Combining recognition, conflict-monitoring and feedback-related ERPs to detect concealed autobiographical information

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Abstract

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Running Head: Detecting concealed information with fCIT

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This study examined neural signatures associated conflict-monitoring, recognition and feedback processing in a novel feedback Concealed Information Test (fCIT), and also examined whether all the ERPs can be used to detect concealed autobiographical information. Participants were randomly assigned to one of two groups (guilty or innocent) and then tested in the fCIT while undergoing electroencephalograms (EEGs). Results show that the probe (participants' name) elicited more negative N200, more positive recognition P300 than irrelevants among guilty participants, and feedback following the probe elicited a larger feedback P300 than feedback following irrelevants. Further, we found that all indicators, including conflict-monitoring N200, recognition P300, and feedback P300, could significantly discriminate between guilty and innocent participants. Combining them is highly effective in discriminating between guilty and innocent participants (AUC = 0.96). These findings not only shed light on the neural processing of fCIT, but also suggest the potential of using fCIT to detect concealed autobiographical information.

Keywords: N200; P300; FRN; Feedback P300; Concealed Information Test; Principal Component Analysis

INTRODUCTION

For centuries, researchers have devoted much effort towards detecting concealed information. The CIT has been established as reliable and valid for detecting the status of information recalled by examinees. An Event-Related Potential (ERP) P300, which reflects the process of recognition and memory, has been widely used with the CIT (Allen, Iacono, & Danielson, 1992; Ellwanger, Rosenfeld, Sweet, & Bhatt, 1996; Meijer, Smulders, Merckelbach, & Wolf, 2007; for a review, see Rosenfeld, 2019). Recently, we presented evidence that ERPs associated with feedback processing during a novel fCIT can accurately identify concealed, crime-related information (Sai, Lin, Hu, & Fu, 2014; Sai et al., 2016; Sai et al., 2020; Zheng et al., 2022). This study concurrently examines ERPs associated with conflict-monitoring, recognition and feedback processing in an autobiographical information-based fCIT, and also whether those ERPs can be used to detect concealed autobiographical information.

ERPs (more specifically the P300) have been used in CIT for over thirty years (Ben-Shakhar, 2012; Kubo & Nittono, 2009; Lu et al., 2018; Rosenfeld, 2011; Rosenfeld, Biroschak, & Furedy, 2006; Rosenfeld, Sitar, Wasserman, & Ward, 2018). The P300 is an endogenous ERP component that occurs between 300 and 800 ms after stimulus onset, and is often elicited by rare, recognized, and meaningful items (Johnson, 1986). Since crime-related information (the probe) is highly meaningful to guilty suspects, the probe will elicit a larger P300 than irrelevant stimuli within that group; for innocent participants (who know nothing about the crime), the probe stimulus is indistinguishable from the irrelevants, in which case there is no significant difference in P300 amplitude between the two. A number of studies have demonstrated that P300 can effectively discriminate between guilty and innocent participants (Ben-Shakhar & Nahari, 2018; Farwell & Donchin, 1991; Lukács et al., 2016; Meixner & Rosenfeld, 2011, 2014; Rosenfeld, 2005; Rosenfeld et al., 1988; Rosenfeld, Labkovsky, Davydova, Ward, & Rosenfeld, 2017; Winograd & Rosenfeld, 2011).

However, limitations to the P300-based CIT exist. For example, CIT is susceptible to countermeasures and information leakage, leading to a significant reduction in lie detection efficiency (Rosenfeld et al., 2004; Zheng et al., 2022; Kim et al., 2022; Rosenfeld et al., 2008; also see a review by Rosenfeld, 2019). In consequence, many researchers have sought ways of enhancing the utility of the P300-CIT (Hu, Pornpattananangkul, & Rosenfeld, 2013; Hu & Rosenfeld, 2012; Rosenfeld et al., 2013; Rosenfeld, Hu, & Pederson, 2012).

A number of recent studies have introduced a new variant of CIT that adds feedback regarding participants' concealment performance. The advantage of this fCIT is to combine both recognition P300 and feedback-related ERPs to detect concealed information. For example, Sai et al. (2016) asked participants to conduct a mock crime (theft of a ring), and then undergo the fCIT to detect concealed information. The authors focused on two well-known feedback-related ERPs: a negativity around 200-300ms (called the feedback-related negativity, FRN, or a reward-related positivity after principal component analysis method) (Luo, Sun, Mai, Gu, & Zhang, 2011; Sato et al., 2005; Yeung and Sanfey, 2004; see a review, Proudfit, 2015); and a positivity around 300-500ms (called the feedback P300) after feedback stimuli. According to their findings, for guilty participants, feedback following a probe elicited greater feedback-related negativity (FRN) and feedback P300 than feedback following irrelevants. On the other hand, for innocents, no significant differences were found for FRN and feedback P300 between feedback following a probe and feedback following irrelevants. Individual analyses showed that both FRN and feedback P300 proved highly effective in discriminating guilty from innocent participants. Furthermore, combining feedback-related ERPs and recognition P300 yielded a near-perfect detection efficiency (AUC = 99%). Further, Sai et al. (2020) repeated the fCIT mock crime (Sai et al., 2016) and investigated whether the feedback stage would influence the detection efficiency in the recognition CIT stage. This study successfully replicated the high detection efficiency and found that the detection efficiency of recognition P300 was basically the same in the classic CIT or in the fCIT (CIT with feedback). The most recent study (Zheng et al., 2022) also adopted the fCIT in mock crime to explore whether the mental countermeasures could compromise the deception efficiency of feedback-related ERPs in fCIT, just like the recognition P300 in the classic CIT paradigm. They found that, unlike the decreased recognition P300 efficiency, the FRN and feedback P300 remain the same efficiency with or without the countermeasures in the fCIT. These findings suggest great promise for the use of feedback-related ERPs in detecting concealed information in mock crime.

