Cogn Affect Behav Neurosci (2014) 14:49–61
DOI 10.3758/s13415-013-0237-8

An attentional-adaptation account of spatial negative priming: Evidence from event-related potentials

Xiaonan L. Liu · Matthew M. Walsh · Lynne M. Reder

Abstract *Negative priming* (NP) refers to a slower response to a target stimulus if it has been previously ignored. To examine theoretical accounts of spatial NP, we recorded behavioral measures and event-related potentials (ERPs) in a target localization task. A target and distractor briefly appeared, and the participant pressed a key corresponding to the target's location. The probability of the distractor appearing in each of four locations varied, whereas the target appeared with equal probabilities in all locations. We found that response times (RTs) were fastest when the prime distractor appeared in its most probable (frequent) location and when the prime target appeared in the location that never contained a distractor. Moreover, NP effects varied as a function of location: They were smallest when targets followed distractors in the frequent distractor location—a finding not predicted by episodic-retrieval or suppression accounts of NP. The ERP results showed that the P2, an ERP component associated with attentional orientation, was smaller in prime displays when the distractor appeared in its frequent location. Moreover, no differences were apparent between negative-prime and control trials in the N2, which is associated with suppression processes, nor in the P3, which is associated with episodic retrieval processes. These results indicate that the spatial NP effect is caused by both short- and long-term adaptation in preferences based on the history of inspecting unsuccessful locations. This article is dedicated to the memory of Edward E. Smith, and we indicate how this study was inspired by his research career.

Keywords Negative priming · Attentional adaptation · ERPs · P2 · N2 · P3

For this article, we used event-related potentials (ERP) to address an issue related to cognitive control: Specifically, how implicitly varied base rates of information in the environment affect covert shifts of attention in a spatial localization task. The work builds on previous research for which the primary dependent measure was response times (RT; Reder, Weber, Shang, & Vanyukov, 2003). The third author's first and most influential advisor, Ed Smith, was a leader in using RT (Smith, 1968), and he had a keen interest in how the human mind selectively processes rapidly presented information. That work on selective attention (Smith, Haviland, Reder, Brownell, & Adams, 1976) was just one of Smith's many research projects addressing cognitive control and selective attention. He remained interested in attention throughout his career, and frequently returned to the question of how do humans come to focus on some features of a stimulus and to ignore others (e.g., Polk, Drake, Jonides, Smith, & Smith, 2008).

One of Smith's many strengths was his tendency to use converging measures to address questions of interest. He did not shy away from challenging existing interpretations and theories and excelled at finding alternative explanations for data sets. He was an early adopter of new methodologies, RT being his first foray into new methods, and neuroimaging being one of his last. This article is written in the spirit of Ed Smith's approach to science: In it, we attempt to discriminate among multiple theories related to the allocation of attention in a spatial localization task, which can be construed as challenging current theories. The arguments rely on different methodologies, the

X. L. Liu · M. M. Walsh · L. M. Reder
Department of Psychology, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA

X. L. Liu · M. M. Walsh · L. M. Reder
Center for the Neural Basis of Cognition, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA

L. M. Reder (✉)
Department of Psychology, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213-3890, USA
e-mail: reder@cmu.edu

first being the methodology that Ed Smith promoted when he was a young academic (RT), and the other being of the class of neuroimaging methods that Ed promoted later in life.

The paradigm that we used to explore theories of selective attention in a spatial localization task involves presenting targets and distractors in an array simultaneously, after which participants must press a key to indicate the location of the target. Performance is degraded when the target is in a position that contained a distractor on the previous display. A number of competing theories have attempted to explain this *negative-priming* (NP) effect. NP refers to a slower response to a target stimulus if it has previously been ignored. In the typical NP paradigm, participants view a prime display followed by a probe display. Both displays contain a distractor, which participants must ignore, and a target, which they must attend to. NP has spawned a large body of research (Fox, 1995; May, Kane, & Hasher, 1995; Neill & Valdes, 1992, 1996; Neill, Valdes, Terry, & Gorfein, 1992; Tipper, 1985; Tipper, Brehaut, & Driver, 1990). The phenomenon has been studied in different experimental paradigms such as letter naming (Tipper & Cranston, 1985), picture naming (Tipper, 1985), and target localization (Neill et al., 1992; Tipper et al., 1990). This article will primarily focus on NP effect in a target localization task. Most research on the spatial NP effect has centered on two theories—the *suppression account* (Banks, Roberts, & Ciranni, 1995; Driver, Mcleod, & Dienes, 1992; Houghton, Tipper, Weaver, & Shore, 1996; Tipper & Cranston, 1985) and the *episodic retrieval account* (Neill & Valdes, 1992; Neill et al., 1992).

The suppression account has been implemented as a neural network model (Houghton & Tipper, 1994; Houghton et al., 1996). When a distractor appears, the activation value of the mental representation of that distractor increases above its baseline level. Distractor activation interferes with target processing. When the external presentation of the distractor is terminated, the internal representation of the distractor is suppressed to a sub-baseline level of activation. These states of inhibition remain when the probe is displayed. Consequently, in a target localization task, responses to targets that occupy the former distractor location are impaired relative to targets that appear in novel locations.

The episodic retrieval account provides a qualitatively different explanation of NP (e.g., Neill, 1997; Neill & Valdes, 1992). Episodic retrieval posits that, as a byproduct of ignoring a distractor stimulus, a tag is associated with the representation of the distracting information. This “ignore me” tag competes with other associated tags (e.g., “attend to me”) when the system needs to decide whether to process a stimulus further. According to Neill, the “ignore me” tag produces maximal interference in NP trials due to its recent occurrence making the tag salient.

Other theories have been offered to account for NP effects. For example, the inhibition of return (IOR) account describes a tendency to inhibit orienting toward visual locations that have been recently attended (Posner & Cohen, 1984). It has also been offered as an explanation for the spatial negative-priming effect (Christie & Klein, 2001). In addition, the feature mismatch account (Park & Kanwisher, 1994) claims that NP occurs because of the mismatch of features between prime and probe displays. The mismatch of features between prime and probe displays requires more time to analyze than when they match, thereby producing NP.

In the standard target localization task, targets and probes appear with equal frequency in each location. The suppression and episodic retrieval accounts have been largely successful in accounting for NP in this task. However, these theories have recently been challenged by a variant of the target localization task in which the probability of the distractor varied by target location (Reder et al., 2003). In addition to replicating the standard NP result (i.e., participants were slower to locate a target that appeared in a location that previously contained a distractor), Reder et al. (2003) found that when the distractor appeared in the location that frequently contained a distractor (frequent location), reaction times (RTs) were shortest. Conversely, when the distractor appeared in the location that infrequently contained a distractor (infrequent location), RTs were longest. More surprisingly, the size of the NP effect (difference of RTs between NP and control trials) was smallest in the frequent distractor location and was greatest in the infrequent distractor location.[1]

According to the logic of episodic retrieval, NP effects should be greatest in locations where distractors dominate. Specifically, the more frequently distractors appear in a location, the more the episodic traces (“tags”) of “no response” are associated with that location. Thus, the more often a distractor appears in a specific location, the stronger that association. A stronger association increases the conflict between the “no response” tag and the requirement to respond to the probe display (containing a target), hence the prediction of a larger NP effect in the frequent distractor location. The results of Reder et al. (2003), however, showed that the size of NP effect was smallest in the frequent distractor location.

