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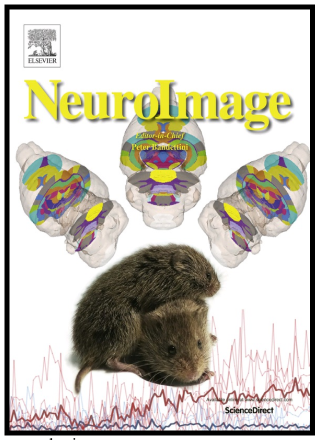

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PII: S1053-8119(16)30427-X
DOI: http://dx.doi.org/10.1016/j.neuroimage.2016.08.042
Reference: YNIMG13400

To appear in: *NeuroImage*

Received date: 29 March 2016
Revised date: 17 August 2016
Accepted date: 19 August 2016

Cite this article as: Giorgio Ganis, David Bridges, Chun-Wei and Haline E Schendan, Is anterior N2 enhancement a reliable electrophysiological index o concealed information?, *NeuroImage* http://dx.doi.org/10.1016/j.neuroimage.2016.08.042

Is anterior N2 enhancement a reliable electrophysiological index of concealed information?

Giorgio Ganis[1,2,3,4], David Bridges[1,2], Chun-Wei[1,2], and Haline E. Schendan[1,2]

[1] School of Psychology, University of Plymouth, Plymouth, UK

[2] Cognition Institute, University of Plymouth, Plymouth, UK

[3] Department of Radiology, Harvard Medical School, Boston, MA 02115, USA

[4] Massachusetts General Hospital, Athinoula A. Martinos Center for Biomedical Imaging, Charlestown, MA 02129, USA

Corresponding author:

Giorgio Ganis, School of Psychology, Portland Square, Plymouth University, Drake Circus, Plymouth, PL4 8AA

e-mail: giorgio.ganis@plymouth.ac.uk

Abstract

Concealed information tests (CITs) are used to determine whether an individual possesses information about an item of interest. Event-related potential (ERP) measures in CITs have focused almost exclusively on the P3b component, showing that this component is larger when lying about the item of interest (probe) than telling the truth about control items (irrelevants). Recent studies have begun to examine other ERP components, such as the anterior N2, with mixed results. A seminal CIT study found that visual probes elicit a larger anterior N2 than irrelevants (Gamer and Berti, 2010) and suggested that this component indexes cognitive control processes engaged when lying about probes. However, this study did not control for potential intrinsic differences among the stimuli: the same probe and irrelevants were used for all participants, and there was no control condition composed of uninformed participants.

Here, first we show that the N2 effect found in the study by Gamer and Berti (2010) was in large part due to stimulus differences, as the effect observed in a concealed information condition was comparable to that found in two matched control conditions without any concealed information (Experiments 1 and 2).

Next, we addressed the issue of the generality of the N2 findings by counterbalancing a new set of stimuli across participants and by using a control condition with uninformed participants (Experiment 3). Results show that the probe did not elicit a larger anterior N2 than the irrelevants under these controlled conditions.

These findings suggest that caution should be taken in using the N2 as an index of concealed information in CITs. Furthermore, they are a reminder that results of CIT studies (not only with ERPs) performed without stimulus counterbalancing and suitable control conditions may be confounded by differential intrinsic properties of the stimuli employed.

KEYWORDS: Event-related potentials, N2, concealed information, deception, cognitive control

1. Introduction

Concealed information test (CIT) paradigms have been used with many techniques (behavioral, autonomic, electrophysiological, hemodynamic) to develop methods that may eventually be used in forensic settings (Ganis, Rosenfeld, Meixner, Kievit, & Schendan, 2011; Rosenfeld, Ben-Shakhar, & Ganis, 2012; Verschueure, Ben-Shakhar, & Meijer, 2011). A common type of CIT paradigm (the 3-stimulus paradigm [3S]) employs 3 types of stimuli, (Rosenfeld et al., 2012): probes ("crime" items), irrelevants (control, unfamiliar items), and targets (Fig. 1). The main comparison of interest in this paradigm is between the probe and the irrelevants (typically, the mean of the irrelevants). If the probe elicits a stronger response than the irrelevants in a person, then one can infer that this person is familiar with the probe. In addition, if this person denies having information about the probe, then one can infer that deception may be taking place. Conversely, if there is no difference between probes and irrelevants, one may conclude that the person has no information about the probe.

Event-related potential (ERP) studies using the CIT, the focus of the present work, have investigated mostly the P3b component as a robust index of recognition of concealed information, with probes showing a larger P3b than the irrelevants (e.g., Farwell & Donchin, 1991; Meijer, Selle, Elber, & Ben-Shakhar, 2014; Rosenfeld et al., 1988; Rosenfeld, Soskins, Bosh, & Ryan, 2004). However, a few recent studies have begun to examine possible effects of concealed information on another family of ERP components, collectively referred to as the anterior N2, motivated by the hypothesis that these components may reflect cognitive control or attention orienting processes triggered by the probe (Gamer & Berti, 2010, 2012; Ganis & Schendan, 2013; Hu, Pornpattananangkul, & Rosenfeld, 2013). We focus on the seminal study by Gamer and collaborators (Gamer & Berti, 2010) because it is the first and the one that reported the largest N2 effects to date. Their study used a 3S CIT paradigm with playing cards and showed a robust N2 effect: a larger anterior N2 to the probe than to the average of the 4 irrelevants. This finding led the authors to conclude that the amplitude of the anterior N2 reflects the early engagement of cognitive control processes related to conflict monitoring (between truthful and deceptive responses) when lying about the probe. However, there was no stimulus counterbalancing: For all participants, the probe was the jack of spades, the target was the king of spades, and the irrelevants were the ace, 9, 10, and queen of spades. Further, there was no control condition with uninformed participants. Consequently, it is possible that this N2 effect was due instead to intrinsic differences between the probe and the irrelevants or to the relative similarity of probes and irrelevants to the target item. Indeed, anterior N2 (and P3) effects are known to be modulated by many factors, including stimulus complexity (Shigeto, Ishiguro, & Nittono, 2011) and similarity to the target stimuli (Azizian, Freitas, Parvaz, & Squires, 2006; Marchand, Inglis-Assaff, & Lefebvre, 2013). This methodological issue also applies to the interpretation of some of the results of two fMRI studies that used the same paradigm and stimuli (Gamer, Bauermann, Stoeter, & Vossel, 2007; Gamer, Klimecki, Bauermann, Stoeter, & Vossel, 2012). These two studies discussed the potential effect of stimulus differences and used a second stimulus set to address this issue (Euro banknotes).

These observations highlight a key assumption of the CIT logic: The irrelevants and the probe should not have any systematic differential properties (e.g., perceptual complexity, apriori emotional valence, and so on) that are unrelated to concealed information. This assumption should always be tested, especially when stimuli cannot be counterbalanced, by testing the stimuli in a control group of uninformed participants for whom both the probe and irrelevants carry no differential crime-relevant information (Lykken, 1959): If the probe shows a different response from the irrelevants in this control group, then the effects may be due to some intrinsic properties of the items. A control group is especially important in 3S CIT paradigms because the responses to the probe and irrelevants are also sensitive to their relationship with the target item (Azizian, Freitas, Parvaz, et al., 2006; Marchand et al., 2013).

Indeed, the anterior N2 findings in CIT paradigms have been inconsistent. For example, besides the results just described, for visual stimuli, no N2 differences were found in a second study (Gamer & Berti, 2012), a smaller N2 to probes than irrelevants (i.e., the opposite pattern) was reported in a third study (Ganis & Schendan, 2013), and a larger N2 for probes than irrelevants was found in a fourth study using a modified CIT paradigm, but only in a "high-awareness" condition (Hu et al., 2013). Note that most studies have used only 3 midline electrodes, making it difficult to determine whether the same N2 components were observed in the different studies.

The aim of this paper is to try to resolve the issue of whether concealed information in the visual modality is reliably associated with a larger anterior N2 in a 3S CIT paradigm, possibly due to the early engagement of cognitive control processes.

First, we replicated the original study that reported a larger anterior N2 to probes (relative to the mean of the 4 irrelevants) in a 3S CIT paradigm, which was attributed to cognitive control processes engaged by probes (Gamer & Berti, 2010), and tested two alternative explanations for this effect. The first explanation hypothesizes that the N2 effect may be due to the figure cards used in Gamer et al (2010) being perceptually more complex and more meaningful than nonfigure cards, since they include bodies, faces, and patterned clothing (Shigeto et al., 2011). According to this explanation, the probe (jack of spades) would generate a larger N2 than the mean of the 4 irrelevants by virtue of perceptual or semantic factors (since 3 out of 4 irrelevants were nonfigure cards). To test this hypothesis, we asked participants simply to acknowledge seeing each card on the screen by pressing a single button, without giving them any information about any of the cards, so that any ERP differences would be due to intrinsic differences among the cards (onset detection condition, Experiments 1 and 2). The second explanation hypothesizes that the N2 effect is due to response conflict produced by the higher similarity of the probe (relative to the irrelevants) to the target (Azizian, Freitas, Parvaz, et al., 2006; Marchand et al., 2013). In the CIT task used by Gamer and Berti, the king of spades is the only item that required a “yes” response (target), whereas all other items required a “no” response. Since the jack of spades (the probe) is more similar to the king of spades (the target) than the average irrelevant, the jack may produce a response conflict because it is initially perceptually categorized as the target item but subsequently requires a different response (“no”) than the target item (“yes”). We tested this hypothesis by asking participants to perform a target detection task (king of spades), without providing information about any other card (target detection condition, Experiment 1). This condition is the equivalent of a standard control group because participants are uninformed about the probe (jack of spades). For comparison, we also conducted the original concealed information version of the task, which was identical to the previous (target detection) condition, but now participants were also informed about the probe and had to conceal knowing it (concealed information condition, Experiment 2).

Second, we tested the generality of the anterior N2 claims by conducting a 3S CIT study with informed and control uninformed conditions (within-participant, N=34) and with stimuli counterbalanced across participants (Experiment 3).

