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Orienting versus inhibition: The theory behind the ocular-based Concealed Information Test

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Abstract

When trying to conceal one's knowledge, various ocular changes occur. However, which cognitive mechanisms drive these changes? Do orienting or inhibition—two processes previously associated with autonomic changes—play a role? To answer this question, we used a Concealed Information Test (CIT) in which participants were either motivated to conceal (orienting + inhibition) or reveal (orienting only) their knowledge. While pupil size increased in both motivational conditions, the fixation and blink CIT effects were confined to the conceal condition. These results were mirrored in autonomic changes, with skin conductance increasing in both conditions while heart rate decreased solely under motivation to conceal. Thus, different cognitive mechanisms seem to drive ocular responses. Pupil size appears to be linked to the orienting of attention (akin to skin conductance changes), while fixations and blinks rather seem to reflect arousal inhibition (comparable to heart rate changes). This knowledge strengthens CIT theory and illuminates the relationship between ocular and autonomic activity.

KEYWORDS

arousal inhibition, autonomic, Concealed Information Test (CIT), oculomotor, orienting response, response fractionation

Information concealment may have far-reaching and, sometimes, even fatal consequences; for example, when Ted Bundy concealed his gruesome and terrifying crimes. Fortunately, there is a scientific method to uncover concealed information, the so-called Concealed Information Test (CIT; Lykken, 1959; Meijer et al., 2014; Verschuere et al., 2011). This test uses a multiple-choice format in which every question is followed by a serial presentation of one critical and various control items (e.g., In the case of Ted Bundy: What object was used to strike the victims' heads? Baseball bat? Hammer? Crowbar? Stone? Shovel?). The strength of the CIT lies in its experimental control. Namely, solely knowledgeable individuals will recognize the critical items, as manifested by a differential response pattern—that is, the CIT effect. The earliest CIT studies relied on *physiological* responses induced by the autonomic nervous system (ANS), namely, increased skin conductance responses (SCRs), reduced respiration, and slowed heart rate (HR; e.g., Cutrow et al., 1972; Geldreich, 1941, 1942; Lykken, 1959, 1960). In the late 1980s, some CIT researchers also successfully implemented pupil size in the CIT, while other *ocular* measures remained largely ignored until recently (i.e., Janisse & Bradley, 1980; Lancry-Dayan et al., 2018; Leal & Vrij, 2010;

[Correction added on October 20, 2022, after first online publication: The University name in the second affiliation has been modified as Hebrew University of Jerusalem.]

Lubow & Fein, 1996; Millen et al., 2017; Peth et al., 2013, 2016; Schwedes & Wentura, 2012, 2016).

Although eye-movement-based CIT research is on the rise, most CIT studies and ensuing theories surround the ANS-based measures. The most influential theoretical account in this domain relies on the orienting response (Lieblich et al., 1970; Lykken, 1974; see klein Selle et al., 2018 for a review): a pattern of behavioral and physiological responses to a change in stimulation or a new stimulus (Sokolov, 1963a). A key feature of this response is its sensitivity to stimulus significance. Thus, in the CIT, each new stimulus should produce an orienting response, but significant, critical, stimuli should produce increased orienting responses—possibly driving the CIT effect. Another more recent theoretical account relies on the construct of arousal inhibition. Specifically, inhibition theory states that attempts at inhibition of physiological arousal, induced by critical stimuli, drive the CIT effect (Verschuere et al., 2007). Imagine, for instance, the previous example of Ted Bundy. Ted might not only recognize (and orient to) the correct item (i.e., a crowbar), but also, in order to seem innocent, attempt to inhibit his physiological arousal. Attempts at arousal inhibition, however, come with a physiological cost (Pennebaker & Chew, 1985) and may reduce both HR and respiration, as typically observed in the CIT (e.g., Dan-Glauser & Gross, 2011). As such, also arousal inhibition may account for, or at least contribute, to the CIT effect. Recently, a series of studies revealed that different ANS measures in the CIT may actually reflect different underlying mechanisms: while the SCR reflects orienting to significant information, respiration, and HR reflect inhibition attempts (klein Selle et al., 2016, 2017, 2019; Suchotzki et al., 2015). This fractionation of responses challenged the unitary theoretical thinking about the CIT and inspired similar research using event-related potentials (ERPs; klein Selle et al., 2021; Matsuda & Nittono, 2018; Rosenfeld et al., 2017). These additional studies suggest that the P3 component of the ERP, just as the SCR, reflects an orienting process. The question, however, remains which mechanisms drive the different ocular responses in the CIT.

Although we are not aware of a study that has directly examined this, there are empirical findings that suggest a role for both orienting and inhibition. In a typical CIT, critical items reduce the number of blinks and fixations (i.e., the periods of relatively stable eye position between gaze shifts), but increase the duration of fixations, as well as pupil size. Pupil dilation was already associated with orienting in the classical works of Lynn (1966) and Sokolov (1963b). Hence, it is not surprising that pupil responses co-vary with the hallmark measure of orienting—that is, skin conductance (Bradley et al., 2008). Blinks and fixations, on the other hand, seem more related to inhibition. This may be especially true for startle blinks (i.e., rapid and intense blinks induced by unexpected or aversive stimuli), as shown by Verschuere et al. (2007). This study combined the CIT with a startle eye-blink paradigm and showed that startle blink-responding was affected by inhibition, but not orienting. When considering fixations, previous CIT studies have shown that fixation durations increase when participants answer deceptively, and aim to conceal the critical items, compared to when answering honestly. Moreover, fixation durations have been shown to increase even more when participants are instructed on how to conceal (e.g., Lancry-Dayan et al., 2018; Millen et al., 2020; Millen & Hancock, 2019). These findings suggest that the effort to conceal, and associated inhibition attempts, may drive longer fixations in the CIT (see also Cook et al., 2012). This hypothesis is supported by various non-CIT studies that observed fewer and longer fixations when individuals expect an aversive stimulus that can be avoided (Merscher et al., 2022; Rösler & Gamer, 2019). Such reduced visual exploration has been tied to inhibitory processes similar to "freezing" responses in rodents. Taken together, although the above summary does not unequivocally determine the driving forces of the ocular-based CIT, it supports the notion of response fractionation. Specifically, it suggests that the different ocular measures—just as the autonomic responses—may reflect different cognitive mechanisms and underlying theoretical constructs.