Tipper’s original suppression account (1985) stated that NP was a short-term process and consequently, the effect of NP should not depend on the differential probabilities of distractors in different locations. This is because differential probabilities take time to be assimilated and a short-term process would not be sensitive to that. Similarly, according to the feature mismatch account, NP should not vary as a function of distractor probabilities. In order to account for long-term negative priming, this theory was modified to enable memory to store the suppressed episodes (Tipper, 2001). The revised suppression theory seems to make the same

---

[1] The NP effect was not due solely to the difference in RTs for negative-prime trials as compared to the corresponding control trials: The absolute RTs for NP trials showed this pattern as well.

predictions as the Episodic Retrieval Theory—when a distractor appears in a frequent distractor location, this location will be inhibited more strongly and the NP effect will be greatest. Again, this is the opposite of what we observed in several studies. As for the IOR account, studies have shown that IOR can be present at multiple locations and that its magnitude is largest for the location that was examined most recently (e.g., Snyder & Kingstone, 2000). As we discussed in Reder et al. (2003), there was evidence that IOR contributed to the RT pattern, but the data clearly indicated that the attentional adaptation processes were dominant. As we noted there, whether or not IOR is observed may depend on the nature of the task. In our studies, it is clear that although IOR may be able to explain the behavioral data associated with the prime displays, it cannot account for the differential negative-priming effect (see Reder et al., 2003, for a detailed discussion of this point).

More recently, there has been interest in determining whether differential probabilities affect attentional processes (Baker, Olson, & Behrmann, 2004; Druker & Anderson, 2010; Geng & Behrmann, 2002; Hoffmann & Kunde, 1999). These studies have demonstrated that people are sensitive to spatial probability distributions. Targets in frequent target locations are detected more quickly than targets in rare target locations, and targets are detected more slowly when a distractor appears in the location that frequently contains a target (Reder & Weber, 1997; Reder et al., 2003) demonstrating that differential probabilities of distractors in locations also influence attentional processes.

In this article, we test an attentional adaptation account based on the role of spatial probability to explain the NP effect. Given that the allocation of attention among locations is biased by the spatial probability of the distractors, the results of Reder et al. (2003) can be explained in terms of long-term attentional adaptation based on the spatial distributions. The suppression and episodic retrieval accounts tacitly assume that both the target and distractor locations are inspected in parallel and allocation of attention to each location is equivalent. In contrast, we propose that a subject detects the locations of the two stimuli in parallel, but differentially *allocates* attention to each stimulus. This differential allocation of attention affects which location gets more attention. If a target occupies the location that gets the most attention, the response will be fast. Otherwise, the response will be slower.

The history of success and failure of inspection, based on where targets and distractors have previously appeared, affects the tendency to allocate attention to each location. Our theory relates to the attention-based rehearsal hypothesis (Awh & Jonides, 2001; Smith & Jonides, 1998), which states that spatial memory rehearsal is achieved by covert shifts of spatial selective attention to memorized locations. These covert shifts of attention enhance neural signals representing the attended location and/or decrease neural signals representing unattended locations (Postle, Awh, Jonides, Smith, & D'Esposito, 2004). We propose that participants, on the basis of their *actual* history of successes and failures, learn to allocate attention to locations that rarely or never contain a distractor. When the low-frequency distractor location contains a distractor during the prime display, the system is likely to allocate attention to that location. Recent attentional allocation is weighted more heavily (in the short term), thus creating a strong bias to ignore that location should something appear there in the next (probe) display. Conversely, when the frequent distractor location contains a distractor during the prime display, attention is not likely to be drawn there, and thus that location is unlikely to experience a (short-term) failure when the probe display appears. In other words, when distractors appear in the frequent location, participants are biased to ignore them. This minimizes the NP effect because the distractor on the prime display has not been processed.

Using ERPs as a converging measure

It is useful to employ converging methodological techniques to better understand the mechanisms underlying a phenomenon such as NP. ERPs represent a particularly useful tool for studying NP owing to their excellent temporal resolution. Several ERP components are relevant to adjudicating the underlying mechanism of NP. The *P2*, an ERP component that peaks about 200 ms after stimulus onset, is typically elicited by visual stimuli and has primarily been associated with visual search and attention. The *N2* component, which peaks 200–350 ms after stimulus onset, is associated with suppression and conflict monitoring (Eimer, 1993; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). The *P3* component, typically observed between 250–500 ms after stimulus onset, is thought to reflect the degree of effort required to evaluate a stimulus (Donchin & Coles, 1988; Gibbons, Rammsayer, & Stahl, 2006). Several recent ERP studies have enhanced our understanding of NP (Buchner & Naumann, 2006; Gibbons, 2006, 2009; Gibbons & Frings, 2010; Mayr, 2003; Mayr & Buchner, 2006). In the following section, we will describe ERP data used to support the suppression and episodic retrieval accounts of negative priming.

ERP evidence intended to support the suppression account

Although many ERP studies have focused on NP, only a few have examined NP in a spatial localization task. Ruge and Naumann (2006) found that the posterior N2 was larger for NP trials than for control trials. This result is consistent with the suppression account of NP because the N2 is believed to be an index of attentional inhibition (Eimer, 1993; Nieuwenhuis et al., 2003). Likewise, Gibbons (2006) found that the posterior N2 component was larger for NP than control trials, indicating a persisting inhibition of the prime distractor location. In addition, Gibbons (2006) found a larger frontal N2 component that suggested inhibition of the prime response.

Although both studies found a larger N2 in the NP condition, they only compared NP to a control condition. Neither study included a positive priming (PP) condition (trials in which the location of the target on the probe display matches the location of the target on the prime display). Without a comparison with a PP condition, it is difficult to determine whether the N2 component reflects NP, or is merely a differential response to any stimulus that is repeated in a given location from prime to probe display.

ERP evidence intended to support the episodic retrieval account

Support for the episodic retrieval account comes from a different type of NP paradigm. Eriksen and Eriksen (1974) demonstrated NP in a flanker task in which participants had to identify a centrally presented digit that was flanked by two other digits. The flanking digits were identical to one another but different from the target, (e.g., 6–4–6). In the NP condition, the flankers on the prime display served as the target on the subsequent probe display (e.g., 3–6–3). In the control condition, no prime digits were repeated on the probe display. In three ERP studies of NP that used the flanker task (Gibbons, 2006, 2009; Stahl & Gibbons, 2007), the P3 component was smaller for NP and PP trials than for control trials. The critical feature shared by these two conditions is that the probe target is a repeated prime stimulus; in other words, both conditions contain retrieval cues. Therefore, the smaller P3 amplitude was taken as support for the episodic retrieval account, according to which “a smaller P300 reflects a perceived prime–probe similarity which may correspond to a central concept of episodic retrieval theories, i.e., the ‘retrieval cue’” (Gibbons & Frings, 2010, p.340).

Using ERP to resolve the apparent inconsistencies

The ERP data reviewed above seem consistent with two different accounts of NP depending on which paradigm is used. Even though few studies provide direct ERP evidence for either the IOR or feature mismatch accounts, these account also make unique predictions based on the postulated underlying mechanisms. The feature mismatch account would predict a larger P3 amplitude on NP than on PP trials. As we stated earlier, P3 amplitude is thought to reflect the effort to evaluate a stimulus, and more effort is required for NP trials due to the mismatch between prime and probe displays. The IOR account would also predict larger N2 and P3 components for NP trials because participants need to overcome the IOR to return to a spatial location that previously contained an item.

However, as stated earlier, none of these theories can explain the behavioral findings of Reder et al. (2003). The goals of this article are to determine whether the findings of Reder et al. will replicate in a modified ERP version of the experiment, and to test whether the ERP components will support the attentional adaptation account of those behavioral findings.

