Fall 10-26-2004

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Recommended Citation
Leynes, P. A., Landau, J., Walker, J., & Addante, R. J. (2005). Event-related potential evidence for multiple causes of the revelation effect. Consciousness and cognition, 14(2), 327–350. https://doi.org/10.1016/j.concog.2004.08.005

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Consciousness and Cognition 14 (2005) 327–350

Consciousness and Cognition

www.elsevier.com/locate/concog

Event-related potential evidence for multiple causes of the revelation effect☆

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Received 24 June 2004
Available online 26 October 2004

Abstract

Asking people to discover the identity of a recognition test probe immediately before making a recognition judgment increases the probability of an old judgment. To inform theories of this ‘‘revelation effect,’’ event-related potentials (ERPs) were recorded for revealed and intact test items across two experiments. In Experiment 1, we used a revelation effect paradigm where half of the test probes were presented as anagrams (i.e., a related task) and the other items were presented intact. The pattern of ERP results from this experiment suggested that revealing an item decreases initial familiarity levels and caused the revealed items to elicit similar levels of activity. In Experiment 2, half of the probes were preceded by an addition task (i.e., an unrelated task). The pattern of ERP effects in this study were distinct from those observed in Experiment 1. More specifically, revealed item ERPs were more negative than intact ERPs at frontal electrodes and more positive at parietal electrodes early in the interval. Later in the epoch, revealed item ERPs were more negative than intact items. These data suggest that related tasks decrease familiarity and alter the signal-to-noise ratio of old and new items, whereas unrelated tasks affect processing in a different way (perhaps by changing decision processes)

☆ Experiment 1 was supported by a Phi Kappa Phi Student-Faculty Research Fellowship granted to Jessica Walker and Andrew Leynes and was presented at the Eighth Annual Meeting of the Cognitive Neuroscience Society, March 2001. Experiment 2 was supported by a Phi Kappa Phi Student-Faculty Research Fellowship granted to Richard Addante and Andrew Leynes. Andrew Leynes was also supported by The College of New Jersey's internal research granting program, SOSA.

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doi:10.1016/j.concog.2004.08.005

that also results in the revelation effect. The implications for current theories of the revelation effect are discussed.

Keywords: Event-related potentials; Revelation effect; Recognition

1. Introduction

In the typical recognition memory experiment, people study a list of items (e.g., words or pictures) and then must identify the studied items on a test that contains the studied items and several new items. Many factors influence the accuracy of recognition judgments including (but not limited to) encoding tasks (Craik & Lockhart, 1972), decision criterion (Green & Swets, 1966), and the composition of the test list (Deese, 1959; Roediger & McDermott, 1995).

Recent research demonstrates that another variable, the physical appearance (or initial perception) of the test probe, also affects people's recognition decisions (Watkins & Peynircioglu, 1990; Whittlesea, Jacoby, & Girard, 1990). For example, when people discover the identity of a test probe before rendering a recognition judgment, they are more likely to call the item "old" as compared with a word presented in its original intact format. This phenomenon, dubbed the *revelation effect*, is elicited by many tasks. The available evidence shows that people are more likely to call a test probe "old" if it is unfolded one letter at a time (e.g., -T----, -T-E--, ST-E--, ST-E-T, STRE-T, and STREET; LeCompte, 1995; Peynircioglu & Teckan, 1993; Watkins & Peynircioglu, 1990), if the probe is an anagram that must be unscrambled (Peynircioglu & Teckan, 1993; Watkins & Peynircioglu, 1990; Westerman & Green, 1996), if the entire probe or individual letters must be rotated (Peynircioglu & Teckan, 1993; Watkins & Peynircioglu, 1990), if the probe is degraded (Luo, 1993), if an unrelated anagram must be solved before reading the intact probe (Westerman & Green, 1996), and if a numerical addition task must be solved before the test probe (Niewiadomski & Hockley, 2001).

One theoretical explanation for the revelation effect draws on the logic of the dual-process theories of recognition (e.g., Jacoby, 1991; Jacoby & Dallas, 1981; Mandler, 1980). By this account, people make a recognition decisions based on two separate pieces of evidence. On the one hand, people can claim to recognize an item if they actually recollect the circumstance and details of their original encounter with the item. On the other hand, recognition may be based solely on a strong feeling that they encountered the item earlier (i.e., the item feels familiar). In terms of the revelation effect, some have suggested that the process of discovering the identity of the test probe temporarily increases its familiarity (Luo, 1993; Peynircioglu & Teckan, 1993) or the global activation (Westerman & Green, 1998). People then mistake this increased familiarity as evidence that the item originated from the study list and this produces more "old" responses for both old items (targets) and new items (lures).

Although this increment-to-familiarity account has intuitive appeal and some experimental support, this account fails to explain all of the experimental findings. For example, Westerman and Green (1996) found a revelation effect when the revealed item and the recognition test probe were different words. Similarly, Niewiadomski and Hockley (2001) found a revelation effect when participants completed an unrelated nonverbal task (i.e., numerical addition) immediately before judging the test probe. Consequently, the increment-to-familiarity account has difficulty explaining how solving an anagram or solving a nonverbal task increases the familiarity of an unrelated test probe.

Another piece of evidence that is difficult to explain with the increment-to-familiarity account comes from Hicks and Marsh (1998) revelation experiments where they examined the format of the recognition test. In their study, after studying a list of words, participants saw two test probes (i.e., a two-alternative forced choice, 2AFC, recognition test) and were instructed to select which one they studied. One of the test probes was revealed, and the other was presented intact. If a temporary increase in familiarity produces the revelation effect, then this paradigm should produce a revelation effect similar to the one where people judged each item separately. However, Hicks and Marsh (1998) found that people were actually less likely to call the revealed items old. To explain the revelation effect, Hicks and Marsh appealed to a signal detection theory (SDT) of recognition memory and suggested that as people try to decode the test probe, this temporarily activates a variety of alternative words in memory. This decoding process decreases the signal-to-noise ratio because the average familiarity values of the old and new words become more similar. In this situation, people relax their decision criteria and this artificially increases the number of hits and false alarms.

Niewiadomski and Hockley (2001) proposed the criterion flux account which also posits a criterion shift explanation for the revelation effect, (see also Hockley & Niewiadomski, 2001). According to both the criterion flux and the decrement-to-familiarity (Hicks & Marsh, 1998) accounts, the revelation process causes people to adopt a more liberal decision criterion. The criterion flux account proposes that any task that disrupts working memory processes during the recognition decision process (e.g., a numerical problem or solving an anagram) causes a temporary loss of list information which results in participants adopting a more liberal decision criterion. Conversely, Hicks and Marsh argued that people relax their decision criteria because of a decrease in familiarity (i.e., the signal-to-noise ratio) of the revealed test probes. Thus, both accounts agree that the revelation effect results from a shift in criterion but they differ on the genesis of the criterion shift. Whittlesea and Williams (2001a, 2001b) have proposed an alternative explanation for the revelation effect that we will address in Section 4.

Because many of these theoretical explanations make strikingly similar predictions about the revelation effect and they seem to be able to explain the same behavioral data, we believe that cognitive neuroscience may help to uncover the cognitive mechanisms that produce the revelation effect. Specifically, direct measures of brain activity can provide insight into the mental processes that contribute to memory, and, in this case, event-related potentials (ERPs) appear to be particularly well suited to the task. ERPs measure brain activity time-locked to the appearance of stimuli and provide excellent temporal resolution of moment-to-moment changes in cognitive processing. Previous studies indicate that memory processes affect ERP activity. For example, studied items tend to elicit more positive ERP activity than unstudied items (this is sometimes referred to as an old/new ERP effect; see Rugg, 1995 for a review). Researchers have used ERPs to examine predictions made by theories of recognition memory. For example, research indicates that the types of subjective bases described in the dual process theory appear to elicit different patterns of old/new ERP differences (see Curran, 2000 or Mecklinger, 2000 for a review). Familiarity is typically observed as an old/new ERP difference at frontal electrode sites that begins approximately 300–500 ms after the onset of the test probe. In contrast, recollection has been linked with an old/new ERP difference at parietal electrode sites approximately 400–600 ms after the onset of the probe. In addition, frontal ERP effects that occur later in the course of memory processing (approximately 800 ms after stimulus onset) seem to reflect more difficult decisions, such as discriminating between different sources (e.g., Leynes, 2002; Leynes, Bink, Marsh, Allen, & May, 2003; Ranganath & Paller, 2000; Wilding & Rugg, 1996).

