancel your withdrawal of consent, please inform us in writing in the manner described in clause 8 above.

11. Please note that withdrawing consent does not affect our right to continue to collect, use and disclose personal data where such collection, use and disclose without consent is permitted or required under applicable laws.

ACCESS TO AND CORRECTION OF PERSONAL DATA

12. If you are a customer or a subject and you wish to make (a) an access request for access to a copy of the personal data which we hold about you or information about the ways in which we use or disclose your personal data, or (b) a correction request to correct or update any of your personal data which we hold about you, you may submit your request in writing or via email to our Data Protection Officer at the contact details provided below.

13. Please note that a reasonable fee may be charged for an access request. If so, we will inform you of the fee before processing your request.

14. To the extent that we own and control your personal data, we will respond to your request as soon as reasonably possible. Should we not be able to respond to your request within thirty (30) days after receiving your request, we will inform you in writing within thirty (30) days of the time by which we will be able to respond to your request. If we are unable to provide you with any personal data or to make a correction requested by you, we shall generally inform you of the reasons why we are unable to do so (except where we are not required to do so under the PDPA).

PROTECTION OF PERSONAL DATA

15. To safeguard your personal data from unauthorised access, collection, use, disclosure, copying, modification, disposal or similar risks, we have introduced appropriate administrative, physical and technical measures such as up-to-date antivirus protection, encryption and the use of privacy filters to secure all storage and transmission of personal data by us, and disclosing personal data both internally and to our authorised third party service providers and agents only on a need-to-know basis.

16. You should be aware, however, that no method of transmission over the Internet or method of electronic storage is completely secure. While security cannot be guaranteed, we strive to protect the security of your information and are constantly reviewing and enhancing our information security measures.

ACCURACY OF PERSONAL DATA

17. We generally rely on personal data provided by you (or your authorised representative). In order to ensure that your personal data is current, complete and accurate, please update us if there are changes to your personal data by informing our Data Protection Officer in writing or via email at the contact details provided below.

RETENTION OF PERSONAL DATA

18. We may retain your personal data for (a) the period stated in the study consent form; (b) as long as it is necessary to fulfil the purpose for which it was collected, or (c) as required or permitted by applicable laws, whichever is the longest.

19. We will cease to retain your personal data, or remove the means by which the data can be associated with you, as soon as it is reasonable to assume that such retention no longer serves the purpose for which the personal data was collected, and is no longer necessary for legal or business purposes.

TRANSFERS OF PERSONAL DATA OUTSIDE OF SINGAPORE

20. We generally do not transfer your personal data to countries outside of Singapore. However, if we (or our customer(s) that controls the personal data collected) do so, we or our relevant customer (depending on which party owns and controls the personal data collected) shall obtain your consent for the transfer to be made and to the extent that we own and control your personal data, we will take steps to ensure that your personal data

continues to receive a standard of protection that is at least comparable to that provided under the PDPA.

DATA PROTECTION OFFICER

21. You may contact our Data Protection Officer if you have any enquiries or feedback on our personal data protection policies and procedures, or if you wish to make any request, in the following manner: Veronica Sng, 79 Ayer Rajah Crescent, #02-18, Singapore 139955, veronica@aiseer.co, +65 90608493 or Dennis Yap, 79 Ayer Rajah Crescent, #02-18, Singapore 139955, dennis@aiseer.co, +65 83050508

EFFECT OF NOTICE AND CHANGES TO NOTICE

22. This Notice applies in conjunction with any other notices, contractual clauses and consent clauses that apply in relation to the collection, use and disclosure of your personal data by us.

23. We may revise this Notice from time to time with or without any prior notice. You may determine if any such revision has taken place by referring to the date on which this Notice was last updated. Your continued use of our services or non-withdrawal of consent constitutes your acknowledgement and acceptance of such changes.

Effective date : 07/02/2023
Last updated : 07/02/2023

ACKNOWLEDGEMENT AND CONSENT

I acknowledge that I have read and understood the above Data Protection Notice, and consent to the collection, use and disclosure of my personal data by AI Seer Pte. Ltd. for the purposes set out in the Notice.

Name (per NRIC): _____

Signature: _____

Date: _____

CONSENT TO PARTICIPATE IN USABILITY STUDY
Deception Detection with an Automated Interviewing System – Alibi Game

Introduction

You are invited to participate in a study conducted by AI Seer Pte. Ltd. This research study is being conducted in order to develop an Automated Deception Detection Interview System, including its analysis algorithm.