The adaptation of attention account predicts that P2 amplitudes of prime displays will be smallest when distractors appear in the frequent distractor location. Davis (1964) found that P2 was larger for relevant than irrelevant stimuli. Posner and Rothbart (1998) have proposed a network for visual selective attention that involves both frontal and posterior cortices and may provide a framework for interpreting the cognitive correlates of the P2. The P2 component is thought to reflect automatic stimulus processing that is influenced by early allocation of attention and attentional shifts in processing (Eimer, 1993; Hillyard, Hink, Schwent, & Picton, 1973; Näätänen & Picton, 1987). This component is also associated with the evaluation of task-relevant stimuli (Potts, 2004; Potts, Martin, Burton, & Montague, 2006) and reorientation of attention from nontargets to targets (Ofek & Pratt, 2004). When one of the stimuli appears in the frequent distractor location, attention will not be drawn there because of the prior history of failure (i.e., the stimulus rarely turns out to be the target, invariably a distractor). Therefore, when distractors appear in the frequent distractor location, less attentional-switching and reorientation processes will be involved, as participants are more likely to first look elsewhere to find the target. Unlike other accounts of NP, the attentional adaptation account does not predict differences between NP and control trials for either the N2 or P3 components in probe displays.

In summary, we will vary the probability of the distractor by location in a target localization task. We expect to observe smaller P2 amplitudes when the prime distractor is in the frequent distractor location due to fewer shifts of attention. That is, when the distractor is in the frequent location, attention will likely be drawn to the correct location, thereby obviating the need to shift attention.

Method

Participants

Nineteen right-handed participants (nine males and ten females with a mean age of 21) were recruited from Carnegie Mellon University. All participants had normal or corrected-to-normal vision, and none had a known history of neurological disorder. Each participant received $15.

Written informed consent was obtained from participants prior to the experiment.

Materials and design

For each trial, participants viewed a prime display followed by a probe display. Each display contained four locations, one of which contained a target and one of which contained a distractor. For NP trials, the probe target appeared in the location that previously contained the prime distractor. For PP trials, the probe target appeared in the location that previously contained the prime target. The probe distractor in these trials did not appear in the location that contained the prime distractor. For control trials, the probe target appeared in a location that was previously unoccupied.

The probability of distractors varied across the four locations—0%, 20%, 20%, and 60%—for both prime and probe displays (Fig. 1).[2] The assignment of locations to probabilities was randomly determined for each participant with the constraint that the 0% and 60% probability locations were always on opposite sides of the screen. Targets appeared in each location with equal probability (25%). The absolute numbers (for all displays) of distractors appearing in each location were 510, 170, 170, and 0 for the frequent, medium frequent-side (medium frequency distractor location in the same hemifield as the frequent distractor location), medium never-side (medium frequency distractor location in the same hemifield as the location that never has a distractor), and never locations, respectively. The absolute number of targets was 212 or 213 in each location. The experiment contained 205 control trials, 110 NP trials, and 110 PP trials occurring in random order and determined separately for each participant. In all, 425 trials were presented.

As shown in Fig. 1, the four positions in which targets and distractors appeared formed a V-shape. A horizontal bar was displayed at each location below where a stimulus would appear and remained on the screen at all times. The widest horizontal distance between two positions (the top of the V) measured 45 mm and subtended approximately 5.16º of visual angle. The smallest horizontal distance measured 17 mm (subtending 1.94º), and the vertical distance measured 12 mm (subtending 1.38º). The stimuli (a white O and a white X) subtended 0.4º vertically and 0.22º horizontally. A small white cross (a "+" sign), subtending 0.32º horizontally and vertically, was centered in the middle of the display and served as a fixation point. The background was black.

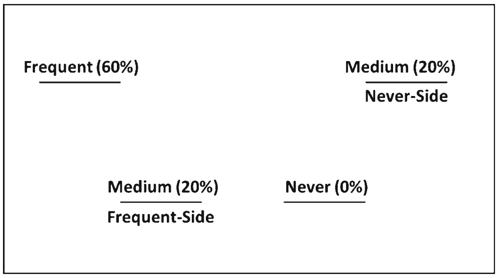

Fig. 1 Probability of the distractor in each location.

Procedure

Participants responded to the location of the target on a computer keyboard using four response keys (D, C, K, and M) that mapped spatially onto the four stimulus locations. This procedure was also used in Reder et al. (2003). The keys were marked with yellow stickers. Participants were instructed to position their left index finger and middle finger on the C and D keys, respectively, and their right index finger and middle finger on the M and K keys, respectively, for all trials. Participants were informed that every display would contain a target (O) present in one of four locations, and a distractor (X) present in one of the remaining three locations. Participants were instructed to respond to the target as quickly and as accurately as possible. At the start of each trial, the word "Ready?" appeared at the center of the screen (Fig. 2). The participant pressed the space bar to continue, and the prompt disappeared. After a delay of 1,500 ms, a fixation cross appeared at the center of the screen for 500 ms, followed by the prime display for 150 ms. The screen turned blank, and the

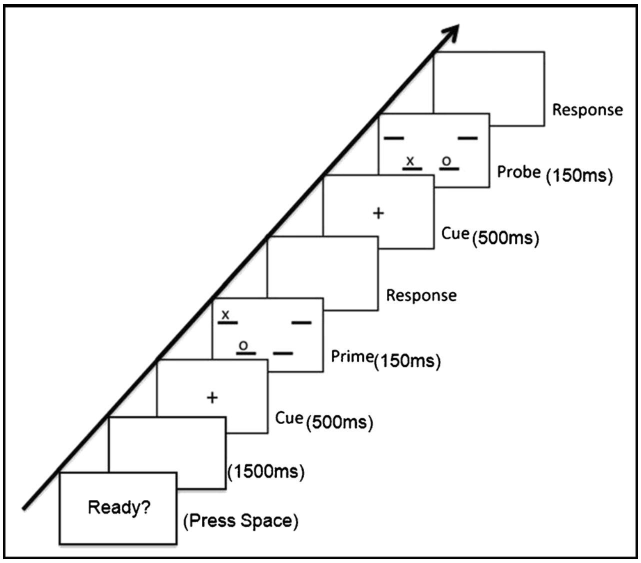

Fig. 2 Trial procedure.

---

[2] The design was modified from that of Reder et al. (2003) in order to address the need for many observations per condition in ERP research. We omitted the rare condition due to insufficient trials. Instead, we included two bilateral medium-frequency locations, one in the same hemifield as the frequent distractor, and the other in the same hemifield as the never distractor location.

participant responded to indicate the target location. Immediately following the participant's response, another fixation cross appeared for 500 ms, followed by the probe display, again for 150 ms. The participant then indicated the location of the target in the second display. After the participant responded, the next trial began.

ERP recording

Participants sat in an electrically shielded booth. Stimuli were presented on a standard CRT monitor situated behind radio-frequency shielded glass. ERP recordings were made using 32 Ag–AgCl sintered electrodes (10–20 system) and a bio-amplification system (Neuroscan Inc., Sterling, VA). Impedances were adjusted to be less than 5 kΩ. Data were sampled at a rate of 1 kHz with a band pass filter of 0.1–200 Hz. Vertical eye movements were recorded using electrodes placed above and below the orbit of the left eye. Horizontal eye movements were monitored with an additional pair of electrodes placed at the external canthi. The right mastoid served as the reference electrode, and scalp recordings were algebraically re-referenced offline to the average of the right and left mastoids.

