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Category-based inhibition of focused attention across consecutive trials

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Abstract

The distractor previewing effect (DPE) refers to the behavioral phenomenon that search times increase for oddball targets containing features recently associated with the absence of a target. Previous work using a color-oddball search task showed that the DPE covaried with the N2pc component of the event-related potential (an index of attention allocation) but not with other components, suggesting that the DPE reflects shifts in attentional sets. We sought to determine whether the previous results could generalize to a category-oddball search task. Results showed that the DPE co-occurred with N2pc effects in about 60% of the participants, and the DPE occurred with no N2pc effects in the rest of the participants. These results support a domain-general, attention-based account of the DPE, but also suggest that the attention-based DPE account requires some modifications.

Descriptors: Distractor-previewing effect (DPE), Category-based inhibition, Intertrial effects, Attention shift, N2pc

A growing number of studies suggest that searching a visual scene for a target can be influenced by recent events (e.g., Goolsby & Suzuki, 2002; Maljkovic & Nakayama, 1994, 1996, 2000), such that search times increase or decrease depending on the relationship of target features in the current scene with features shown in a previous scene. The distractor-previewing effect (DPE) is an example of this intertrial effect in visual search (Ariga & Kawahara, 2004; Caddigan & Lleras, 2010; Goolsby, Grabowecky, & Suzuki, 2005; Goolsby & Suzuki, 2002; Levinthal & Lleras, 2008; Lleras, Levinthal, & Kawahara, 2009; Lleras, Kawahara, Wan, & Ariga, 2008; Wan & Lleras, 2010)[1]. The DPE has been observed extensively in color-oddball search tasks: the reaction time (RT) to identify the target is shorter when a current distractor's color has been passively viewed in a preceding target-absent trial (distractor color previewed, or DP) than when the target's color was viewed in the preceding target-absent trial (target color previewed, or TP). However, specific theoretical mechanisms responsible for the DPE remain somewhat unclear.

The DPE and Visual Selective Attention

Previously, Shin, Wan, Fabiani, Gratton, and Lleras (2008) investigated the locus of the DPE in a color-oddball search task using event-related potentials (ERPs, Fabiani, Gratton, & Federmeier, 2007). They measured separate ERP components reflecting different levels of processing and found that the DPE corresponded only with the N2pc component, which has been linked to deployment of selective attention to a target location (Luck & Hillyard, 1994)—that is, target selection in visual space. Thus, Shin et al. concluded that the DPE is closely associated with deployment of selective attention.

In visual search tasks, the N2pc emerges between 200 and 300 ms after a target onset as an increased negativity at posterior electrode sites contralateral (relative to ipsilateral) to the hemifield to which attention was allocated. Thus, it can be isolated by subtracting the potentials between two homologous sites as a function of the target side (i.e., left and right hemifield), and these difference waveforms obtained from each target side are averaged together. Typically, the largest effect is found at an electrode pair PO7 and PO8 (Luck, Girelli, McDermott, & Ford, 1997; Woodman & Luck, 2003), consistent with the reports that the N2pc is primarily generated from the occipitotemporal area (Luck et al., 1997; Hopf et al., 2000; Hopf, Boelmans, Schoenfeld, Heinze, & Luck, 2002). The amplitude of the N2pc is presumed to reflect the extent to which attention is allocated to a target (Luck et al., 1997; Woodman & Luck, 2003), and N2pc onset latency reflects the time at which focused attention is deployed to a target location (Woodman & Luck, 2003).

In Shin et al. (2008), the N2pc rose earlier and was larger in the DP than in the TP condition, presumably due to more and earlier allocation of attention resources to the target in the DP than in the

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1. The DPE may be similar to negative priming (Tipper, 1985) in the sense that both are intertrial repetition effects. However, they differ in that whereas negative priming requires to-be-ignored and to-be-attended items in a visual scene to occur, the DPE does not require this selective attention to occur. Only one item presented in the target-present scene can generate a DPE (Ariga, Lleras, & Kawahara, 2004).