The primary goal of the present study was to examine the mechanisms underlying the ocular-based CIT. This was accomplished by using the CIT paradigm of klein Selle et al. (2019). In each trial of this paradigm, after selecting one card and deciding whether to conceal or reveal it (decision stage), participants actually try to conceal or reveal their selection (CIT stage; see Figure 1). Item-significance and associated orienting responses are expected to be equal in the two conditions (conceal versus reveal), while only in the conceal condition, participants are also expected to try and inhibit their physiological arousal. Importantly, in addition to tracking oculomotor behavior, we measured participants' skin conductance and HR. This brings us to the second aim of the current study, which was to replicate the previously observed dissociation of autonomic measures. Altogether, the obtained results may expand current theoretical accounts of the CIT and enhance our understanding of how oculomotor changes relate to the autonomic nervous system.

1 | METHOD

1.1 | Participants

A total of 37 participants (73% female) were recruited through an online portal of the *University* of *Würzburg*. Participants'

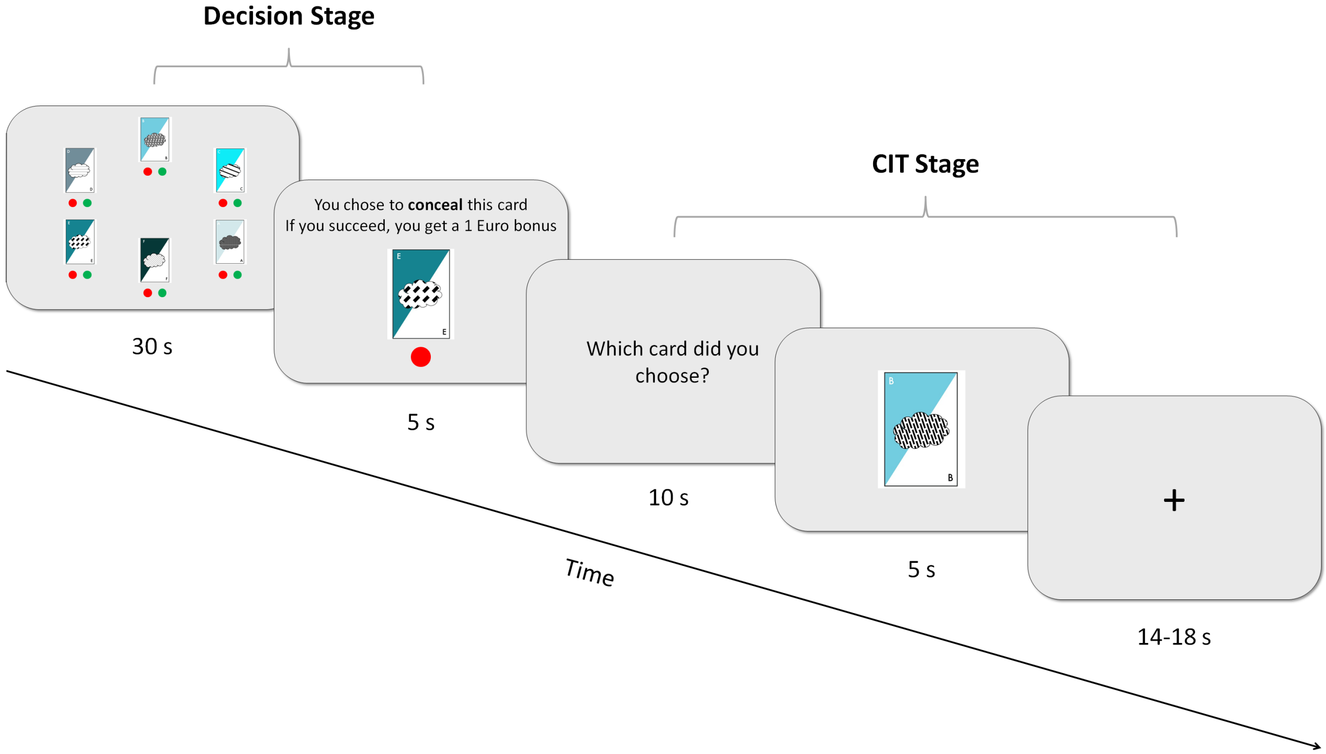

FIGURE 1 Experimental design. First, in the decision stage, participants had to select one card out of six and decide if they want to conceal (red circle) or reveal (green circle) it in the following Concealed Information Test (CIT) stage, all within 30s. Next, seven cards were serially displayed during the CIT stage (only the first buffer card is shown here).

average age was 25.40 years (*SD* = 4.1, range = 18–36). All participants signed an informed consent form, indicating that participation was voluntary (and could be terminated at any stage), and were reimbursed for their time by either course credits or a monetary compensation (approximately 12 Euros). The study complied with the guidelines of the local ethics committee and was conducted according to the principles expressed in the Declaration of Helsinki.

From this initial sample, one participant had no physiological data, because the experimental program crashed before the data were saved. Further, the CIT SCR-data of two participants were excluded due to non-responsivity (see Data Pre-Processing). Thus, analyses of the two physiological measures were based on data of either 34 (SCR) or 36 (HR) participants. Analyses of the ocular measures were based on data of all 37 participants. An a-priori power-analysis revealed a necessary sample size of about 34 participants in order to detect a medium-sized effect (i.e., Cohen's *d* of 0.5), with a statistical power of .80. As we performed a large variety of statistical tests (using different dependent measures), we could not rely on a single effect size obtained in previous studies. Consequently, our power analysis was based on a medium-sized effect, as pre-registered (https://aspredicted.org/ms7vi.pdf).

1.2 | Procedure

After obtaining informed consent, the experimenter connected the SCR and HR electrodes. Then, following a resting period of 2 minutes (i.e., baseline measurement), the experimenter provided verbal instructions about an upcoming card-game. This game consisted of eight randomly presented trials and each trial was composed of a *decision* and a *CIT* stage (see Figure 1). To enhance participant's attention, a short break was inserted after every second trial. Before starting the card-game, all participants also had to pass a short practice stage familiarizing them with the procedure.