2. Materials and Methods

2.1 Subjects

Thirteen naïve healthy volunteers took part in Experiment 1 (9 females and 4 males) and another thirteen participated in Experiment 2 (10 females and 3 males). Thirty-six naïve healthy volunteers recruited from the University of Plymouth (UoP) took part in Experiment 3 for course credit (25 females and 11 males). The data for two participants in Experiments 1 and 2 and two participants in Experiments 3 could not be used, due to a technical problem (one participant) and to excessive eye movements (three participants). All participants had normal or corrected vision, and no history of neurological or psychiatric disease. All procedures were approved by the UoP Ethics Board.

2.2 Stimuli

In Experiments 1 and 2, the stimuli were 6 playing cards similar to those used in the study by Gamer and Berti: the ace, 9, 10, jack, queen and king of spades (Fig 2a). The king and jack of spades were always used as the target and probe cards, respectively, in the corresponding conditions in which a target card (target detection and concealed information conditions) and a probe card (concealed information condition) were defined. The cards subtended approximately 2.5 x 3.5 degrees of visual angle.

In Experiment 3, to minimize stimulus confounds, stimuli were the single digits 3, 4, 5, 6, 7, and 8, green against a black background (Fig 2b). Probes and targets varied across participants (there were twelve probe-target pairs: 3-5, 3-6, 4-6, 4-7, 5-7, 5-8, 6-3, 6-8, 7-3, 7-4, 8-4, and 8-5; these pairs were drawn randomly from the 20 possible pairings in which the numerical distance between the probe and the target was at least 2). For each participant, the same probe-target pair was used for the uninformed and informed conditions. Each digit subtended approximately 2 x 2 degrees of visual angle.

2.3 Procedure

After setting up the EEG cap and electrodes, participants were seated on a comfortable chair, 115 cm from a computer screen in a dark room. A total of 210 stimuli were presented in Experiments 1 and 2, whereas 420 stimuli were presented in Experiment 3 (70 per item type). Each stimulus was presented for 1000 ms, with an average interstimulus interval (ISI) of 2000 ms, randomly varying between 1900 and 2100 ms. In all three experiments, two task conditions were tested in separate blocks of trials, and participants responded with their dominant hand.

In Experiment 1, for the first task (onset detection, uninformed), participants were asked to press a single button each time they saw a card on the screen. In the second task (target detection, uninformed), participants pressed a button if they saw the target (always the king of spades) and a second button for all other cards. This task was always carried out after the onset detection condition.

In Experiment 2, the first task was the same onset detection, uninformed condition used as the first condition in Experiment 1. Critically, the second task (concealed information, informed) was a standard 3S CIT paradigm in which participants were asked to conceal knowledge of the probe (always the jack of spades) while carrying out the target detection task. Just before this task started, participants were instructed to choose a "secret" card (probe) from a set of 5 envelopes (all containing the jack of spades) and to deny having information about this card throughout the test. Thus, for this task the pattern of button presses was identical to that in the second, target detection, uninformed task of Experiment 1, except for concealed knowledge of the probe (being absent in Experiment 1 vs. present in Experiment 2). This task was always carried out after the onset detection condition.

In Experiment 3, the first and second tasks were the second tasks in Experiments 1 and 2, respectively, but modified for use with the digit stimuli. In the first task (target detection, uninformed), participants pressed a button when they saw the target digit and a second button for all other digits. In the second task (concealed information, informed; i.e., the 3S CIT paradigm), participants were asked to conceal knowledge of the probe, while carrying out the target detection task. Just before this task started, participants were instructed to choose a “secret” digit (probe) from a set of 5 envelopes (all containing the same digit assigned by design to that participant), to keep it face down on their lap, and to deny having information about this digit throughout the test so as to fool the experimenter. Participants were told that their facial expression, eye movements, and brain signals would be monitored during the test to find signs of deception. The stimulus sequences used in these two tasks were the same, in order to avoid confounds due to local statistical properties of the sequences. Thus, the pattern of button presses was identical in both tasks, and the only difference between tasks was the concealed information about the probe.

2.4 Electrophysiological Data Acquisition

The EEG was sampled at 8192 Hz using a Biosemi ActiveTwo system . EEG data were collected from 64 active Ag/AgCl electrodes arranged according to the 10-20 system, and loose lead electrodes (UltraFlat Active electrodes, Biosemi) below the right eye, to monitor eye blinks and vertical eye movements, and the left and right mastoids. Horizontal eye movements were monitored using 2 loose electrodes placed on the outer canthi of the right and left eyes. The data were downsampled off-line to 512 Hz before further processing. For analyses, data were re-referenced off-line to the average of the two mastoids for consistency with most of the existing literature on the topic.

2.5 Behavioral Analyses

One-way ANOVAs with item type as a within-subject factor (irrelevants, probes, and targets) were conducted on both response times (RTs) and accuracy rate for each condition. Follow-up t-tests were carried out to compare pairs of items of interest. Two-way ANOVAs were conducted to compare the item effects across conditions, as needed. Receiver Operating Characteristic (ROC) and linear discriminant analyses were also carried out in Experiment 3 to determine the accuracy with which RTs could be used to classify concealed and no concealed information cases (Swets, 1996).

2.6 ERP Analyses

ERPs were averaged off-line for an epoch of 1,000 ms, including a 100 ms baseline. Trials contaminated by blinks, eye movements, muscle activity or amplifier blocking were rejected off-line. Although the figures show data low-pass filtered at 30 Hz (to avoid visually distracting high frequency noise in the plots), all analyses were conducted on unfiltered data.

Analyses focused on probes and irrelevants because they shared the same response, but the target item was also analyzed in Experiments 1 and 2 to better understand the effects on the figure card irrelevant (queen). Furthermore, although the focus of the study is the N2, results will be reported also for the P3b for comparison with previous studies. Repeated measures ANOVAs were conducted on the mean amplitude of the average ERPs. Two time windows were used for the main analyses, which were centered around the mean peak latency of the N2 (250-300 ms) and the P3b (400-600 ms). To assess the overall pattern of results "lateral" ANOVAs were carried out on lateral electrodes (27 pairs) and used three factors: Item Type, Site, and Hemisphere. "Midline" ANOVAs were carried out on the midline sites (10) and used 2 factors: Item Type and Site. "3-site midline" ANOVAs were also conducted on standard 10-20 sites Fz, Cz, and Pz to compare the results with previous studies. The item type factor in the ANOVAs included the probe (or the target) and the average of all 4 irrelevants.

In Experiments 1 and 2, planned comparisons were carried out on the N2 and the P3b at sites FCz and Pz, respectively comparing: i) the probe and the target with the average of all irrelevants, ii) the figure irrelevant (queen) with the average of the nonfigure irrelevants, and iii) the figure irrelevant with the probe and the target. An additional analysis on these sites combined latency and amplitude measures for comparison with previous studies. For each condition and participant, this second analysis identified the most negative 50 ms segment between 200 and 350 ms at FCz for the N2, and the most positive 50 ms segment between 350 and 800 ms at Pz for the P3b, and the average amplitude within these segments went into the analyses (Gamer & Berti, 2010).

For Experiment 3 it was important to show that any differences between the probe and the irrelevants in the concealed information task were larger than any in the target detection, uninformed condition. To carry out such a direct comparison, the factor of Task condition (concealed information vs. target detection) was added to the same ANOVAs.

Receiver Operating Characteristic (ROC) and linear discriminant analyses were conducted in Experiment 3 to determine the accuracy with which P3b data could be used to classify concealed and no concealed information cases in order to compare with previous studies.

Finally, a correlation analysis was carried out on N2 and P3b amplitude and RTs.

3. Results

3.1 Experiments 1 and 2: Onset Detection, Uninformed

Across Experiments 1 and 2, 24 participants carried out the onset detection, uninformed task. The results for this task will be described for the entire group encompassing participants from both experiments. Note that in this uninformed task the “probe” and the “target” were only nominally defined because participants actually had no concealed information, and they were not given a target. Behavioral results in this task showed neither significant differences in RTs nor accuracy among any pairs of item types, $t(23) < 1.72$, $p > .05$, in all cases (Fig 2c), and so they will not be further discussed.

3.1.1 N2 (250-300 ms). Despite no concealed information, the N2 was larger for the probe than for the average of the irrelevants in the omnibus ANOVAs. This N2 effect had a frontocentral distribution, resulting in an interaction between item and site. The same pattern was observed for the comparison between the target and the irrelevants (Fig 3 and Supplementary Table S1).

The N2 was also assessed at site FCz (Fig. 3 and Supplementary Table S2). Both mean and peak amplitude measures revealed that the N2 to the probe (jack) and the target (king) was larger than that to the irrelevants. Both measures also revealed that the N2 to the figure card irrelevant (queen) was reliably larger than that to the average of the 3 nonfigure card irrelevants. Finally, the N2 to the figure card irrelevant was not different from that to the probe and the target.

In sum, the main determinant of N2 amplitude was whether the stimulus was a figure card or not, with figure cards eliciting a much larger N2 than nonfigure ones.

3.1.2 P3b (400-600 ms). The P3b for the probe did not differ from the average of the irrelevants in the lateral ANOVA. The midline ANOVA revealed an interaction between item and site because the probe was slightly more positive than the irrelevants at central sites. A similar pattern was found when comparing the target and the irrelevants (Fig. 3 and Supplementary Table S1).

The P3b was also assessed at site Pz (Fig. 3 and Supplementary Table S2). For both mean and peak amplitude analyses, the P3b to the probe and the target did not differ significantly from that of the irrelevants. Finally, there was a trend for the P3b to the figure irrelevant card to be smaller than to the average of the 3 nonfigure card irrelevants, the probe, and the target. In sum, the P3b was only marginally affected by stimulus properties in this task.

Insert Supplementary Table 1 here

Insert Supplementary Table 2 here

3.2 Experiment 1: Target Detection, Uninformed

Note that in this uninformed task the "probe" was only nominally defined because participants actually had no concealed information.

3.2.1 Behavior. Response times were slower for the probe and the target than the irrelevants, $t(11)=5.82$, $p<.001$ and $t(11)=4.48$, $p<.001$, respectively. Furthermore, accuracy for the probe tended to be lower than for the target, $t(11)=2.05$, $p=.07$ (Fig. 2d).

3.2.2 N2 (250-300 ms). The N2 results were similar to those of the onset detection task. The omnibus ANOVAs showed that the N2 to the probe was more negative than that to the irrelevants. This N2 effect interacted with the site factor, and it had a frontocentral distribution. A similar general pattern was found for the comparison between the target and the irrelevants (Fig.4 and Supplementary Table S1).

