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N200 and P300 as orthogonal and integrable indicators of distinct awareness and recognition processes in memory detection

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Abstract

In an event-related potential (ERP)-based concealed information test (CIT), we investigated the effect of manipulated awareness of concealed information on the ERPs. Participants either committed a mock crime or not (guilty vs. innocent) before the CIT, and received feedback regarding either specific (high awareness) or general (low awareness) task performance during the CIT. We found that awareness and recognition of the crime-relevant information differentially influenced the frontal-central N200 and parietal P300: Probe elicited a larger N200 than irrelevant only when guilty participants were in the high awareness condition, whereas the P300 was mainly responsive to information recognition. No N200-P300 correlation was found, allowing for a combined measure of both yielding the highest detection efficiency in the high awareness group (AUC = .91). Finally, a color-naming Stroop task following the CIT revealed that guilty participants showed larger interference effects than innocent participants, suggesting that the former expended more attentional resources during the CIT.

Descriptors: Event-related brain potentials, N200, P300, Concealed information test, Memory detection, Response monitoring, Stroop task, Ego depletion, Complex trial protocol

The concealed information test (CIT) was designed to identify the memory status of information possessed by an examinee, regardless of his or her explicit and possibly deceptive verbal report (e.g., denying the recognition of crime-relevant information; for a recent overview, see Verschuere, Ben-Shakhar, & Meijer, 2011). In a typical CIT, examinees are presented with a rare crime-related information item (i.e., probe) embedded randomly in a series of frequent crime-irrelevant items (i.e., irrelevant, Lykken, 1959). For guilty examinees who acquired the crime-related information during the crime, the probe is expected to be recognized and thus processed differently than the unrecognized irrelevant. In contrast, for the innocent examinee who does not know the critical detail of the crime, the probe is just another irrelevant and no systematic processing difference is expected between probe and irrelevant. The dominant theoretical account of the CIT involves the orienting response (OR, Sokolov, 1963), which states that a personally significant stimulus (here, the crime-relevant detail known only to the guilty examinee) among a stream of neutral stimuli will elicit a complex of physiological changes including dilation of pupils, increased phasic skin conductance, and decreased heart rate (Verschuere & Ben-Shakhar, 2011).

Based on the OR framework, it has been theorized that stimulus significance is a key factor contributing to the CIT effects. Specifically, the more the signal value or salience of the item, the more likely it is to be discriminated from irrelevant stimuli. In previous studies, a range of other factors were also found to influence the CIT results, including memory strength (e.g., central vs. peripheral status of crime details, Gamer, Kosiol, & Vossel, 2010; Nahari & Ben-Shakhar, 2011), motivation to pass the test (e.g., low vs. high motivation, Elaad & Ben-Shakhar, 1989; Gustafson & Orne, 1963), and deceptive responding (being deceptive vs. keeping silent, Elaad & Ben-Shakhar, 1989; Furedy & Ben-Shakhar, 1991. For a meta-analysis, see Ben-Shakhar & Elaad, 2003). These factors, despite their possibly nonoverlapping mechanisms, may similarly contribute to the stimulus significance or noteworthiness (Elaad & Ben-Shakhar, 1989). Thus, the probes would be more salient, leading to enhanced autonomic nervous system (ANS) responses compared to responses to irrelevants.

A personally significant stimulus among a stream of relatively neutral stimuli can also elicit changes in brain activity as measured by event-related brain potentials (ERPs). Specifically, it has been argued that the P300, an endogenous ERP component that occurs 300–800 ms poststimulus onset, can be used as an index of processing meaningful, significant, memorized, or task-related stimuli (Donchin & Coles, 1988; Polich, 2007). This attribute of P300 lends itself well to memory detection and CITs (Allen, Iacono, & Danielson, 1992; Farwell & Donchin, 1991; Rosenfeld et al., 1988; for a review, see Rosenfeld, 2011).

It has been found that many of the factors influencing the ANS-based CIT also influence P300-based CITs. For example, when participants have the intention to conceal the probe, larger P300s are elicited than when they have no intention to conceal the information, possibly because the information becomes more salient under the intention-to-conceal condition (Kubo & Nittono, 2009; see also Meijer, Smulders, Merckelbach, & Wolf, 2007). Recently, Rosenfeld, Hu, and Pederson (2012) investigated the

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effect of deceptive instruction and feedback during a "3-stimulus" P300-CIT (Rosenfeld, 2011), in which on each trial either a probe, irrelevant, or target stimulus is presented. It was found that when participants gave deceptive responses, and were receiving feedback regarding their deceptive responses, the probe-irrelevant P300 differences were larger than when participants were neither instructed to lie, nor given deception-related feedback during the CIT (see also Verschuere, Rosenfeld, Winograd, Labkovsky, & Wiersema, 2009).

Despite the dominant role of stimulus salience in both ANS-based and ERP-based CITs, other mechanisms have also been proposed that are independent of ORs. For instance, Verschuere, Crombez, Koster, Bockstaele, and De Clercq (2007) found that concealed information was associated with reduced startle modulation, which was attributed to participants' inhibition of their physical reactions toward concealed information. However, the hypothetical inhibition process did not add incremental effects over and above the orienting responses.

Another possible mechanism underlying the CIT that is independent of ORs may be response/performance monitoring during the CITs. For instance, Gamer and Berti (2010) recorded ERPs and skin-conductance responses (SCRs) simultaneously during a CIT. They found frontal-central N200 activity in response to previous memorized stimuli. Moreover, the N200 and SCR were not correlated. The SCRs were indicators of ORs during the CIT; however, the N200s were hypothesized to represent the performance-monitoring demand involved in the CIT (but see Matsuda, Nittono, Hirota, Ogawa, & Takasawa, 2009). Indeed, the frontal-central N200 is found in tasks that require higher demand for cognitive control or response monitoring (Bartholow et al., 2005; Folstein & van Petten, 2008; Hu, Wu, & Fu, 2011; Kopp, Rist, & Mattler, 1996; Liotti, Woldorff, Perez, & Mayberg, 2000; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; van Veen & Carter, 2002; Wu, Hu, & Fu, 2009), and are likely to reflect the activity of dorsal anterior cingulate cortex (Botvinick, Cohen, & Carter, 2004; Nieuwenhuis et al., 2003; Yeung & Cohen, 2006).