Please note that this procedure (i.e., card-game) is analogous to that of one of our previous studies (klein Selle et al., 2019). As such, the description of the methods partly overlap. Moreover, our stimuli (i.e., cards) are identical to those from the previous study and were created using Adobe Illustrator CC and organized in nine categories, each containing seven cards with a colored background and a uniquely filled shape; categories 1–8 were used in the actual card game, while category nine was used in the practice stage (all stimuli can be found on https://osf.io/gdfqa/).

1.2.1 | Decision stage

Six cards of the same category were simultaneously displayed in each trial (the 7th card of each category was used as catch item in the later CIT stage). Participants had 30 s to decide which of these cards they would like to conceal or reveal. This 30 s time interval is defined as "decision window." Participants were asked to think for at least 10 s before making their decision and to carefully consider, per trial, which card they might succeed to conceal/reveal. Overall, each participant had to conceal in at least three and reveal in at least three, out of eight, trials. This allowed participants to freely decide when to conceal and when to reveal, however, prevented a situation in which they would select only 0–2 cards for either condition. Participants clicked with a computer mouse on the red or green circle below the card if they wanted to conceal or reveal, respectively. The location (left/right) of the red and green circles changed randomly across trials. Once one of the circles was pressed, the card above was highlighted with a yellow frame and all the other cards turned gray. Participants were instructed to report their decision as soon as they reached it and were told that this decision is final. The time interval between card display and the selection is defined as "decision time." After 30 s, the selected card was displayed for 5 s together with the selected red\green circle (see Figure 1).

1.2.2 | CIT stage

Every trial of the CIT stage began with a question "Which card did you choose?", displayed for 10 s, followed by a serial display of 7 cards (each for 5 s): 1 buffer, 1 critical, 4 control, and 1 catch cards. The critical items were previously selected in the decision stage and all other items in the trial were cards from the same category. Catch items were unique as they also had a number drawn in their center. Participants were requested to say these numbers out loud to ensure their engagement in the task. When any other card was displayed, participants were requested to remain silent. Importantly, the buffer item was always displayed first and all other items were displayed in a random order. Fourteen to eighteen seconds passed between the display of each two items. Overall, 8 question-trials × 7 items were presented.

In line with klein Selle et al. (2016, 2017, 2019), participants were informed that the recognition of critical cards in the CIT stage would elicit various automatic responses. Then, participants were motivated to either allow (when they chose to reveal), or not to allow (when they chose to conceal), these responses and the detection of the critical cards. Consequently, while participants under both conditions should orient to the significant critical information, they should inhibit their physiological arousal only when motivated to conceal. A one Euro bonus was promised for each card that the participants successfully concealed/revealed.

Following the CIT stage, a recognition test was employed to assess participants' memory of the selected cards. In each recognition trial, all cards belonging to a single category were presented simultaneously and participants clicked on the critical (earlier selected) card. Next, we also assessed if the concealed and revealed cards were equally significant to participants by asking them to rate the level of significance of all eight critical cards and eight randomly chosen control cards, on a scale of 1 (= *not at all*) to 9 (= *extremely*). Finally, participants rated on a scale of 1 (= *not at all*) to 6 (= *very much*) their level of motivation and effort to conceal/reveal the critical cards, their effort to inhibit arousal and how fast they thought they selected the critical cards (after reaching a decision). Following this self-report survey, participants were briefly informed about the rationale of the experiment and were reimbursed for their time.

1.3 | Data acquisition

The experiment was conducted in a sound attenuated room with dedicated air-conditioning. Presentation of questions and stimuli, as well as recording of the behavioral responses, was accomplished with SR Research Experiment Builder software. All stimuli (cards) were presented on an Asus VG248QE monitor (60 Hz refresh rate, 1920 × 1080 pixels), at a viewing distance of approximately 500 mm, capturing 9.1 × 12.1 degrees of visual angle (horizontal × vertical) in the CIT stage.

An EyeLink 1000 Plus desktop-mount setup (SR Research Ltd.; Ottawa, Ontario, Canada) was used to measure oculomotor behavior (at a sampling rate of 1000 Hz). After an initial blink detection, eye-movement data were parsed into saccades and fixations using EyeLink's standard parser configuration. An eye-movement was defined as a saccade when the deviation of consecutive samples exceeded 30°/s velocity or 8000°/s^2 acceleration. Samples gathered from time intervals between saccades were defined as fixations.

A Biopac MP160 system with AcqKnowledge 5.0 (BioPac Systems; Goleta, CA, USA) was used to measure skin conductance and HR (at a sampling rate of 500 Hz). Skin conductance was measured at the thenar and hypothenar eminences of the participant's nondominant hand by a constant voltage system (0.5 V) using a bipolar recording with two Hellige Ag/AgCl electrodes (diameter = 1 cm) filled with 0.05 M NaCl electrolyte. The electrocardiogram (ECG) was recorded using 3 M RedDot Ag/AgCl disposable electrodes attached to the manubrium sterni and the left lower rib cage. The reference electrode was placed at the right lower rib cage. The obtained ECG signal was filtered using a band pass of 1–35 Hz (Biopac's hardware filter).

1.4 | Data pre-processing

All data were pre-processed using Matlab R2016a (The MathWorks, Natick, MA) and we closely followed the pre-registered protocol (see https://aspredicted.org/ms7vi.pdf) unless otherwise noted. Ocular and physiological responses were separately scored for the decision as well as the CIT stage.

1.4.1 | Ocular responses

Similar to previous eye-tracking studies on decision-making (Glaholt & Reingold, 2009a, 2009b), we determined the mean number of fixations and the total dwell time on each card during the decision stage. Analyses of the CIT stage focused on the average number of fixations and the mean fixation duration per card (Peth et al., 2013; Schwedes & Wentura, 2012, 2016) which was calculated by summing the duration of all fixations and dividing it by the total number of fixations (during the 5-sec card presentation). In addition to these pre-registered analyses, we also extracted the mean number of blinks and the pupil size for each card. Pupil size data were transformed from arbitrary units to mm following recommendations of Hayes and Petrov (2016) and samples with missing data (e.g., due to blinks) were excluded. For the CIT stage, all ocular measures were calculated during item presentation (i.e., 0–5 s following stimulus onset). For the blink data, we additionally considered the 5 s interval following stimulus offset since previous studies reported a blink rebound effect during this period (e.g., Peth et al., 2016). Analyses of the decision stage focused on the time period until participants reported their decision to either conceal or reveal a specific card (i.e., the decision time).