Although the high detection efficiency was consistently found in fCIT, most of the above studies examined the utility of using fCIT to detect crime-related information. Specifically, participants in those studies were asked to perpetrate a mock crime (stealing a ring) and then attempt to conceal their knowledge of crime-related information. What remains unclear is whether the fCIT might be used to detect concealed autobiographical information (e.g., a name) that has obvious significance in terms of societal goals. For example, terrorists conceal their identities to commit attacks, while spies conceal theirs to more easily engage in illegal activities (Meixner & Rosenfeld, 2011; Verschuere, Crombez, Koster, & De Clercq, 2007). Thus, another purpose of the present study is to examine whether the fCIT can be utilized to detect this sort of concealed autobiographical information.

In addition, N200 has also been used to detect concealed information in several previous studies. N200 is a negative ERP component that appears around 200-300ms and is found to be associated with cognitive control such as conflict monitoring (Donkers & Van Boxtel, 2004; Enriquez-Geppert, Konrad, Pantev, & Huster, 2010). Since concealing a probe requires more cognitive control than telling the truth to the irrelevant, researchers have hypothesized that probe elicit a more negative N200 than irrelevants. However, the findings are mixed. Some studies have found that probe elicit a more negative N200 than irrelevants, while others have not (for a meta-analysis, see Sai, Cheng, Shang, Fu, & Verschuere, 2023). It should be noted that most previous studies used the baseline to peak method to analyze the N200. It is uncertain if the N200 effect observed in prior research is accurate, as the N200 and P300 are close together and often overlap. To address this issue, the present study used PCA (Principal Component Analysis) to untangle the N200 from the P300 to examine the N200 effect in the CIT.

Taken together, the present study examined whether fCIT can be used to detect autobiographical information. Besides feedback-related ERPs, we also examined the N200 and recognition P300 in fCIT to see whether combining recognition P300, conflict monitoring N200 and feedback-related ERPs could further improve the detection of autobiographical information. We anticipated that (1) probe stimuli would elicit a bigger N200 than irrelevant stimuli in guilty participants, but not in innocent participants; (2) probe stimuli would elicit a greater recognition P300 than irrelevant stimuli in guilty participants, but not in innocent participants; (3) feedbacks following a probe would elicit a larger FRN and feedback P300 than feedbacks following irrelevants in guilty participants, but not in innocent ones; and (4) combining N200, recognition P300, FRN, and feedback P300 might potentially yield very high deception-detection classification efficiencies.

2 Methods

2.1 Participants

Τηε σαμπλε σιζε ωας βασεδ ον πρειους ΕΡΠ-βασεδ φ̒ΙΤ ρεσεαρςη ιν ωηιςη λαργε ανδ μοδερατε-το-λαργε εφφεςτς ωερε φουνδ φορ τηε ιντεραςτιον εφφεςτ βετωεεν τηε στιμυλυς ανδ γρουπ (εφφεςτ σιζες ρανγινγ φρομ ηπ2 = ***0.18 το 0.59· Σαι ετ αλ. 2016, 2020).*** *Φορ ουρ ποωερ αναλψσις, υσινγ Γ*Ποωερ 3.1 (Φαυλ, Ερδφελδερ, Βυςηνερ, & Λανγ, 2009) ανδ σελεςτινγ 'ΑΝΟ̆Α: Ρεπεατεδ μεασυρες, ωιτηιν-βετωεεν ιντεραςτιον', α μοδερατε εφφεςτ σιζε οφ φ = 0.25, αν αλπηα ρεθεςτιον ςριτεριον οφ 0.05, ποωερ οφ 0.95, τωο γρουπς ανδ φουρ μεασυρεμεντς, α ςορρελατιον οφ 0.5 ανδ α* *νονσπηερισιτψ ςορρεςτιον οφ 1, ωε ρεχυιρεδ α μινιμυμ σαμπλε οφ 36 παρτιςιπαντς φορ τηε ςυρρεντ ρεσεαρςη δεσιγν. ὃνσιδερινγ ποτεντιαλ δροπουτ (ε.γ., δατα χυαλιτψ), ωε τηερεφορε ρεςρυιτεδ σιξτψ παρτιςιπαντς (23 μαλες, μεαν αγε = 20.7 ψεαρς, ΣΔ = 2.2 ψεαρς) φορ τηε φ῞ΙΤ στυδψ, ανδ τηεψ ωερε παιδ 60 ΡΜΒ (αππροξιματελψ 9.18 ΥΣΔ) φορ τηειρ τιμε. Αλλ παρτιςιπαντς ηαδ νορμαλ ορ ςορρεςτεδ-το-νορμαλ ισιον, ανδ ωερε ριγητ-ηανδεδ. Νονε ηαδ ανψ ηιστορψ οφ νευρολογιςαλ ορ πσψςηιατρις δισορδερ. Νο παρτιςιπαντς ωερε εξςλυδεδ φρομ τηε ΕΡΠ αναλψσες. Τηε στυδψ ωας ςονδυςτεδ ιν αςςορδανςε ωιτη γυιδελινες αππροεδ βψ τηε Ετηιςς ὃμμιττεε οφ Ηανγζηου Νορμαλ Υνιερσιτψ.*

2.2 Προςεδυρες

Υπον εντερινγ τηε λαβορατορψ, εαςη παρτιςιπαντ προιδεδ ινφορμεδ ςονσεντ, ανδ ωας τηεν ρανδομλψ ασσιγνεδ α ρολε οφ γυιλτψ ορ ιννοςεντ. Φορ αλλ παρτιςιπαντς, α ῄινεσε σταρ΄ς ναμε (‘Δεηυα Λιυ’) ωας υσεδ ας τηε ταργετ. Φουρ οτηερ ναμες ωερε ασσιγνεδ ας ιρρελεαντς. Φορ τηε γυιλτψ γρουπ, τηε παρτιςιπαντ΄ς οων ναμε ωας τηε προβε, ωηερεας φορ τηε ιννοςεντ γρουπ, τηε προβε ωας αν ιρρελεαντ ναμε. Παρτιςιπαντς ωερε υνφαμιλιαρ ωιτη αλλ οφ τηε ιρρελεαντ ναμες. Παρτιςιπαντς φρομ βοτη γρουπς ρεςειεδ τηε σαμε ινστρυςτιονς: τηεψ ωερε ασκεδ το ιμαγινε βεινγ αρρεστεδ βψ πολιςε δυρινγ αν αιρπορτ βοαρδινγ προςεδυρε. Το προε τηειρ ιννοςενςε, τηεψ ωερε ρεχυιρεδ το πασς α λιε δετεςτορ τεστ.