Based on the idea that familiarity and recollection produce different ERPs, Azimian-Faridani and Wilding (in press) recorded ERPs when words were presented intact or preceded by an anagram unrelated to the test probe (i.e., the Westerman & Green, 1996 paradigm). They found that intact item ERPs were more positive than the revealed ERPs 300–500 ms after the onset of the test probe. Because this effect is in the same temporal period as the familiarity related ERP effects, they interpreted this result as evidence that revelation is associated with a decrease in familiarity, supporting the decrement-to-familiarity account (Hicks & Marsh, 1998). Although Azimian-Faridani and Wilding's data are valuable, there are a number of difficulties with interpreting these findings. First, in their analysis of the ERPs they collapsed across response type and analyzed old and new item ERPs without regard for the subject's response. They claimed this procedure eliminated criterion influences on ERP data because they were not creating ERPs based on responses. Unfortunately, the decision criterion is set for both old and new items; therefore, it is unclear how this procedure eliminated any criterion differences between the judgments for the intact and revealed items. More importantly, because the revelation effect is usually more robust for false alarms, examining ERP differences between hits and false alarms would be informative. Another problem with this study is that it only examined one of many paradigms that elicit the revelation effect. This issue is important because Verde and Rotello (2004) provide evidence indicating that there may be more than one cause for the revelation effect. Consequently, there is a clear need to explore the generality of these findings before theories of the revelation effect can be advanced.

The purpose of Experiment 1 was to extend the ERP literature on the revelation effect by comparing ERP activity elicited by discovered test probes (i.e., a related task) to the activity elicited by intact test probes. Importantly, ERP differences have been observed when the form of the information is changed from study to test indicating that the ERP differences are not merely produced by identical perceptual representations of the information (Kazmerski & Friedman, 1997; Paller & Gross, 1998). In addition, ERPs elicited by accurate and inaccurate responses were examined to provide a detailed examination of ERP activity. Any ERP differences between these items could provide important evidence about how the perceptual differences from revealing items at test alter the cognitive processing on a memory test.

Experiment 2 capitalized on the strengths of the ERP technique versus traditional behavioral measures. Recent behavioral evidence has suggested that related and unrelated tasks produce different changes that ultimately cause the revelation effect (Verde & Rotello, 2004). ERPs can provide more detailed evidence of changes in cognitive processing than behavioral measures; therefore, the purpose of Experiment 2 was to determine if unrelated tasks (i.e., an addition problem) produce different patterns of ERPs, which would be additional evidence that there are multiple causes of the revelation effect.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-four students from The College of New Jersey (7 males, 17 females), aged 18–22, volunteered in exchange for course credit. In addition, an incentive of $25 was offered to the participant who had the best memory and fastest reaction time among those tested. All participants were right handed (Oldfield, 1971), reported that they had normal or corrected-to-normal vision, and did not have a history of neurological disease.

2.1.2. Apparatus

The participants sat in a chair located in an electrically shielded chamber facing a VGA computer monitor located 110 cm away. Each character presented on the monitor extended 0.4° of visual angle vertically and horizontally. Participants were monitored by closed circuit television with a two-way communication system and they responded by pressing keys on a computer keyboard.

2.1.3. Stimuli

Four hundred eight letter words served as the stimuli in the experiment (word frequency was 10 or more occurrences per million; Kucera & Francis, 1967). Of these 400 words, 200 were randomly chosen for each participant by the software to be targets (i.e., old words) during the test phase. In addition, half of the old and half of the new words were randomly chosen by the software to be revealed as anagrams during the recognition test. All anagrams were formed by switching the third and sixth letters of the word (e.g., RA*T*IO*N*AL vs. RA*N*IO*T*AL).

2.1.4. Procedure

The experimental session consisted of a study phase and a test phase. Participants studied 200 words for a nonspecific memory test. Each study word was presented one at a time in the center of the computer screen, remaining on the screen for only 500 ms with a 500 ms time lapse between each word. We selected this study procedure because rapid presentation increases participant's reliance on familiarity and tends to produce a more robust revelation effect (Landau, 2001). The entire study phase lasted approximately 3.5 min.

After a brief delay (approximately 5 min), each participant then completed a recognition memory test consisting of 400 words, 200 target words and 200 new words (i.e., lures). In addition, half of the targets and lures were presented as anagrams (i.e., revealed), and the other half were presented in their intact format. Before the test, participants were told that half of the words on the test (including both intact words and anagrams) were old and half were new. They were generally instructed to determine if each word was old or new and to register their recognition responses on the keyboard. Furthermore, participants were instructed that some of the items would appear as anagrams on the test. On these trials, participants were told to mentally solve the anagram (by switching the 3rd and 6th letters) and then to determine if the item was old or new. The computer proceeded to the next trial after the recognition response was recorded (for both intact and revealed items).

2.1.5. ERP recording procedures

Potentials were sampled at a rate of 150 Hz from 20 Ag/AgCl electrodes mounted in an elastic cap (Neuromedical Supplies) and referenced to the left mastoid online and referenced to the average of the left and right mastoids offline. Electrodes were placed over the frontal lobes (Fp1, Fp2, F7, F3, Fz, F4, F8, FC3, FCz, and FC4), temporal lobes (FT7, FT8, T7, T8, TP7, and TP8), parietal lobes (CP3, CPz, CP4, P7, P3, Pz, P4, and P8), occipital lobes (O1 and O2), and at the central position on the scalp (C3, Cz, and C4). Vertical electrooculogram (vEOG) was recorded bipolarly using two Ag/AgCl electrodes affixed above and below the subject's left pupil. Horizontal electrooculogram (hEOG) was recorded bipolarly from identical electrodes and attached to the outer canthi of both eyes. Interelectrode impedance was below 5 kΩ. EEG and EOG signals were recorded with a Contact Precision Instruments amplifier with a 0.01–40 Hz bandpass (−3 dB attenuation). During the test phase, EEG and EOG were sampled for 300 ms before the probe word and for 2700 ms after the probe word. The data were digitally filtered off-line using a 30 Hz lowpass filter (−3 dB/oct). Occular artifacts were corrected using the algorithm developed by Semlitsch, Anderer, Schuster, and Presslich (1986). Trials on which ERP amplitudes exceeded ±150 μV were excluded from the analyses.

2.2. Results and discussion

Unless specified otherwise, all results reported in this article are significant at the $\alpha = 0.05$ level.

2.2.1. Behavioral response data

As is conventional in the revelation effect literature, we analyzed the proportion of old items called old (i.e., hits) and new items incorrectly identified as old (i.e., false alarms) as a function of item status (revealed or intact). A 2×2 within-subjects analysis of variance with factors of item status (intact vs. revealed) and item type (hits vs. false alarms) indicated that participants registered more hits than false alarms, $F(1,23) = 131.0$. Although overall responses did not vary across intact and revealed items ($F(1,23) = 3.36$, $p = .08$), the interaction between item status and item type was significant, $F(1,23) = 6.08$. Post hoc analyses found that the hit rates for the intact ($M = .65$, $SD = .07$) and revealed targets were not different ($M = .66$, $SD = .10$), $t(23) < 1$. However, people were more likely to call revealed lures old ($M = .51$, $SD = .11$) as compared with intact lures ($M = .45$, $SD = .10$), $t(23) = 2.57$. Failure to find a reliable revelation effect for the targets is consistent with the previous literature. Hicks and Marsh's (1998) meta-analysis of the revelation effect literature showed that the revelation effect is typically larger for lures than targets and that the targets sometimes fail to produce a significant revelation effect.

In general, revealed items tend to produce a decreased measure of responder sensitivity (d') and a more relaxed decision criteria (i.e., more negative C values). For comparison, we also analyzed these signal detection measures. Analysis of d' found that sensitivity was lower for the revealed ($M = .43$, $SD = .21$) items as compared with the intact items ($M = .54$, $SD = .28$); $F(1,23) = 4.59$. The decision criterion analysis found that participants were slightly more liberal for revealed items ($M = -.24$, $SD = .26$) than intact items ($M = -.15$, $SD = .19$); however, this difference was only marginally significant, $F(1,23) = 3.56$, $p = 0.07$. These findings are consistent with the results from previous revelation effect investigations.

Reaction times for correct responses are presented here for comparison to other ERP investigations of memory. Intact hits ($M = 1584$, $SD = 403$) were identified faster than revealed hits ($M = 2638$, $SD = 828$; $F(1,23) = 71.93$), and intact correct rejections ($M = 1886$, $SD = 492$) were also identified faster than revealed correct rejections ($M = 3668$, $SD = 1627$; $F(1,23) = 42.60$).

2.2.2. ERP data

The first comparison of interest examined the traditional old/new effects reported in many ERP studies of recognition; thus, ERPs elicited by hits and correct rejections were analyzed for intact and revealed items separately. This initial comparison was followed by additional comparisons (described later) in an effort to elucidate how revelation affects ERP activity. To quantify the ERP effects in all comparisons, eight amplitude measures were computed as the average activity relative to a 300 ms pre-test word baseline over consecutive 300 ms intervals beginning 300 ms after the onset of the test probe (i.e., 300–600, 600–900, 900–1200, 1200–1500, 1500–1800, 1800–2100, 2100–2400, and 2400–2700 ms). These amplitude measures were selected to be consistent with prior ERP investigations of recognition memory and to allow for a sensitive analysis of ERP effects given the lack of comparable ERP data for revealed items. The eight intervals were selected to capture ERP activity leading up to the average response time to judge old revealed items (i.e., 2600 ms). Each of the eight intervals were analyzed at frontal (i.e., F3, Fz, F4, FC3, FCz, and FC4) and parietal electrode regions (i.e., CP3, CPz, CP4, P3, Pz, and P4) using a within-subjects analysis of variance with factors of item type, anterior/posterior (frontal and parietal), and electrode site. The electrode sites were selected based upon the apparent differences in the grand average ERP data and previous ERP studies of recognition. Interactions involving item type and electrode sites, which indicate a difference in ERP topography across electrode sites, were evaluated after after ERPs were scaled to eliminate amplitude differences between the conditions (McCarthy & Wood, 1985). When appropriate, analyses incorporated the Geisser-Greenhouse correction for nonsphericity (corrected degrees of freedom are reported).