1.4.2 | Physiological responses

Processing of physiological data was comparable to klein Selle et al. (2019). In short, SCR amplitudes were calculated as the largest increase in skin conductance. In order to derive HR scores from the ECG-recordings, R-peaks were first detected automatically, and R-R-periods were converted to beats per minute. After a semi-automatic artifact detection and rejection procedure (cf. klein Selle et al., 2016, 2017, 2019), a real-time scaling was applied, yielding one HR value per second. HR changes during the decision and the CIT stage were baseline-corrected using the average HR value in the last 3 s preceding the decision window or the stimulus onset in the CIT stage, respectively. For the decision stage, SCR amplitudes were scored during the time period before a decision was reached and ΔHR scores were averaged across this decision-time interval. For the CIT stage, SCR amplitudes were scored during the presentation of each card (i.e., 1–5 s) and ΔHR scores were averaged across 15 s following stimulus onset (Gamer et al., 2008).

1.4.3 | Standardization, outlier detection, and data aggregation

For the decision stage, all 48 ocular responses (per item) and eight physiological responses (per trial) were standardized within subjects to identify outliers. Since no response score deviated more than five *SD*s from the mean, no response was eliminated from the sample. For the analyses of the decision stage, raw data were averaged across trials, separately for the reveal and the conceal condition (for physiological data), or across items separately for critical and control items in the conceal and reveal conditions (for ocular measures), respectively. For the CIT stage, all 56 ocular and 56 physiological responses were standardized within trials to minimize habituation effects (Ben-Shakhar & Elaad, 2002). Specifically, the standard scores were computed by subtracting the mean response computed across all critical and control items within a trial (i.e., excluding buffer and catch items) from each response to an individual item and dividing this difference by the respective standard deviation. Using the same criterion as specified above, 3.9% of ocular responses (number of fixations, fixation duration, number of blinks, pupil size) and 6.1% of physiological responses (SCR, HR) were identified as outliers and correspondingly eliminated from the sample. Furthermore, if participants had an *SD* of SCR amplitudes below 0.01 μS in the first (trials 1 to 4) or second block (trials 5 to 8) of the experiment after outlier rejection, the respective block was eliminated due to skin-conductance non-responsivity. This was the case for the whole SCR data of two participants as well as the second block of one additional participant. For the statistical analyses of the CIT stage, we calculated separate detection scores for the conceal and the reveal condition by averaging the standardized responses of critical items for each ocular and physiological measure.

1.5 | Data analyses

All data were analyzed using R software (version 3.6.1) and we closely followed the pre-registered protocol (see https://aspredicted.org/ms7vi.pdf). The data and analysis scripts can be accessed on: https://osf.io/gdfqa/.

The raw physiological measures of the decision stage were analyzed with paired samples *t*-tests (comparing conceal and reveal conditions), while the ocular measures from this stage were analyzed by a 2 (motivation: conceal vs. reveal) by 2 (item-type: critical vs. control) repeated measures ANOVA. Finally, we report the results of two computerized classifiers, that is, a support vector machine classifier without a kernel and a naive Bayesian classifier, that tried to predict participants' choice (in the decision stage). In other words, by using the ocular changes during decision-making, the classifiers aimed to classify the different stimuli (i.e., cards) of each trial, as either critical (i.e., chosen) or control (i.e., non-chosen). Importantly, classifier training and testing were done separately for the conceal and reveal trials, in order to compare prediction accuracies between the two conditions (using paired samples *t*-tests).

In the main CIT-stage analyses, paired samples *t*-tests compared detection scores between the conceal versus reveal conditions. Subsequently, to examine whether the detection scores were significantly different from 0 (i.e., whether the CIT effects were significant), we also ran a one-sample *t*-test for each condition. After the main analysis, paired samples *t*-tests compared memory performance, as well as motivation and efforts (to conceal/reveal), in the conceal versus reveal conditions. Furthermore, the significance ratings were analyzed by a 2 (motivation: conceal vs. reveal) by 2 (item-type: critical vs. control) repeated measures ANOVA.

We report Cohen's d and Cohen's f values as effect sizes for *t*-tests and ANOVAs, respectively (Cohen, 1988). We also used the BayesFactor package (Morey & Rouder, 2018) extension for R (R Core Team, 2020) to compute *Jeffreys*-Zellener-Siow (JZS) Bayes Factors (BFs; Jeffreys, 1998). We used a Cauchy prior (r) with a *scale* parameter of *0.707* (the default setting in R). When reporting *t*-tests, either the BF_{10} (quantifying the evidence for the alternative hypothesis) or the BF_{01} (quantifying the evidence for the null hypothesis) is added. When reporting ANOVA results, either the $BF_{Inclusion}$ or $BF_{Exclusion}$ is added, reflecting a comparison of all models including (or excluding) a particular effect to those without (or with) the effect. Thus, the $BF_{Inclusion}$ reflects the evidence in the data for including a main or interaction effect, similar to BF_{10} for simple comparisons (see van den Bergh et al., 2020).

2 | RESULTS

2.1 | Decision stage

Before analyzing the ocular/physiological responses from the decision stage, we compared the average decision time (in seconds) between the conceal ($M = 14.81$ s, $SD = 3.81$ s) and reveal ($M = 15.10$ s, $SD = 3.51$ s) conditions, but no significant difference was found: $t(35) = -.54$, $p = .591$, $d = 0.09$ (95% CI = [−.23, .41]), $BF_{01} = 4.93$.

2.1.1 | Ocular measures

We analyzed two raw ocular measures: mean number of fixations and dwell-time. The ANOVA on the number of fixations revealed a significant main effect of item-type: $F(1,36) = 551.21$, $f = 3.91$, $p < .001$, $BF_{Inclusion} = 3.89 \times 10^{47}$, indicating more fixations on the critical (chosen) card than on the control cards on average during decision-making. Moreover, it revealed a significant Motivation × Item-Type interaction: $F(1,36) = 4.13$, $f = .34$, $p < .05$, $BF_{Inclusion} = 1.09$. This interaction reflects the larger critical-control difference in the reveal, $t(35) = 23.56$, $p < .001$, $d = 3.87$ (95% CI = [2.92, 4.82]), $BF_{10} = 1.89 \text{ x } 10^{20}$, than in the conceal condition, $t(35) = 15.36$, $p < .001$, $d = 2.53$ (95% CI = [1.86, 3.19]), $BF_{10} = 2.47 \times 10^{14}$. The main effect of motivation was insignificant ($p > .05$). The ANOVA on dwell-time revealed a significant main effect of item-type: $F(1,36) = 630.13$, $f = 4.18$, $p < .001$, $BF_{Inclusion} = 5.90 \times 10^{49}$, reflecting longer dwell-times on critical (chosen) than on control cards during decision-making. The main effect of motivation and the Motivation × Item-type interaction were insignificant ($p > .05$).