Αφτερ πλαςινγ ΕΕΓ ελεςτροδες ον τηε παρτιςιπαντ, τηε λιε-δετεςτιον προςεσς βεγαν. Τηε ςοηορτ ωας πρεσεντεδ ωιτη α σεριες οφ ναμες ον α ςομπυτερ σςρεεν· εαςη ινδιιδυαλ ωας ασκεδ το ρεσπονδ το ‘Ι ρεςογνιζε τηε ναμε’ βψ πρεσσινγ τηε λεφτ βυττον, ορ το ` `Ι δο νοτ ρεςογνιζε τηε ναμε΄ ΄ βψ πρεσσινγ τηε ριγητ βυττον (τηε ρεσπονσε βυττονς ωερε ςουντερβαλανςεδ αςροσς παρτιςιπαντς ιν βοτη γρουπς). Ας αν εξαμπλε, ωηεν πρεσεντεδ ωιτη ‘Δεηυα Λιυ,’ τηε ρεσπονσε ουγητ το ηαε βεεν, ‘Ι ρεςογνιζε τηε ναμε,’ σινςε αλλ παρτιςιπαντς ωερε φαμιλιαρ ωιτη Δεηυα Λιυ. Νοτε τηατ παρτιςιπαντς ωερε ασκεδ το ανσωερ τρυτηφυλλψ, εξςεπτ ιν τηοσε ςασες ωηερε γυιλτψ παρτιςιπαντς ωερε πρεσεντεδ ωιτη τηειρ οων ναμες. Ιν τηις ινστανςε, παρτιςιπαντς ωερε ασκεδ το λιε βψ ανσωερινγ ‘Ι δο νοτ ρεςογνιζε τηε ναμε,’ τηερεβψ δενψινγ αλλ γυιλτ. Τηε λιε δετεςτορ τηεν δετερμινεδ ωηετηερ τηε παρτιςιπαντ ωας λψινγ, ανδ προιδεδ ιμμεδιατε φεεδβαςκ. Φεεδβαςκ ‘+4’ μεαντ τηατ τηε δετεςτορ ιντερπρετεδ τηε ρεσπονσε ας τρυτηφυλ, ωηερεας φεεδβαςκ ‘-2’ ινδιςατεδ α ‘λιε.’ Ηοωεερ, υνκνοων το τηε παρτιςιπαντς, τηεσε φεεδβαςκς ωερε πρεσεντεδ ρανδομλψ.

Παρτιςιπαντς ωερε σεατεδ ρουγηλψ 1 μετερ αωαψ φρομ α ςομπυτερ σςρεεν. Εαςη τριαλ βεγαν ωιτη α 500 ± 100 ms fixation point, following which a name was presented for 300 ms. In response to the name, participants were instructed to press the appropriate button as quickly and accurately as possible. After a 1000 ms blank, a pentagram appeared on the screen for 2500 ms; this signified that the lie detector was analyzing the veracity of the response. Finally, feedback in the form of a ‘ ‘+4’ ’ (telling the truth) or ‘ ‘-2’ ’ (telling a lie) appeared for 1000 ms (see Figure 1).

Thus, the feedback stage inhered in four conditions: probe-truth (success); probe-lie (failure); irrelevant-truth (success); and irrelevant-lie (failure). The target repeated 60 times with real feedback, which was provided according to the participants' real performance. The probe and four irrelevants repeated 60 times; 30 of these were followed by “+4” feedback, while the other 30 were followed by “-2”. Thus, there were 6*60 = 360 total trials. After sets of 40 trials (approximately 4 minutes), participants were given short breaks. The experiment lasted roughly 37 minutes.

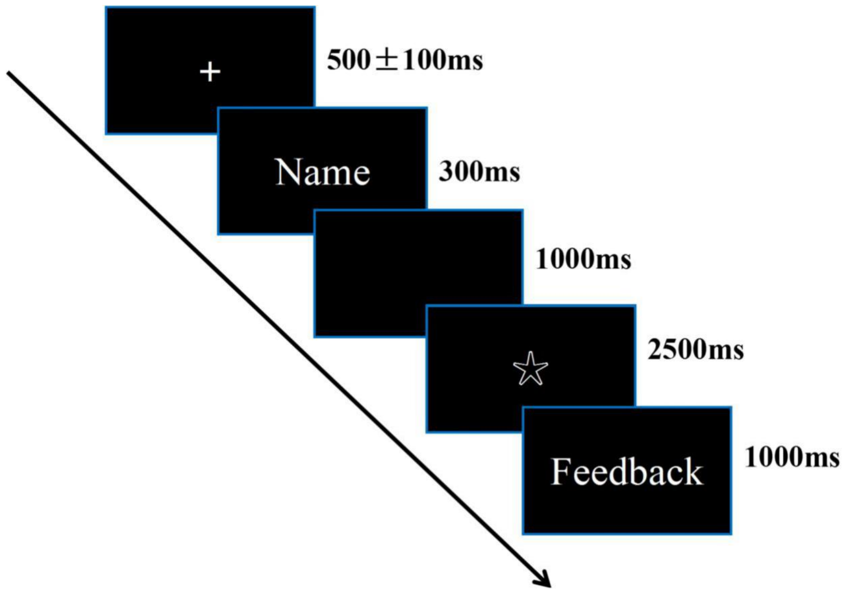

Figure 1. Task structure

2.3 EEG acquisition and ERP quantification

Continuous EEGs were recorded from 32 scalp sites using Ag/AgCl electrodes embedded in elastic caps (Brain Products, Germany) according to the international 10–20 system. Online recordings were referenced to the right mastoid. Electrode impedance were kept below 10 kΩ. The sampling rate was set to 1000 Hz.

For offline analyses, all data were processed with BrainVision Analyzer software (Brain Products, Germany). Continuous EEGs were filtered with a 30Hz low-pass filter and a 0.1Hz high-pass filter. Ocular Correction ICA was used to remove eye movements. Continuous EEGs were then segmented into 1,200 ms epochs and were time-locked to either the probe/irrelevant stimuli or to the positive/negative feedback stimuli. The 1,200 ms epoch contained a 200 ms pre-stimulus baseline, and a 1,000 ms time window after stimulus onset. The irrelevant ERPs were averaged across all four irrelevant items. Trials with signals exceeding 100 µV were defined as artifacts and excluded from averaging.