ERP analysis

The continuous data were segmented from –200 to 1,000 ms relative to trial onset for stimulus-locked analyses, and from –500 to 500 ms for response-locked analyses. Data were corrected for ocular artifacts using a regression analysis (Semlitsch, Anderer, Schuster, & Presslich, 1986). Epochs were baseline corrected over the prestimulus interval for stimulus-locked analyses, and over the entire epoch for response-locked analyses (Luck & Hillyard, 1990). Trials contaminated with voltages above $100\,\mu\text{V}$ or below $-100\,\mu\text{V}$ were excluded from further analyses. The segmented data were then averaged across trials within participants for each condition and smoothed using a 30-Hz low-pass filter. For statistical analyses, 32 electrodes were divided into anterior (F1, FPZ, F2, F7, F3, FZ, F4, F8), central (FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, T8, TP7, CP3, CPZ, CP4, TP8), and posterior (P7, P3, PZ, P4, P8, POZ, O1, OZ, O2) regions. The dependent measures in the ERP analyses were the mean amplitudes of the ERP components in the given time ranges and electrode regions. Amplitudes were compared using repeated measures analyses of variance (ANOVAs) with Electrode Region, Distractor Location, and Trial Type as factors. The Greenhouse–Geisser correction was used when the assumption of sphericity was violated. All post-hoc tests were evaluated with a Bonferroni correction to protect against alpha slippage.

Results

Behavioral results

Prime displays

Effects based on distractor location We first analyzed the effect of distractor location on performance for prime displays. Figure 3 presents the mean RTs for correct responses as a function of distractor location. This graph collapses over the locations of the target for each of the three possible distractor locations.[3] We found a significant effect of distractor location on RTs, $F(2, 36) = 3.45$, $p < .05$, $\eta_p^2 = .16$. RTs were reliably faster when the distractor was in the frequent distractor location than in medium never-side location, $t(18) = 3.03$, $p < .01$, $d = 0.70$, but not when the distractor was in the medium frequent-side location, $t < 1.5$. When the two medium-probability distractor locations were collapsed, RTs were reliably faster when the distractor was in the frequent distractor location, $t(18) = 2.23$, $p < .05$, $d = 0.51$. No significant difference in accuracy emerged for prime displays as a function of distractor location (frequent location, 98%; medium frequent-side location, 98%; medium never-side location, 97%), $F < 2$.

Effects based on target location Although targets were equally probable in all four locations, previous research has demonstrated that the time to identify a target in a given location is strongly affected by the probability of a distractor being shown in that location (Reder et al., 2003). Figure 4 presents the mean RTs for correct responses as a function of target location. The effect of target location was significant, $F(3, 54) = 3.68$, $p < .05$, $\eta_p^2 = .17$, such that RTs were faster when targets appeared in the never distractor location rather than the medium never-side location, $t(18) = 4.05$, $p < .001$, $d = 0.96$. RTs were marginally faster when the target appeared in the medium frequent-side location than when the target appeared in the frequent distractor location, $t(18) = 1.87$, $p < .1$, $d = 0.44$. Participants responded faster to targets when they appeared in the medium frequent-side location rather than the medium never-side location, $t(18) = 2.52$, $p < .05$, $d = 0.60$. No other comparisons for RTs were reliable, and we observed no reliable effects on accuracy (frequent location, 0.98%; medium frequent-side location, 0.96%; medium never-side location, 0.98%; never location, 0.98%), all Fs < 2.0.

Probe displays

Figure 5 presents the mean RTs as a function of trial types. An ANOVA revealed significant effects of trial type on accuracy, $F(2, 36) = 12.72$, $p < .01$, $\eta_p^2 = .41$, and correct RTs, $F(2, 36) =$

---

[3] There are only three locations because distractors could not be in the never distractor location.

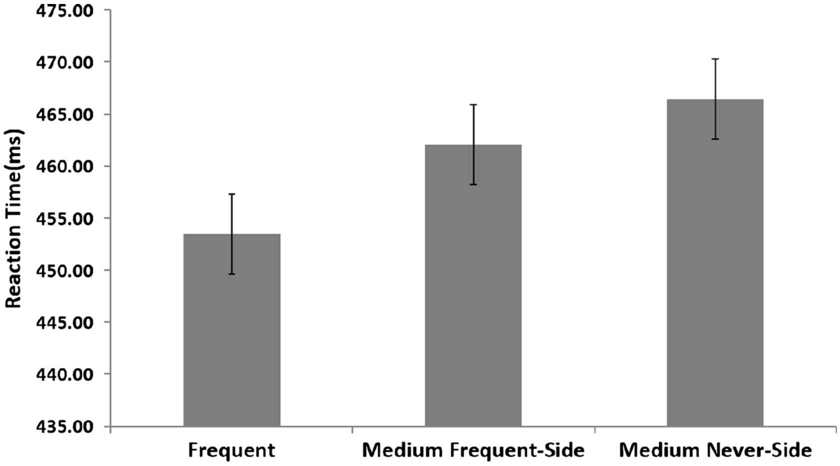

Fig. 3 Mean correct response times (with standard error bars) for prime displays, based on the position of the distractor, collapsed over target locations (note that distractors cannot occur in the *never* location).

24.25, $p < .001$, $\eta_p^2 = .57$: Participants responded more slowly on NP trials than on control trials, $t(18) = 6.30$, $p < .001$, $d = 1.46$, and PP trials, $t(18) = 5.55$, $p < .001$, $d = 1.31$. RTs did not differ between PP and control trials, $t < 1.5$. The accuracy of PP trials (99%) was significantly higher than on NP (96%), $t(18) = 5.50$, $p < .001$, $d = 0.75$, and control (97%), $t(18) = 3.00$, $p < .05$, $d = 0.57$, trials. Accuracy did not vary between NP and control trials, $t < 1.55$.

Next, for each of the three locations that could contain a distractor, we computed the difference in mean correct RTs between NP and control trials for probe displays (NP costs), and we examined these NP costs by distactor location, as is shown in Fig. 6. An ANOVA revealed a significant main effect of location on the size of the NP effect for RTs, $F(2, 36) = 3.26$, $p < .05$, $\eta_p^2 = .153$: NP costs were greater in the medium frequent-side distractor location than for either the frequent distractor location, $t(18) = 2.66$, $p < .05$, $d = 0.58$, or the medium never-side location, $t(18) = 2.13$, $p < .05$, $d = 0.51$.

In order to rule out the possibility that differences in NP costs across locations are driven exclusively by differences in the RTs for control trials, we examined the absolute RTs for NP and controls trials as a function of the target's location. An ANOVA revealed a significant main effect of location on the RTs for control trials, $F(2, 36) = 4.27$, $p < .05$, $\eta_p^2 = .192$. RTs were longer in the medium never-side distractor location than for either the frequent distractor location, $t(18) = 11.82$, $p < .1$, $d = 0.43$, or the medium frequent-side location, $t(18) = 2.43$, $p < .05$, $d = 0.57$. For NP trials, we found a marginally significant effect of location on RTs, $F(2, 36) = 2.63$, $p < .1$, $\eta_p^2 = .127$. Although the effect of target location for NP trials was only marginally significant, the specific contrasts were reliable. The RTs were significantly longer in the medium frequent-side distractor location than in the frequent distractor location, $t(18) = 2.24$, $p < .05$, $d = 0.53$, and the medium never-side distractor location, $t(18) = 2.06$, $p < .05$, $d = 0.46$.