2.2.3. Traditional old/new ERP effects

The top of Fig. 1 plots the grand average ERPs elicited by hits and correct rejections at left and right frontal and parietal electrodes. The bottom of Fig. 1 plots the ERPs elicited by false alarms and misses. The ERPs elicited by the revealed items are very similar, whereas the intact ERPs elicited by false alarms and hits appear to be more positive than both miss and correct rejection ERPs.

2.2.3.1. Intact hits vs. correct rejections. The main effect of item type (hit vs. CR) was significant for intact items during the 300–600 ms, ($F(1,23) = 4.89$), 600–900 ms ($F(1,23) = 7.62$), 900–1200 ms ($F(1,23) = 13.21$), and 1500–1800 ms intervals ($F(1,23) = 5.49$). It was also marginally significant during the 1200–1500 ms ($F(1,23) = 3.57$, $p = .07$), 1800–2100 ms ($F(1,23) = 4.15$, $p = .05$), and 2400–2700 ms intervals ($F(1,23) = 3.58$, $p = .07$). No significant interactions involving the factor of item type were observed for intact items during any of the intervals.

To further explore this result, we performed follow-up analyses that compared ERP amplitudes in the frontal and parietal electrode regions separately. The post hoc analyses revealed a significant main effect of item type at frontal electrode sites for each of the seven intervals tested [300–600 ms: $F(1,23) = 5.43$; 600–900 ms: $F(1,23) = 8.46$; 900–1200 ms: $F(1,23) = 19.94$; 1200–

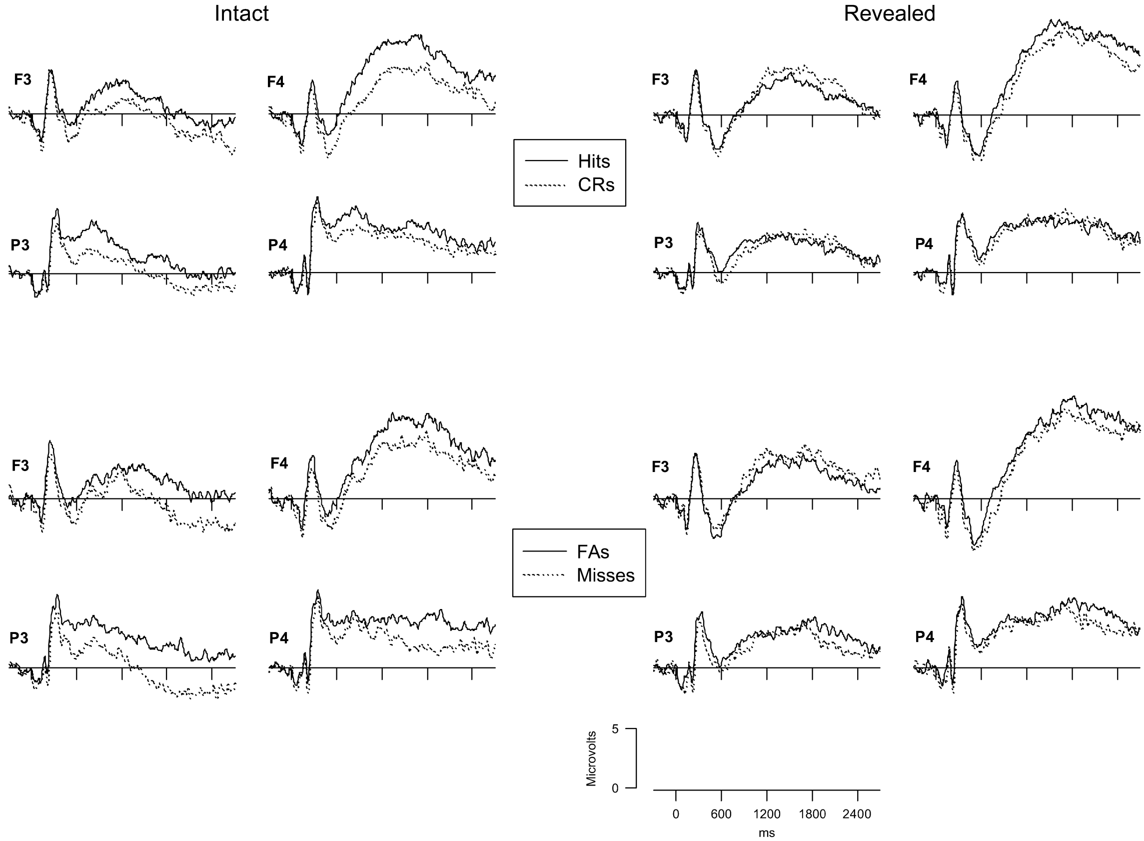

Fig. 1. Experiment 1 grand average ERPs recorded at left and right frontal electrode sites (F3 and F4) and left and right parietal electrode sites (P3 and P4). ERPs elicited by intact items appear in the left half of the figure, whereas ERPs elicited by revealed items appear in the right half of the figure. Hit and correct rejection ERPs are plotted in the top half of the figure, and false alarm and miss ERPs are plotted in the bottom half of the figure. Positive voltage is plotted upward in all graphs. The zero point on the x-axis corresponds to the onset of the test probe and axis ticks are placed at 600 ms increments.

1500 ms: $F(1,23) = 5.80$; 1500–1800 ms: $F(1,23) = 5.59$; 1800–2100 ms: $F(1,23) = 4.71$; 2400–2700 ms: $F(1,23) = 4.73$]. The post hoc analyses of parietal ERPs revealed a significant main effect of item type for only the 600–900 ms ($F(1,23) = 5.58$) and 900–1200 ms intervals ($F(1,23) = 5.47$). None of the interactions involving item type were significant for either analysis.

2.2.3.2. Revealed hits vs. correct rejections. The analysis of item type (hits vs. CRs) for revealed items did not yield any significant main effects, largest $F = 2.33$, $ps > .05$. In addition, no significant interactions involving the factor of item type were found for the revealed items (the largest $F = 1.64$, $ps > .05$).

The analysis of old and new ERPs for the intact and revealed items indicates that intact hits elicited more positive ERPs than intact correct rejections. This old/new ERP effect at the frontal electrode sites began approximately 300 ms after the presentation of the probe and lasted for approximately 1800 ms. A second old/new ERP effect was found at the parietal electrode sites but this effect began about 600 ms after the onset of the probe and lasted for 600 ms. Neither of these old/new effects were observed for the revealed items.

Because the revelation effect was significant for the lures only, the absence of old/new ERP differences in the revelation condition may have been produced by a selective increase in the ERP amplitudes elicited by new items. Although most ERP studies report differences between old and new items, recent evidence shows that false alarms can also elicit more positive ERPs. Curran (2000) reported that false alarms to lures (which differed in their plurality from studied words) elicited more positive ERPs than correct rejections suggesting that the false alarms possessed higher familiarity levels than correctly rejected lures. Thus, the revelation manipulation in the present experiment may have increased the familiarity levels of new words without affecting the familiarity of old items. Keeping with this logic, we compared false alarm ERPs to those elicited by correct rejections under the assumption that false alarms would possess more familiarity than new words called "new." Thus, ERP differences in the revealed condition might be limited to a difference between false alarms and correct rejections if revelation specifically affected familiarity of new items.

2.2.3.3. Intact false alarms vs. correct rejections. The results of the ERP analysis of false alarms and correct rejections was very similar to those reported for hits versus correct rejections. The main effect of item type (FA vs. CR) was significant for intact items beginning 300 ms after the onset of the probe and ending several hundred milliseconds later [300–600 ms: $F(1,23) = 7.50$; 600–900 ms: $F(1,23) = 4.80$; 900–1200 ms: $F(1,23) = 7.35$; 1200–1500 ms: $F(1,23) = 9.99$; 1500–1800 ms: $F(1,23) = 4.67$; 1800–2100 ms: $F(1,23) = 8.04$; 2400–2700 ms: $F(1,23) = 5.36$]. No significant interactions involving the factor of item type were observed for intact items during any of the intervals.