For ERPs time-locked to CIT stimuli (i.e., probe vs. irrelevant), we focused on the P300 component at Pz which often occurs between 350 - 550 ms (Matsuda & Nittono, 2018; Matsuda, Nittono, Hirota, Ogawa, & Takasawa, 2009), the P200 component at FCz which often occurs (between 150 - 250 ms) (Tacikowski, Cygan, & Nowicka, 2014; Xu et al., 2011), and the N200 component at FCz which often occurs between 250 - 350 ms (Ganis, Bridges, Hsu, & Schendan, 2016; Hu, Wu, & Fu, 2011). These recognition-related components were quantified using temporal PCA, a technique that extracts linear combinations of data points meeting certain criteria which tend to distinguish between consistent patterns of electrocortical activity (Dien and Frishkoff, 2005). This analysis was conducted using the ERP PCA Toolkit, version 2.86 (Dien, 2010). This PCA used 1200 time points (200 ms before CIT-stimuli onset served as baseline) from each participant's averaged ERP as variables, with participants and conditions as observations. Promax rotation was used (Dien, Khoe, & Mangun, 2007), and eleven temporal factors were extracted based on the resulting scree plot (Cattell, 1966). Of these factors, nine factors accounted for more than 1% of the total variance in the data. We selected the positive component peaking at 384 ms as the recognition-P300, the positivity component at 206 ms as the P200, and the negativity component at 316 ms as the N200 for further calculation (see Table 1).

For feedback-locked ERPs, we concentrated on the FRN at Fz which occurs 250-350 ms and the feedback-P300 at Pz which occurs 350-550ms (Foti, Weinberg, Dien, & Hajcak, 2011; **Sai et al., 2016**). Since the FRN and the feedback-P300 are largely overlapped, we also conducted a temporal PCA to analyze them.

This PCA was performed with promax rotation, using 1200 time points (200 ms before feedback onset served as the baseline) from each participant's averaged ERP as variables, with participants and conditions as observations. Based on scree plots, 13 factors were extracted and 6 factors accounted for more than 1% of the total variance in the data. We selected the positive component peaking at 282 ms as the FRN and the positivity component at 424 ms as the feedback P300 for further calculation (see Table 1 and Table S1). The waveforms for each factor were reconstructed (i.e., converted to microvolts) by multiplying the factor pattern matrix with the standard deviations. These factors were scored using the peak values (Foti et al., 2011), which were applied to subsequent analyses, including analyses of variance (ANOVA), and ROC analyses.

All analyses were conducted using SPSS 20.0. For ANOVA, the Greenhouse-Geisser correction was applied when the assumption of sphericity was violated. Post-hoc comparisons were computed with Fisher's Protected Least Significant Difference. Effect size was estimated by the partial eta squared value$\eta_\pi{}^2$.

In addition, Bayes factors (JZS BFs, with scaled r = 0.707, as in Rouder, Speckman, Sun, Morey, & Iverson (2009) were reported as a complement to classical statistics. The BFs serve as a method of quantifying the ratio of the likelihood of the null hypothesis to the likelihood of the alternative hypothesis. The ratio will be stated as favoring either the null hypothesis (no difference) or the alternative hypothesis (Jeffreys, 1998; Kass & Raftery, 1995). For t -tests, the BF_{10} (favoring the alternative hypothesis) or the BF_{01} (favoring the null hypothesis) is reported. For ANOVA effects, the $BF_{\text{Inclusion}}$ (favoring the alternative hypothesis) or $BF_{\text{Exclusion}}$ (favoring the null hypothesis) is reported, reflecting a comparison of all models containing a particular effect to those without the effect (also see Klein Selle, Gueta, Harpaz, Deouell, & Ben-Shakhar, 2021). A BF value of [?] 3 was regarded as moderate evidence for the respective hypothesis (Kass & Raftery, 1995). BFs were computed using JASP (Version 0.14.1, https://jasp-stats.org/).

Table 1

PCA factors selected for statistical analysis.

	Corresponding ERP components	Temporal factors	Temporal loading peaks	Variance explained (
Conflict-monitoring	N200	TF06	316 ms	1.49
Recognition	Recognition P300	TF03	384 ms	5.27
Feedback	FRN	TF04	282 ms	1.81
	Feedback P300	TF01	424 ms	17.50

3 Results

3.1 *N200 (a negativity peaking at 316 ms corresponded to N200 at FCz, see Figure 3a*)

We conducted a two-way 2 (within-subject: probe vs. irrelevant) by 2 (between-subject: guilty vs. innocent) mixed ANOVA on N200 amplitude. The results showed a significant main effect of stimulus type, F (1, 58) = 10.54, p = 0.002,$\eta_\pi{}^2$ = 0.15, $BF_{\text{Inclusion}}$ = 686.91, with more negative N200 elicited by the probe than by the irrelevant (-2.92 ± 0.58 µV vs. -1.45 ± 0.40 µV). There was no significant main effect of group: F (1, 58) = 3.26, p = 0.08, $BF_{\text{Exclusion}}$ = 0.01. As expected, there was a significant stimulus type × group interaction: F (1, 58) = 18.70, p < 0.001,$\eta_\pi{}^2$ = 0.24, $BF_{\text{Inclusion}}$ = 575.74. Follow-up tests showed that among guilty participants, the probe elicited more negative N200 than the irrelevant (-4.70 ± 0.82 µV vs. -1.28 ± 0.57 µV, F (1, 58) = 28.66, p < 0.001,$\eta_\pi{}^2$ = 0.33, BF_{10} = 217.48). In contrast, no differences in N200 amplitude were found between the probe and irrelevant for innocent participants (-1.14 ± 0.82 µV vs. -1.63 ± 0.57 µV, F (1, 58) = 0.58, p = 0.45, BF_{01} = 3.16). For grand-averaged ERPs and their scalp distributions that are time-locked to CIT stimuli, see Figures **2 and 4** .