The significant main effects of item-type suggest that ocular changes during decision-making could be used to predict the decision-outcome (i.e., which card was chosen?). With the number of fixations and mean dwell-time as predictors, a support vector machine classifier reached an average classification accuracy (across participants) of 89% in the conceal condition and 88% in the reveal condition. When comparing conditions, no significant difference was observed: $t(36) = .47$, $p = .642$, $d = 0.08$ (95% CI = [−.25, .40]), $BF_{01} = 5.10$. Similar results were obtained when using a naive Bayesian classifier; classification accuracy reached 93% in the conceal and 92% in the reveal condition. Again, no significant condition-difference was observed: $t(36) = .85$, $p = .400$, $d = 0.14$ (95% CI = [−.19, .46]), $BF_{01} = 4.04$. In other words, ocular changes (i.e., number of fixations and dwell time) during decision-making predicted with an average accuracy of ~90% which cards were ultimately selected. The motivation to conceal or reveal the chosen card did not significantly affect this result.

2.1.2 | Physiological measures

Comparing the raw physiological responses (SCR and HR) between conceal and reveal conditions did not yield any significant result (all p's > .05).

2.2 | Main analyses: CIT Stage

2.2.1 | Ocular measures

Critical items in the CIT (compared to controls) are typically associated with a decrease in the number of blinks and fixations, but an increase in fixation duration and pupil size. To explore these ocular CIT effects, we analyzed the average Z-scores of critical items—that is, detection scores (see Data Pre-Processing in the Methods section).

Significantly larger *fixation* detection scores were found in the conceal than in the reveal condition; number of fixations: $t(36) = -3.95$, $p < .001$, $d = 0.65$ (95% CI = [.29, 1.00]), $BF_{10} = 80.40$; fixation duration: $t(36) = 3.22$, $p = .003$, $d = 0.53$ (95% CI = [.18, .87]), $BF_{10} = 12.91$ (see Figure 2). When comparing the detection scores of each condition to 0, significant CIT effects were found in the conceal; number of fixations: $t(36) = -4.17$, $p < .001$, $d = 0.69$ (95% CI = [.32, 1.04]), $BF_{10} = 144.96$; fixation duration: $t(36) = 4.47$, $p < .001$, $d = 0.74$ (95% CI = [.37, 1.10]), $BF_{10} = 325.02$, but not in the reveal condition. Actually, the number of fixations showed an opposite effect in the reveal condition, reflecting an increase rather than a decrease for critical items, $t(36) = 2.31$, $p = .027$, $d = 0.38$ (95% CI = [.04, .71]), $BF_{10} = 1.85$. In other words, only when motivated to conceal, participants fixated less, but longer, on the critical items (see Figure 2).

Significantly larger *blink* detection scores were again found in the conceal as compared to the reveal condition: $t(35) = -2.82$, $p = .008$, $d = 0.47$ (95% CI = [.12, .81]), $BF_{10} = 5.20$. This effect was however only observed for the 5–10 s post-stimulus period, not for the 0–5 s stimulation period: $t(35) = .10$, $p = .920$, $d = 0.02$ (95% CI = [−.31, 34]), $BF_{01} = 5.56$. When analyzing the two conditions separately, a significant blink CIT effect was found in the conceal: $t(35) = -2.37$, $p = .024$, $d = 0.39$ (95% CI = [.05, .73]), $BF_{10} = 2.05$, but not in the reveal condition: $t(36) = 1.23$, $p = .228$, $d = 0.20$ (95% CI = [−.13, .53]), $BF_{01} = 2.80$. Taken together, only when motivated to conceal, participants blinked significantly less after seeing the critical items (see Figure 2).

Significantly larger *pupil-size* detection scores were observed in the reveal than in the conceal condition: $t(36) = -7.74$, $p < .001$, $d = 1.27$ (95% CI = [.83, 1.70]), $BF_{10} = 3.35 \times 10^6$. When analyzing the two conditions separately, a significant CIT effect was found in the reveal: $t(36) = 13.40$, $p < .001$, $d = 2.20$ (95% CI = [1.60, 2.80]), $BF_{10} = 4.29 \times 10^{12}$, but not in the conceal condition: $t(36) = 1.84$, $p = .075$, $d = 0.30$ (95% CI = [−.03, .63]), $BF_{01} = 1.24$ (see Figure 2 as well as Figure 3a for the pupil size time-course).

2.2.2 | Physiological measures

Critical items in the CIT (compared to controls) typically yield increased SCR, but decreased HR. To explore these autonomic CIT effects, we used a similar approach as for the ocular measures and analyzed the average Z-scores of critical items—that is, detection scores.

Significantly larger *SCR* detection scores were observed in the reveal than in the conceal condition, $t(33) = -5.96$, $p < .001$, $d = 1.02$ (95% CI = [.60, 1.43]), $BF_{10} = 16241.91$ (see Figures 2 and 3b). The SCR CIT effect was, however, significant in both conditions; conceal: $t(33) = 2.91$, $p = .006$, $d = 0.50$ (95% CI = [.14, .85]), $BF_{10} = 6.29$; reveal: $t(33) = 12.30$, $p < .001$, $d = 2.11$ (95% CI = [1.50, 2.71]), $BF_{10} = 1.02 \times 10^{11}$. Although these results echo the pupil size findings (reveal > conceal), they are not completely consistent with the SCR findings from three previous studies (klein Selle et al., 2016, 2017, 2019). In these studies, similar SCR CIT effects were observed in the two motivational conditions. Possible explanations for this discrepancy are provided in the Discussion.