To further explore the results, we followed these analyses with subsidiary analyses that compared ERP amplitudes in the frontal and parietal regions separately. The post hoc analyses revealed a significant main effect of item type at frontal electrode sites for six of the seven intervals tested [300–600 ms: $F(1,23) = 6.36$; 900–1200 ms: $F(1,23) = 7.14$; 1200–1500 ms: $F(1,23) = 9.63$; 1500–1800 ms: $F(1,23) = 5.22$; 1800–2100 ms: $F(1,23) = 7.92$; 2400–2700 ms: $F(1,23) = 5.25$]. Additionally, the main effect of item type was marginally significant for the 600-900 ms interval, $F(1,23) = 3.91$, $p = .06$. The post hoc analyses of parietal ERPs found a significant main effect of item type for six of the seven intervals tested [300–600 ms: $F(1,23) = 7.33$; 600–900 ms: $F(1,23) = 5.36$; 900–1200 ms: $F(1,23) = 6.51$; 1200–1500 ms: $F(1,23) = 8.16$; 1800–2100 ms: $F(1,23) = 7.18$; 2400–2700 ms: $F(1,23) = 4.85$]. The main effect of item type was marginally significant during the 1500–1800 ms interval, $F(1,23) = 3.47$, $p = .08$. None of the interactions were significant for the analyses of either the frontal or parietal electrode sites.

2.2.3.4. Revealed false alarms vs. correct rejections. The analysis of item type (FA vs. CR) for revealed items did not reveal any significant main effects nor any significant interactions involving the factor of item type, largest $F = 3.21$, all $p\text{s} > .05$.

To complete the ERP analyses, we compared ERPs elicited by intact and revealed items with the same response. Thus, ERPs elicited by hits were compared to false alarms and in a second comparison correct rejections were compared to misses. None of the analyses for either condition (revealed or intact items) achieved significance at the $\alpha = 0.05$ level.

2.2.4. ERP comparisons between revealed and intact items

One possible explanation for the ERP effects reported earlier is that revealing items introduces a latency jitter that blurs the traditional old/new ERP effects observed on most recognition tests. According to this explanation, revealing items at test introduces more variance in the time that it takes to identify the probes. This variation causes variation in the onset of memory related ERP effects. Therefore, the typical old/new ERP effects are randomly distributed across the epoch, and the jitter would produce the null effects observed for revealed item ERPs.

To address this potential explanation, we compared hits and correct rejections across conditions. If revealing items does, in fact, blur old/new ERP effects, then we expected the ERP amplitudes for intact hits to be more positive than revealed hits. At the very least, we might observe different amplitudes as a function of time.

Table 1 presents the mean ERP amplitudes at the midline electrodes for hits (top half of the table) and correct rejections (bottom half of the table). Examination of the peak amplitudes (indicated in bold type) for hits reveals a pattern that could result from jitter. ERPs elicited in both conditions peaked first at parietal electrodes and later at frontal electrodes. However, intact hit ERPs peaked earlier and appear to be greater than revealed hit ERPs, which is the pattern expected from latency jitter. Although intact correct rejection ERPs show a similar pattern as hits, ERPs for revealed correct rejections peak first at central sites and appear to be greater than intact correct rejection amplitudes. This pattern of results is inconsistent with a jitter explanation. These effects are more clearly observed in Fig. 2 which contrasts intact and revealed ERPs for hits, correct rejections, and false alarms. These descriptive observations were followed with statistical analyses to further explore this alternative argument.

Table 1
Mean ERP amplitudes (μV) at the midline electrodes for intact and revealed items

Time interval	Intact				Revealed			
	Pz	CPz	FCz	Fz	Pz	CPz	FCz	Fz
Hits								
600–900	**5.594**	4.947	1.357	1.091	3.477	3.019	−.282	−.600
900–1200	4.523	**4.954**	3.075	3.067	**4.402**	5.018	4.155	4.485
1200–1500	3.445	4.066	**3.237**	**3.371**	4.399	**5.460**	4.149	4.082
1500–1800	3.45	3.808	3.073	3.055	3.968	5.154	**4.155**	**4.485**
1800–2100	2.264	2.352	1.709	1.835	3.341	4.372	3.205	3.572
2100–2400	1.366	1.181	0.625	0.652	2.865	3.769	2.906	3.074
2400–2700	1.152	0.964	0.567	0.548	1.880	2.386	1.962	2.170
Correct rejections								
600–900	**3.791**	3.118	−.590	−.404	2.741	1.988	−1.274	−1.278
900–1200	3.179	**3.151**	0.432	0.842	4.050	4.271	2.044	2.089
1200–1500	2.344	2.905	**1.271**	**1.695**	4.441	**5.083**	3.426	3.978
1500–1800	1.634	1.959	0.576	1.084	**4.460**	5.010	**3.817**	**4.618**
1800–2100	0.547	0.524	−.554	−.310	3.712	4.458	3.345	4.149
2100–2400	−.099	−.003	−.859	−.544	2.58	3.503	2.522	3.196
2400–2700	−.325	−.089	−1.260	−1.373	1.551	2.155	1.367	1.867

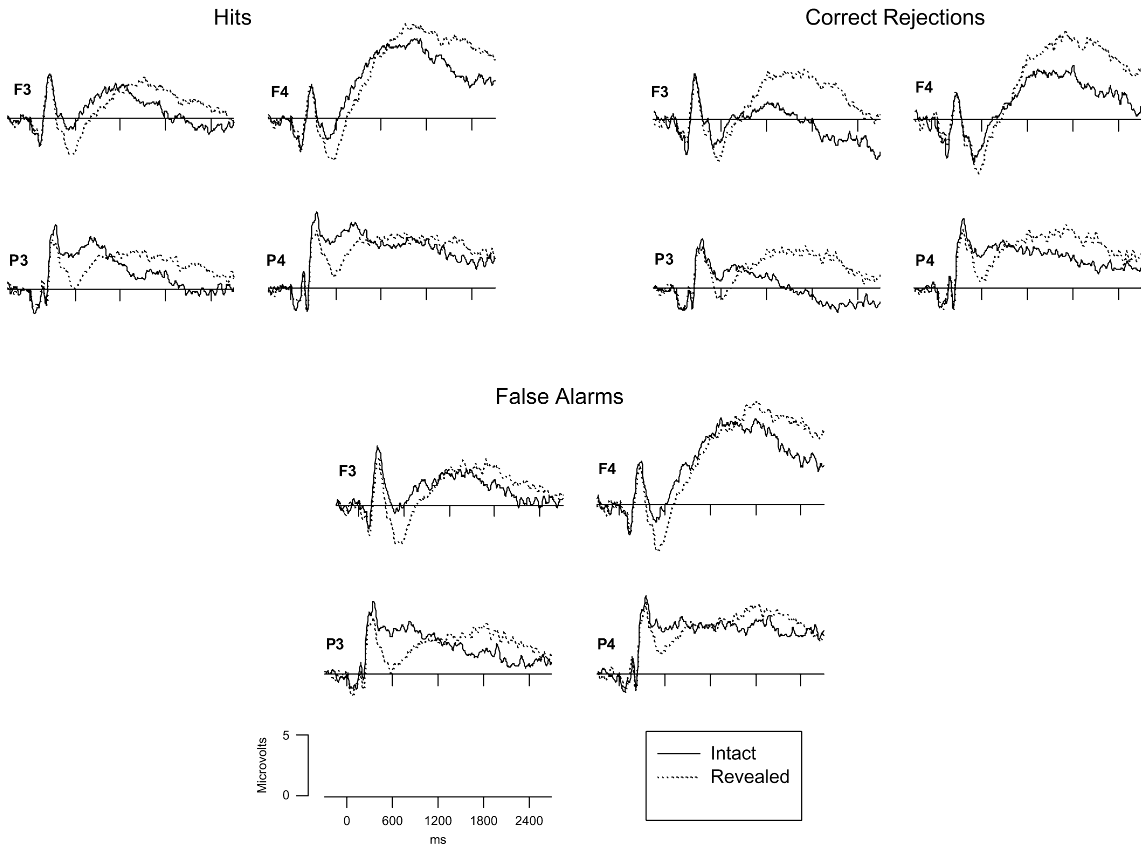

Fig. 2. Experiment 1 grand average ERPs at left and right frontal electrode (F3 and F4) and left and right parietal electrodes (P3 and P4) are plotted for intact (solid line) and revealed items (dotted line). ERPs elicited by hits, correct rejections, and false alarms are displayed in the graphs in the upper left hand, upper right hand, and bottom of the figure, respectively.

2.2.4.1. Intact hits vs. revealed hits. The main effect of Condition (Intact vs. Revealed) was significant for hits during the first two ERP intervals [300–600 ms: $F(1,23) = 10.00$; 600–900 ms: $F(1,23) = 8.55$], which indicated that intact ERPs were reliably more positive than revealed items. Later in the interval, the opposite pattern emerged in that revealed hits were more positive than intact hits [1800–2100 ms: $F(1,23) = 4.73$; 2100–2400 ms: $F(1,23) = 7.33$; 2400–2700 ms, Condition × Site: $F(2.95, 67.85) = 3.01$]. Thus, the hit ERP amplitudes were larger for the intact items, and the peak amplitudes for the revealed condition appear to occur later in the epoch—a pattern which is consistent with the jitter argument.