ERP results

Prime displays

Figure 7 presents stimulus-locked waveforms in each region for prime displays based on the location of the distractor, collapsed over the locations of the target. The P2 component was analyzed in the range from 150 to 270 ms. We observed

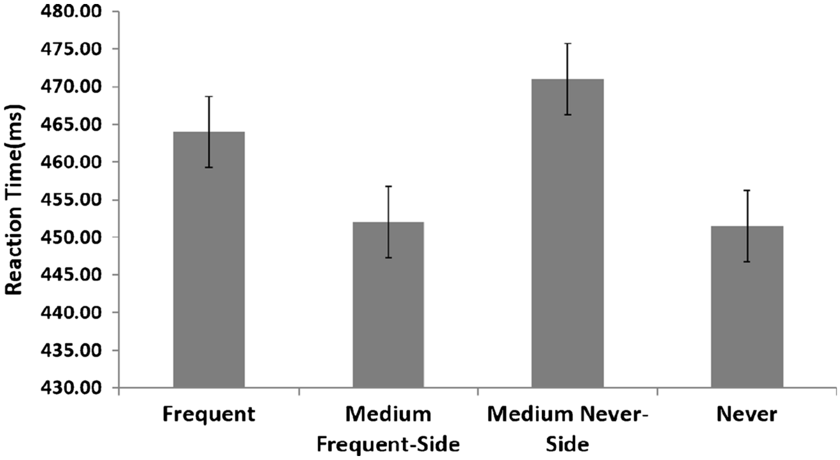

Fig. 4 Mean correct response times (with standard error bars) for prime displays, based on target position (note that position is defined in terms of the frequency of distractors in that location; targets were equally probable in all locations).

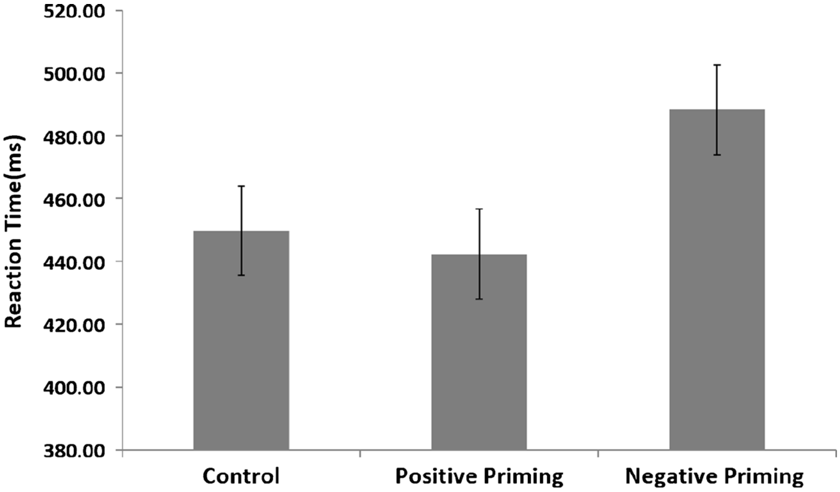

Fig. 5 Mean correct response times (with standard error bars) for probe displays, based on trial type.

significant main effects of distractor location, $F(2, 36) = 12.31$, $p < .001$, $\eta_p^2 = .406$, and electrode region, $F(2, 36) = 20.11$, $p < .001$, $\eta_p^2 = .528$. P2 amplitudes were greater when distractors were in the medium frequent-side location rather than either the frequent, $t(18) = 4.41$, $p < .001$, $d = 1.04$, or the medium never-side, $t(18) = 3.59$, $p < .01$, $d = 0.84$, location.

P2 amplitudes were greater in the anterior region than in either the central region, $t(18) = 4.21$, $p < .01$, $d = 0.99$, or the posterior region, $t(18) = 5.26$, $p < .001$, $d = 1.25$. P2 amplitudes were also greater in the central region than the posterior region, $t(18) = 3.27$, $p < .05$, $d = 0.77$. The interaction between distractor location and electrode region was also significant, $F(4, 72) = 5.37$, $p < .01$, $\eta_p^2 = .23$: Although the effect was present over all regions, it was maximal at anterior sites. The mean amplitudes when distractors were in medium frequent-side locations were significantly (or marginally significantly) higher than when distractors were in the frequent and medium never-side locations. [Anterior region, $t(18) = 4.98$, $p < .001$, $d = 1.77$; $t(18) = 4.23$, $p < .001$, $d = 0.99$; Central region, $t(18) = 4.47$, $p < .001$, $d = 1.06$; $t(18) = 3.49$, $p < .01$, $d = 0.83$; Posterior region, $t(18) = 2.74$, $p < .05$, $d = .64$; $t(18) = 1.99$, $p < .1$, $d = 0.47$].

Probe displays

We analyzed probe displays as a function of trial type. Figure 8 shows the waveforms for probe displays, based on trial types. The N2 component was analyzed in the range from 220 to 310 ms. An ANOVA revealed no effect of trial type, $F < 1$, and no interaction between trial type and electrode region, $F < 2$.

Because the latency of the P3 component appeared to differ by trial type, we analyzed P3 latencies to determine whether a response-locked analysis was justified. The latency of the P3 was defined as the time point at which the P3 reached the peak within the time window between 300 and 500 ms. The repeated measures ANOVA showed an effect of trial type, $F(2, 36) = 9.36$, $p < .001$, $\eta_p^2 = .34$, such that P3 latencies were delayed for NP trials relative to control, $t(18) = 3.89$, $p < .005$, $d = 0.92$, and PP, $t(18) = 3.28$, $p < .05$, $d = 0.77$, trials. We found no reliable difference in peak latencies between control and PP trials, $t < 1.5$.

To reduce the influence of latency differences on P3 amplitudes, we used a response-locked analysis to compare P3 amplitudes among the conditions (Fig. 9). This approach has been used elsewhere when the times to categorize a stimulus

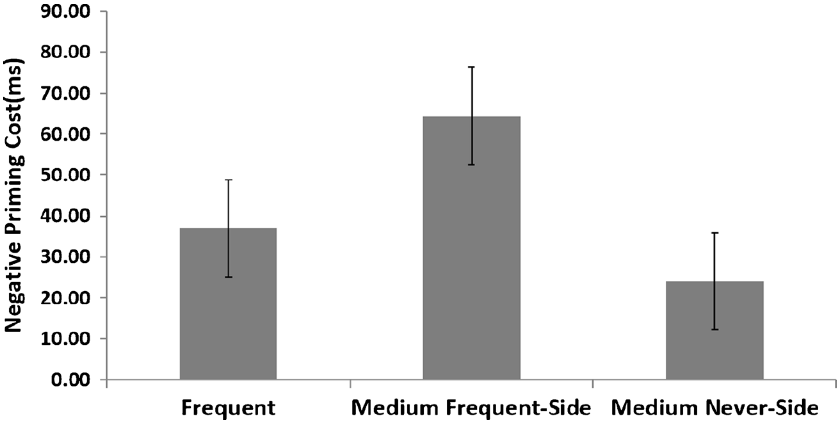

Fig. 6 Negative-priming costs (i.e., the difference in mean correct response times between negative-prime and control trials for probe displays) for each possible location that could contain a distractor.