Both mean and peak amplitude measurements at FCz showed that the N2 to the probe and the target was more negative than to the average of the irrelevants (Fig. 4 and Supplementary Table S2). Both measures also revealed that the N2 to the figure card irrelevant was larger than that to the average of the 3 nonfigure card irrelevants. Finally, the N2 to the figure card irrelevant was not different from that to the probe and the target.

In sum, as for the onset detection condition, the main factor in determining N2 amplitude was whether the stimulus was a figure card or not, with figure cards eliciting a much larger N2 than nonfigure ones.

3.2.3 P3b: (400-600 ms). P3b results differed from those of the onset detection task. The probe did not differ significantly from the irrelevants in the omnibus ANOVAs (Supplementary Table S1). In contrast, the target was much more positive than the irrelevants in both analyses.

For both analyses, the effect was modulated by site, as it was larger at central sites (Fig. 4 and Supplementary Table S1).

The P3b was also assessed at site Pz (Supplementary Table S2). For both mean and peak amplitude analyses, the P3b to the probe and the target was larger than that to the average of the irrelevants, in contrast to the null effects in the uninformed task condition. Both measures indicated that the figure irrelevant elicited a significantly larger P3b than the average of the nonfigure card irrelevants. Finally, the P3b elicited by the figure irrelevant was significantly smaller than that elicited by the target.

In sum, both uninformed tasks yield similar results for the N2, whereas the P3b becomes larger for figure than nonfigure cards only when a figure card becomes the target. This indicates that ERP differences reflect in part stimulus factors, that is, differences between probe and irrelevants are based on figure vs. nonfigure card status for the N2, but on similarity to the figure card target for the P3b.

3.3 Experiment 2: Concealed Information

3.3.1 Behavior. RTs were slower for the probe and the target than for the irrelevants, $t(11)=8.67$, $p<.001$ and $t(11)=9.15$, $p<.001$, respectively. Accuracy was lower for the probe than the target and the irrelevants, $t(11)=8.74$, $p<.001$ and $t(11)=9.96$, $p<.001$, respectively (Fig. 2c).

3.3.2 N2 (250-300 ms). The N2 results were similar to those for the other two uninformed tasks. Omnibus ANOVAs showed that the probe was more negative than the irrelevants, and this N2 effect interacted with the site factor (Fig. 5 and Supplementary Table S1), since it had a central distribution. The main effect of item did not reach significance in omnibus ANOVAs when comparing targets and irrelevants. However, the interaction of item type and site was significant, with targets more negative than irrelevants at central sites (Fig. 5 and Supplementary Table S1).

The N2 was also assessed at site FCz (Fig. 5 and Supplementary Table S2). Both mean and peak amplitude measures revealed that the probe was more negative than the average of the irrelevants. Both measures also showed that the figure card irrelevant was more negative than the average of the 3 nonfigure card irrelevants. Finally, the mean amplitude measure showed that the figure card irrelevant was more negative than the target.

3.3.3 P3b (400-600 ms). The P3b for probes was significantly more positive than that to irrelevants in omnibus ANOVAs, and this effect was larger at central sites. Furthermore, the target was significantly more positive than the probe and the irrelevants (Supplementary Table S1). These effects were larger at central sites, as revealed by the interaction of item and site (Fig. 5 and Supplementary Table S1).

The P3b was also assessed at site Pz (Fig. 5 and Supplementary Table S2). As for the target detection task in Experiment 1, the probe and the target were more positive than the average of the irrelevants. Furthermore, the figure card irrelevant was more positive than the average of the nonfigure card irrelevants, but not different from the figure card probe, suggesting that the probe effect is primarily driven by stimulus similarity to the target. Note, while Figure 5 shows that positivity becomes larger for the probe than the figure irrelevant after 500 ms, this is not the P3b peak proper but a later positive complex, which might be an index of episodic recollection of the probe memory (Paller, Voss, & Boehm, 2007; Rugg & Curran, 2007). Finally, the figure card irrelevant was less positive than the target.

3.3.4 Comparison of N2 effects between tasks. The amplitude of the N2 for the probe and the mean of the irrelevants at site FCz was compared across all 3 pairs of tasks. There was no significant interaction of item and task in any of the analyses, all ps > .1, all $\eta^2 < .1$, indicating that the N2 effect was comparable across tasks.

Thus, the difference in N2 amplitude between the probe and the nonfigure irrelevants in the concealed information task was comparable to that found in the uninformed tasks, confirming that stimulus differences are the main factor. The P3b difference between the probe and the nonfigure irrelevants was comparable to that found in the uninformed target detection task, confirming that stimulus similarity to the figure card target is a key factor.

3.4 Experiment 3

3.4.1 Behavior: Target Detection. There was a main effect of item type on the RTs ($F[2,66] = 6.34$, $p<.005$, $\eta^2 = .16$, Fig 2d). Follow-up contrasts showed no difference in RTs between the probes and the irrelevants, $t(33)=1.42$, $p>.1$. They also showed longer RTs for the target than for the probe and the irrelevants ($t[33]=2.66$, $p<.05$ and $t[33]=2.95$, $p<.05$, respectively). Finally, there was no effect of item type on accuracy, ($F[2,66] = .23$, $p > .1$, $\eta_p^2 <.01$).

3.4.2 Behavior: Concealed Information. There was a main effect of item type on the RTs, ($F[2,66] = 35.45$, $p < .001$, $\eta_p^2 = .52$, Fig 2d). Follow-up contrasts showed that RTs were longer for probes than irrelevants, $t(33) = 5.36$, $p < .001$. Furthermore, RTs for targets were longer than for probes and irrelevants ($t[33]=4.35$, $p<.001$, $t[33]=7.55$, $p<.001$, respectively). There was also an effect of item type on accuracy, ($F[2,66] = 9.0$, $p < .001$, $\eta_p^2 = .21$). Follow-up analyses revealed that accuracy for the probe was lower than for irrelevants, $t(33)=2.29$, $p < .05$. Finally, accuracy for the target was lower than for the probe, and the irrelevants ($t[33] = 2.55$, $p < .05$ and $t[33] = 3.52$, $p < .001$, respectively).

3.4.3 Behavior: Comparison between tasks. An ANOVA on the RTs with task (target detection vs concealed information) and item type (probe vs irrelevants) as within-subject factors showed that the probe was slower than the irrelevants ($F[1,33] = 14.96$, $p < .001$, $\eta_p^2 = .31$), and more so in the concealed information than in the target detection task ($F[1,33] = 27.57$, $p < .001$, $\eta_p^2 = .46$). An ANOVA on accuracy also showed that the probe was less accurate then the irrelevants in the concealed information than in the target detection task ($F[1,33] = 4.75$, $p < .05$, $\eta_p^2 = .13$).

3.4.4 Behavior: Discrimination Analyses. A ROC analysis was carried out on the probe – irrelevant RT difference scores for the target detection and concealed information tasks. The Area under the Curve was .83 ([.74, .93]), and a linear discriminant analysis showed that cases from the two conditions could be classified with 72% accuracy on average (one-out cross-validation), based on the RTs.

Insert Supplementary Table 3 here

3.4.5 N2 (250-300ms): Target Detection. In contrast to the stimulus-related effects in Experiments 1 and 2, the N2 showed no differences between the probe and the irrelevants. Omnibus ANOVAs revealed neither a main effect of item type nor an interaction between item type and site (Fig. 6, Supplementary Fig. 1, and Supplementary Table S3).

An ANOVA on the standard sites Fz, Cz, and Pz comparing the probe and the irrelevants revealed neither a main effect of item ($F[1,33] = .19$, $p > .1$, $\eta^2 = .006$), nor an interaction of item with site ($F[2,66] = 1.33$, $p > .1$, $\eta_p^2 = .039$). A similar ANOVA comparing the target and the irrelevants showed a main effect of item ($F[1,33] = 13.06$, $p < .001$, $\eta^2 = .28$) and an interaction of item with site ($F[2,66] = 23.42$, $p < .001$, $\eta_p^2 = .42$). Finally, an ANOVA comparing the target and the probe showed a main effect of item ($F[1,33] = 14.18$, $p < .001$, $\eta_p^2 = .30$) and an interaction of item with site ($F[2,66] = 25.65$, $p < .001$, $\eta_p^2 = .44$).

Planned focal analyses on these 3 sites showed no differences between the probe and the irrelevants ($t[33] < 1$, $p > .1$ for all contrasts), but significant differences between the target and the irrelevants at site Fz, $t(33) = 3.83$, $p < .001$, and between the target and the probe at sites Fz and Cz ($t[33] = 5.74$, $p < .001$ and $t[33] = 2.45$, $p < .005$, respectively).

3.4.6 P3b (400-600ms): Target Detection. In contrast to the effects in Experiments 1 and 2, the P3b showed no differences between the probe and the irrelevants. Omnibus ANOVAs revealed neither a main effect of item type nor an interaction between item type and site (Fig. 6, Supplementary Fig. 1, and Supplementary Table S3).

An ANOVA on the standard sites Fz, Cz, and Pz comparing the probe and the irrelevants revealed neither a main effect of item, ($F[1,33] = .05$, $p > .1$, $\eta^2 = .001$), nor an interaction of item with site, ($F[2,66] = 0.28$, $p > .1$, $\eta_p^2 = .01$). A similar ANOVA comparing targets and irrelevants showed a main effect of item, ($F[1,33] = 182.35$, $p < .001$, $\eta_p^2 = .85$), and an interaction of item with site, ($F[2,66] = 98.70$, $p < .001$, $\eta_p^2 = .75$). Finally, a similar ANOVA comparing targets and probes showed a main effect of item, ($F[1,33] = 179.50$, $p < .001$, $\eta_p^2 = .85$), and an interaction of item with site, ($F[2,66] = 98.13$, $p < .001$, $\eta_p^2 = .75$).

Planned focal analyses on these 3 sites, showed no significant differences between probes and irrelevants ($t[33] < 1$, $p > .1$ for all contrasts), but large differences between targets and irrelevants, and between targets and probes ($t[33] > 3.5$, $p < .001$ for all contrasts).

In sum, when stimulus factors are well-controlled in a target detection task in which participants are uninformed about a probe (i.e., no concealed information), neither the N2 nor the P3b differ between probes and irrelevants, and only the P3b shows a target effect.