However, it should be noted that in previous CITs that reported the N200 (e.g., Gamer & Berti, 2010; Matsuda et al., 2009), the ERPs were recorded simultaneously with ANS activities. Such a procedure is not a standard ERP-CIT because the intertrial interval is usually longer in ANS-based CITs (20–30 s, also see Gamer & Berti, 2010, in which a shorter interstimulus interval (ISI) of 7–9 s was used) than in ERP-based CITs (2.0–5.0 s). Thus, it remains to be investigated whether or not the N200 will be observed in a more temporally typical ERP-CIT, and what psychological processes it represents. Moreover, since the P300 is the most established indicator in the ERP-CIT (see Rosenfeld, 2011), it would be informative to see if N200 does play an additional role in the ERP-CIT, and whether the N200 can add incremental validity above and beyond the P300 in classification efficiency. We pose these two questions here for the first time using the complex trial protocol (Rosenfeld et al., 2008, details below).

In the present complex trial protocol study, we used a feedback manipulation designed to increase participants' attention to the probe-irrelevant dimension and thus awareness of probe occurrence. As noted above, we have recently found that providing participants periodic feedback regarding their deceptive responses during their P300-based, 3-stimulus CIT protocol enhances the test's sensitivity (Rosenfeld et al., 2012). However, as that protocol has proven vulnerable to countermeasures (Mertens & Allen, 2008; Rosenfeld, Soskins, Bosh, & Ryan, 2004), we here apply the periodic feedback manipulation, also for the first time, to the more countermeasure-resistant, complex trial protocol (Rosenfeld et al., 2008).

Specifically, we intended to provide participants with feedback regarding their performance during the CIT. In a high awareness condition, participants received feedback that directed their attention to the concealed information (the feedback suggested that they recognized or were aware of the probe stimulus). This manipulation was hypothesized to direct participants' attention to the specific stimulus that was important to them (i.e., the probe). Moreover, we hypothesized that as participants received high awareness feedback regarding the possible concealed information during the CIT and were thus made more attentive to the probe-irrelevant distinction, they were more likely to engage in monitoring their responses to the probe, and this heightened performance/response monitoring process would be reflected in frontal-central N200 activity (e.g., Bartholow et al., 2005; Gamer & Berti, 2010), as well as an enhanced parietal P300 activity (e.g., Rosenfeld et al., 2012). In contrast, participants in the low awareness condition received feedbacks regarding their general task performance (e.g., "You are following the task instruction well"), and these feedbacks were designed not to impact N200 or P300 activity.

Finally, after finishing the ERP test, participants here performed a Stroop color-naming task that requires cognitive control (MacLeod, 1991). We hypothesize that as guilty participants would devote more attention resources in processing personally significant crime-related information in the CIT, they should show larger interference in the Stroop task than their innocent counterparts. This prediction is based on the "ego-depletion" phenomenon (Baumeister, Vohs, & Tice, 2007). Specifically, because people's general cognitive resources are limited, engaging in a cognitive demanding task will lead to inferior performance in a following task that also requires cognitive control. This is also the first investigation based on a Stroop task after the main CIT to examine whether or not processing personally significant information consumes additional cognitive resources among guilty participants.

Method

Participants

Sixty participants were recruited from the Northwestern University student population for partial course credits (30 females; age range: 19–22. Five additional participants were excluded because of excessive movement or artifacts during the ERP sessions). The study was approved by the Northwestern Institutional Review Board.

Materials and Procedure

After signing consent, participants were asked to randomly draw one of six sealed envelopes that contained instructions and a group assignment. Specifically, they were instructed not to reveal their group status until the end of the experiment. The experimenter was thus blind to participants' group status during the test session. Via instructions, participants were randomly assigned to two groups: guilty or innocent. Guilty groups were instructed to enact a mock crime: stealing an object hidden in an envelope from a professor's (J.P.R) mailbox in the main office of the Department of Psychology. Specifically, the object (here, a ring) was not revealed to participants before they actually stole it from the envelope. Thus, the crime-relevant knowledge was acquired only during the mock

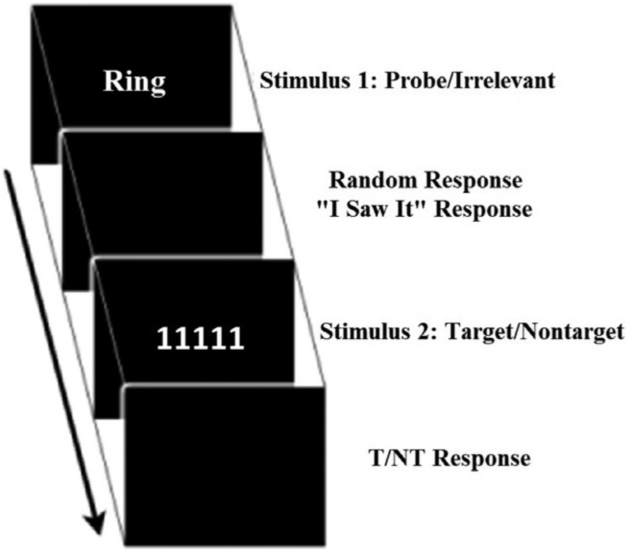

Figure 1. Task structure of the complex trial version of concealed information test.

crime. Innocent participants were asked only to sign their initials on a sheet of paper outside the main office.

Upon finishing the task, participants returned to the lab for the remaining tests. Participants were then randomly assigned to one of two feedback conditions: low or high awareness feedback. Thus, participants were randomly assigned to one of four possible groups: high awareness-guilty group; high awareness-innocent group; low awareness-guilty group; low awareness-innocent group (see below for awareness feedback manipulations).

The ERP-based concealed information test. The complex trial protocol version of the CIT was structured as in Hu, Hegeman, Landry, and Rosenfeld (2012). Each trial began with a 100-ms baseline period for the recoding of prestimulus electroencephalogram (EEG) that was used for ERP amplitude calculation. The probe or irrelevant was then presented on the center of the screen for 300 ms. Then, following a random ISI lasting 1,400–1,700 ms, the target/nontarget stimulus was presented also for 300 ms. The next trial began 2,400 ms following the offset of the target/nontarget stimulus. There were 350 trials in total, consisting of a probe and six irrelevants (bracelet, necklace, watch, cufflink, locket, wallet), each repeated 50 times, for a total of 50 probes and 300 irrelevants presented in a random order. This test lasted for approximately 30 min. Before the test, all participants were informed via the written instructions that something was stolen from a faculty member's mailbox, and the brainwave test was intended to identify who was the criminal.