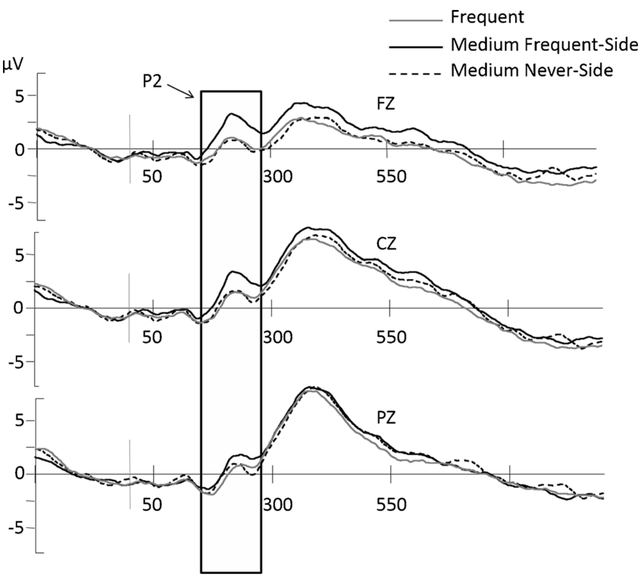

Fig. 7 Event-related potential waveforms for prime displays, based on distractor position.

and to subsequently respond vary among conditions (Luck & Hillyard, 1990). The P3 component was analyzed in the range between –100 and 100 ms (surrounding each response). The main effect of trial type was significant, $F(2, 36) = 6.30$, $p < .005$, $\eta_p^2 = .26$, as was the interaction between trial type and electrode region, $F(4, 72) = 6.66$, $p < .001$, $\eta_p^2 = .27$. P3 amplitudes were significantly larger during PP trials than during control or NP trials in the anterior [control, $t(18) = 4.06, p < .01, d = 0.97$; NP, $t(18) = 3.85, p < .01, d = 0.91$] and central [control, $t(18) = 3.17$, $p < .05$, $d = 0.75$; NP, $t(18) = 3.01, p < .05, d = 0.71$] regions. P3 amplitudes did not vary by trial type over the posterior region, $t < 1$. No reliable difference emerged between NP and control trials, $t < 1$. The results were basically consistent with the patterns that we observed in the stimulus-locked waveforms (Fig. 8).[4]

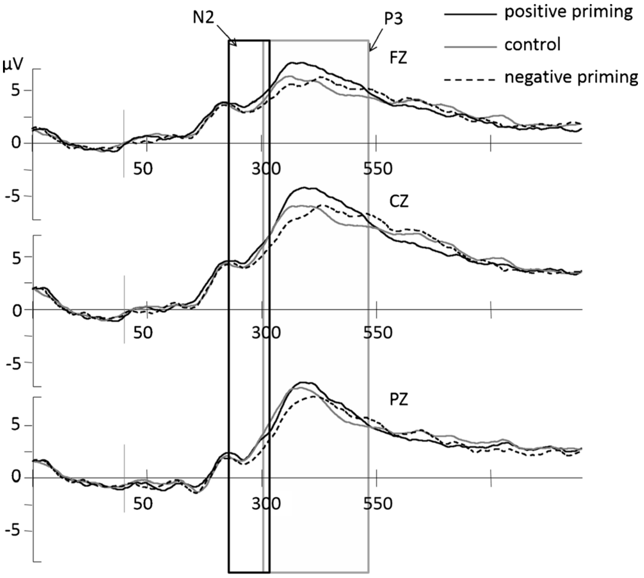

Fig. 8 Stimulus-locked event-related potential waveforms for probe displays, based on different trial types.

We did not find significant differences for either the N2 or P3 when comparing NP with control trials. Given the theoretical importance of these null results, we examined whether these null effects were due to a lack of statistical power by conducting a post hoc power analysis using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009; Faul, Erdfelder, Lang, & Buchner, 2007), with power ($1 - \beta$) set at .80 and $\alpha = .05$. The recommended effect sizes used for this assessment are as follows: small ($\eta_p^2 = .01$), medium ($\eta_p^2 = .06$), and large ($\eta_p^2 = .14$) (Cohen, 1992). The post hoc analyses revealed that the statistical powers for this study were .20 for detecting a small effect, .93 for detecting a medium effect, and .99 for detecting a large effect. Thus, we had more than adequate power (i.e., power = .80) at the moderate to large effect size levels.

Discussion

The goal of this study was to advance a theoretical account of NP using behavioral and ERP measures. It follows from the Attentional Adaptation account that participants learn to allocate attention to locations that are likely to contain targets and less likely to contain distractors. It also follows that prime RTs should be fastest and the P2 component smallest when prime distractors appear in expected locations. Most important, this account predicts that NP costs will be smallest when targets follow distractors in the frequent distractor location. The reason for this prediction is that participants are less likely to allocate attention to the frequent distractor location and thus are also less likely to have processed the distractor in the prime display for those trials. Consistent with these predictions, RTs were fastest and the P2 was smallest when distractors appeared in the frequent distractor location. NP costs, in turn, were smallest when targets followed distractors in the frequent location. Predictions of the suppression and episodic retrieval accounts were not supported in that we failed to find differences between NP and control trials for either the N2 or P3 components.

A tacit assumption in our account is that adaptation occurs on two time scales. The first-order, distractor-location effects, arise from the gradual accumulation of information about the spatial distributions of targets and distractors over trials, whereas the second-order, NP effects, mainly reflect the transient impact of the prime display. Note, a single mechanism that discounted trial history in a negatively accelerated manner could produce adaptation on both time scales (Reder et al., 2003).

---

[4] Although the response-locked waveforms appear to differ from –400 to –200 ms, the effect of trial type was not significant in this time window, $F < 1.5$.

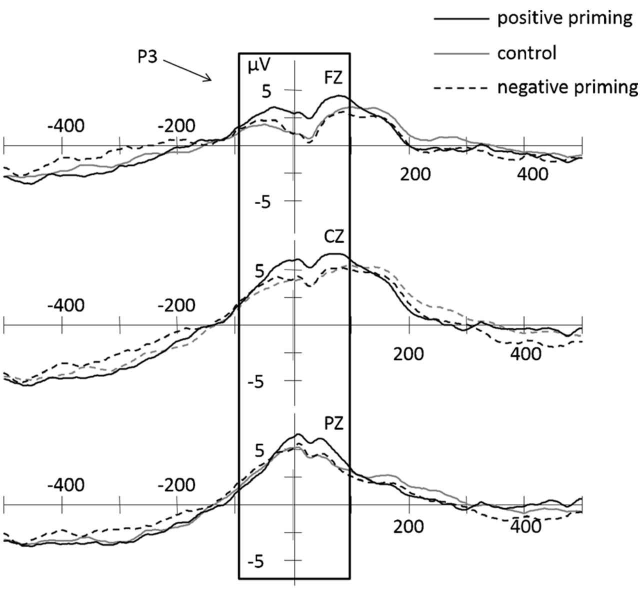

Fig. 9 Response-locked event-related potential waveforms for probe displays, based on trial type.

NP costs in spatial location paradigms are typically quite small, on the average of 20 ms (Neill et al., 1992; Tipper et al., 1990). Our NP effects were much larger, on the order of 70 ms when distractors appeared at the medium frequent-side distractor location. The allocation of attention account explains why we observed comparatively large NP costs (see Reder et al., 2003). In the typical spatial location paradigm, distractors and targets appear with equal frequency in all locations. Without the bias manipulation we employed, participants are equally likely to inspect a target or distractor first because there is no reason to prefer one location to another. When participants inspect the target first on the prime display, no NP effect will emerge for the subsequent probe display. Only when the distractor is examined first on a prime display does a NP effect occur. In our study, when the distractor appeared in a location that frequently contained a distractor, participants were less likely to inspect the distractor first resulting in a smaller negative-priming effect on average. Conversely, when the distractor appeared in locations that less frequently contained a distractor, participants were more likely to inspect the distractor first, resulting in comparatively large NP costs. On the basis of this explanation, it is clear that RTs to locate targets on prime displays should be fast when they appear in the never distractor location, and slow when they appear in the frequent distractor location.[5]

The pattern that begs for an explanation is why targets at the medium frequent location in the same hemifield as the frequent distractor location are detected more quickly than targets at the medium frequent location in the same hemifield as the never distractor location. To understand this pattern of results, consider four distractor/target configurations. First, if the target and distractor are both in the hemifield with the frequent distractor location (35% of all the trials), the subject will inspect the medium location first as it is more likely to contain the target. Thus, RTs will be fast when the target appears in the medium frequent-side location (22.5% of all the trials, 90% of trials when targets were in the medium frequent-side location). Second, if the target and distractor are both in the hemifield with the never distractor location (5% of all the trials, 20% of trials when targets were in the never location), the subject will inspect the never location first as it is certain to contain the target. Thus, RTs will be fast when the target appears in the never distractor location. Third, when the target appears in the medium never-side location (25% of all the trials, 100% of trials when targets were in the medium never-side location), the distractor cannot appear in the same hemifield. Participants will sometimes inspect the wrong hemifield first and will need to re-allocate attention to the other hemifield. Thus, RTs will be slow when the target appears in the medium never-side location. Fourth and finally, when the target appears in the medium frequent-side location and the distractor appears in the medium never-side location (2.5% of all the trials, 10% of trials when targets were in the medium frequent-side location), participants will sometimes inspect the wrong hemifield first. But because these configurations occur infrequently, average RTs remain low when the target appears in the medium frequent-side location.