3.2 Recognition P300s (a positivity peaking at 384 ms corresponded to recognition-related P300 at Pz, see Figure 3b)

For recognition-P300, we conducted a two-way 2 (within-subject: probe vs. irrelevant) by 2 (between-subject: guilty vs. innocent) mixed ANOVA on the P300 amplitude. The results showed a significant main effect of stimulus type, F (1, 58) = 64.25, $p < 0.001$, $\eta_\pi{}^2 = 0.53$, $\text{BF}_{\text{Inclusion}} = 6.34 \times 10^{10}$, with a larger P300 elicited by the probe than by the irrelevant (7.17 ± 0.80 µV vs. 3.79 ± 0.60 µV). There was also a significant main effect of group:F (1, 58) = 9.87, $p = 0.003$,$\eta_\pi{}^2 = 0.15$, $\text{BF}_{\text{Inclusion}} = 1.50 \times 10^7$, indicating that the P300 in the guilty group was significantly larger than in the innocent group (7.60 ± 0.95 µV vs. 3.36 ± 0.95 µV). As expected, there was a significant stimulus type × group interaction: F (1, 58) = 49.37, $p < 0.001$,$\eta_\pi{}^2 = 0.46$, $\text{BF}_{\text{Inclusion}} = 5.85 \times 10^6$. Follow-up tests showed that among guilty participants, the probe elicited significantly larger P300 than the irrelevant (10.76 ± 1.13 µV vs. 4.43 ± 0.85 µV, F (1, 58) = 113.13, $p < 0.001$,$\eta_\pi{}^2 = 0.66$, $\text{BF}_{10} = 3.96 \times 10^6$). In contrast, no differences in P300 amplitude were found between the probe and irrelevant for innocent participants (3.57 ± 1.13 µV vs. 3.15 ± 0.85 µV,F (1, 58) = 0.49, $p = 0.49$, $\text{BF}_{01} = 2.91$). For grand-averaged ERPs and their scalp distributions that are time-locked to CIT stimuli, see Figures **2 and 4** .

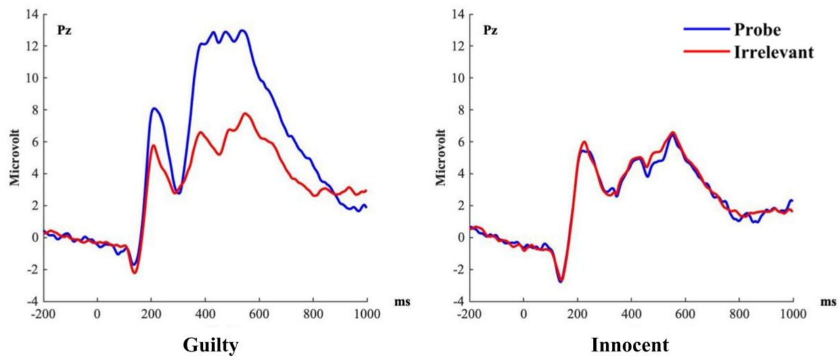

Figure 2. Grand-average probe/irrelevant evoked ERP waveforms from Pz

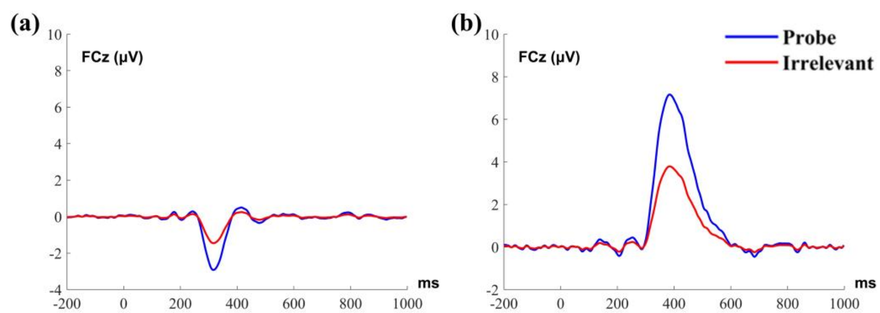

Figure 3. PCA-extracted ERP waveforms during conflict-monitoring and recognition stages combining the guilty and innocent groups. (a) A negativity peaking at 316 ms corresponded to the conflict-monitoring related N200 at FCz. (b) A positivity peaking at 384 ms corresponded to the recognition-related P300 at Pz.

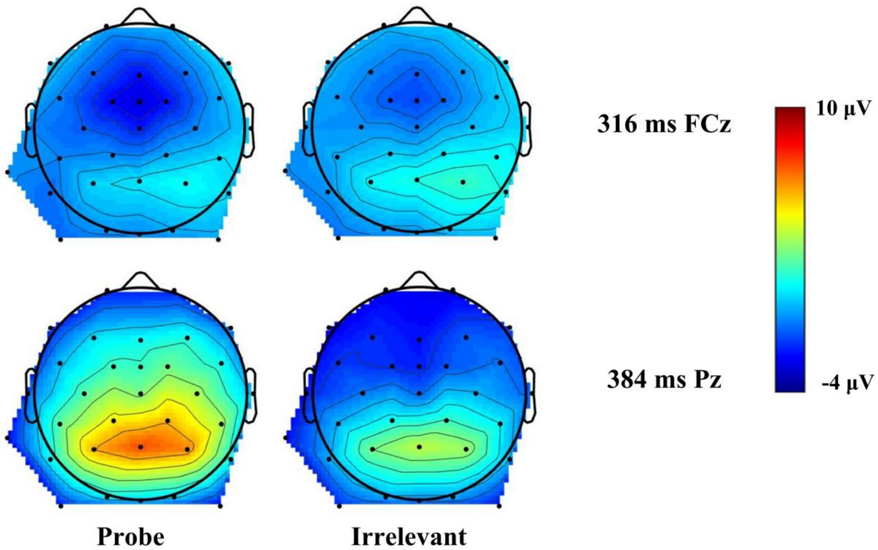

Figure 4. Scalp topographies of temporal Principle Component Analyzed-ERPs locked to CIT stimuli (probe vs. irrelevant).