During the task, participants first saw either a probe or one of the six irrelevants on a given trial (see Figure 1). Participants were told to respond randomly on a five-button box by pressing one of the five buttons chosen randomly with their left hand as soon as they saw the stimulus (see Rosenfeld & Labkovsky, 2010). This was the stimulus acknowledgement or the "I saw it" response. They were warned that the experimenter would pause the experiment every 20–40 trials and ask them to repeat aloud the stimulus just presented. Failure to correctly identify more than one stimulus was indicative of inattentive noncooperation and the participant data would be dropped. However, there was no attrition for this reason. The "I saw it" response was followed by a string of numbers (either 11111, 22222, 33333, 44444, or 55555). Participants were asked to make a target/no-target decision with their right hand upon seeing the string of numbers. If the string of numbers was "11111," they were told to press the right button (target) of the response box with their middle finger, and to press the left button of the response box with their index finger if the stimulus was any other string of numbers (nontarget). The target and nontarget occurred at an equal probability following probe and irrelevant stimuli.

Awareness manipulations. During the CIT, one of six possible feedback messages was presented for 10 s on the monitor about every 5 min directly following the target/nontarget responses (a full list of the feedbacks used is provided in the Appendix). Specifically, in the low awareness feedback group, participants received neutral feedback messages regarding their general task performance, such as "From our analysis, you are following instructions well/you are doing a good job." In the high awareness group, however, participants received nonveridical feedbacks regarding possible crime-relevant information, such as "From our analysis, you seem to recognize one of the items/there is a certain item that seems to be special to you."

Stroop task. Upon finishing the ERP-CIT, participants were led to a different room to take an ostensibly unrelated Stroop task, a measurement of response inhibition that is frequently used to study whether a person is cognitively depleted by earlier tasks (e.g., Richeson & Shelton, 2003; for a review, see Baumeister et al., 2007). In the Stroop task, participants were presented with color words in which the font color differed from the word meaning. Participants were asked to press buttons that identified the color of the font instead of the word meanings (e.g., press the button indicating red color in response to the word GREEN printed in red color). Each trial began with a fixation cross lasting for 500 ms in the center of the monitor. This fixation was followed by a color name or a neutral string, XXXX, to which participants were instructed to respond according to the font color. This stimulus disappeared until participants pressed a button, regardless of accuracy. After a random interval of 500–1,000 ms, the next trial was started. Participants finished 60 incongruent trials in which the color name was printed in a different color (e.g., GREEN printed in red color), 60 congruent trials in which the color name was printed in a same color (e.g., RED printed in red color), and 60 neutral trials in which XXXX was printed in a color (e.g., XXXX printed in red color). These 180 trials were randomly presented to participants.

The Stroop interference effect was calculated by subtracting reaction times associated with neutral trials from those associated with incongruent trials.

Data Acquisition

EEG was recorded using Ag/AgCl electrodes attached to three midline sites: Fz, Cz, and Pz. Scalp electrodes were referenced to linked mastoids. Electrode impedance was kept below 5 kΩ. Electrooculogram (EOG) was recorded differentially via Ag/AgCl electrodes placed diagonally above and below the right eye to record vertical and horizontal eye movements as well as eye blinks. EOG voltages were called artifacts if above 50 μV, and all data from associated trials were rejected. The forehead was connected to the chassis of the isolated side of the amplifier system ("ground"). Signals were passed through Grass P511K amplifiers with a 30-Hz

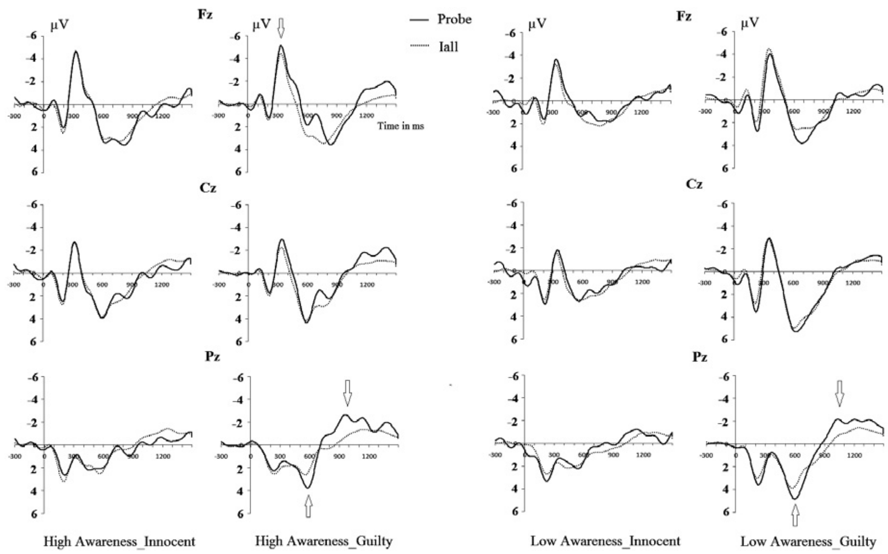

Figure 2. Grand averaged ERPs (low-pass filter at 6 Hz for display purposes) from midline electrodes Fz, Cz, and Pz for participants in the four conditions: high awareness_innocent; high awareness_guilty; low awareness_innocent; low awareness_guilty. Positivity is downward. The up arrows indicate the peak of P300 (Pz), and the down arrows indicate the peak of N200 (Fz) and the negative peak of P300 (Pz).

low-pass filter and 0.3-Hz high-pass filter (3 dB). Amplifier output was passed through a 16-bit A/D converter sampling at 500 Hz. For display purposes, single sweeps and averages were digitally filtered offline from 0 to 6 Hz (3-dB point) to remove higher frequencies.