This account also explains why the negative-prime costs are largest when the distractor appears in the medium frequent-side location on the prime display. Because participants frequently encode the distractor at that location during the prime display, they exhibit strong negative-priming effects when the target subsequently appears at that location. When the distractor appears in the medium never-side location on the prime display, however, participants are unlikely to inspect that location. Because participants rarely encode the distractor at that location during the prime display, they exhibit weaker negative-priming effects when the target subsequently appears at that location.

The ERP data provide converging evidence for this account of the processes engaged in this NP task. For the prime displays, we found that the P2 was reduced when distractors appeared in their frequent location or in the medium never-side location as compared with when distractors appeared in the medium frequent-side location. As we noted in the introduction, the P2 component is considered a signature of attention, orientation, or selective attention (Eimer, 1993; Hillyard et al., 1973; Näätänen & Picton, 1987). This discovery of a reduced P2 when distractors appeared in the frequent location and the medium never-side location is consistent with the proposal that participants were less likely to allocate attention to those locations.

---

[5] This adaptation does not require explicit knowledge: Reder et al. (2003) found that participants were unaware of the distribution of distractors, even though their performance was affected by it.

In contrast to prior studies (Gibbons, 2006; Ruge & Naumann, 2006), and to the predictions of suppression theory, we found that the N2 component did not differ between NP, PP, and control trials. Those studies only compared NP and control trials. As such, it is not possible to determine whether the N2 was induced by NP or simply by the repetition of information at a spatial location.

Importantly, when the experimental design does not bias participants to expect targets to repeat in certain locations, NP effects can be explained in terms of IOR, as stated in the introduction (Christie & Klein, 2001; Milliken, Tipper, Houghton, & Lupiáñez, 2000; Tian, Klein, Satel, Xu, & Yao, 2011; Tipper, Driver, & Weaver, 1991). IOR postulates that attention is less likely to return to locations that were just explored. Therefore, the IOR account might explain the small behavioral positive effect[6] and larger P3 amplitudes for PP trials observed in our study because IOR applies to both distractor and target locations. In previous studies (Gibbons, 2006; Ruge & Naumann, 2006), an N2 may have been evoked because participants needed to overcome IOR to return to a spatial location that previously contained an item. In our task, we did not find a larger N2 for NP trials because IOR is less likely to dominate processes when there is a strong bias in attentional allocation (see the arguments for why in Reder et al., 2003).

Also, in contrast with previous studies (Gibbons, 2006, 2009; Stahl & Gibbons, 2007) and the predictions of the episodic retrieval account, we found that the P3 amplitude was *larger* for PP trials than for NP or control trials. As we reviewed in the introduction, Gibbons found that the P3 was larger for control trials than for NP or PP trials. The P3 effect was taken as support for the episodic retrieval account, as a smaller P3 reflects higher prime-probe similarity. Perhaps the different pattern is due to the fact that Gibbons employed a flanker task. Conceivably, differences in the ERP component structures reflect underlying differences in the mechanisms engaged in the flanker versus the spatial localization task. Our ERP results are also inconsistent with the feature mismatch account. This account predicts larger P3 amplitudes for NP trials than control trials because feature mismatch requires more effort to analyze stimuli, a result that is the opposite of what we found. At the very least, the finding of an enhanced P3 for PP trials is inconsistent with the view that episodic retrieval or feature mismatch produce NP in a spatial localization task.

One possible concern with our ERP results is that we did not observe lateralized ERPs (e.g., N1pc) associated with negative priming (Ruge & Naumann, 2006). This may relate to aspects of our design that precluded certain analyses. That is, given that we varied the probability of distractors by location, certain trial types would have insufficient numbers of trials in some locations when further partitioned by hemisphere. The design we chose was motivated by our primary goal of providing converging evidence for the attentional-adaptation account. Therefore, the most important analysis in our study concerns attention allocation and the processes involved in switching locations. It is unfortunate that one cannot easily address laterality questions of NP when conducting ERP studies that vary base-rates.

To conclude, throughout his career, Ed Smith studied how the human mind selectively processes rapidly presented information. He used converging measures to challenge existing interpretations, and to advance new theories of cognitive control and attention. In much the same way, we used converging measures, reaction times (RTs) and event-related potentials (ERPs), to challenge existing interpretations of negative priming, and to advance a novel account of attentional adaptation. The behavioral results of our study support this account, but are inconsistent with other theories. Likewise, the neural results are in line with this account, but not with other theories. These converging sources of evidence make a compelling case for an attentional adaptation account of negative priming. Finally we note that Ed would not be content to "accept" a theory—and nor are we. The more basic message of this article is that alternate measures and targeted methodological departures from standard paradigms can force re-evaluations of existing theories. By following Ed's example, we can continue to refine ours and others' theories of negative priming.

Author note This work was supported by the National Institute of Mental Health Grant Nos. 5R01MH052808 and T32MH019983. We thank J.T. Bates for programming assistance, K. Halfmann and I. Cutler for help with data collection, and A. Manelis and C. Paynter for comments on previous drafts of the manuscript.

References

Awh, E., & Jonides, J. (2001). Overlapping mechanisms of attention and spatial working memory. *Trends in Cognitive Sciences, 5,* 119–126. doi:10.1016/S1364-6613(00)01593-X

Baker, C. I., Olson, C. R., & Behrmann, M. (2004). Role of attention and perceptual grouping in visual statistical learning. *Psychological Science, 15,* 460–466. doi:10.1111/j.0956-7976.2004.00702.x

Banks, W. P., Roberts, D., & Ciranni, M. (1995). Negative priming in auditory attention. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 1354–1361.

Buchner, A., & Naumann, E. (2006). Brain-electrical correlates of negative priming. *Journal of Psychophysiology, 20,* 157–159.

Christie, J., & Klein, R. M. (2001). Negative priming for spatial location? *Canadian Journal of Experimental Psychology, 55,* 24–38. doi:10.1037/h0087350

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112,* 155–159. doi:10.1037/0033-2909.112.1.155

Davis, H. (1964). Enhancement of evoked cortical potentials in humans related to task requiring decision. *Science, 145,* 182–183.

---

[6] One might have expected faster RTs in PP trials because of the response repetition. Motor savings may have been obscured by the requirement to overcome IOR at those spatial locations, however.

Donchin, E., & Coles, M. G. H. (1988). Is the P3 component a manifestation of context updating? *Behavioral and Brain Sciences, 11,* 357–374.