3.4.7 N2 (250-300ms): Concealed Information. Although the N2 at central sites showed no differences between the probe and the irrelevants, a frontopolar N2 did, but in the opposite direction of the standard N2 effect of Gamer and Berti (2010). The lateral site ANOVA in this time window revealed an interaction between item and site (Table 3, Supplementary Fig. 6, and Fig. 7), as the N2 for the probe was smaller than for the irrelevants at far anterior frontal sites (frontopolar, instead of the frontocentral N2 in Experiments 1 and 2). The midline site ANOVA showed a similar pattern.

An ANOVA on the standard sites Fz, Cz, and Pz comparing the probe and the irrelevants showed neither an effect of item, ($F[1,33] = 2.16$, $p > .1$, $\eta_p^2 = .01$) nor an interaction of item with site ($F[2,66] = .30$, $p > .1$, $\eta_p^2 = .01$). An ANOVA comparing the target and irrelevants showed a main effect of item, ($F[1,33] = 7.28$, $p < .05$, $\eta_p^2 = .18$), and an interaction of item with site, ($F[2,66] = 20.89$, $p < .001$, $\eta_p^2 = .39$). Finally, a similar ANOVA comparing the target and the probe showed an interaction of item with site, ($F[2,66] = 17.42$, $p < .001$, $\eta_p^2 = .35$).

Planned focal analyses on standard Fz, Cz, and Pz sites showed no differences between the probe and the irrelevants, $t(33) < 1$, $p > 0.1$ for all contrasts, but significant differences between the target and the irrelevants and between the target and the probe at sites Fz and Cz ($t[33] > 3.0$, $p < .005$ and $t[33] > 3.0$, $p < .005$, respectively).

3.4.8 P3b (400-600ms): Concealed Information. The standard CIT effect on the P3b was replicated. Omnibus ANOVAs revealed both a main effect of item and an interaction of item with site because the probe was more positive than the irrelevants, and this effect was maximal at parietal sites (Fig. 7, Supplementary Fig. 2, and Supplementary Table S3).

An ANOVA on the standard sites Fz, Cz, and Pz comparing the probe and the irrelevants revealed an effect of item, ($F[1,33] = 19.17$, $p < .001$, $\eta_p^2 = .37$) and an interaction of item with site ($F[2,66] = 29.15$, $p < .001$, $\eta^2 = .47$). A similar ANOVA comparing the target and the irrelevants showed a main effect of item, ($F[1,33] = 144.87$, $p < .001$, $\eta_p^2 = .81$), and an interaction of item with site, ($F[2,66] = 161.04$, $p < .001$, $\eta_p^2 = .83$). Finally, a similar ANOVA comparing targets and the probe showed a main effect of item, ($F[1,33] = 83.78$, $p < .001$, $\eta_p^2 = .72$), and an interaction of item with site, ($F[2,66] = 51.99$, $p < .001$, $\eta_p^2 = .61$).

Planned focal analyses showed significant differences between the probe and the irrelevants at Fz, Cz, and Pz, $t(33) > 2$, $p < .05$, for all contrasts, as well as differences between the targets and the irrelevants, and between the target and the probe, $t(33) > 3.5$, $p < .001$ for all contrasts.

In sum, when stimulus factors are well-controlled in a CIT task the N2 is slightly larger for the irrelevants than the probe at anterior frontal sites, whereas the P3b is larger for the target and the probe than the irrelevants.

3.4.8 Direct comparison between the target detection and concealed information tasks. An ANOVA with the additional within-subject factor of task (concealed information vs target detection) was used to determine whether the probe – irrelevant effects found in the concealed information task persisted when compared directly to the target detection task.

For the N2, the lateral ANOVA revealed a 3-way interaction of item, site, and task (Supplementary Table S3), confirming that the N2 effect in the concealed information task was present and larger relative to the target detection task, which showed no evidence of a probe effect. A trend for the same interaction was found in the midline ANOVA.

For the P3b, the omnibus ANOVAs confirmed that the effects found in the concealed information task were larger and persisted when compared with the target detection task, as demonstrated by main effects of item, and interactions between item and task (Supplementary Table S3).

In sum, N2 and P3b differences between the probe and the irrelevants were present and significantly larger in the concealed information task relative to the target detection task, which showed no such evidence.

3.4.9 Correlation Between ERPs and RTs and Discrimination Analyses. A rank correlation analysis was carried out between RTs and the amplitude of the anterior N2 at site FPz and of the P3b at site Pz (probe – average of the irrelevants for all measures). For N2 amplitude there was no correlation with the RTs ($r = 0.18$, $ps > 0.1$). In contrast, for P3b amplitude there was a positive correlation in the concealed information condition, $r = .44$, $p < 0.01$.

A ROC analysis was carried out on the probe – irrelevant difference in P3b amplitude at Pz for the target detection and concealed information conditions. The Area under the Curve was .81 ([.70, .91]), and a linear discriminant analysis showed that cases from the target detection and concealed information conditions could be classified with 70% accuracy (one-out cross-validation). The same analysis performed on the combined P3b amplitude and RTs (with equal weights, after normalization) showed a slight improvement, .88 ([.80, .96]), but the difference was not significant, $z = 1.10$, $p > .1$. A linear discriminant analysis also showed a slightly improved accuracy of 75% (one-out cross-validation).

4 Discussion

Experiments 1 and 2 reported a larger N2 to the probe than to the irrelevants, replicating prior work (Gamer & Berti, 2010), but it also demonstrated that this effect was not due to concealed information per se, because similar N2 differences were also found in the control conditions without concealed information.

The large N2 differences in the onset detection task were likely due to stimulus (e.g., perceptual and/or knowledge) differences between figure and nonfigure cards since in this task there were minimal task requirement (simple go RT task) and the same response was used for all stimuli. The main factor modulating N2 amplitude in this condition was whether a stimulus was a figure or a nonfigure card, with figure cards (jack, queen, and king of spades) eliciting a larger N2 than nonfigure cards (ace, nine, and ten of spades). These findings are consistent with previous work showing that the anterior N2 is larger for stimuli of greater complexity in a simple viewing task (Shigeto et al., 2011) because figure cards are visually more complex than nonfigure cards. In their study, Shigeto and collaborators used abstract polygons of increasing complexity, thus minimizing the effect of semantic factors. In addition to being more complex, figure cards are also associated with richer knowledge than nonfigure cards, as they depict faces and bodies. Furthermore, figure and nonfigure cards also differ in their meaning and use in many card games. Thus the anterior N2 effect is likely to reflect also differences along these dimensions, generally consistent with findings that a frontal N3 complex, which may include the anterior N2, reflects interactive activation of visual knowledge that indicates the meaning of the stimulus and phenomenological awareness, according to a multi-state interactive account of visual cognition (Schendan & Ganis, 2015).

After the N2, all stimuli elicited a relatively small P3b component in this task and there were no significant differences in P3b amplitude among the stimuli. This lack of a P3b difference is not surprising because there was a single response for all stimuli, all stimuli were equally unfamiliar, and there were half figure and half nonfigure cards and so there were no obvious "oddballs" (Polich, 2007). In sum, in the onset detection task stimuli may have been implicitly classified as figure or nonfigure cards due to their relative similarity to each other, resulting in a large anterior N2 for the more complex and semantically richer figure cards, but in no P3b differences.

The target detection task introduced a potential response conflict factor because the probe (jack) and the figure card irrelevant (queen) requiring a “no” response, were perceptually more similar to the target (king) requiring a “yes” response than to the nonfigure irrelevants requiring a “no” response. Some accounts of the anterior N2 predict that higher conflict monitoring conditions should be associated with a larger anterior N2 (Folstein & Van Petten, 2008). The amplitude of the anterior N2 to the probe in this task was indeed larger than that to the irrelevants, but this effect was not significantly different from that in the onset detection task. In fact, the overall pattern of effects was comparable to that found in the onset detection task. This indicates that either there was no effect of conflict monitoring processes on the N2, or that these effects may have been swamped by the much larger effects due to stimulus differences observed in the onset detection task.

After the N2, a typical P3b target effect was found for the target stimulus, since this stimulus was task-relevant and it required a unique response (Polich, 2007). Importantly, and in contrast with the onset detection task, a larger P3b was also elicited by the probe and by the figure card irrelevant than by the nonfigure irrelevants. This supports the finding that the amplitude of the P3b elicited by an irrelevant in a CIT is affected by its similarity to the target stimulus (Azizian, Freitas, Watson, & Squires, 2006; Marchand et al., 2013).

The concealed information task revealed a larger anterior N2 to the probe than the nonfigure irrelevants, as found in a previous study using these stimuli (Gamer & Berti, 2010). However, the N2 effects elicited by the figure irrelevant was indistinguishable from that elicited by the probe and the N2 difference between the probe and the irrelevants was comparable to that found in the uninformed tasks just described. This confirms the N2 difference between the probe and the nonfigure irrelevants was largely due to stimulus differences.

After the N2, a large P3b was elicited by all figure stimuli, especially by the target. These P3b effects were comparable to those in the target detection task. Specifically, the P3b was larger for the target and the probe than the nonfigure irrelevants (Rosenfeld et al., 2012; Rosenfeld, Hu, Labkovsky, Meixner, & Winograd, 2013). In this task there is also a late positive complex overlapping the P3b for the probe, which may be an index of episodic recollection of the probe memory (Paller et al., 2007; Rugg & Curran, 2007). Note that in this task the nonfigure card irrelevant and the probe elicited a P3b with comparable amplitude, which may seem in contrast with previous studies showing P3b effects of concealed information on the P3b (Rosenfeld et al., 2004). This is probably because the target and the probe in this task induced a large P3b on the similar irrelevant card figure, eliminating the P3b effect due to the concealed information manipulation. As for the target detection task, the P3b was also larger for the figure irrelevant than the nonfigure irrelevants, probably due to its similarity with the target and the probe (Azizian, Freitas, Watson, et al., 2006; Marchand et al., 2013).

Thus, the N2 and P3b effects with this paradigm and stimuli seem to be largely due to intrinsic differences and similarities between the stimuli employed. These results emphasize the need to be cautious when interpreting CIT results from studies without control groups, especially if the irrelevant and probe items are not counterbalanced across participants. CIT studies in which the stimuli cannot be counterbalanced should always include a control group (or condition) to ensure that any differences between probes and irrelevants are not due to intrinsic properties of the stimuli. Such a condition can be run between participants or within participants, when possible. This control condition should include the same stimuli as the CIT task, but participants should not have been exposed to the probe. Probe-irrelevant differences in the CIT task should always be significantly larger relative to the probe-irrelevant differences in the control condition.