Analysis Methods for ERP-CIT

After artifact-contaminated trials were rejected, N200 amplitude along three midline sites (Fz, Cz, and Pz), and P300 amplitude at Pz were measured. Specifically, the amplitude of the N200 was defined as the average of the maximal negative 100-ms segment during the 200–400 ms poststimulus time window relative to the 100-ms prestimulus baseline (for a similar method to quantify N200 amplitude, see Gamer & Berti, 2010). The amplitude of the P300 was defined in a peak-peak manner as recommended by Soskins, Rosenfeld, and Niendam (2001), and as done in previous studies (e.g., Hu et al., 2012). Specifically, the algorithm searched from 300 to 800 ms for a maximal positive 100-ms segment average. The midpoint of the segment is defined as the P300 latency. The algorithm continued to search from P300 latency to 1,300 ms for the maximum average 100-ms negativity. The difference between the maximal positive segment and the maximal negative segment is defined as the P300 peak-peak amplitude.

Finally, we conducted receiver operating characteristic (ROC) analyses to investigate the classification efficiency of each ERP component in each feedback condition. This approach is adopted from signal detection theory (e.g., Green & Swets, 1966), and has often been used to estimate the detection efficiency in memory detection research (see Ben-Shakhar & Elaad, 2003). The ROC curve here represents the degree of separation between the distributions of the detection score (e.g., probe-Iall differences) between guilty and innocent participants. The area under the ROC curve (AUC) is a threshold-independent indicator of discrimination efficiency of a test. It varies between 0 and 1, with a chance level of 0.5 and with a perfect classification level of 1. Here, the ROC analyses were conducted based on the probe-Iall differences in N200 and P300 amplitudes from the ERP-CIT, in high and low awareness conditions separately. Moreover, we compared the ROC values between low and high awareness conditions (for methods, see Hanley & McNeil, 1982; McNeil & Hanley, 1984).

Results

All within-subject analysis of variance (ANOVA) results are reported with Greenhouse-Geisser corrected p value when $df > 1$. Partial eta squared values (η^2) are used to estimate effect size.

N200

We first conducted an omnibus 3 Sites (Fz vs. Cz vs. Pz) × 2 Stimulus Type (probe vs. average of all irrelevant, Iall) × 2 Awareness manipulation (high vs. low awareness) × 2 Group (guilty vs. innocent) mixed model repeated measures ANOVAs on N200 amplitudes, with the first two factors as within-subject variables and the third and the fourth variables as between-subjects variables.

Grand averaged ERPs (Figure 2) suggest that N200 was largest at Fz, followed by Cz, and smallest at Pz. This was statistically supported by a significant main effect of sites, $F(2,56) = 170.81$, $p < .001$, $\eta^2 = .75$. Paired comparison tests showed that N200 at Fz (−4.11 ± .25 μV) was significantly more negative than at Cz (−2.37 ± .27 μV) and Pz (.39 ± .22 μV, both ps < .01), and N200 at Cz was more negative than at Pz ($p < .01$). This was also consistent with previous findings that N200s were characterized by a frontal-central distribution (e.g., Gamer & Berti, 2010).

We then focused our analysis at Fz,[1] as it was where the N200 was largest (see Figure 3 for the bar graph). A 2 Stimulus Type (probe vs. average of all irrelevant, Iall) × 2 Awareness manipulation (high vs. low awareness) × 2 Group (guilty vs. innocent) mixed model repeated measures ANOVA was conducted on N200

1. We also conducted the same ANOVA analyses based on N200 amplitudes measured at Cz. Results were the same as the analyses on N200 amplitudes measured at Fz, as shown in the text.

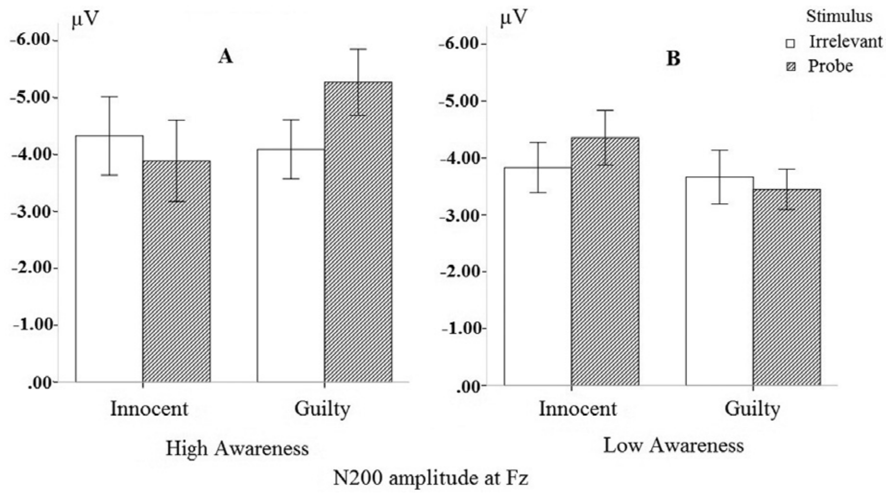

Figure 3. Mean ± *SEM* of N200 amplitudes (Fz) for participants in the four conditions.

amplitudes. Results showed that there was a significant three-way interaction: $F(1,56) = 6.83$, $p < .05$, $\eta^2 = .11$. No other effects were significant (*p*s > .2).

To understand this three-way interaction, we conducted two 2 (probe vs. Iall) × 2 (guilty vs. innocent) ANOVAs in high and low awareness conditions separately. In the high awareness group, the ANOVA yielded a significant Stimulus × Group interaction, $F(1,56) = 6.32$, $p < .05$, $\eta^2 = .18$, see Figure 3A. However, this interaction was not significant in the low awareness group, $F(1,56) = 1.37$, $p > .2$, $\eta^2 = .05$, see Figure 3B. Further inspection of Figure 3B suggested that, in the low awareness condition, the N200 to probe was larger than irrelevant in the innocent group, whereas the N200 to probe was somewhat smaller than irrelevant among the guilty participants, although these differences were not significant (*p*s > .5).

We followed the significant interaction in the high awareness groups by conducting paired sample tests comparing the N200 of probe and irrelevant across innocent and guilty groups. It was found that the probe elicited significantly higher N200s than did irrelevant stimuli in the guilty group, $t(14) = 2.47$, $p < .05$, but not in the innocent group, $t(14) = 1.01$, $p > .3$.