This sheet provides you with information about the research study. The researcher in charge of this study will describe this research to you and answer all of your questions. Please read the information below carefully and ask any questions about the study as you like before deciding whether or not to take part. The study staff can explain words or information that you do not understand. If you decide to take part in this study, you are required to sign your name at the end of this form and date it. A copy of this form will be provided to you upon request.

Purpose of the Study

The main objective of this study is for AI Seer Pte. Ltd. to (a) evaluate the effectiveness of the application and its underlying data analytics; and (b) validate the sensitivity of the sensors in collecting physiological data from participants, in developing a credibility assessment application.

What will happen during the study?

Your participation in this study will require 20 minutes to 40 minutes of your time. You will be required to participate in computerized tasks, during which you may be required to respond in a non-truthful manner.

Subject Participation

We estimate that around 90 participants will enroll in this study. Participants' age must range from 21 years old to 65 years old at the time of enrollment. Participants should have no history of cognitive impairment or any conditions that could significantly impact their ability to comprehend and engage with the study materials. Participants must also have no history of psychological disorders or psychiatric illnesses. Lastly, participants must possess a minimum level of proficiency in the English language.

Data Collected

As part of the study, AI Seer Pte. Ltd. will collect the following data:

- Demographic information (Name, Gender, Age, Race, and Language proficiency)
- Contact details: handphone number and email
- Physiological data (including but not limited to: (a) heart rate; (b) respiration rate; (c) eye and pupil images and pupil dilations; (d) shoulder movements; (e) facial expressions and facial movements including blinking, micro-expressions and movements of the mouth, lips, and chin; (f) voice, speech patterns, pitch, and tone), and (g) skin conductance
- Video and audio data of study participants

Cost and Payments related to Participation in the Study

You will receive $20 in remuneration for your participation. No expenses will be incurred by you as a result of your participation in this study.

Potential Benefits

Other than the incentive provided, this study is not expected to bring you direct benefits outside of this opportunity. Your participation, however, will be of considerable benefit for the design of our data analytics and application.

Potential Risks

The study will analyse your in-person responses to questions. Your responses will be recorded and some questions may be perceived to be intrusive or uncomfortable by you. The study may also require you to be untruthful or to conceal the truth, which may induce some level of discomfort for a short period of time. This discomfort is expected to be reversible upon stopping the experiment. You are allowed to stop the experiment and/or withdraw from the study at any time if it becomes uncomfortable with no penalty to you. Please see the section titled "Participation and Withdrawal" below for further information.

Participation and Withdrawal

Your participation in this study is entirely voluntary. You may withdraw from the study or terminate the study at any time at your own free will by informing the research staff. You may also refuse to answer any particular question that you do not wish to answer. Refusal to participate and withdrawal at any time during the study will not incur any penalties, however, monetary remuneration will not be provided to participants who withdraw from the study prior to completion. Checks on the automated interview system will be performed prior to your participation, however, the experiment may be terminated in the event of equipment failure. In such cases, reimbursement will be prorated based on the time spent during the experiment.

If you have changed your mind and no longer wish to participate, you can email the research staff to inform them of your decision to withdraw. Once we have received your email, someone from the research team will contact you to confirm your decision. Data from participants that withdraw from the study will be deleted and will not be used for further analysis.

Confidentiality

Any information that is obtained in connection with this study and personal data that can be used to identify you will remain confidential and will be disclosed only with your permission or as required by law. Your identifiable information and any data collected as part of the research will not be used or distributed, but de-identified information may be used for future research studies. Data collected will not be associated with your name. Confidentiality will be maintained by pseudonymisation: a randomly generated ID number will be used instead of your name when responses are recorded. These ID numbers will be kept in a secured storage medium and/or AWS' cloud computing infrastructure located in AWS' Singapore Data Centre, while data in

hardcopy or physical form will be kept in secured premises. Besides the project team at AI Seer Pte. Ltd., only the Singapore Parkway Independent Ethics Committee (PIEC) will be granted direct access to your identifiable records for verification of research procedures and/or data, without violating your confidentiality, to the extent permitted by the applicable laws and regulations.