Another practical way to deal with these issues is to use multiple probes from the same event of interest (e.g., different aspects of a crime scene) because this would reduce the chance of all probes coincidentally leading to artifactual differences in the same direction.

These findings do not apply only to the ERP technique. Specifically, the results of our study are relevant for the interpretation of fMRI studies conducted with this same stimulus card set (Gamer et al., 2007; Gamer et al., 2012). For instance, since the N2 is larger for the jack of spades than the average irrelevant even in the absence of concealed information, then some of the effects found with these stimuli in the fMRI studies may not index only memory processes related to concealed information. To address this issue, an additional stimulus set (Euro banknotes) was employed in these fMRI studies using two different tasks, and the effects were generally similar to those found with the card stimuli. A few other fMRI studies, some using control groups and stimulus counterbalancing, have reported similar frontoparietal activations to probes (Ganis et al., 2011; Nose, Murai, & Taira, 2009; Peth et al., 2015; Suchotzki, Verschuere, Peth, Crombez, & Gamer, 2015), suggesting that the overall pattern of brain activation is unlikely to be caused by stimulus differences (see for review, Gamer, 2015).

Experiment 3 used a relatively large number of participants and trials to ensure that effects on the N2 reported in previous studies would not be missed. Although all items generated an anterior N2, there was no hint of a difference between irrelevants and the probe at sites Fz, Cz, and Pz, where effects of concealed information have been reported in previous studies. There was only a small effect during the N2 time window at far anterior frontal sites (Fpz, AFz) in the concealed information task, but the N2 to the probe was actually smaller than for the irrelevants

(Fig 7 and Supplementary Fig. 2), the opposite of the predicted direction. This is consistent with previous findings from this group (Ganis & Schendan, 2013), and so it constitutes a replication with the same CIT paradigm, but with different stimuli. The target elicited a typical P3b component, larger than that elicited by the irrelevants, in both target detection and concealed information tasks. Finally, the probe elicited a larger P3b than the irrelevants in the concealed information task, as typically found in these CIT paradigms (Ganis & Schendan, 2013; Rosenfeld et al., 2004). The mean amplitude of the P3b to the probe in the concealed information task was positively correlated with the RTs, indicating that this component may be involved in categorizing the probe.

The stimuli used here were mostly episodic in nature, similar to the episodic dates used in Ganis and Schendan (2013), and the timing and scalp distribution of this N2 effect are very similar to those found in that study. As argued in Ganis and Schendan (2013), the larger far anterior N2 for irrelevants than for the probe could reflect a mismatch effect (Folstein & Van Petten, 2008), since the probe (and the target) was a task-relevant stimulus that matched existing memory representations from salient experimental episodes, whereas the irrelevants were not. Taken at face value, this result suggests that the anterior N2 effect does not index cognitive control processes due to response conflict between probe and target responses, because such effects should produce a larger anterior N2 to probes than irrelevants (Folstein & Van Petten, 2008; Ganis & Schendan, 2013). Furthermore, this result suggests that this N2 effect is unlikely to index attentional orienting (Lykken, 1959) because orienting should also result in a larger N2 to probes. An alternative possibility is that a mismatch effect may mask smaller cognitive control effects with the same timecourse, but in the opposite direction (Folstein & Van Petten, 2008; Folstein, Van Petten, & Rose, 2008). In other words, there may be concurrent N2 effects in opposite directions and the strength of each may depend on the peculiarities of the stimuli and paradigm.

In either case, N2 enhancement does not appear to be a reliable index of concealed information. This conclusion is further supported by the mixed N2 results in the literature. For example, a recent CIT study found no N2 differences between the probe and the irrelevants (Gamer & Berti, 2012) at the Fz, Cz, and Pz sites from which data were recorded. The authors speculated that this lack of an N2 effect may be due to the high perceptual distinctiveness of the stimuli (e.g., USB key versus Compact Disk), requiring fewer cognitive control resources to carry out the CIT task than in their previous study with playing cards, where a robust N2 difference was found (Gamer & Berti, 2010). However, the digits used in our Experiment 3 were very similar to each other as well, since they were defined by a matrix of 7 segments that in some cases differed from each other by just one segment (e.g., 5 and 6, or 6 and 8), and so, according to this explanation, they should have resulted in a robust N2 enhancement for probes, which was not the case. Since the stimuli were not counterbalanced and no uniformed condition was used in both studies by Gamer and collaborators, a more likely explanation is that the pattern of results in their study was dominated by stimulus peculiarities. This explanation is corroborated by a) the large N2 differences they found between central and peripheral items, and b) the results of our Experiments 1 and 2, showing that the N2 effects originally found by Gamer and collaborators (Gamer & Berti, 2010) were still present with the same card stimuli used in two control conditions without concealed information.

A slightly larger anterior N2 to probes than irrelevants was also found in another study (Hu et al., 2013), but only in a "high awareness" condition in which participants were deceptively told throughout the session that the results so far indicated that they recognized one of the stimuli, implying their potential involvement in the mock crime. No effect was found in the low awareness condition, where no such feedback was used. This study used a Complex Trial Protocol, in which participants carry out a target detection task only after processing irrelevants and probes. Although no performance feedback was given to participants in our study, it is difficult to argue that participants were not highly aware of the probe – irrelevant distinction because there was a robust behavioral difference, as well as a large difference in the P3b. In fact, the classification accuracy using the P3b data in Experiment 3 (.81) is slightly higher than that found in the high awareness condition in the study by Hu and collaborators. Further studies will be needed to fully understand the factors that affect the N2 in Complex Trial Protocols.

Although some studies have been conducted in the auditory modality, here we have focused on the visual modality because there are important and poorly understood differences between the N2 family of components in the visual and auditory modalities (Folstein & Van Petten, 2008). The original study by Matsuda and collaborators using Japanese numbers presented in the auditory modality found an enhanced N2 for probes (Matsuda, Nittono, Hirota, Ogawa, & Takasawa, 2009). This finding may be specific to the auditory modality since the spoken probes are recognized faster than visual probes, based on the first phoneme of the word (Marinkovic et al., 2003). Consistent with this, the RTs in that study were at least 100 ms faster than the fastest RTs in our studies. The slow presentation rates used in that study (compared to ours) may also have affected overlapping N2 effects of item similarity in the opposite direction. It is also possible that, despite stimulus pseudo-randomization, there may have been some residual stimulus differences since a control group or task was not used to check for these. Finally, more recent studies in the auditory modality by the same group found only marginally significant N2 effects (Matsuda, Nittono, & Ogawa, 2013), suggesting that a number of factors play a role in N2 effects in CIT paradigms. A systematic comparison will be necessary to determine whether and to what extent concealed information is treated differently in the visual and auditory modalities.

Note that anterior N2 enhancement effects may be more consistent in differentiation of deception paradigms when deception cues are provided prior to the presentation of the stimuli to be responded to and so there is more time for cognitive control processes to unfold (Suchotzki, Crombez, Smulders, Meijer, & Verschuere, 2015).

5 Summary and Conclusions

In sum, these N2 findings indicate that the visual probe in 3S CIT paradigms does not necessarily result in an enhanced anterior N2. We suggest that the overall N2 effect observed in CIT studies with visual stimuli may be the superposition of multiple N2 components (Folstein & Van Petten, 2008) with similar timecourses but modulated in opposite ways by different factors such as mismatch with existing knowledge and context, stimulus complexity, and the similarity between stimuli. The way these components add up is probably quite sensitive to the details of the paradigm and stimuli employed. Therefore, N2 enhancement is not a straightforward index of concealed information, at least in the visual modality. The P3b component is more reliably modulated by concealed information in 3S CIT paradigms, but large P3b components can be elicited by irrelevants that are similar to the target. Studies without stimulus counterbalancing or a suitable control group of uninformed participants could misinterpret the resulting N2 and P3b effects.

Figure legends

Figure 1. Diagram of a 3-stimulus (3S) paradigm. Three types of stimuli are used, randomly intermixed. The first stimulus type is referred to as the "probe" and is an infrequent item that is familiar and meaningful to participant. In the field, the probe could be a detail of the crime that only a perpetrator would be familiar with, whereas in the laboratory it could be an item participants stole during a mock crime scenario. The second stimulus type is referred to as an "irrelevant" and is a control item that is not familiar or meaningful to participants. In the field, this is an item that could plausibly have been at the crime scene, but was not. During the task, participants deny having information about the irrelevants (truthfully) and probes (deceptively, if the person actually is familiar with the probe and wants to conceal such information) by pressing the same "No" button in response to both stimulus types (depicted in red for the probe). The third stimulus type is referred to as the "target", and participants are instructed to press a "Yes" button in response to this stimulus. Targets are used to ensure that participants are engaged in the task, and do not simply press the same "No" button on every trial without paying attention.

Figure 2. Stimuli and behavioral results. a) Card stimuli used in Experiments 1 and 2; b) Digit stimuli used in Experiment 3; c) Response times (top panel) and accuracy (bottom panel) for Experiments 1 and 2 (N=24 for the onset detection, uninformed condition and N=12 for the target and concealed information conditions); d) Response times (top panel) and accuracy rates (bottom panel) for Experiment 3 (N=34 for both conditions). Horizontal segments indicate significant contrasts ($p < .05$).

Figure 3. The left side of the figure shows the grandaverage ERP data in Experiments 1 and 2 (N=24), onset detection task, for the four irrelevants (1♠, 9♠, 10♠, Q♠), the probe (J♠), and the

target (K♠). Note that in this task the probe and the target are only nominally defined, since neither concealed information nor target instructions are provided. The right side of the figure shows the corresponding scalp distributions. On average there were 32 artifact-free trials (minimum = 26) for each item, per participant. The top panel shows the N2 at site FCz as well as the N2 scalp distribution maps (250-300 ms). The bottom panel shows the same data for the P3b at site Pz (400-600 ms).