In sum, the N200 results showed that for guilty participants who recognized the probe and were receiving feedback regarding the probe (i.e., in the high awareness condition), the probe was associated with larger N200 than the irrelevant. This effect was not found in the low awareness-guilty group, nor in any innocent groups. Thus, high awareness and probe recognition appear to work jointly to generate this N200 effect.

P300

For P300, we conducted a three-way 2 (probe vs. Iall) × 2 (guilty vs. innocent) × 2 (high vs. low awareness) mixed model ANOVA on peak-peak P300 amplitude at Pz where P300 is usually the maximum (see Figure 4). The results revealed a significant main effect of stimulus type: $F(1,56) = 23.97$, $p < .001$, $\eta^2 = .30$, with larger probe-P300 (6.81 ± .50 μV) than irrelevant-P300 (5.43 ± .34 μV). Moreover, a significant group effect was also

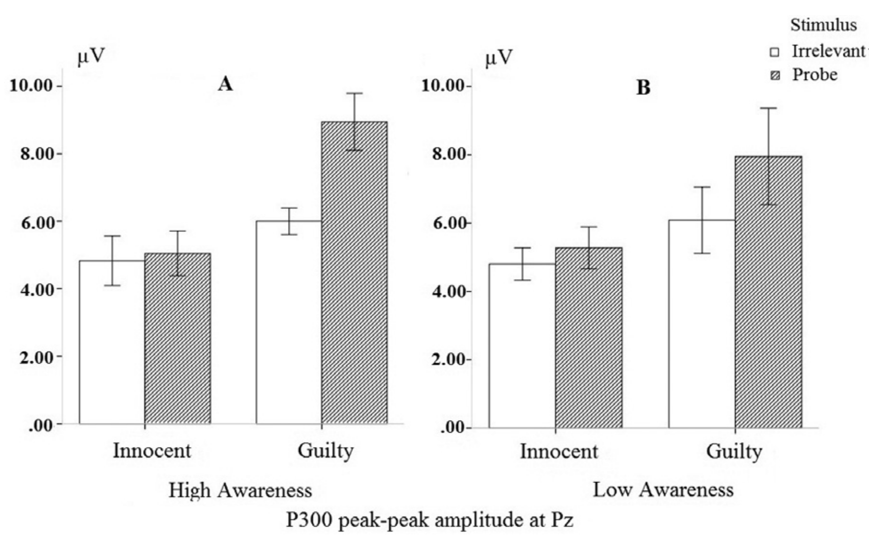

Figure 4. Mean ± *SEM* of P300 peak-peak amplitudes (Pz) for participants in the four conditions.

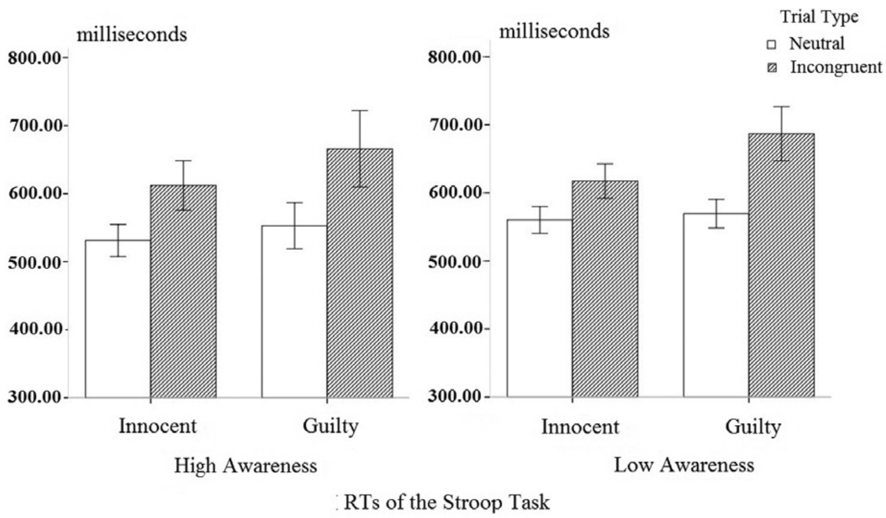

Figure 5. Mean ± SEM of reaction times (RTs) from the incongruent and neutral trials in the color-naming Stroop task.

found: $F(1,56) = 8.55$, $p < .01$, $\eta^2 = .13$, which suggested that the P300 in the guilty groups was significantly larger than that in the innocent groups (7.25 ± .50 vs. 4.99 ± .31 μV). As expected, a Stimulus Type × Group two-way interaction was found: $F(1,56) = 13.42$, $p < .001$, $\eta^2 = .19$. No effects regarding awareness were found (ps > .2).

To understand this Stimulus × Group interaction, we compared the probe and irrelevant stimuli in guilty and innocent groups separately, collapsing awareness conditions. Paired sample t tests showed that the P300 to probe stimuli were significantly larger than the P300 to irrelevant stimuli in the guilty groups (8.45 ± .81 vs. 6.04 ± .51 μV, $t(29) = 4.43$, $p < .001$) but not in the innocent groups ($p > .2$).

Although we did not obtain the expected three-way interaction, nor awareness effects, in the P300 analyses, this could be due to larger P300 amplitude variance among low awareness-guilty participants than among high awareness-guilty participants, as suggested by Figure 4. To statistically test this hypothesis, we compared the probe and Iall P300 amplitude variances between high and low awareness-guilty participants using Levene's test for equality of variances. Results showed that the P300 amplitude variances were indeed larger among low awareness- than among high awareness-guilty participants (for Iall P300 variances, $p < .05$; for probe P300 variances, $p < .08$).

Another way to investigate the awareness effect was to examine the effect size in the low and high awareness-guilty groups. Here, Cohen's d was used to estimate the degree of separation between probe and irrelevant among guilty participants, based on the means and the pooled standard deviations of probe and irrelevant, in low and high awareness-guilty participants separately. Results showed that although the probe elicited larger P300 than irrelevant in both groups (ts > 2, ps < .05), the effect size in the high awareness group was more than three times larger than that in the low awareness group (for high awareness-guilty, Cohen's $d = 1.53$ vs. Cohen's $d = 0.40$ for low awareness-guilty).