3.3 FRN at Fz (a positivity peaking at 282 ms corresponded to FRN at Fz, see Figure 6a)

In the feedback stage, a mixed 2 (stimulus type: probe vs. irrelevant) by 2 (feedback type: success"+4"vs. failure"-2") by 2 (group: guilty vs. innocent) ANOVA was performed on the FRN amplitude with the first two variables as within-subject variables and the third variable as a between-subject variable. *Results revealed no significant main effect of stimulus type, F (1, 58) = 0.34, p = 0.56,* $BF_{Exclusion} = 12.80$. *Unexpectedly, there was no significant two-way interaction between stimulus type and group F (1, 58) = 0.66, p = 0.42,* $BF_{Exclusion} = 28.22$. *The remaining interactions were not significant: stimulus × feedback: (F (1, 58) = 1.35, p = 0.25,* $BF_{Exclusion} = 22.08$*); feedback × group: (F (1, 34) = 0.05, p = 0.82,* $BF_{Exclusion} = 16.02$*); stimulus × feedback × group interaction: (F (1, 58) = 0.23, p = 0.63,* $BF_{Exclusion} = 574.78$*).* For grand-averaged ERPs and their scalp distributions elicited by feedback stimuli, see Figures **5 and 7** .

3.4 Feedback P300s (a positivity peaking at 424 ms corresponded to feedback-locked P300 at Pz, see Figure 6b)

Regarding feedback P300, another mixed 2 (stimulus type: probe vs. irrelevant) by 2 (feedback type: success vs. failure) by 2 (group: guilty vs. innocent) ANOVA was performed on the feedback-P300 component. Results revealed a significant main effect of stimulus type, $F\ (1, 58) = 39.63$, $p < 0.001, \eta_{\pi}{}^{2} = 0.41$, $BF_{Inclusion} = 1.36 \times 10^{10}$, revealing a more positive feedback-P300 following feedback regarding the probe than the irrelevant (7.30 ± 0.89 µV vs. 4.45 ± 0.73 µV). Notably, there was a significant two-way interaction between stimulus type and group,$F\ (1, 58) = 63.77$, $p < 0.001, \eta_{\pi}{}^{2} = 0.52$, $BF_{Inclusion} = 1.52 \times 10^{8}$. Follow-up tests indicated that the probe elicited a more positive feedback-P300 than the irrelevant did in the guilty group: 10.15 ± 1.26 µV vs. 3.70 ± 1.04 µV, $F\ (1, 58) = 101.97$, $p < 0.001, \eta_{\pi}{}^{2} = 0.64$, $BF_{10} = 5.61 \times 10^{5}$. However, among innocent participants, there was no difference in the feedback-P300 between the probe and the irrelevant (4.44 ± 1.26 µV vs. 5.21 ± 1.04 µV,$F\ (1,58) = 1.43$, $p = 0.24$, $BF_{01} = 0.33$). Other significant interactions were not found: stimulus × feedback: ($F\ (1, 58) = 0.06$, $p = 0.81$, $BF_{Exclusion} = 4.29$); feedback × group: ($F\ (1, 58) = 1.61$, $p = 0.21$, $BF_{Exclusion} = 1.34$);*stimulus × feedback × group interaction* : ($F\ (1, 58) = 0.006$, $p = 0.94$, $BF_{Exclusion} = 7.04$). For grand-averaged ERPs elicited by feedback stimuli, see Figure 2. For grand-averaged ERPs and their scalp distributions elicited by feedback stimuli, see Figures **5 and 7.**

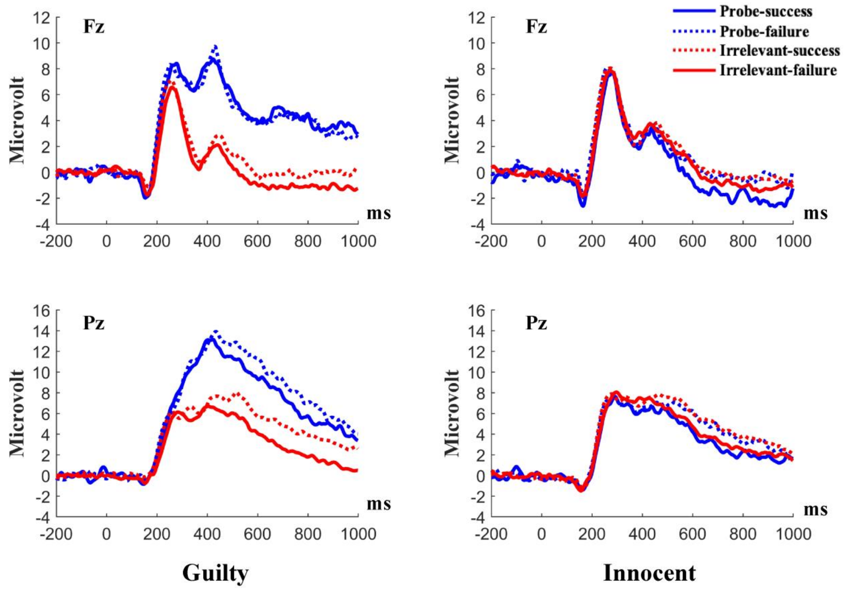

Figure 5. Grand-average ERP waveforms (before PCA transformation) during the feedback stage.

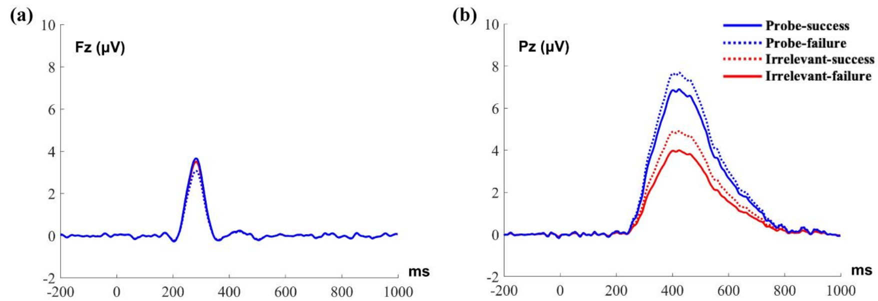

Figure 6. PCA-extracted ERP waveforms during the feedback stage combining the guilty and innocent groups. (a) *a positivity peaking at 282 ms corresponded to the FRN at Fz. (b)* a positivity peaking at 424 ms corresponded to the feedback-locked P300 at Pz.