Figure 4. The left side of the figure shows the grandaverage ERP data in Experiments 1 (N=12), target detection task, for the four irrelevants (1♠, 9♠, 10♠, Q♠), the probe (J♠), and the target (K♠). Note that in this task the probe is only nominally defined, since no concealed information is provided. The right side of the figure shows the corresponding scalp distributions. On average there were 29 artifact-free trials (minimum = 26) for each item, per participant. The top panel shows the N2 at site FCz as well as the N2 scalp distribution maps (250-300 ms). The bottom panel shows the same data for the P3b at site Pz (400-600 ms).

Figure 5. The left side of the figure shows the grandaverage ERP data in Experiments 2 (N=12), concealed information task, for the four irrelevants (1♠, 9♠, 10♠, Q♠), the probe (J♠), and the target (K♠). The right side of the figure shows the corresponding scalp distributions. On average there were 31 artifact-free trials (minimum = 25) for each item per participant. The top panel shows the N2 at site FCz as well as the N2 scalp distribution maps (250-300 ms). The bottom panel shows the same data for the P3b at site Pz (400-600 ms).

Figure 6. Grand average ERPs elicited at sites Fpz, Fz, Cz, and Pz by irrelevants (dashed line), probes (black solid line), and targets (red solid line) in Experiment 3 (N=34), target detection task (left panel). Note that in this task the probe is only nominally defined, since no concealed information is provided. ERPs between -100 and 900 ms are shown negative up and referenced to the average of the mastoids. On average there were 65 trials (minimum = 55; median = 65) for each item, per participant. The right panel shows the scalp distribution of the ERP difference between probes and irrelevants for the N2 (250-300 ms) and the P3b (400-600 ms).

Figure 7. Grand average ERPs elicited at sites Fpz, Fz, Cz, and Pz by irrelevants (dashed line), probes (black solid line), and targets (red solid line) in Experiment 3 (N=34), concealed information task (left panel). ERPs between -100 and 900 ms are shown negative up and referenced to the average of the mastoids. On average there were 65 trials (minimum = 46; median = 65) for each bin, per participant. The right panel shows the scalp distribution of the ERP difference between probes and irrelevants for the N2 (250-300 ms) and the P3b (400-600 ms).

Supplementary Figure 1. Grand average ERPs elicited by irrelevants (dashed line), probes (black solid line), and targets (red solid line) in Experiment 3 (N=34), target detection condition. ERPs between -100 and 900 ms at all scalp recording sites are shown, negative up and referenced to the average of the mastoids. On average there were 65 trials (minimum = 55; median = 65) for each item, per participant.

Supplementary Figure 2. Grand average ERPs elicited by irrelevants (dashed line), probes (black solid line), and targets (red solid line) in Experiment 3 (N=34), concealed information condition. ERPs between -100 and 900 ms at all scalp recording sites are shown, negative up and referenced to the average of the mastoids. On average, there were 65 trials (minimum = 46; median = 65) for each bin, per participant.

Acknowledgments

Research supported by Research Executive Agency European Union, Seventh Framework Programme (FP7), Marie Curie Career Integration Grant: CIG09-GA-2011-293850-CoND, and by the Research Executive Agency European Union FP7 Marie Curie Initial Training Networks (ITN) FP7-PEOPLE-2013-ITN-604764 Innovative Doctoral Programme (IDP): COGNOVO. The funding sources had no involvement in the study design; in the collection, analysis and interpretation of data ; in the writing of the manuscript; and in the decision to submit the article for publication.

GG designed and implemented the studies, supervised data collection, analyzed the data, and wrote the manuscript. DB contributed to study implementation, collected the data and contributed to data analysis. CW contributed to data analyses. HS contributed to study design and to manuscript preparation.

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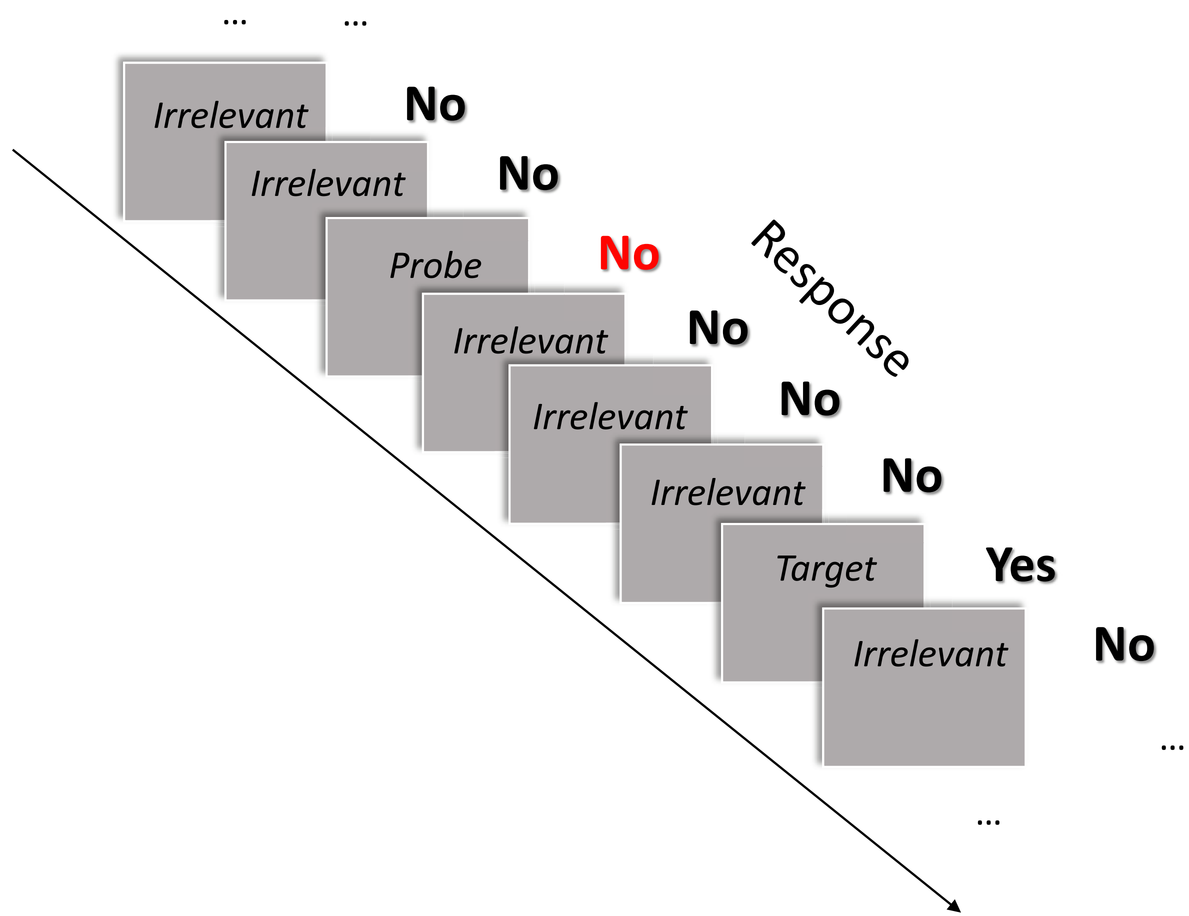
Conflict of Intrest