Significantly larger *HR* detection scores were observed in the conceal than in the reveal condition: $t(35) = -4.04$, $p < .001$, $d = 0.67$ (95% CI = [.31, 1.03]), $BF_{10} = 99.84$ (see Figure 2). When examining the two conditions separately, a significant HR CIT effect was observed in the conceal: $t(33) = -5.72$, $p < .001$, $d = 0.95$ (95% CI = [.55, 1.34]), $BF_{10} = 9992.50$, but not in the reveal condition: $t(35) = 1.02$, $p = .317$, $d = 0.17$ (95% CI = [−.16, .50]), $BF_{01} = 3.47$. Thus, HR decreased when attempting to conceal, but not reveal, the critical cards (see Figures 2 and 3c). This finding replicates earlier results by klein Selle et al. (2016, 2017, 2019). Moreover, it mimics the current fixation and blink findings (conceal > reveal).

2.3 | Memory and subjective ratings

The memory-performance data obtained after the CIT stage indicated significantly better recognition of critical cards in the reveal (M = 95%, SD = 11%) than in the

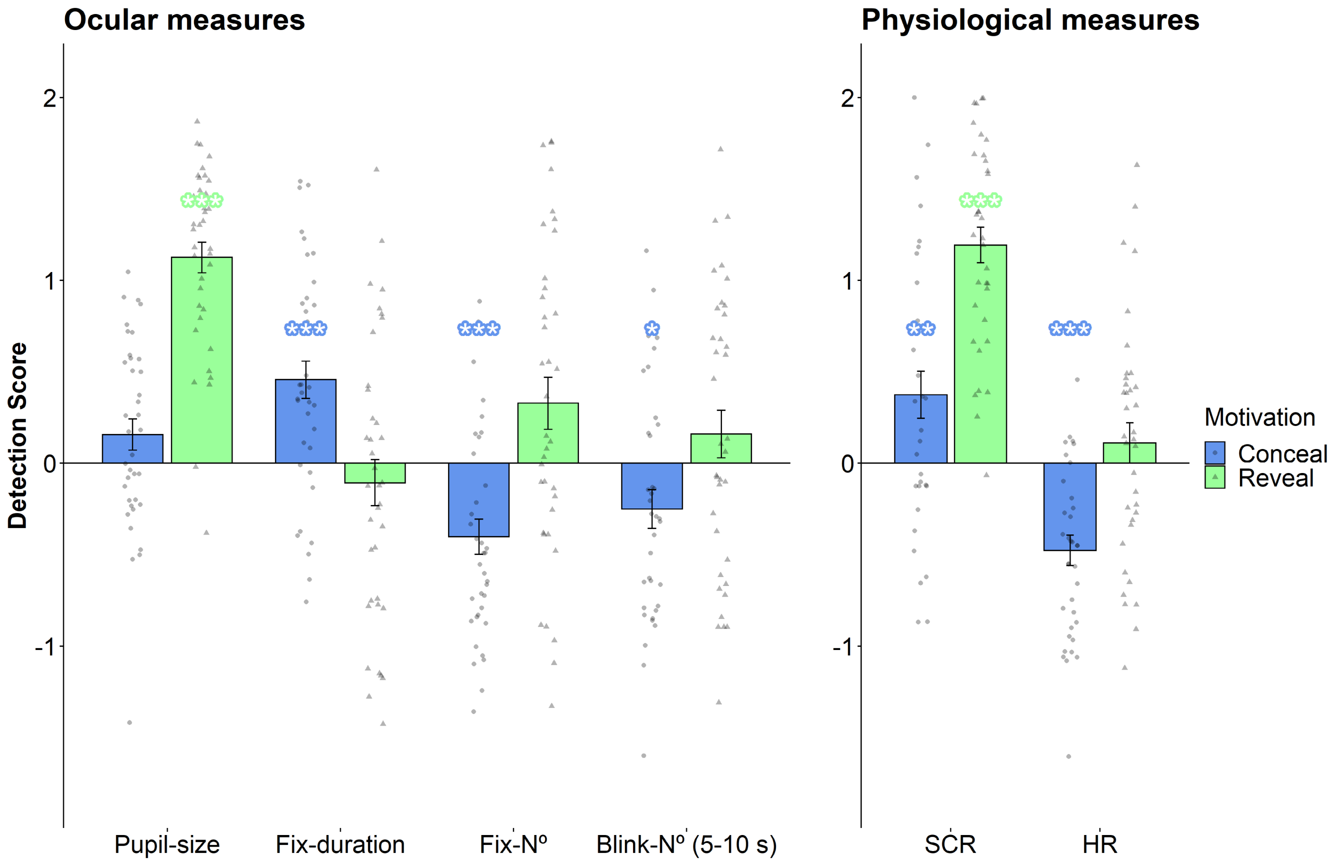

FIGURE 2 Detection scores (i.e., average *Z*-scores of critical items) for four ocular and two physiological measures. Dots indicate values of individual participants and error bars indicate standard errors of the mean. All significant CIT effects are marked with asterisks (* for $p < .05$, ** for $p < .01$, *** for $p < .001$).

conceal condition (M = 89%, SD = 18%), $t(36) = -2.10$, $p = .043$, $d = 0.35$ (95% CI = [.01, .67]), $BF_{10} = 1.25$.

The significance ratings showed a significant main effect of item-type: $F(1,36) = 189.38$, $f = 2.29$, $p < .001$, $BF_{Inclusion} = 2.23 \times 10^{33}$, and a significant Motivation × Item-Type interaction: $F(1,36) = 10.90$, $f = .55$, $p = .002$, $BF_{Inclusion} = 2.80$. The interaction results from a larger critical-control difference in the reveal, $t(36) = 15.25$, $p < .001$, $d = 2.51$ (95% CI = [1.84, 3.16]), $BF_{10} = 1.96 \times 10^{14}$, than in the conceal condition, $t(36) = 9.18$, $p < .001$, $d = 1.51$ (95% CI = [1.03, 1.98]), $BF_{10} = 1.71 \times 10^{8}$. This result is in line with the memory-performance data and suggests that participants chose more significant cards to reveal, than to conceal. Importantly, these results can explain larger SCR and pupil size CIT effects in the reveal condition (please see Discussion).

As can be seen in Table 1, the data from the self-report survey showed no significant difference between the *motivation* to conceal (in conceal trials) and reveal (in reveal trials) the critical items. Similar results were obtained for the *effort* to conceal and reveal the critical items. Self-reported inhibition attempts were, as predicted, significantly higher in the conceal compared to in the reveal condition. Finally, when considering the decision stage, participants indicated to press quickly on the red/green circles (M = 4.32, SD = 0.97). This suggests a high synchronization between participants' actual decisions and corresponding behavior (i.e., button presses).