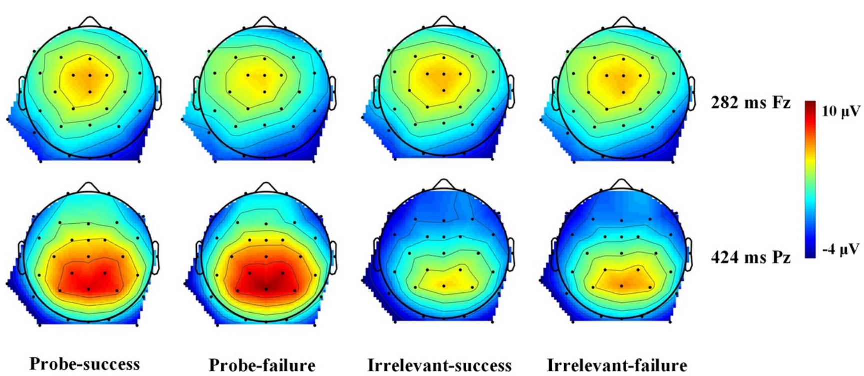

Figure 7. Scalp topographies of temporal Principle Component Analyzed-ERPs locked to feedback (success vs. failure) following the probe or irrelevant.

3.5 Correlations between N200, recognition-P300 and feedback-ERPs

To explore the neural activity difference between the recognition phase (probe vs. irrelevant) and the feedback phase (success vs. failure following probe and irrelevant), we compute the Pearson's correlation in both guilty and innocent participants. Specifically, the difference scores (probe minus irrelevant) for the N200, recognition-P300, FRN and feedback-P300 were calculated. Since our main purpose is to distinguish between probe and irrelevants, the FRN and feedback-P300 were collapsed across successes and failures. Results showed that among guilty participants, there were no correlations between recognition components and feedback components: rs (30) = -0.26 - 0.29, $ps > 0.12$. The correlation between FRN and feedback P300 was also significant, r (30) = 0.56, $p = 0.001$ (for detailed statistical results, see Table 2). The innocent group did not show any significant correlations between ERP activities ($rs < 0.33$, $ps > 0.08$; for detailed statistical results, see Table 3). The correlation between P200 and other ERP components can be found in the supplementary materials (see Table S2).

Table 2

Correlations between N200, recognition-P300 and feedback-related components among guilty group

	N200	Recognition-P300	FRN	Feedback-P300
N200				
Recognition-P300	-0.16			
FRN	0.20	0.29		
Feedback-P300	-0.26	0.25	0.56**	

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 3

Correlations between N200, recognition-P300 and feedback-related components among innocent group

	N200	Recognition-P300	FRN	Feedback-P300
N200				
Recognition-P300	0.11			
FRN	-0.03	-0.16		
Feedback-P300	0.28	0.04	0.33	

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

3.6 Individual Classification Efficiency

To determine the individual classification efficiency of each ERP component, we conducted a Receiver-Operating Characteristic (ROC) analysis that was based on the probe-minus-irrelevant amplitude for each ERP component (N200 at FCz, recognition P300 at Pz, FRN at Fz, and feedback P300 at Pz). We used guilty or innocent group status as the dependent variable. Results (see Table 4) show that all these ERP components, except for the FRN, can effectively distinguish guilty from innocent participants above chance (95% confidence intervals were given in parentheses): AUCs = 0.77 - 0.96, $ps < 0.001$. The ROC based on the FRN was not significantly different from chance level (AUC = 0.54, $p = 0.58$). Finally, we examined whether combining all these ERP components might further improve individual classification efficiency. Specifically, probe-minus-irrelevant amplitude for each ERP activity were transformed into standardized z-scores across all guilty and innocent individuals. We then averaged these four z-scores into a single measure for each participant (Hu et al., 2013; Sai et al., 2016). This ROC analysis yielded an AUC of 0.91. And the highest AUC (0.96) was obtained when combining N200, recognition P300 and the feedback P300 (see Table 4). The individual classification efficiency of P200 (AUC = 0.88) and that of P200 in combination with other ERP components (AUC = 0.99) can be found in the supplementary materials (see Table S3).

Table 4

Receiver operation characteristic (ROC) analyses

	AUC	95% Confidence Intervals
Conflict-monitoring-N200	0.77^{***}	0.64 - 0.89
Recognition-P300	0.91^{***}	0.82 - 0.99
FRN	0.54	0.39 - 0.69
Feedback-P300	0.96^{***}	0.92 - 1.00
FRN and Feedback-P300	0.80^{***}	0.69 - 0.91
N200 and P300	0.93^{***}	0.86 - 0.99
P300 and Feedback-P300	0.96^{***}	0.90 - 1.00
N200, P300 and Feedback-P300	0.96^{***}	0.91 - 1.00
All four indices	0.91^{***}	0.82 - 1.00

$^{*}p < 0.05$, $^{***}p < 0.001$

4 Discussion

This study examined four different ERP components in the fCIT and examined whether they can be used to detect concealed autobiographical information. We found that: (1) probe stimuli elicited a more negative N200, and positive recognition P300 than irrelevant stimuli in guilty participants, but not in innocent ones; (2) feedback following the probe elicited more positive feedback P300 than feedback following irrelevants in guilty participants, but not in innocent ones; and (3) ROC results showed that combining conflict-monitoring N200, recognition P300 and feedback-P300 yields a high classification efficiency (AUC = 0.96). These findings provide evidence that fCIT can effectively detect concealed autobiographical information.

Based on the correlation results, we observed that the only significant correlation is between FRN and feedback P300 in the guilty group. This can be explained by their shared neural processes related to feedback. Moreover, the absence of correlation among N200, recognition P200, and feedback ERPs indicates that these components likely represent distinct neural processes. Consequently, we have categorized them into conflict-monitoring N200, recognition P300, and feedback ERPs for further discussion.