The authors declare they have no conflict of interest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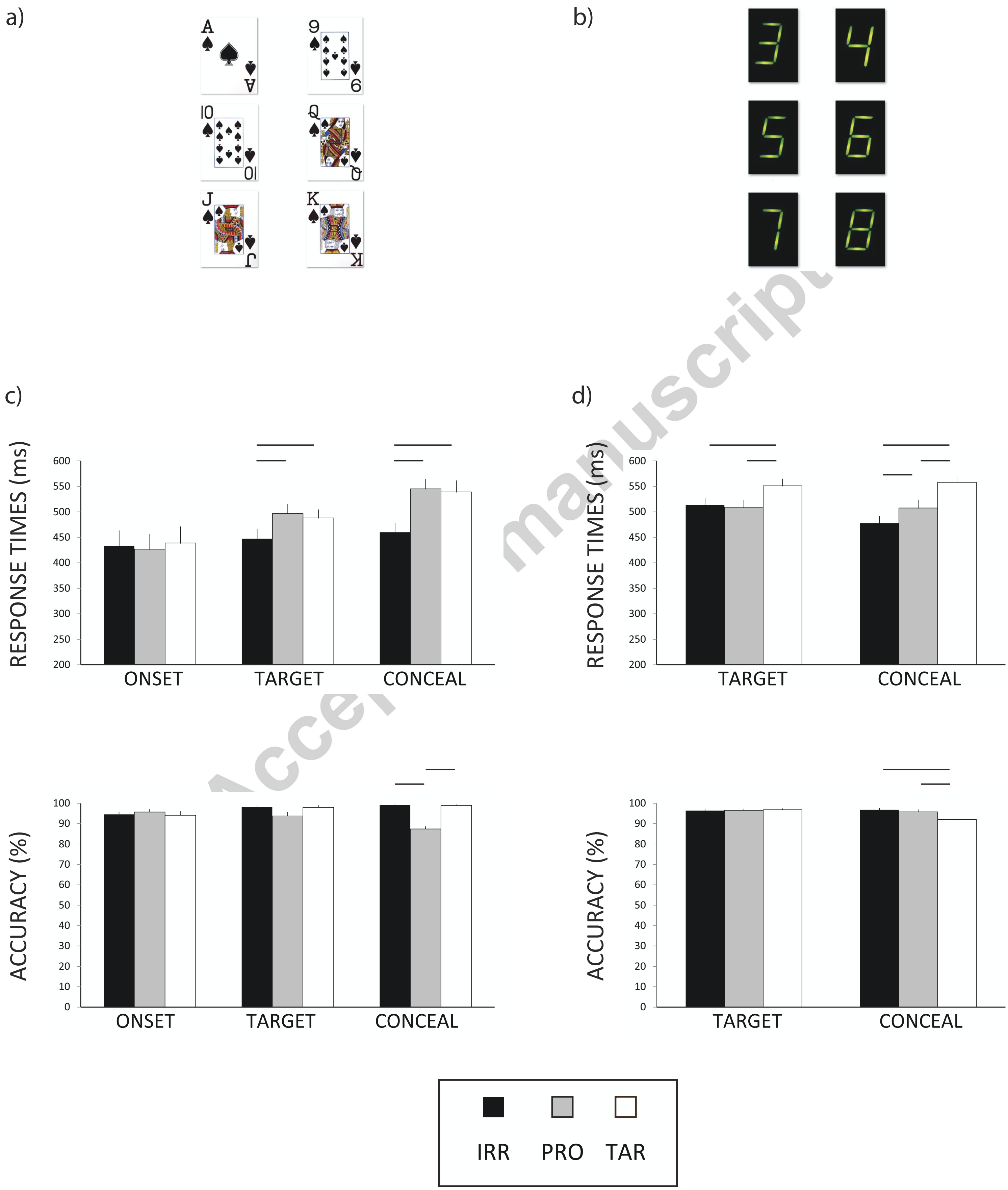
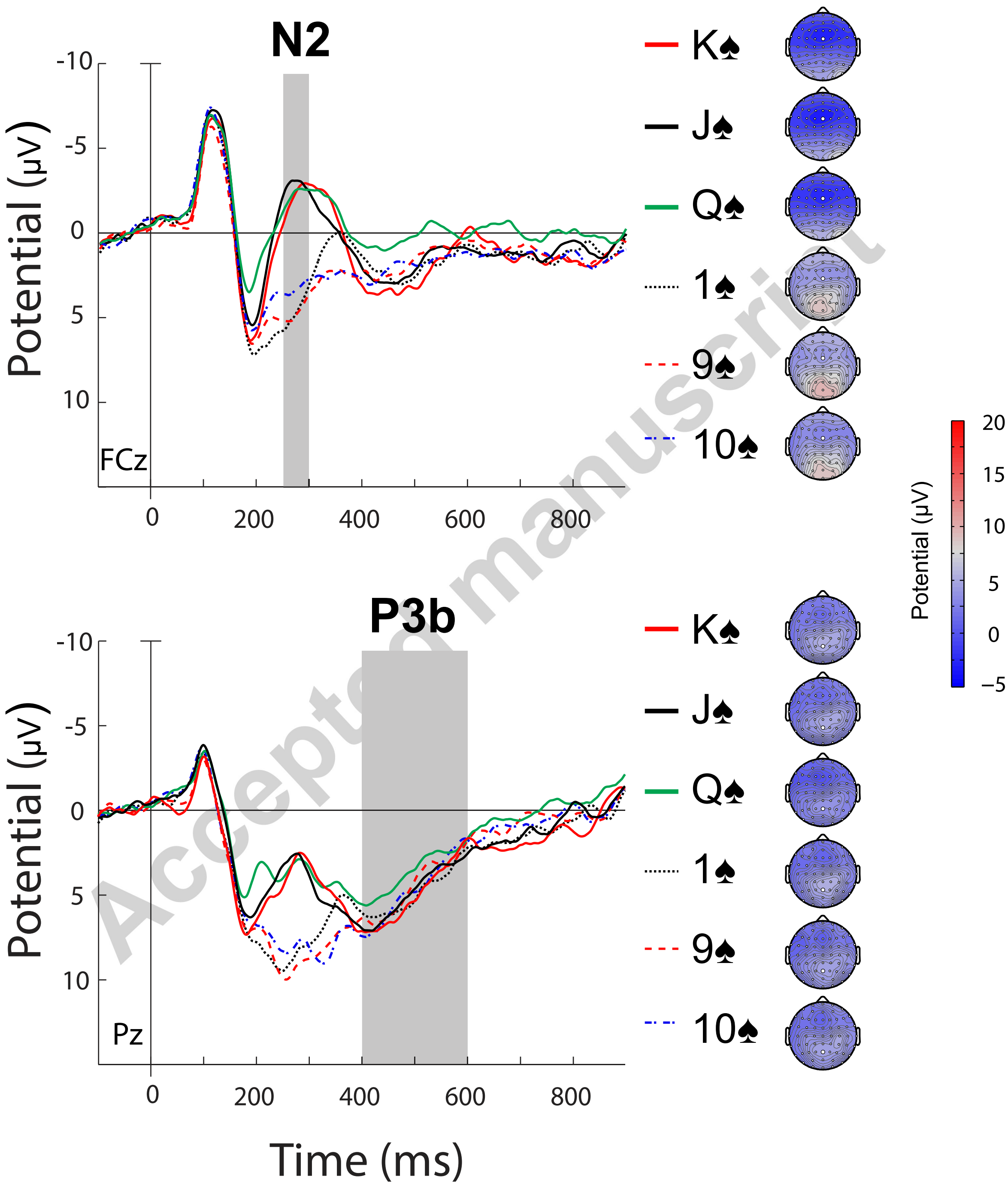
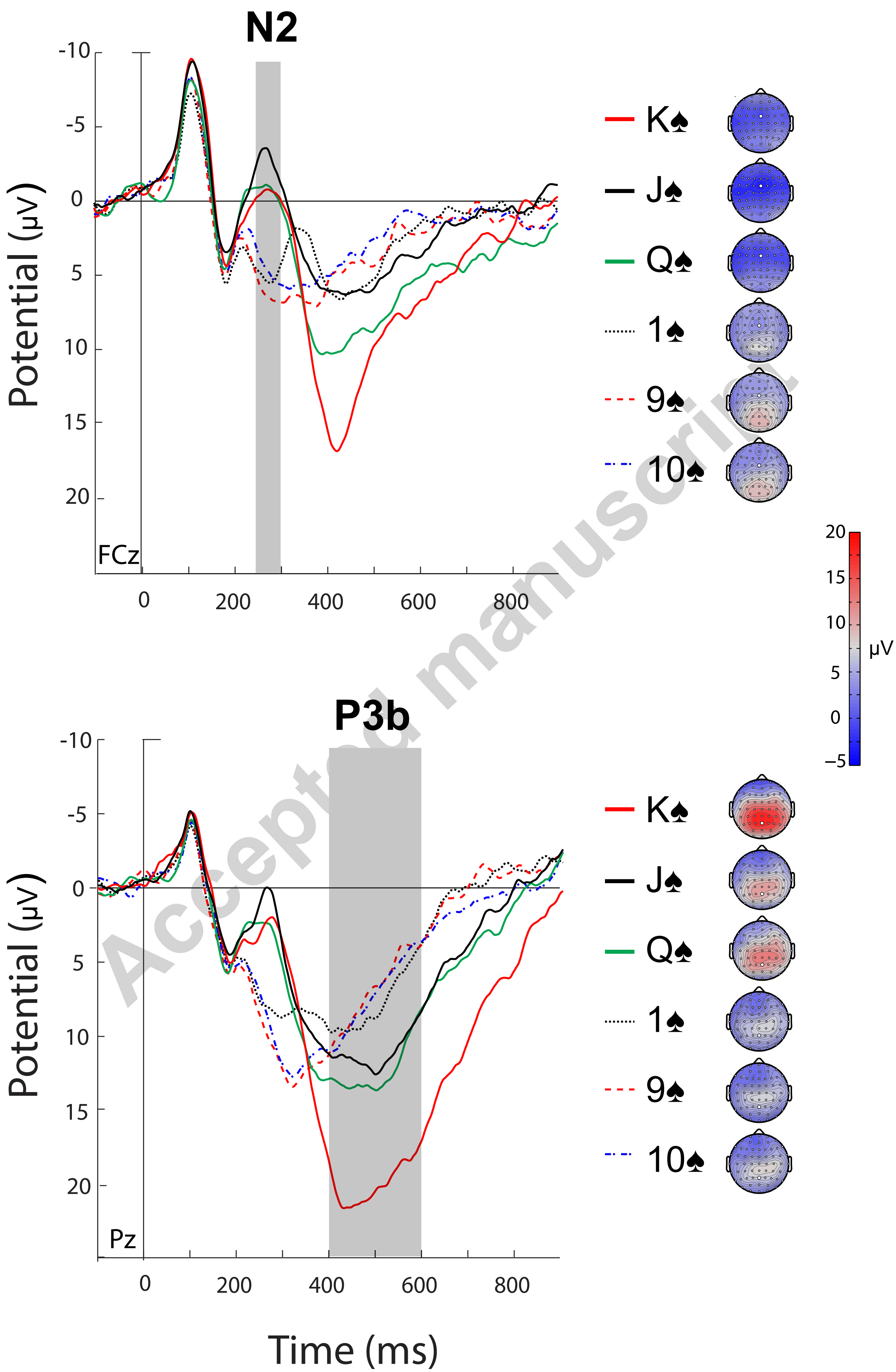

a)
b)
c)
d)
RESPONSE TIMES (ms)
600
550
500
450
400
350
300
250
200
ONSET
TARGET
CONCEAL
ACCURACY (%)
100
90
80
70
60
50
40
30
20
10
0
IRR
PRO
TAR


N2
P3b
Potential (μV)
Time (ms)
FCz
Pz
K♠
J♠
Q♠
1♠
9♠
10♠
-10
-5
0
5
10
200
400
600
800
Potential (μV)
20
15
10
5
0
−5