3 | DISCUSSION

The present study examined the underlying mechanisms of the ocular-based CIT by manipulating whether participants were trying to conceal or reveal a previously selected item. Interestingly, the fixation and blink CIT effects (i.e., reduced number of blinks and fixations, longer fixation durations) were confined to the conceal condition. This suggests that these measures reflect inhibition attempts induced by the motivation to conceal, not orientation to significant stimuli. Pupil dilation, on the other hand, occurred in both motivational conditions and was even stronger in the reveal condition. This result clearly speaks against inhibition theory concerning pupil dilation, as there is less need for inhibition in the reveal than in the conceal condition. We therefore

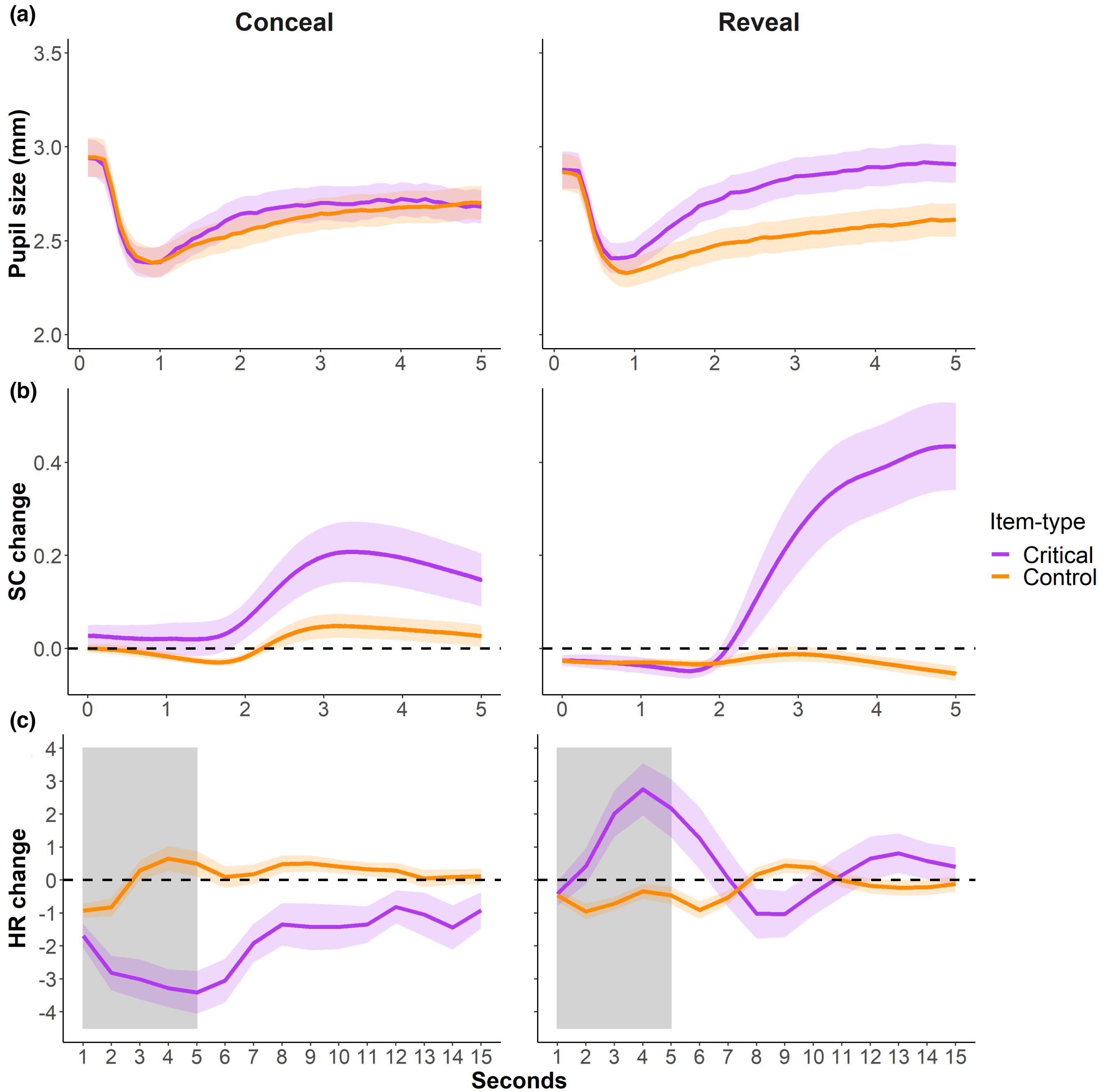

FIGURE 3 Time-course of pupil size, skin conductance (SC), and heart rate (HR), for critical and control items in the conceal and reveal conditions. Shading around the waveforms represents the standard error of the mean across subjects. Panel a: Pupil size time-course during card presentation in the Concealed Information Test (CIT) stage. The pupil size time-course was smoothed by averaging each 100 samples (sampling rate was 1000 Hz); Panel b: SC time-course during card presentation in the CIT stage. SC values were baseline-corrected by subtracting the average SC value in the 3 s preceding stimulus onset; Panel c: HR time-course in the CIT stage. The gray rectangles mark the 5 s of card presentation. HR values were baseline-corrected by subtracting the average HR value in the 3 s preceding stimulus onset.

suggest that the pupil CIT effect rather reflects an orienting response.