In sum, our P300 analyses showed that probe stimuli elicited larger P300 than irrelevant stimuli among participants who recognized the probe (i.e., guilty participants). Moreover, the effect size of probe-irrelevant difference was much larger among high awareness-guilty participants than low awareness-guilty participants.

Stroop Effect

The Stroop interference was calculated as the difference of reaction times (RTs) between incongruent and neutral blocks (see Figure 5). We conducted a 2 Block (incongruent vs. neutral) × 2 Group (guilty vs. innocent) × 2 Awareness condition (high vs. low awareness) mixed model repeated measures ANOVA on participants' interferences scores. The first factor was within-subject while the second and third factors were between-subjects.

Results showed that there was a significant main effect of block, $F(1,56) = 72.74$, $p < .001$, $\eta^2 = .57$, suggesting that participants responded more slowly, as expected, in the incongruent block than in the neutral block (645.56 ± 20.51 vs. 553.49 ± 12.55 ms, see Figure 5). There was also a significant Block × Group interaction, $F(1,56) = 4.61$, $p < .05$, $\eta^2 = .08$. No other effect was significant (ps > .2).

To understand the interaction, we conducted an independent t test comparing the interference (RT_incongruent—RT_neutral blocks) between innocent and guilty groups, collapsing across the two awareness conditions. Results showed that the interference effect was significantly larger in the guilty group than in the innocent group (115.24 ± 17.35 ms vs. 68.90 ± 12. 42 ms, $t(58) = 2.17$, $p < .05$), as hypothesized.

In sum, participants showed the classic Stroop interference effect. However, the interference was larger among participants who previously performed a task involving meaningful information processing (recognition) than among participants who previously performed a task without such information processing (i.e., guilty vs. innocent). High or low awareness did not moderate this interference effect.

Correlation Between Electrophysiological Measures

We explored whether N200 and P300 correlate in guilty participants. Specifically, the mean N200 and P300 amplitude

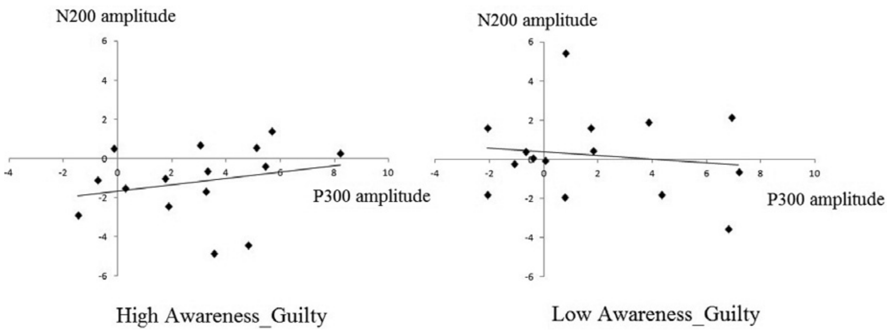

Figure 6. Scatter plots of probe-Iall N200 and P300 amplitude differences among guilty participants in the high awareness and in the low awareness condition separately.

differences between probe and Iall were computed for each participant. Results showed that there was no correlation across participants between N200 and P300: $r(13) = .25$, $p > .3$ in the high awareness-guilty group and $r(13) = -.15$, $p > .6$ in the low awareness-guilty group (see Figure 6). Across the two awareness conditions combined, no correlation between N200 and P300 was found, $r(28) = .05$, $p > .8$. This suggested that the N200 and P300 may indicate different information processing mechanisms occurring during the CIT.

Classification Efficiency

For forensic psychophysiology purposes, it is informative to investigate how well the guilty and innocent participants can be differentiated based on electrophysiological markers associated with concealed information. Moreover, in the present study, our awareness data and the N200-P300 findings also raised two further questions concerning: (a) whether the high awareness manipulation allowed better classification efficiency compared to the low awareness condition, and (b) whether the N200 and P300 activities could be combined to further increase the classification efficiency.

N200. The ROC analyses showed that N200 at Fz can effectively discriminate guilty from innocent participants above a chance level, but only in the high awareness condition (AUC = .72, $p < .05$), and not in the low awareness condition (AUC = .41, $p > .3$). Moreover, the AUC in the high awareness condition was significantly larger than the AUC in the low awareness condition ($z = 2.17$, $p < .05$).

P300. In the high awareness condition, the P300 could effectively differentiate guilty from innocent participants (AUC = .79, $p < .01$). However, the AUC in the low awareness condition was not significantly different from chance level (AUC = .55, $p > .6$). Because of these results, and despite the lack of effect of awareness in the above-mentioned three-way ANOVA on P300 in which awareness was treated as an independent variable, the ROC results suggested additional ANOVAs as follows: two separate 2 Group (guilty vs. innocent) × 2 Stimuli (probe vs. Iall) mixed model ANOVAs on P300 amplitudes in separate high and low awareness conditions (see Figure 4) found that there was a significant Group × Stimulus interaction only in the high awareness condition, $F(1,28) = 14.07$, $p < .01$, $\eta^2 = .33$, suggesting the probe-Iall difference was larger among guilty than innocent participants in this condition. No such interaction was found in the low awareness condition, $F(1,28) = 2.63$, $p > .1$, $\eta^2 = .09$.

The comparison between the AUCs in the two awareness conditions revealed that the AUC in the high awareness condition was higher than the AUC in the low awareness condition, though this difference only approached significance at .05 level ($z = 1.39$, $p = .08$).

Combining N200 and P300. Given that N200 and P300 were not correlated with each other among guilty participants, it seemed that combining these two indices would further improve the test's classification efficiency. To combine the N200 and P300, the probe-Iall difference was transformed into standard z scores across participants for N200 and P300, using each distribution's mean and standard deviation. Since the N200 is with a negative sign, we multiplied the z score of N200 by −1. The z scores from N200 and P300 were then averaged into a single measure (see also Hu & Rosenfeld, 2012; Nahari & Ben-Shakhar, 2011). The ROC analyses based on this combined measurement achieved the highest classification efficiency (AUC = .91, $p < .001$) compared with the N200 or P300 indicators alone in the high awareness condition, but not in the low awareness condition (AUC = .48, $p > .8$). Moreover, the AUC based on the combined measure in the high awareness condition was higher than the corresponding AUC in the low awareness condition ($z = 3.47$, $p < .01$, see Table 1).