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Potential (µV)
FCz
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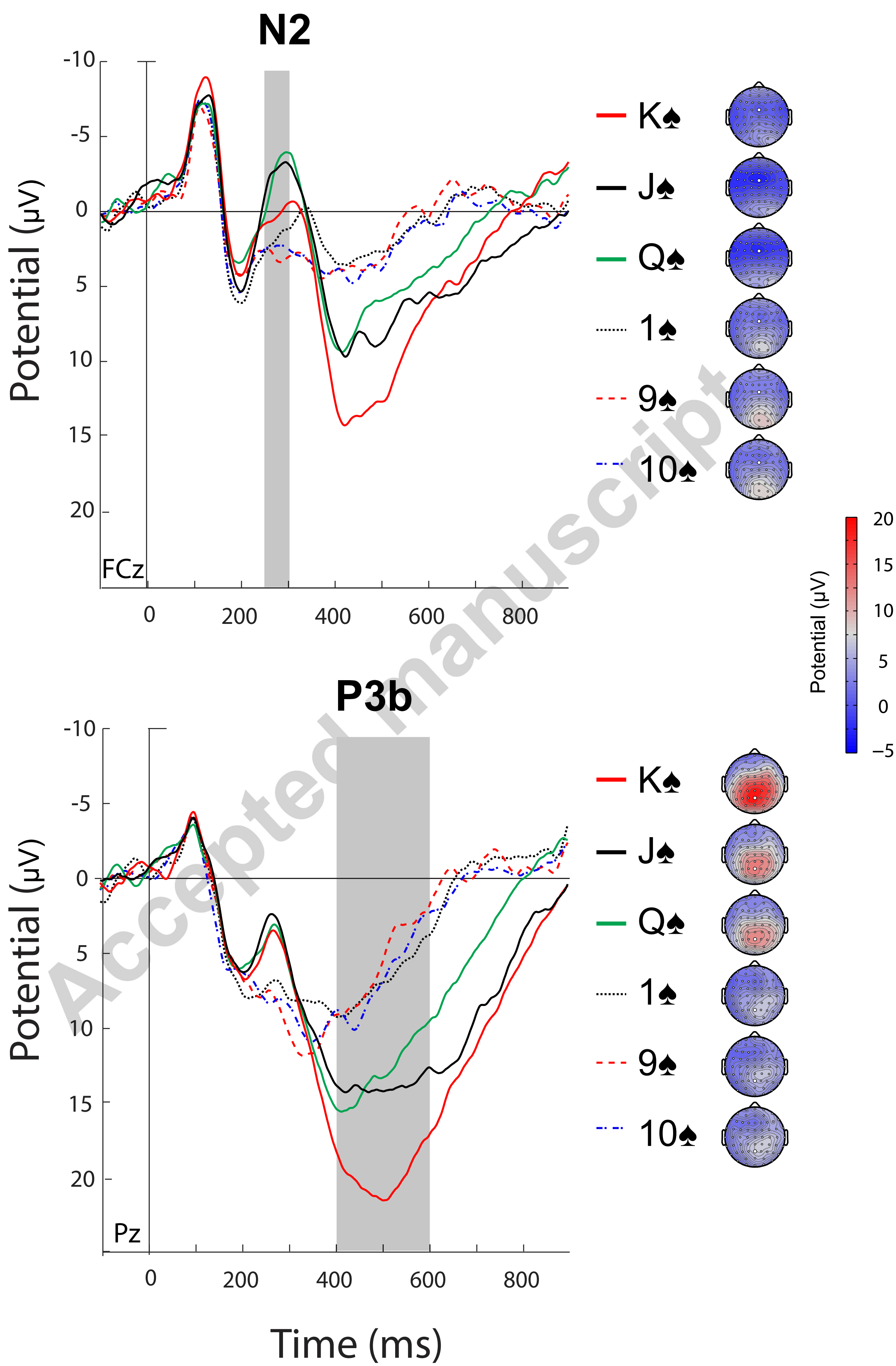
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Potential (µV)
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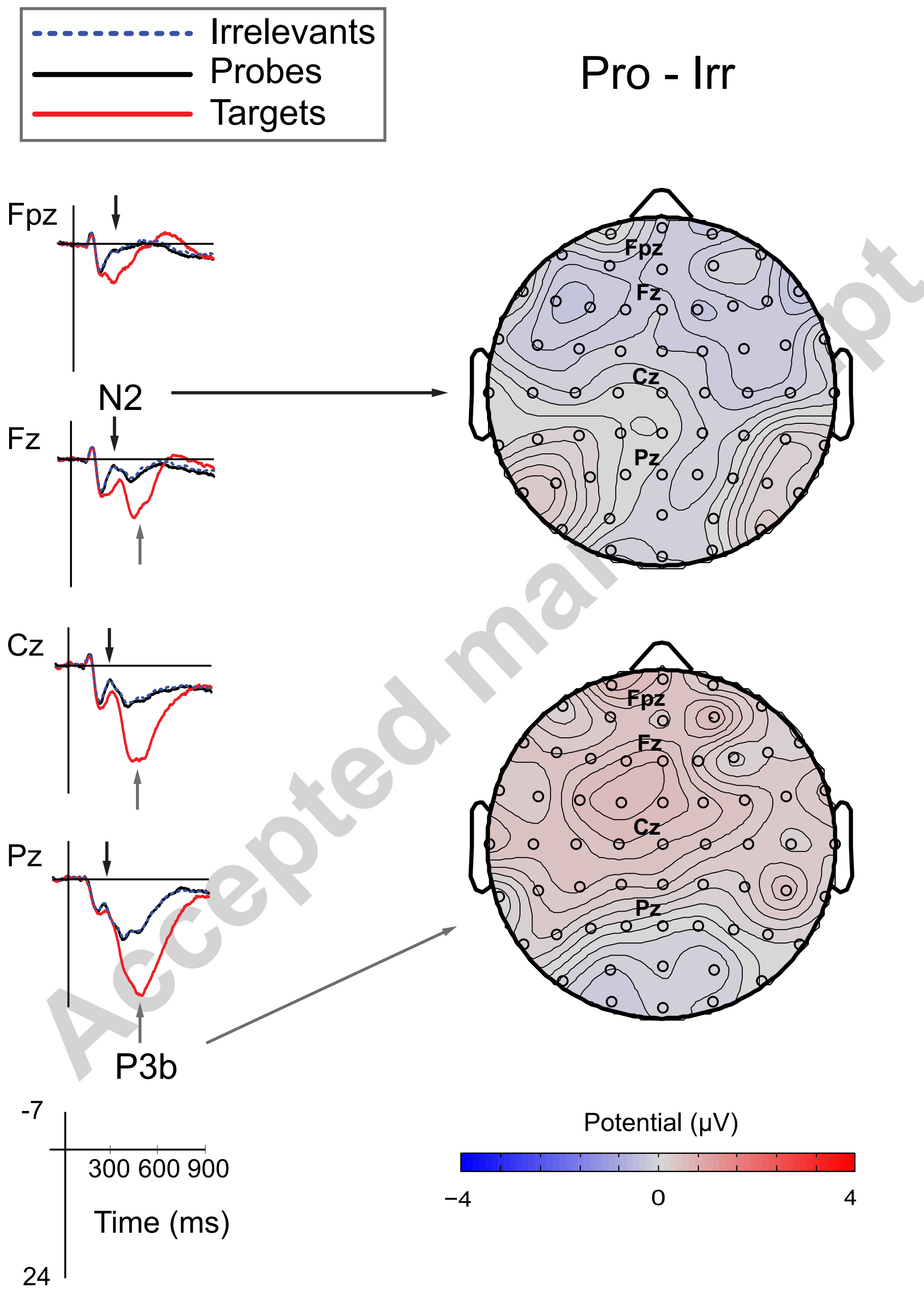
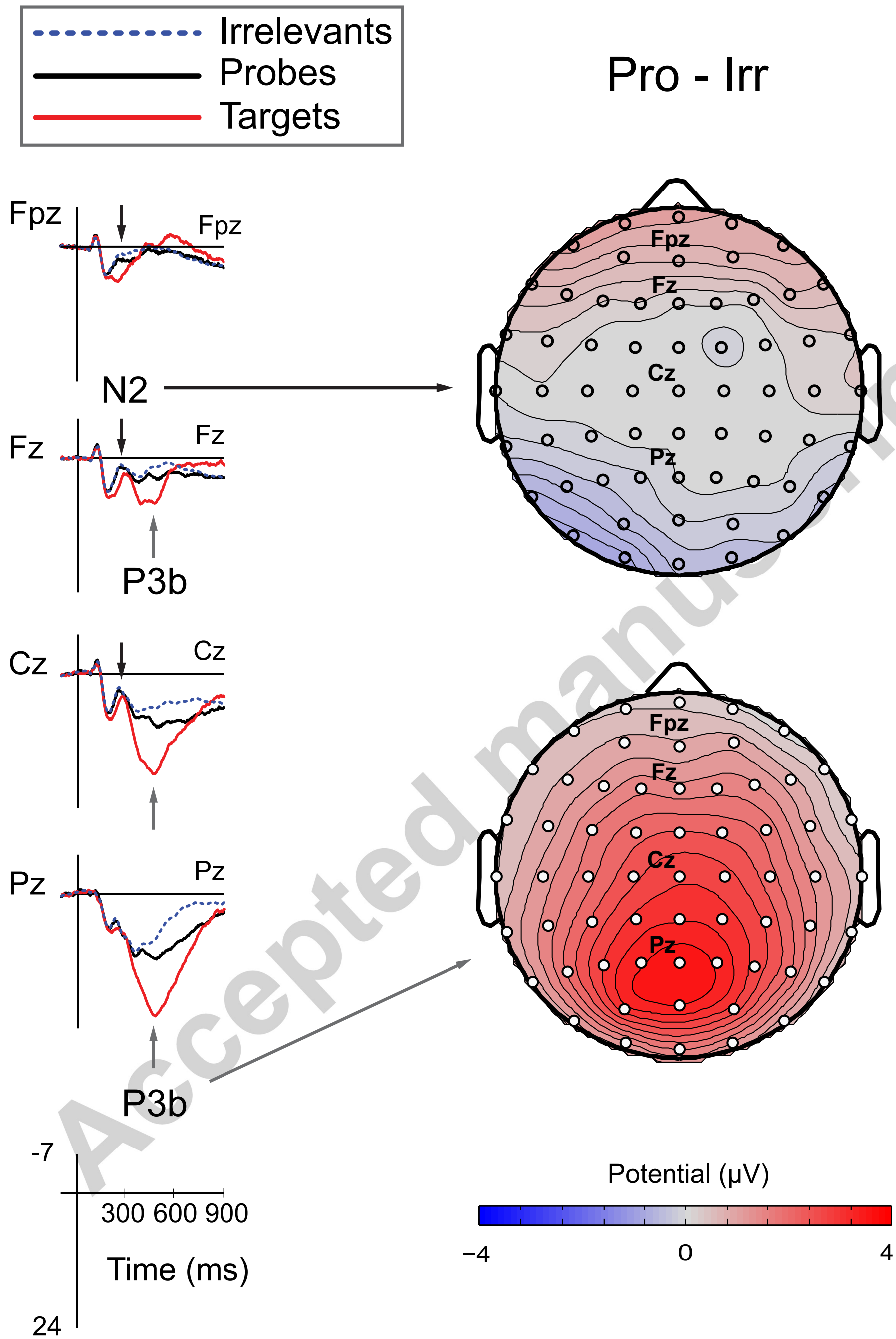


Irrelevants
Probes
Targets
Pro - Irr
Fpz
Fz
Cz
Pz
N2
P3b
-7
24
300 600 900
Time (ms)
Potential (µV)
−4
0
4


Irrelevants
Probes
Targets
Pro - Irr
Fpz
Fz
Cz
Pz
N2
P3b
P3b
-7
24
300 600 900
Time (ms)
Potential (μV)
−4
0
4