2.2.5. Intact CR vs. revealed CR

The analyses comparing intact and revealed correct rejections revealed a significant main effect of Condition during the first interval [300–600 ms: $F(1,23) = 5.52$], reflecting the more positive intact ERPs very early. However, revealed ERPs began to be more positive than intact ERPs (indicated by significant main effects of condition) beginning approximately 1200 ms into the epoch and continuing for the duration of the epoch [1200–1500 ms: $F(1,23) = 10.26$; 1500–1800 ms: $F(1,23) = 11.97$; 1800–2100 ms: $F(1,23) = 15.68$; 2100–2400 ms: $F(1,23) = 16.51$; 2400–2700 ms: $F(1,23) = 8.47$]. As a result, these effects do not appear to be a simple case of latency jitter. If that was the case, then revealed correct rejections should elicit smaller amplitudes or simply be shifted back in time, as was the case for hits. Instead, revealed correct rejections elicited more positive amplitudes during the time intervals that typical old/new effects were observed for intact items. Thus, a latency jitter argument simply cannot explain the observed pattern of effects.

2.2.5.1. Intact FAs vs. revealed FAs. One last comparison of interest is the contrast of ERPs elicited by false alarms in both condition. This is an important comparison given the fact that the revelation effect often manifests itself as an increase in false alarms for revealed items (Hicks & Marsh, 1998). As is evident in Fig. 2, the pattern of differences for false alarm ERP data was similar to that observed for hits and correct rejections. Early in the interval, intact items elicited more positive ERP amplitudes than revealed items [300–600 ms: $F(1,23) = 8.87$; 600–900 ms: $F(1,23) = 6.99$]. Later in the epoch, revealed items began to be more positive than intact items [Condition × Site: $F(2.75, 63.25) = 3.49$]. This effect was weaker than that observed in the comparison of hits and correct rejections because the main effect of condition was only marginally significant during the late intervals [1800–2100 ms: $F(1,23) = 3.38$, $p = .079$; 2100–2400 ms: $F(1,23) = 4.05$, $p = .056$].

2.3. Experiment 1 discussion

In Experiment 1, we measured ERPs as people made recognition judgments for intact and revealed items. The behavioral data indicate that our subjects produced the typical revelation effect, and the signal detection measures indicated that the revelation process decreased responder sensitivity and produced a more liberal decision criterion, which is consistent with the effects reported in the revelation effect literature (cf., Hicks & Marsh, 1998).

One of the goals of Experiment 1 was to measure ERPs in a paradigm that used a related task to generate the revelation effect to provide information that would help differentiate among the various theoretical accounts of the revelation effect. Our examination of the more traditional recognition memory ERP effects in the present data indicated that intact items elicited an old/new ERP difference that was not present for the revealed items. At first glance, the absence of old/new ERP effects for revealed items appears to contradict the recognition ERP literature; however, the old/new effect is not always observed (e.g., Jordan & Thomas, 1999; Rugg, Cox, Doyle, & Wells, 1995; Rugg & Doyle, 1992). Our analysis of the behavioral data indicated a robust revelation effect for the lures but not in the targets. We examined the possibility that revealing items only affected lures and their associated ERP activity while not affecting hits by averaging and analyzing ERPs elicited by false alarms. This analysis yielded results similar to the hits and correct rejections comparison. False alarms elicited more positive ERPs than correct rejections in the intact condition regardless of whether the item was old or new (cf., Curran, 2000). These results did not extend to the revealed items because there were no ERP differences among the four types of items in the revealed condition. The absence of ERP differences in the revealed condition resulted from a selective increase in ERPs elicited by the new items. These ERP data indicate that the revelation process caused these items to elicit similar levels of ERP activity regardless of the item's true status. Importantly, the revealed item ERPs appeared to be functionally equivalent to ERPs elicited by intact old items.

Direct comparisons of hits, correct rejections, and false alarms elicited by intact and revealed item ERPs provided additional evidence that the revelation process alters the usual cognitive processing that people engage during a recognition decision. Across all comparisons, we observed two general ERP differences between intact and revealed items. Early in the recording interval (300–600 ms), intact items elicited more positive ERPs than revealed items. Later in the interval, revealed item ERPs were more positive than intact item ERPs. ERP studies of recognition have identified two ERP old/new differences that differ in time and location. Some have suggested that the early (300–500 ms) frontal old/new ERP difference reflects familiarity, whereas recollection is a later (600–900 ms) old/new difference at the parietal sites (Curran, 2000; Mecklinger, 2000). The early ERP effects between revealed and intact items are similar to the familiarity-related difference ("FN400") reported by Curran (1999, 2000). In our experiment, revealed items elicited more negative ERPs than intact items beginning 300 ms after the onset of the test probe at electrodes across the scalp. Assuming that early ERPs reflect the initial assessment of familiarity, this means that revealed items do not elicit the initial feelings of familiarity elicited by intact items. This difference is most likely due to their altered form at test. Instead, it appears that revealing items at test actually serves to *decrease* familiarity (cf., Azimian-Faridani & Wilding, in press; Hicks & Marsh, 1998).

Although the early ERP differences appear to reflect a change in familiarity, ERP differences that occur later in the epoch have been connected to recollection or more elaborate decision processes (see Mecklinger, 2000). In the present study, revealed items elicited more positive ERPs than intact items late in the recording epoch. These results mirror those observed when people identify incomplete line drawings (Cycowicz & Friedman, 1999), and collectively, they suggest that discovering the identity of test probes produces positive ERPs across the scalp. These ERPs are somewhat similar to those elicited by old items on a recognition test; however, the widespread topography suggests that it does not specifically reflect an increase in either familiarity or recollection that produce more localized ERP activity.

Taken together, the ERP data from the Experiment 1 suggest that revealing an item initially decreases familiarity. Later in the course of processing, the revealed items (regardless of item type and decision) elicit similar brain activity (as indicated by the absence of traditional old/new effects). Hicks and Marsh (1998) argued that the revelation process activates a variety of alternative memory traces and this decreases the level of familiarity. This decreased familiarity makes the recognition judgment more difficult because it is now more difficult to distinguish between old and new items. To differentiate between old and new items, people adopt a more liberal decision criterion, increasing the number of "old" responses. Thus, the ERP results of Experiment 1 are entirely consistent with the decrement-to-familiarity account because revealed items caused an initial decrease in familiarity followed by similar levels of brain activation for all item types.

3. Experiment 2

Recently, Verde and Rotello (2004) provided evidence that the revelation effect is not the function of a single cognitive process. More specifically, they found that the revelation effect causes a shift in sensitivity when the revealed items are identical to the test probes. This idea is consistent with the results from Experiment 1, which had people solve anagrams of the test probe before they rendered a recognition judgment. However, Verde and Rotello's evidence indicates that the revelation effect is produced by a shift in response bias when the revealed items are unrelated to the test probe. These observations appear to be inconsistent with another ERP study that used unrelated anagrams to elicit the revelation effect (Azimian-Faridani & Wilding, in press). In that study, Azimian-Faridani and Wilding present evidence that they argued was consistent with the decrement-to-familiarity account.

Therefore, the purpose of Experiment 2 was to measure ERPs using an unrelated task. We used the paradigm developed by Niewiadomski and Hockley (2001) because they found a robust revelation effect for probes that were preceded by a numerical addition problem. This paradigm has the added advantage of generating the revelation effect using a non-verbal task. If Verde and Rotello's hypothesis is correct, then we should observe a different pattern of ERP effects when the task is unrelated to the probe compared to when the task is related to the probe. Alternatively, if we see ERP effects similar to those in Experiment 1, this would be support for the decrement-to-familiarity account.

3.1. Method

3.1.1. Participants

Thirty students from The College of New Jersey (17 males, 13 females), aged 18–22, volunteered in exchange for course credit. In addition, an incentive of $25 was offered to the participant who had the best memory and fastest reaction time among those tested. All participants were right handed (Oldfield, 1971), reported that they had normal or corrected-to-normal vision, and did not have a history of neurological disease.

3.1.2. Apparatus and procedure

The materials and procedures were the same as those used in Experiment 1 with the following exceptions. Items were not revealed at test. Instead, an addition problem immediately preceded half of the test probes. The problems involved adding three digit numbers whose sum did not exceed 999. The software randomly determined the numbers for each participant. This paradigm was pilot tested to ensure that behavioral performance would be similar to that observed in Experiment 1, and this testing indicated that the procedures used in Experiment 1 would need to be altered in order to adapt this paradigm. The addition problems added substantial length to the experiment; therefore, we reduced length of the study and test phases of the experiment. For each participant, the computer randomly selected 170 words from the pool of 400 items to be studied. Half of the targets and half of the lures were then randomly designated as "revealed items" (i.e., preceded by an addition task). This modification resulted in 85 items of each type (i.e., intact targets, intact lures, revealed targets, and revealed lures). The study time was increased from 500 ms in experiment 1 to 3500 ms in the present experiment. These changes created conditions that were adequate for ERP recording and created behavioral responding that was nearly equivalent to that observed in Experiment 1.