4.1 Conflict-monitoring N200

Although some studies have found a more negative N200 for the probe compared to the irrelevant stimuli, some studies have reported null or opposite results (Gamer and Berti, 2010, 2012, Ganis et al., 2016,also see a review Sai et al. 2023). One possible reason for this discrepancy maybe due to N200 overlapping with neighboring components such as P200 and P300. In our current study, we used PCA to separate the N200 from other components and found that the probe indeed elicited a more negative N200 than the irrelevants in guilty group. This may be because guilty participants need to conceal their knowledge about the probe stimuli, which required more control monitoring compared to truth-telling about irrelevant stimuli. However, caution is advised when utilizing the N200 as an indicator to detect concealed information, as highlighted by Ganis et al. (2016). Their research suggests that the N200 elicited by probes larger than irrelevant stimuli might be attributed to differences in the stimuli, potentially leading to the absence of the CIT effect under controlled conditions (Gamer and Berti, 2010, Ganis et al., 2016). It's worth noting that our experiment differed from theirs, as our stimuli exclusively consisted of traditional Chinese names with two or three words, ensuring uniformity in the stimulus presentation. In contrast to their study, where N200 yielded null results, our findings demonstrated a significant CIT effect for N200. This discrepancy might be attributed to our utilization of PCA, which effectively isolated the genuine N200 response from other components, such as P200 and P300, (Daffner et al., 2015; Kayser et al., 1998). Additionally, it should be noted that the stimuli used in this study were autobiographical information, further studies should use the PCA method to examine whether the effect of N200 can also be found in mock-crime situations.

4.2 Recognition P300

We found that the probe elicited a greater recognition P300 than the irrelevants among guilty participants, but not among innocent ones. This is consistent with findings from most previous P300-based CIT studies (Olson, Rosenfeld, Kim, & Perrault, 2018; Rosenfeld, Shue, & Singer, 2007; Rosenfeld, Soskins, Bosh, & Ryan, 2004). P300 is a complicated ERP component with multiple neural sources, apparently connected to working memory, attention, and recollection (Linden, 2005; Polich, 2007). In this concealed autobiographical-information test scenario, since the probe (the subject's own name) is highly meaningful to guilty participants, it is not surprising to find that the probe elicited a larger P300 in guilty individuals.

4.3 Feedback ERPs

Unexpectedly, the feedback-related negativity (FRN) triggered by feedback following probes and irrelevants did not exhibit a significant difference in either the guilty or innocent groups. This outcome diverged from some prior studies (Sai et al., 2016; Zheng et al., 2022), yet it aligned with the findings of Sai et al. (2020). One plausible explanation for this discrepancy lies in the fact that FRN might be associated with rapid outcome evaluation in the fCIT. As a result, the level of participant engagement within the fCIT could potentially influence FRN outcomes. Instances of low engagement (e.g. participants not attending to feedback, lacking belief in or indifference toward the feedback) might account for the observed null effect of FRN. This matter merits further exploration and discussion in subsequent fCIT studies.

Furthermore, consistent with previous fCIT studies (Sai et al., 2016, 2020; Zheng et al., 2022), feedback following the probe elicited greater feedback P300 than that which followed irrelevants only in the guilty group, not in the innocent group. Previous studies suggest that participants' motivational state modulates the feedback P300 (Hajcak, Holroyd, Moser, & Simons, 2005; Luo et al., 2011). Particularly, outcomes could elicit a larger feedback P300 when participants were motivated to deceive (Luo et al., 2011). In the fCIT, guilty participants are strongly motivated to conceal the probe (e.g. their own names), so that feedback following the probe elicited a larger feedback P300 than feedback following irrelevants. However, with respect to innocent participants, like other irrelevant items the probe (e.g. the guilty name) was meaningless to them; hence there was no significant difference in the feedback P300 between the probe and irrelevants.

4.4 Individual analysis

In the current fCIT, we successfully identified a distinct conflict-monitoring N200 component by employing PCA analysis to separate it from the overlapped ERPs. The analysis revealed a fine AUC value of 0.77. This finding reaffirmed the role of N200 in lie detection, which is consistent with previous studies (Hu et al., 2013; Ganis et al., 2016).

In addition, recognition P300 can effectively distinguish guilty participants from innocent ones with an AUC of 0.91. However, it should be noted that this result is not consistent with the low AUCs (0.70 - 0.82) found in previous fCIT studies (Sai et al. 2016, 2020; Zheng et al., 2022). One possible reason is that we used autobiographical information for the current fCIT, whereas those studies used incidentally-acquired information as the concealed information. Autobiographical information is more meaningful than information incidentally acquired, which may, in turn, lead to more accurate lie detection (Gronau, Ben-Shakhar, & Cohen, 2005; Noordraven & Verschuere, 2013; Rosenfeld et al., 2006).

Consistent with previous fCIT studies (Sai et al., 2016, 2020; Zheng et al., 2022), our ROC results show that the feedback P300 can effectively distinguish between guilty and innocent participants, with a high AUC of 0.96. Taken together, our findings across these studies demonstrate that the feedback P300 shows promise in detecting both concealed autobiographical and incidentally-acquired information. Unfortunately, combining the conflict-monitoring N200 and recognition P300 with feedback P300 couldn't achieve a higher deception detection efficiency. Nonetheless, when incorporating the P200 component from the discovery analysis, the combined AUC of multiple indicators (P200, N200, P300, and feedback P300) could achieve a value of 0.99 (see the*supplementary materials*).

4.5 Conclusion

In sum, our study examines whether fCIT can be used to detect concealed autobiographical information. We found that the probe elicited a conflict-monitoring more negative N200 and a more positive recognition P300 than the irrelevants in the guilty participants, but not in the innocent participants. We also note that feedback following the probe elicited a greater feedback P300 than feedback following the irrelevants, again, in the guilty but not the innocent group. Further, individual analyses found that conflict-monitoring N200 (AUC=0.77), recognition P300 (AUC=0.91), and feedback P300 (AUC=0.96) could efficiently distinguish guilty from innocent participants. Exploratory analysis found that when the P200 component is included as an additional indicator, the deception detection efficiency of the combination of P200, N200, P300 and feedback P300 can reach a near-perfect AUC of 0.99. These results provide evidence that combining recognition, conflict-monitoring and feedback-related ERPs can effectively detect concealed autobiographical information in fCIT.

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Author Notes

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Conflict of interest

The authors have no conflict of interests to declare.