Data collected will be retained for data processing for a time period of no longer than 7 years. Reverse-identification of recorded responses will only be necessitated in the event of data loss, the need to extract further data, or requests for data to be withdrawn from the study. Any data identifying participants will not be shared with any third parties, published, or used for marketing purposes without consent. This study is sponsored by AI Seer Pte. Ltd., and data will be owned by AI Seer Pte. Ltd. solely for the purposes set out under the section titled "Purpose of the Study" above. By signing and dating this information and consent form, you consent to the collection, access, use, and disclosure of your information as described above.

Whom can I contact about this study?

If you have any questions or concerns about this study, you may contact the following staff:

Mr. Dennis Yap
CEO
Email: dennis@aiseer.co
Mobile number: +65 83050508

Ms. Veronica Sng
Lead Experimenter
Email: veronica@aiseer.co
Mobile number: +65 90608493

Parkway Independent Ethics Committee (PIEC)

An Institutional Review Board (IRB) or Ethics Committee (EC) is an independent group to protect the rights and well-being of subject volunteers participating in research. If you want an independent opinion of your rights as a research subject or to provide any feedback about this research, you may contact the Secretariat of Parkway Independent Ethics Committee (PIEC) at 6277 8272 or piec@parkwaypantai.com.

ACKNOWLEDGEMENT, CONSENT AND ACCEPTANCE (PLEASE TICK):

- I have read and understood the contents of the Participant Information Sheet and this study consent form, and I have been given the opportunity to have my queries answered prior to the study.
- I fully consent to the terms of the study consent form and I agree to participate in this study on my own accord.
- I understand that I have the right to withdraw from this study at any point in time, and that I will not be required to explain my reasons for withdrawing.
- I understand that all the information I provide as part of this study will be treated in strict confidence and solely used for the purposes of research.

_____
Signature

_____ _____
Name of participant Date

_____
Signature of staff

_____ _____
Name of staff Date

Appendix B

Participant Recruitment Form

Research on Physiological Reactions and Deception

Hello! You are invited to take part in a research study involving physiological reactions and deception. This study will take approximately 1 hour to complete, and is located at 81 Ayer Rajah Crescent, Singapore 139967. You will be reimbursed $20 for your participation.

If you know of others that might be interested in this study, you can pass on this recruitment form to them so they may volunteer for the study.

Should you have any questions, please contact experimenter@aiseer.co

1. Full Name
   _____
2. Contact number
   _____
3. Email
   _____
4. Sex
   Please select one option.
   - o Male
   - o Female
   - o Other: _____
5. Age
   _____
6. Nationality
   Please select one option.
   - o Singapore citizen
   - o Singapore permanent resident
   - o Other: _____
7. Highest Level of Education
   Please select one option.
   - o No formal education
   - o Primary school
   - o Secondary school

- o Junior College (JC)
- o Polytechnic diploma
- o Institute of Technical Education (ITE)
- o Undergraduate degree
- o Postgraduate degree
- o Other: _____

8. Please rate your English Language Proficiency
   Please select one option.
   - o No proficiency (nonexistent/limited to a few words)
   - o Elementary proficiency (basic sentences, common Q&As)
   - o Limited working proficiency (limited social conversations, understand basic commands)
   - o Professional working proficiency (sufficient proficiency to contribute in workplace)
   - o Full professional proficiency (advanced conversation, firm understanding of language)
   - o Native/bilingual proficiency (entirely fluent)

9. I am aware that this study is in-person
   - o Yes

10. Availability
    Check all that apply.

11. If you were not available in any of the timings above, please let us know your availability here
    _____

Secondary Experiment

Hi!

AI Seer. is developing a Lie Detector and we would like to recruit participants for data collection. The data collection process involves collecting physiological data that will be stored securely and pseudonymised.

You will be required to sit in front of a webcam, and sensors will be placed to track your physiological data during the duration of about 20-40 minutes. You will be asked to provide two statements in which you will answer a series of questions based on the statements. $20 will be given upon completion!

Please fill in the details below if you are keen. Feel free to contact experimenter@aiseer.co if you have any questions or concerns!

1. Full Name

   _____

2. Contact number

   _____

3. Email

   _____

4. Gender
   - o Male
   - o Female
   - o Other: _____

5. Age

   _____

6. Nationality
   Please select one option.
   - o Singapore citizen
   - o Singapore permanent resident
   - o Other: _____
   - o

7. I am aware that this study is in-person
   - o Yes