In the present study, participants obviously selected the cards in the decision stage based on strategic considerations. As a result, more significant cards were selected for the reveal than for the conceal condition (as reflected in the self-report significance ratings). Consequently, orienting responses, and orienting-associated CIT effects, should be larger in the reveal than in the conceal condition—which was indeed the case for the pupil CIT effect. Importantly, the idea that pupil dilation is associated with an orienting response, is supported by both older and more recent work (Lynn, 1966; Nieuwenhuis et al., 2011; Sokolov, 1963b). When considering fixations and blinks, previous studies

TABLE 1 Descriptive statistics of the self-report survey for both the conceal and reveal motivational conditions; mean (*SD*); *p*-value; Cohen's *d* +95% CI and BF

	Mean (*SD*)				
	Conceal	**Reveal**	***p*-value**	**Cohen's *d* +95% CI**	**BF**
Motivation (conceal/reveal)	5.60 (.64)	5.57 (.55)	.786	0.05 [−.28, .37]	5.46 (BF_{01})
Effort (conceal/reveal)	5.35 (.68)	5.27 (.77)	.539	0.10 [−.22, .42]	4.726593 (BF_{01})
Inhibition attempts	4.87 (1.03)	1.65 (1.06)	<.001	2.37 [1.73, 3.00]	3.69e+13 (BF_{10})

from a variety of research fields—for example, using aversive stimuli—have tied decreased numbers of blinks and fixations, as well as increased fixation durations, to inhibitory processes that result in a reduced exploration of the environment (e.g., Lancry-Dayan et al., 2018; Merscher et al., 2022; Millen et al., 2020; Millen & Hancock, 2019; Rösler & Gamer, 2019). Hence, these studies indirectly support the current findings which suggest that the fixation and blink CIT effects are associated with inhibition, not orienting. Taken together, our findings support the notion of response fractionation in the CIT, which holds that different ocular measures are driven by different underlying mechanisms and therefore relate to different theoretical constructs.

The observed ocular fractionation echoes physiological findings. Specifically, an HR CIT effect, just as the fixation and blink effects, was obtained only in the conceal condition. This is in line with three previous studies by klein Selle et al. (2016, 2017, 2019) and supports the idea that HR slowing in the CIT is caused by inhibition attempts. On the other hand, the SCR CIT effect, just as the pupil size effect, was larger in the reveal than in the conceal condition. The three previous studies (klein Selle et al., 2016, 2017, 2019) observed no significant conceal-reveal difference in the SCR. Yet, the first two studies reported slightly larger SCR CIT effects in the conceal (Cohen's *d*: 1.47 and 2.05) than in the reveal (Cohen's *d*: 1.39 and 1.54) condition, while only the third study reported a larger Cohen's *d* in the reveal (0.99) than in the conceal (0.62) condition. The distinct experimental design of the third, and the current, study might explain this observed discrepancy. Specifically, while klein Selle et al. (2016, 2017) requested participants to either conceal or reveal the exact same critical information, klein Selle et al. (2019) requested participants to choose which information to conceal and which information to reveal. Hence, as in the present study, memory and subjective significance of the critical cards were higher in the reveal versus conceal condition, which may explain the larger SCR (and pupil) CIT effects. Note that this difference in item significance is a limitation of the present study and, hence, future studies should preferably remove the decision stage and present participants with the same stimuli in conceal and reveal conditions.[1] Regardless, if the increase in sympathetic arousal reflected in SCR and pupil size is indeed driven by orienting, and no differences should be observed between the two motivational conditions, it is not too surprising that some experiments find a difference in one direction, while others find the opposite effect.

As explicated above, our results suggest that the pupil size CIT effect is driven by orienting, while the blink and fixation CIT effects are driven by inhibition attempts. It should be noted, however, that increases in pupil size and reductions in blinks and fixations have also been observed under high cognitive load (e.g., Bagley & Manelis, 1979; Drew, 1951; Goldstein et al., 1992; Hess & Polt, 1964; Pivik & Dykman, 2004; van der Wel & van Steenbergen, 2018). Hence, the question arises whether cognitive load plays a role in the CIT and whether it could explain the ocular CIT effects. There are at least two reasons why the answer to this question is probably "no": (1) cognitive load is generally low in the CIT, especially when participants remain silent (as in the current design), and (2) self-reported cognitive effort was similar in the conceal and reveal conditions, while the ocular effects were significantly different. Nevertheless, cognitive load may explain why fixations and blinks are sensitive to countermeasures—that is, deliberate actions to avoid detection (see Peth et al., 2016). Such countermeasures are typically directed toward the control items and are assumed to increase cognitive load which should reduce fixation and blink rates. When such blink/fixation suppression to control items resembles that of critical ones, it may obscure the CIT effect with these measures. Thus, taken together, although it seems unlikely that the currently observed ocular and physiological CIT effects reflect underlying cognitive load, future studies will have to

[1]When statistically controlling for item-significance, the pupil and SCR CIT effects remained larger in the reveal than in the conceal condition (*p*'s < .05). However, as the significance ratings are subjective and were not obtained for all control items—participants rated eight randomly selected control cards (one from each card-category)—it is possible that our ratings did not capture the true extent of the conceal-reveal significance difference. Hence, no firm conclusions can be made based on these analyses.

elucidate to what degree cognitive load might additionally modulate these changes in specific conditions (e.g., difficulties in memory retrieval, strategic manipulation of responses).

When analyzing the decision stage, we found that gaze dwelled longer on a card that was ultimately chosen, compared to other cards. Previous studies have already observed such a gaze bias effect during decision making (Glaholt & Reingold, 2009a, 2009b; Shimojo et al., 2003; Simion & Shimojo, 2006), but as far as we are aware of, no previous study has examined whether this bias is modulated by the motivation to conceal versus reveal a stimulus. Our results suggest no influence of such contrasting motivational states and showed that ocular changes during decision-making can predict with high certainty which item will be chosen (~90%), both when motivated to conceal and reveal.

Taken together, the present study suggests that different ocular measures in the CIT are driven by different underlying mechanisms. While changes in pupil size may reflect enhanced orientation to significant information (just as SCR and P3), changes in fixations and blinks may reflect inhibition attempts induced by the motivation to conceal (just as respiration and HR). Beyond illuminating how oculomotor changes relate to the autonomic nervous system, these findings provide a backbone to the newly proposed response fractionation theory of the CIT (e.g., klein Selle et al., 2017). Importantly, a strong theory that allows to derive accurate predictions about how CIT-related cognitive processes drive ocular and physiological responses may encourage forensic usage of the CIT instead of other more dubious polygraph methods (e.g., the Control Question Test; see Iacono, 2011).

AUTHOR CONTRIBUTIONS

Nathalie klein Selle: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; visualization; writing – original draft; writing – review and editing. **Kristina Suchotzki:** Conceptualization; methodology; writing – review and editing. **Yoni Pertzov:** Conceptualization; methodology; supervision; writing – review and editing. **Matthias Gamer:** Conceptualization; funding acquisition; methodology; resources; supervision; writing – review and editing.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest with respect to the authorship or the publication of this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in the Open Science Framework at https://osf.io/gdfqa/.

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