Table 1. *ROC Analyses Based on N200, P300, and N200-P300 Combined*

	Conditions	
ERPs	Low awareness	High awareness
Fz-N200	.41 (.20–.62)	.72 (.53–.90)
Pz-P300	.58 (.36–.81)	.79 (.61–.97)
N200-P300 combined	.48 (.26–.70)	.91 (.80–1.00)

Notes. The areas under the curve (AUC) were calculated from the receiver operating characteristic (ROC) analysis based on Fz-N200 and Pz-P300 (peak-peak measure) in low and high awareness conditions. The 95% confidence intervals of the AUCs are given in parentheses. If the 95% confidence interval does not include .50, then the AUC is significantly larger than .50 (chance) at .05 level.

Discussion

In the present study, we manipulated the attention to (or awareness level of) concealed information among both knowledgeable-guilty and nonknowledgeable-innocent participants. We found evidence that when participants were manipulated to be more aware of the concealed information, guilty participants were better distinguished on virtually all measures from innocent participants, compared to guilty participants receiving low awareness feedback. Specifically, first, the probe-related frontal-central N200 was elicited among guilty participants only when they were receiving specific feedback (in the high awareness condition) regarding the probe-irrelevant dimension. Moreover, this N200 was not correlated with P300 probably because the two components each represent different cognitive processes occurring during memory detection. Second, the P300 effectively discriminated guilty from innocent participants in the high awareness condition but not in the low awareness condition. Third, guilty participants showed larger interference effects than innocent participants in a color-naming Stroop task following the CIT.

P300 is the most studied ERPs component that has been used in memory detection (for a review, see Rosenfeld, 2011). Most previous P300-based CITs examined autobiographical or well-rehearsed information (e.g., Allen et al., 1992; Farwell & Donchin, 1991; Hu et al., 2012; Rosenfeld, Biroschak, & Furedy, 2006; Verschuere et al., 2009). Our present study is among the first P300 CITs to use a more ecologically valid way to introduce the probe to the participants: the crime-relevant information was acquired only during the mock crime, not via instruction nor via rehearsal before the test (see also Winograd & Rosenfeld, 2011).

It is known that incidentally acquired information is not as well detected with P300 as is autobiographical information (e.g., Rosenfeld et al., 2006). Thus, we hypothesized that providing feedback during the CIT to raise participants' awareness of the concealed probe may increase its salience, and thus the evoked P300 amplitude. Although we did not find the critical three-way interaction involving awareness, we did find that (a) the probe-irrelevant P300 difference was larger for guilty than innocent participants only in the high awareness condition, and the P300 ROC analyses showed that the AUC was significantly larger than .5 in the high awareness condition but not in the low awareness condition, and (b) among guilty participants, the effect size of probe-irrelevant differences was larger for high awareness participants than for low awareness participants (Cohen's d: 1.53 vs. 0.40).

It was somewhat surprising that the AUC in the low awareness condition was not significantly different than chance level, despite the significant probe-Iall P300 differences in the low awareness-guilty group, which we previously reported with no awareness manipulations (see Rosenfeld, 2011). This could be due to the more realistic nature of the mock crime we used than previous ERP-based CIT studies. Specifically, participants acquired the crime-relevant information only during the crime act, not through task instruction, nor was the information rehearsed. It is thus possible that the probe was not encoded in depth, compared with previous studies in which the probe was well rehearsed (e.g., Allen et al., 1992; Farwell & Donchin, 1991). Another possible reason could be due to the nature of the feedback in the low awareness group. Specifically, unlike participants in the high awareness group in which the feedback directed their attention to the probe-irrelevant distinction, participants in the low awareness group who received nonspecific feedbacks might become more engaged in the random button press or target/nontarget task, instead of the implicit probe-irrelevant discrimination. In other words, the low awareness feedback could have been distracting. Moreover, participants in the low awareness condition may not monitor their performance (regarding probe-irrelevant discrimination) as actively as those in the high awareness condition. These possible differences could extend the range (variance) of probe-irrelevant P300 differences, as in fact we observed, and thereby decrease the ERP effects to probe.

Despite these concerns, this pattern of results regarding awareness is conceptually consistent with many previous ANS-based or ERP-based CIT findings that factors other than memory strength may contribute to the CIT results (Ben-Shakhar & Elaad, 2003; Elaad & Ben-Shakhar, 1989; Kubo & Nittono, 2009; Meijer et al., 2007; Rosenfeld et al., 2012). We reasoned that as the P300 is elicited by personally significant stimuli, the factors that increase stimulus significance would also increase the corresponding P300 responses. For instance, autobiographical information will elicit a larger P300 than incidentally acquired information probably because of the former's higher salience (Hu et al., 2011; Rosenfeld et al., 2006). Similarly, responding with an intention to deceive or conceal may similarly increase the stimulus salience, and thus increase P300 responses in such conditions (Kubo & Nittono, 2009; Rosenfeld et al., 2012). In the present study, our high awareness feedback was hypothesized to increase guilty participants' awareness of the crime-related information and the probe-irrelevant discrimination, which may augment its significance as a probe, thus the probe-irrelevant P300 differences.

Regarding N200, our study provided the first direct evidence of the experimental manipulations required to elicit N200 in temporally standard ERP-CITs: Specifically, recognition of concealed information per se seems not sufficient to produce the enhanced N200 to the probes. Enhanced N200 to probes was observed among knowledgeable-guilty participants only when they were receiving feedback regarding the specific concealed information. The N200 has been previously suggested to indicate participants' cognitive control or response monitoring processes during effortful tasks such as the flanker task, the Stroop task, the go/no-go task, or tasks that involve deception (see Hu et al., 2011; Liotti et al., 2000; Nieuwenhuis et al., 2003; van Veen & Carter 2002; for a review, see Folstein & van Petten, 2008).