3.2. Results

3.2.1. Behavioral response data

The proportion of old items called old (i.e., hits) and new items incorrectly identified as old (i.e., false alarms) as a function of item status (revealed or intact) were analyzed with a 2×2 within-subjects analysis of variance. A significant main effect of item type (hits vs. false alarms) indicated that there were more hits than false alarms ($F(1,29) = 160.87$) and a significant main effect of item status (intact vs. revealed) indicated there were more old responses for revealed items, $F(1,29) = 31.43$. Importantly, these effects were qualified by a significant interaction between item status and item type ($F(1,29) = 9.58$), which indicated that revelation effect was larger for lures than for targets. Post hoc analyses found that the hit rates for revealed targets ($M = .77$, $SD = .15$) were higher than for intact targets ($M = .70$, $SD = .14$; $F(1,29) = 15.83$), and the false alarm rate was higher for revealed lures ($M = .46$, $SD = .17$) than intact lures ($M = .33$, $SD = .13$), $F(1,29) = 36.00$. Thus, the revelation effect was observed for both targets and lures in the present experiment.

Analysis of responder sensitivity (d') indicated that the ability to detect old and new items did not differ between intact ($M = 1.04$, $SD = .46$) and revealed items ($M = 0.96$, $SD = .48$; $F(1,29) = 2.96$, $p = .10$; cf., Verde & Rotello, 2004). The analysis of decision criterion (C) indicated that participants were more liberal when items were revealed ($M = -.36$, $SD = .42$) than when items were presented intact ($M = -.06$, $SD = .33$; $F(1,29) = 29.11$). The analysis of reaction times to correct responses indicated that intact hits ($M = 1220$, $SD = 257$) were identified faster than revealed hits ($M = 1421$, $SD = 357$; $F(1,29) = 34.41$), and intact correct rejections ($M = 1390$, $SD = 309$) were also identified faster than revealed correct rejections ($M = 1743$, $SD = 389$; $F(1,29) = 118.19$).

3.2.2. ERP data

The ERP data were analyzed in the same manner as in Experiment 1, with the following exception. Five amplitude measures were computed as the average activity relative to a 300 ms pre-test word baseline over consecutive 300 ms intervals beginning 300 ms after the onset of the test probe (i.e., 300–600, 600–900, 900–1200, 1200–1500, and 1500–1800 ms). The later intervals were not analyzed in this experiment because the overall response times were faster in this experiment.

3.2.3. Traditional old/new ERP effects

The top of Fig. 3 plots the grand average ERPs for intact and revealed items. ERPs elicited by hits and correct rejections are displayed in the top half of the figure, whereas the bottom of Fig. 3 plots the ERPs elicited by false alarms and misses.

3.2.3.1. Intact hits vs. correct rejections. Hit ERPs were more positive than correct rejection ERPs during the 300–600 ms interval, Item Type: $F(1,29) = 6.36$. During the 900–1200 ms interval a significant Item Type × Electrode Site interaction was also detected, ($F(2.5,72.5) = 6.51$). No significant interactions involving the factor of item type were observed for intact items during any of the intervals.

Post hoc analyses compared ERP amplitudes in the frontal and parietal electrode regions separately. During the 300–600 ms interval, a significant main effect of item type was observed at both

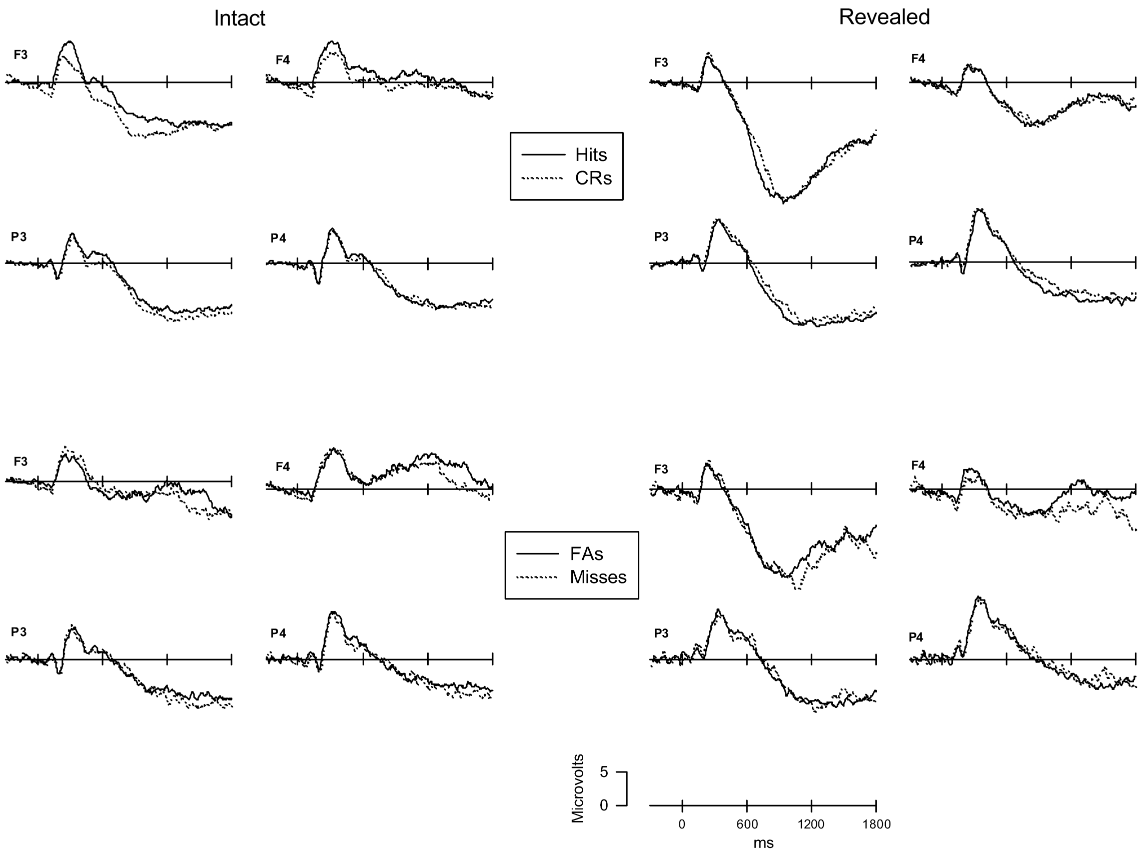

Fig. 3. Experiment 2 grand average ERPs elicited by intact and revealed items are plotted separately. This figure uses the same format as Fig. 1.

frontal ($F(1,29) = 5.17$) and parietal electrodes ($F(1,29) = 7.90$) that indicated hits elicited more positive ERPs than correct rejections. In addition, a significant item type by electrode interaction was observed at parietal electrodes ($F(2.15, 62.35) = 4.23$) that indicated that the old/new ERP difference was larger at left parietal electrode sites. During the 900–1200 ms interval, the item type main effect was only marginally significant at the frontal electrodes, $F(1,29) = 3.81, p = .06$. However, the significant item type by electrode site interaction at parietal electrodes ($F(2.65, 76.85) = 9.39$) indicated that the old/new effect continued to be larger at left parietal electrodes.

3.2.3.2. Revealed hits vs. correct rejections. The analyses revealed significant three-way interactions between Item Type (hit vs. CR), Anterior/Posterior electrode position (frontal vs. parietal), and Electrode Site (left vs. right hemisphere) for the 300–600 ms ($F(4.05, 117.45) = 2.99$) and 600–900 ms intervals, $F(3.4, 98.6) = 3.97$. No other effects were significant. These three-way interactions reflect the tendency for correct rejection ERPs to be slightly more positive than intact ERPs at left frontal electrode sites, whereas there is little difference in the ERPs recorded from the right hemisphere electrode sites. This trend did not reveal any significant differences when post hoc tests were performed; therefore, the effects in the omnibus analysis appear to be the result of very subtle differences rather than a clear difference between hit and correct rejection ERPs.

3.2.3.3. Additional ERP comparisons of intact and revealed words. To be consistent with Experiment 1, several comparisons were analyzed for intact and revealed items separately. More specifically, false alarm ERPs were compared to correct rejections, hit ERPs were compared to false alarms, and correct rejection ERPs were compared to misses. None of these comparisons revealed any significant effects for either intact or revealed items.

3.2.4. ERP comparisons between revealed and intact items

Fig. 4 contrasts intact and revealed ERPs for hits, correct rejections, and false alarms. As in Experiment 1, there are apparent differences between ERPs elicited by intact and revealed items; thus, each comparison was subjected to statistical analyses to further explore the ERP effects observed in this experiment.