Driver, J., Mcleod, P., & Dienes, Z. (1992). Motion coherence and conjunction search—Implications for guided search theory. *Perception & Psychophysics, 51,* 79–85.

Druker, M., & Anderson, B. (2010). Spatial probability aids visual stimulus discrimination. *Frontiers in Human Neuroscience, 4,* 63. doi:10.3389/fnhum.2010.00063

Eimer, M. (1993). Effects of attention and stimulus probability on ERPs in a Go/Nogo task. *Biological Psychology, 35,* 123–138.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143–149. doi:10.3758/BF03203267

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41,* 1149–1160. doi:10.3758/BRM.41.4.1149

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175–191. doi:10.3758/BF03193146

Fox, E. (1995). Negative priming from ignored distractors in visual selection—A review. *Psychonomic Bulletin & Review, 2,* 145–173.

Geng, J. J., & Behrmann, M. (2002). Probability cuing of target location facilitates visual search implicitly in normal participants and patients with hemispatial neglect. *Psychological Science, 13,* 520–525.

Gibbons, H. (2006). An event-related potential investigation of varieties of negative priming. *Journal of Psychophysiology, 20,* 170–185.

Gibbons, H. (2009). Functional brain-electrical correlates of negative priming in the flanker task: Evidence for episodic retrieval. *Psychophysiology, 46,* 807–817.

Gibbons, H., & Frings, C. (2010). Flanker negative priming from spatially unpredictable primes: An ERP study. *International Journal of Psychophysiology, 75,* 339–348.

Gibbons, H., Rammsayer, T. H., & Stahl, J. (2006). Multiple sources of positive-and negative-priming effects: An event-related potential study. *Memory & Cognition, 34,* 172–186.

Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in human brain. *Science, 182,* 177–180.

Hoffmann, J., & Kunde, W. (1999). Location-specific target expectancies in visual search. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1127–1141.

Houghton, G., & Tipper, S. P. (1994). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 53–112). San Diego: Academic Press.

Houghton, G., Tipper, S. P., Weaver, B., & Shore, D. I. (1996). Inhibition and interference in selective attention: Some tests of a neural network model. *Visual Cognition, 3,* 119–164.

Luck, S. J., & Hillyard, S. A. (1990). Electrophysiological evidence for parallel and serial processing during visual-search. *Perception & Psychophysics, 48,* 603–617.

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118,* 35–54.

Mayr, S. (2003). ERP correlates of auditory negative priming. *Cognition, 90,* B11–B21.

Mayr, S., & Buchner, A. (2006). Evidence for episodic retrieval of inadequate prime responses in auditory negative priming. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 932–943. doi:10.1037/0096-1523.32.4.932

Milliken, B., Tipper, S. P., Houghton, G., & Lupiáñez, J. (2000). Attending, ignoring, and repetition: On the relation between negative priming and inhibition of return. *Perception & Psychophysics, 62,* 1280–1296. doi:10.3758/BF03212130

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound—A review and an analysis of the component structure. *Psychophysiology, 24,* 375–425.

Neill, W. T. (1997). Episodic retrieval in negative priming and repetition priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 1291–1305. doi:10.1037/0278-7393.23.6.1291

Neill, W. T., & Valdes, L. A. (1992). Persistence of negative priming: Steady state or decay? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 565–576. doi:10.1037/0278-7393.18.3.565

Neill, W. T., & Valdes, L. A. (1996). Facilitatory and inhibitory aspects of attention. In A. F. Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 77–106). Washington, DC: American Psychological Association.

Neill, W. T., Valdes, L. A., Terry, K. M., & Gorfein, D. S. (1992). Persistence of negative priming: 2. Evidence for episodic trace retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 993–1000.

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective, & Behavioral Neuroscience, 3,* 17–26. doi:10.3758/CABN.3.1.17

Ofek, E., & Pratt, H. (2004). Ear advantage and attention: An ERP study of auditory cued attention. *Hearing Research, 189,* 107–118.

Park, J., & Kanwisher, N. (1994). Negative priming for spatial locations: Identity mismatching, not distractor inhibition. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 613–623. doi:10.1037/0096-1523.20.3.613

Polk, T., Drake, R., Jonides, J., Smith, M., & Smith, E. E. (2008). Attention enhances the neural processing of relevant features and suppresses the processing of irrelevant features in humans: A functional magnetic resonance imaging study of the Stroop task. *Journal of Neuroscience, 28,* 13786–13792.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 531–556). Hillsdale: Erlbaum.

Posner, M. I., & Rothbart, M. K. (1998). Attention, self-regulation and consciousness. *Philosophical Transactions of the Royal Society B, 353,* 1915–1927.

Postle, B. R., Awh, E., Jonides, J., Smith, E. E., & D'Esposito, M. (2004). The where and how of attention-based rehearsal in spatial working memory. *Cognitive Brain Research, 20,* 194–205. doi:10.1016/j.cogbrainres.2004.02.008

Potts, G. F. (2004). An ERP index of task relevance evaluation of visual stimuli. *Brain and Cognition, 56,* 5–13.

Potts, G. F., Martin, L. E., Burton, P., & Montague, P. R. (2006). When things are better or worse than expected: the medial frontal cortex and the allocation of processing resources. *Journal of Cognitive Neuroscience, 18,* 1112–1119.

Reder, L.M., & Weber, K.H. (1997, November). *Spatial habituation and expectancy effects in a negative priming paradigm.* Paper presented at the annual meeting of the Psychonomic Society, Philadelphia, PA

Reder, L. M., Weber, K., Shang, J., & Vanyukov, P. M. (2003). The adaptive character of the attentional system: Statistical sensitivity in a target localization task. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 631–649.

Ruge, H., & Naumann, E. (2006). Brain-electrical correlates of negative location priming under sustained and transient attentional context conditions. *Journal of Psychophysiology, 20,* 160–169.

Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artefacts, applied to the P300 ERP. *Psychophysiology, 23,* 695–703. doi:10.1111/j.1469-8986.1986.tb00696.x

Smith, E. E. (1968). Choice reaction time: An analysis of the major theoretical positions. *Psychological Bulletin, 69,* 77–110. doi:10.1037/h0020189

Smith, E. E., Haviland, S. E., Reder, L. M., Brownell, H., & Adams, N. (1976). When preparation fails: Disruptive effects of prior information on perceptual recognition. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 151–161. doi:10.1037/0096-1523.2.2.151

Smith, E. E., & Jonides, J. (1998). Neuroimaging analyses of human working memory. *Proceedings of the National Academy of Sciences, 95,* 12061–12068.

Snyder, J. J., & Kingstone, A. (2000). Inhibition of return and visual search: How many separate loci are inhibited? *Perception & Psychophysics, 62,* 452–458. doi:10.3758/BF03212097

Stahl, J., & Gibbons, H. (2007). Event-related brain potentials support episodic-retrieval explanations of flanker negative priming. *Experimental Brain Research, 181,* 595–606.

Tian, Y., Klein, R. M., Satel, J., Xu, P., & Yao, D. (2011). Electrophysiological explorations of the cause and effect of onhibition of return in a cue–target paradigm. *Brain Topography, 24,* 164–182.

Tipper, S. P. (1985). The negative priming effect—Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology, 37A,* 571–590.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology, 54A,* 321–343.

Tipper, S. P., Brehaut, J. C., & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed action. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 492–504. doi:10.1037/0096-1523.16.3.492

Tipper, S. P., & Cranston, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. *Quarterly Journal of Experimental Psychology, 37A,* 591–611. doi:10.1080/14640748508400921

Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centred inhibition of return of visual attention. *Quarterly Journal of Experimental Psychology, 43A,* 289–298. doi:10.1080/14640749108400971