The N200 we observed here is thus notable because, unlike the above-mentioned tasks that involve active cognitive control or response conflict, there was no explicit discrimination task in our complex trial version of the CIT: participants were simply required to press one random button upon perceiving the stimulus, regardless of whether probe or irrelevant was presented. In other words, there was no explicit response switching or conflict involved in our task. Despite this absence of explicit response conflict or cognitive control, the N200 under the high awareness condition suggested that participants were still monitoring their internal responses to the probe at an implicit level. This argument is supported by three lines of evidence to be taken together: (1) No correlation was observed between N200 and P300 activities. As the P300 is usually understood to be indicative of stimulus recognition and meaningfulness, the N200 remains as representing cognitive processes other than recognition (i.e., performance monitoring). (2) It has been suggested that processing a meaningful stimulus among frequent meaningless stimuli would automatically trigger a higher level of response monitoring (see also Gamer & Berti, 2010). (3) A previous study found that when participants were told that their performance would be evaluated by the experimenter, they engaged more actively in response monitoring than when they were in the no-evaluation control condition, as evidenced by error-related negativity activities (Hajcak, Moser, Yeung, & Simon, 2005[2]). Our feedback manipulation here was similar to such a performance evaluation manipulation, as we also alerted our participants not only before, but also during, the test that their performance would be evaluated and feedback would be provided. Based on the evidence above and the manipulations to which the N200 responded, we believe that the N200 here reflected that participants in the high awareness condition would be more likely to monitor their responses to the meaningful crime-relevant stimulus.

The interference effects observed from the Stroop task provided evidence that guilty participants devoted more attention resources during the ERP-CIT, thus showing larger interference in the Stroop task than innocent participants. Based on the hypothesis that the general purpose resources for self-control are limited (Baumeister et al., 2007), previous studies show that participants would perform worse in a Stroop task if they had just finished a task that involved active self-control such as temptation resistance or interracial interaction (Richeson & Shelton, 2003; for a review, see Baumeister et al., 2007). Since in the complex trial protocol participants simply respond that they perceive the stimulus and no discrimination task is involved, this seems to suggest that attention resources can be depleted even without active behavioral self-control. Moreover, it is possible that the attention resources consumed in the CIT task were similar to those used in the Stroop task, given that both tasks involve similar brain regions that are involved in cognitive control (e.g., Christ et al., 2009). Future studies could investigate this question more directly by recording brain activities in both tasks.

Despite the fact that guilty participants showed larger interference effects than innocent participants, we failed to support our hypothesis that guilty participants in the high awareness condition would show larger interference effects than those in the low awareness condition. Two reasons may explain this null result: (1) the awareness effect, although evidenced by an online indicator of N200 activities, may be too small to be picked up by the offline, post-CIT Stroop test; and (2) given the possible small effect, the relatively small sample we used here ($N = 15$ in each group) was not able to capture this effect based on behavioral measures. Future studies with larger sample size are warranted to further examine this hypothesis. Nevertheless, our Stroop interference results confirmed our hypothesis that taking a CIT that involves personally significant information consumes attention resources.

For forensic psychophysiology, it is informative to determine how well the ERPs can discriminate guilty from innocent participants. As mentioned above, our ROC analyses suggested that the individual classification was more accurate in the high awareness condition than in the low awareness condition based on N200/P300 amplitude, whereas the classification efficiency in the low awareness condition based on the same indices did not differ from chance level. Moreover, as the uncorrelated N200 and P300 appear to represent nonoverlapping cognitive processes underlying the present task, combining these two measures further increased the test's classification efficiency. Again, combining N200 and P300 resulted in higher classification efficiency among high awareness participants than among low awareness participants.

Although it is tempting to consider adopting the present manipulation in field situations as it demonstrates higher classification efficiency, it should be noted that a direct application of such a bogus feedback manipulation requires caution. Specifically, using bogus feedback in the present experiment was necessary to help us to test our hypothesis, and participants were debriefed thoroughly after the experiment. However, in field situations in which innocent as well as guilty suspects are tested, giving such bogus feedback regarding recognition of certain items may introduce unknown factors (e.g., anxiety, fear, noncooperation) that may distort the test. Moreover, even if suspects could be debriefed after the test, this bogus feedback may cause them to not trust the test during the administration, nor to take it seriously. Thus, such a manipulation is not necessarily preferred to be used in field situations.

Even though a direct application of bogus feedback to direct an examinee's attention is not recommended, the present study shed some light in using more practical strategies to raise an examinee's awareness of concealed information. This could possibly be achieved via different strategies. For instance, before the test, the examiner can inform the suspects honestly that their responses will be monitored and evaluated by the examiner. The examiner can also notify the suspects that they are expected to show distinctive brainwave or behavior responses if they do recognize the probes. The examiner can similarly present a series of test items (including the probe) to reinforce the salience of probe just before the test. Since innocent participants cannot identify the probe, this procedure should not induce false positive results (see Johnson & Rosenfeld, 1992). Future studies are required to test these hypotheses.

2. The error-related negativity (ERN) is a response-locked ERP component that occurs after participants make an error (Gehring, Goss, Coles, Meyer, & Donchin, 1993). The ERN was suggested to reflect similar psychological processes as the frontal-central N200 such as response/conflict monitoring involved in effortful tasks (see Nieuwenhuis et al., 2003; van Veen & Carter, 2002; Yeung & Cohen, 2006; for a review, see Folstein & van Petten, 2008).

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Appendix

Feedbacks for the High Awareness Group

1. From your recent brainwaves, it seems to us that there was a certain item that is special to you. This might be the item that was stolen.
2. Based on your brainwaves in the last several trials, it seems that there is one item that has special meaning to you. These special brainwaves might be caused by you seeing the recognized stolen item.
3. Your recent brainwaves suggest that you recognized one of the items.
4. Based on your brainwaves in the past few minutes, it seems that there is one item that has special meaning to you. This might be the stolen item.
5. From your brainwaves, one item seems to be special to you. We think this might be because you recognize it.
6. From your recent brain activity, you seem to recognize a certain item. This might be the stolen item.

Feedbacks for the Low Awareness Group

1. From your brainwaves, you are following instructions well.
2. Based on your recent brainwaves, you have been paying attention to the task well.
3. From your recent brainwave data, you blinked on some trials.
4. Based on your brainwaves in the past few minutes, you did a good job.
5. From your brainwaves, you followed the task well.
6. From your recent brain activity, you blinked sometimes, but mostly followed the instructions.