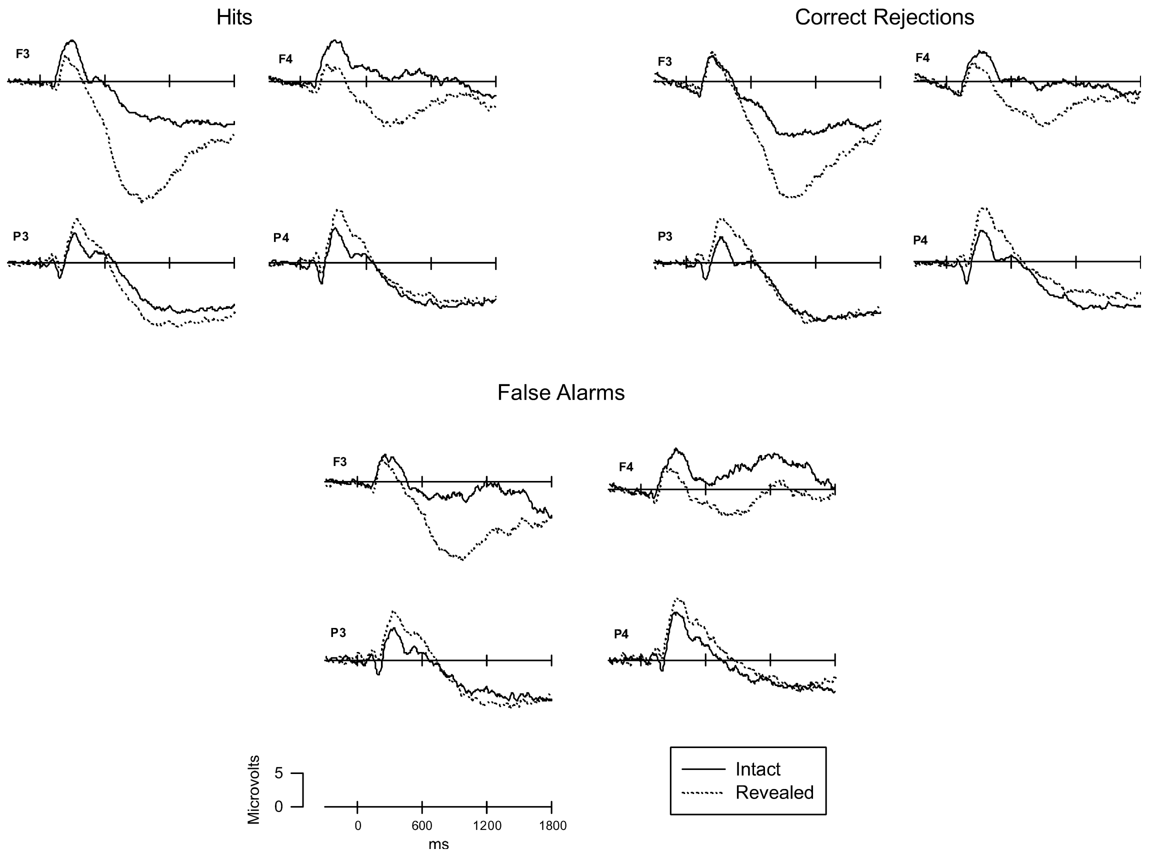

Fig. 4. Experiment 2 grand average ERPs elicited by intact and revealed items are contrasted in the graphs. This figure uses the same format as Fig. 2.

3.2.4.1. Intact hits vs. revealed hits. During the 300–600 ms interval, the condition (Intact vs. Revealed) factor interacted with electrode site positions, Condition × Anterior/Posterior × Site: $F(1.85, 53.65) = 10.16$. The nature of this effect is apparent in Fig. 4 in that intact hits elicited more positive ERPs at frontal electrodes but more negative ERPs at parietal electrodes. During the subsequent intervals, intact hits elicited more positive ERPs than revealed hits as indicated by significant main effects of condition [600–900 ms: $F(1,29) = 12.71$; 900–1200 ms: $F(1,29) = 14.74$; 1200–1500 ms: $F(1,29) = 4.56$]. However, these main effects were accompanied by significant three-way interactions (Condition × Anterior/Posterior × Site) [600–900 ms: $F(2.05, 59.45) = 12.82$; 900–1200 ms: $F(2.75, 79.75) = 6.87$; 1200–1500 ms: $F(3.15, 91.35) = 4.01$], which indicated that that this difference was larger at frontal and left hemisphere electrodes.

3.2.4.2. Intact CR vs. revealed CR. A similar pattern of results was observed for the correct rejections. During the first time interval, intact correct rejection ERPs were more positive at frontal electrodes but more negative ERPs at parietal electrodes than revealed correct rejection ERPs, Condition × Anterior/Posterior × Site: $F(2.9, 84.1) = 9.15$. Intact correct rejections elicited more positive ERPs than revealed correct rejections as indicated by significant main effects of condition for the following two time intervals [600–900 ms: $F(1,29) = 4.55$; 900–1200 ms: $F(1,29) = 4.52$]. However, these main effects were accompanied by significant interactions of electrode position during the 600–900 ms [Condition × Anterior/Posterior, $F(1,29) = 5.09$; Condition × Site: $F(1.75, 50.75) = 4.81$] and 900–1200 ms intervals [Condition × Anterior/Posterior, $F(1,29) = 28.33$; Condition × Site: $F(1.6, 46.4) = 7.62$]. During the last two time intervals, significant interactions involving electrode position were detected for the 1200–1500 ms [Condition × Anterior/Posterior, $F(1,29) = 17.63$; Condition × Site: $F(1.9, 55.1) = 7.33$] and 1500–1800 ms intervals [Condition × Anterior/Posterior, $F(1, 29) = 8.51$; Condition × Site: $F(2.65, 76.85) = 5.58$]. These condition by electrode position interactions indicated that intact correct rejection ERPs were more positive than revealed at frontal and left hemisphere electrodes.

3.2.4.3. Intact FA vs. revealed FA. The pattern of results for false alarm ERPs was similar to that observed for hits and correct rejections. During the first time interval, intact false alarm ERPs were more positive at frontal electrodes but more negative at parietal electrodes than revealed false alarm ERPs, Condition × Anterior/Posterior × Site: $F(2.4, 40.8) = 5.03$. During the 900–1200 ms interval, intact false alarm ERPs were more positive than revealed false alarm ERPs, Condition: $F(1,17) = 6.21$. Significant interactions involving electrode position indicated that this difference was larger at frontal and left hemisphere electrodes Condition × Anterior/Posterior, $F(1,17) = 53.73$; Condition × Site: $F(1.6, 27.2) = 8.58$]. These basic effects persisted during the last two time intervals [1200–1500 ms: Condition × Anterior/Posterior × Site: $F(3.15, 53.55) = 4.85$; 1500–1800 ms: Condition × Anterior/Posterior × Site: $F(3.6, 61.2) = 3.91$].

3.3. Experiment 2 discussion

The purpose of Experiment 2 was to observe the revelation effect and the concomitant changes in ERP activity in a paradigm that utilized an unrelated task to generate the revelation effect. We adopted the paradigm developed by Niewiadomski and Hockley (2001) in which addition problems preceded half of the test probes (i.e., the revealed items). Analysis of the behavioral data indicated a revelation effect for both lures and targets. Responder sensitivity (d') was not affected by the math problems; however, people adopted a more liberal criterion for the items preceded by an addition problem. These behavioral data are entirely consistent with existing studies on the revelation effect (cf., Hicks & Marsh, 1998; Verde & Rotello, 2004).

As with Experiment 1, old/new ERP differences were observed for intact items but not for revealed items. No additional ERP differences were observed from comparisons across different types of items in the revealed and intact conditions. Although this pattern differs from the results of Experiment 1, the recognition ERP literature provides mixed results (when ERPs elicited by errors have been examined) in that sometimes errors elicit similar old/new effects (e.g., Curran, 2000; Finnigan et al., 2002) and other times they do not (e.g., Neville, Kutas, Chesney, & Schmidt, 1986; Wilding & Rugg, 1997).

Three separate analyses contrasted ERPs elicited by hits, correct rejections, and false alarms. These analyses yielded similar results regardless of item type and response. Early in the interval, intact ERPs were more positive than revealed ERPs at frontal electrode sites. The opposite pattern was observed at parietal electrode sites. In subsequent intervals, intact ERPs were more positive than revealed and this difference tended to be larger at frontal and left hemisphere electrodes.

In sum, we observed the same general effects on traditional old/new ERP effects as in Experiment 1. However, direct comparisons of intact and revealed item ERPs presented a different pattern of ERP differences than those observed in Experiment 1.

4. General discussion

Across two experiments, we measured ERPs as people made recognition judgments for intact and "revealed" test probes. Items were revealed in Experiment 1 by presenting the test probe as an anagram that people had to solve before they made a recognition judgment. A numerical addition task was completed prior to judging half of the recognition probes (i.e., revealed items) in Experiment 2. A summary of the basic findings from each of these experiments is presented first followed by a discussion of the implications of these findings for theories of the revelation effect.

4.1. Summary of findings

In Experiment 1, people were more likely to call the revealed items (i.e., anagrams) old as compared with the intact items. A closer analysis indicated that this effect was quite large for the lures but not for the targets. Signal detection measures indicated that the revelation process decreased responder sensitivity and produced a slightly liberal shift in decision criterion. The traditional old/new ERP effects (i.e., old item ERPs are more positive than new item ERPs) were observed for intact items, but these effects were absent for revealed items. Direct ERP comparisons of intact and revealed items indicated that intact items elicited higher levels of familiarity very early in the recording epoch; however, revealed items elicited more positive ERPs later in the epoch. Because the activity of all revealed items was similar, these results appear to be consistent with the decrement-to-familiarity account of the revelation effect (Hicks & Marsh, 1998). In Experiment 2, the revelation effect was detected for both targets and lures. Using numerical addition problems to elicit the revelation effect did not affect responder sensitivity but it did produce a more liberal decision criterion for the revealed items. Examination of traditional old/new ERP effects was consistent with the results of Experiment 1 in that old/new effects were observed for intact but not revealed items. Importantly, comparisons of the ERPs for intact and revealed items uncovered a different pattern of results than those observed in Experiment 1. Although intact items elicited more positive ERPs at frontal electrode sites early in the epoch (consistent with Experiment 1), the opposite pattern was observed at parietal electrode sites where the revealed ERPs were more positive than intact ERPs. Furthermore, intact ERPs were more positive than revealed ERPs for the duration of the epoch, which is the opposite of the effects observed in Experiment 1.

There were a number of similarities across Experiments 1 and 2. First, the old/new ERP effects were observed for intact but not revealed items. Second, comparison of the intact and revealed ERPs produced the same pattern of differences regardless of the type of item contrasted (i.e., hits, correct rejections, and false alarms). These similarities suggest that the pattern of results was not influenced by the fact that the revelation effect was limited to lures in Experiment 1 and was present in targets and lures in Experiment 2. If this had an impact on ERPs, then logic dictates a different pattern of differences for items that show the revelation effect (i.e., lures in Experiment 1) versus items that do not show the revelation effect (i.e., targets in Experiment 1).

4.2. Implications for theories of the revelation effect

Although there are several possible explanations for the revelation effect, a complete theoretical interpretation of the effect has been elusive. Some have argued that discovering the identity of the revealed test probes temporarily increases the feeling of familiarity associated with the test probe (Luo, 1993; Peynircioglu & Teckan, 1993). Despite this contention, Verde and Rotello (2003) have presented ROC curves suggesting that changes in the familiarity of the test probes, by itself, is not sufficient to account for the revelation effect. In contrast, Hicks and Marsh (1998) believe that the revelation process activates alternative memory traces and this decreases the level of familiarity of the test probe (the decrement-to-familiarity account). This decreased familiarity makes the recognition judgment more difficult because the average familiarity values of the studied and non-studied words become more similar. Because this increases the difficulty of distinguishing between old and new words, people adopt a more liberal decision criterion and this increases the number of "old" responses. According to the criterion flux account (Hockley & Niewiadomski, 2001; Niewiadomski & Hockley, 2001) tasks that precede the recognition decision cause people to temporarily become confused about the appropriate decision criteria for the judgment and people become more liberal with their recognition decisions.

Recently, Verde and Rotello (2004) suggested that the revelation effect arises from a confluence of factors. When the revelation task requires people to unscramble and then judge the same item (a related task) a decrease in sensitivity or changes in familiarity produce the revelation effect. However, if the task that precedes the recognition decision is unrelated to the identity of the test probe, then the revelation effect arises solely from a shift in response bias. The goal of these two experiments was to measure ERPs to provide new information that might help differentiate the various theoretical accounts of the revelation effect. Collectively, the results from the two present ERP studies support Verde and Rotello's (2004) argument that the revelation effect is not a singular phenomenon. The results from Experiment 1 demonstrate that the traditional revelation effect paradigm decreased fluency for the revealed items. The change in fluency was accompanied by similar levels of ERP activity for all of the revealed items. Thus, this evidence supports a decrement-to-familiarity account of the revelation effect (Hicks & Marsh, 1998) and suggests that changes in sensitivity produce the revelation effect when revealed items are related to the probe (Verde & Rotello, 2004). However, Experiment 2 indicates that a simple change in fluency does not occur when the task is unrelated to the test probe because different patterns of ERP amplitudes were observed at frontal and parietal electrodes during the time in which familiarity-related ERP effects occur. This conclusion is based on the observation that changes in fluency appear to influence ERP activity that occurs early in the epoch (approximately 300–500 ms after the probe). In Experiment 1, revealed items elicited more negative ERP amplitudes than intact items at frontal and parietal electrode sites early in the epoch, whereas revealed items elicited more positive ERP amplitudes at parietal electrode sites in Experiment 2. As a result, the different patterns of ERP activity early in the epoch between the two experiments favor the interpretation that unrelated tasks are not solely caused by changes in fluency (Verde & Rotello, 2004). Instead, the revelation effect from unrelated tasks might result from a shift in response bias (Niewiadomski & Hockley, 2001). Unfortunately, the conclusion that unrelated tasks produce a shift in response bias cannot be strengthened by a comparison to previous ERP studies that have manipulated decision criterion during recognition because this data is not available. Thus, this claim will need to be reevaluated after direct investigations of decision criterion and recognition-related ERP activity emerge.

Importantly, our data provide a more general context to interpret data from another recent ERP study of the revelation effect (Azimian-Faridani & Wilding, in press). Azimian-Faridani and Wilding presented unrelated anagrams before half of the test probes, and found that revelation decreases familiarity. These results are consistent with Experiment 1 results, but are inconsistent with Verde and Rotello's (2004) argument that unrelated tasks affect decision criterion rather than familiarity. Verde and Rotello noted that related tasks tend to decrease sensitivity, which serves as the basis for their argument that related tasks affect familiarity. In Experiment 1 we found that a related task decreased sensitivity and influenced familiarity-related ERP activity, whereas Experiment 2 presented evidence that an unrelated task does not alter sensitivity and causes ERP differences that cannot be specifically connected to changes in familiarity. Unfortunately, Azimian-Faridani and Wilding did not analyze sensitivity, but d' calculations based upon mean response proportions suggest that their revelation manipulation also decreased sensitivity and affected familiarity-related ERP effects. These observations suggest that the task employed by Azimian-Faridani and Wilding is more akin to a related task than an unrelated task. Perhaps, the verbal nature of the anagram task affected familiarity, whereas unrelated tasks that are non-verbal (e.g., an addition task) tend to influence other recognition factors, such as decision criterion.

As researchers collect more ERP and behavioral data on the revelation effect, we believe that Whittlesea and Williams's discrepancy-attribution hypothesis (Whittlesea & Williams, 2001a, 2001b) might be best suited to explain the various causes of the revelation effect. By their account, as people make recognition judgments, as well as other types of judgments, the discrepancy between how they expect to judge a particular item and how they subjectively experience that item influences their decisions. When an item is processed fluently and people cannot point to any obvious alternative explanation for this fluency, they interpret the surprising feeling of fluency as evidence that they previously encountered the item (called "surprising redintegration" by Whittlesea & Williams, 2001b, p. 27). However, people will attribute the feeling to this other causal agent and subsequently judge the item as new if there is some other plausible explanation for the fluent processing. In addition to this cause of familiarity, Whittlesea and Williams have identified other situations that produce familiarity. For example, the feeling of familiarity can arise when there is a burst of processing fluency in a context that does not appear to create the surprising fluency.

Regarding the revelation effect, the related tasks (as in our Experiment 1) produce familiarity because the probe is initially disguised as an anagram and this produces low levels of fluency. As people solve the anagram, they experience an increase in fluency, which in turn, creates a distinct feeling of familiarity that they attribute to a previous encounter with the item earlier in the experimental session. Unrelated tasks produce the feeling of familiarity via a different process. In this case, the difficult processing in the unrelated task is immediately followed by fluent processing of the probe, and people misattribute the fluent processing to the experience that the stimulus was studied earlier (Whittlesea & Williams, 2001a). Thus, the discrepancy-attribution hypothesis articulates different causes of familiarity that can affect memory judgments. This alternative explanation might explain why the related and unrelated tasks produce different revelation effects and different patterns of ERP activity.

The data from these two experiments demonstrate that ERPs are a useful tool for differentiating the theoretical explanations of the revelation effect. Additionally, these data support the argument that there are distinct kinds of revelation effects. Despite these advances, no single study can answer all the questions. There is a clear need for additional ERP studies of the revelation effect to determine the generality of the findings reported here and to provide additional evidence about how different tasks affect familiarity. The ERP effects observed in Experiment 2 suggest that unrelated tasks produce different revelation effects than related probes. The significance of the ERP effects in Experiment 2 await further clarification from more general studies of recognition memory that examine the influence of decision criteria and sensitivity on ERP activity. For example, these data might indicate that an unrelated task simply causes a liberal shift in decision criterion if studies that directly manipulate decision criteria on recognition tests produce similar results. Alternatively, an unrelated task might cause a temporary loss of criterion setting (Hockley & Niewiadomski, 2001; Niewiadomski & Hockley, 2001) or change the context that is used to evaluate fluency (Whittlesea & Williams, 2001a) and either one of these phenomena might produce the ERP effects observed in Experiment 2. Thus, understanding how these phenomena affect ERP activity can inform our understanding of how unrelated tasks produce the revelation effect.

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