TP condition, suggesting that the DPE occurs due to a shift in attentional set to visual features in the current target-present trial that are not associated with previous search failures (Lleras et al., 2009). In short, when a previous search experience did not result in finding a color-oddball target, the color viewed in the preceding scene is implicitly assessed as a failed feature in the attentional system and tagged negatively in memory, resulting in an attentional bias away from the items containing that feature information in the subsequent trial (Lleras et al., 2009). As a result, behaviorally the DP condition shows a shorter RT than the TP condition.

The DPE in Object- (not Feature-) Based Selection

Extending this logic, the current study investigated whether shifts in attentional set would be observed with objects that can be categorized both perceptually and semantically. This extension of the DPE paradigm from feature-based (e.g., color) to object-based intertrial contingencies is based on the idea that both features and objects can be the unit of attentional selection (Duncan, 1984; Egly, Driver, & Rafal, 1994; He & Nakayama, 1995; Martinez-Trujillo & Treue, 2004; O'Craven, Downing, & Kanwisher, 1999; Schoenfeld et al., 2007; Treisman, 1969). If the DPE is not bound to featural salience of the stimuli (Goolsby et al., 2005) and rather reflects experience-based, trial-by-trial attention shifts, then the DPE also should be observed (i.e., shorter RTs in the DP than in the TP condition) when target-defining features are object based. Moreover, the extent to which this behavioral DPE reflects attentional bias against nonselected, previewed visual information should be evident in the amplitude and onset latency of the N2pc. That is, the N2pc should grow larger and rise earlier at the appearance of a target object whose category was not shown in the previous scene compared with a target whose category was shown in the previous scene.

Object-like stimuli have been used in some previous DPE studies (e.g., Ariga & Kawahara, 2004; Lleras et al., 2009). For example, Ariga and Kawahara (2004) examined whether the DPE occurred at higher perceptual and semantic levels using sex-oddball search tasks and found the presence of a DPE, suggesting that the DPE does occur with objects that can be perceptually discriminated (as same and different) and semantically categorized (as men and women). One complication with this interpretation is that the behavioral response to the sex oddball (e.g., a female face among two faces of the same man) was dictated by the location of a line-bar placed to the left or right side of the target face, not by the target face itself. This additional perceptual feature leads to uncertainty as to the levels of processing that the target face received. It could be that participants selected the sex-oddball target based on the perceptual dissimilarity to the distractor faces, and then responded to the line-bar without determining whether the target was a male or a female face.[2] This possibility makes it difficult to conclude whether the target face was selected due to a simple, configural discrimination of a target from the other faces (i.e., distractors) or to the actual sex difference among the faces. Given the occurrence of the DPE in this study, target selection by perceptual discrimination from distractors may be sufficient for the generation of the DPE.

2. Lleras et al. (2009) also investigated if the DPE occurs in a category oddball and found a significant DPE between the DP and TP conditions. However, they also used a salient feature—a red dot presented close to each stimulus—and asked participants to report the location of this dot, similar to Ariga and Kawahara (2004).

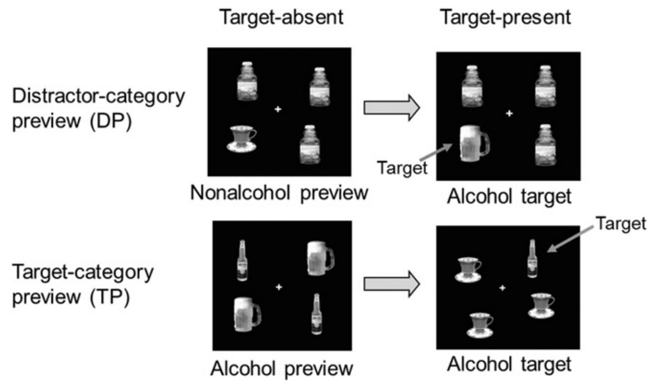

Figure 1. Category-oddball search task. Examples of the target-absent and target-present displays are shown for each trial type. DP represents distractor-category preview. TP represents target-category preview. Although both the target-present displays show alcohol-related pictures as category-oddball targets, the preceding target-absent displays show pictures from different categories. Trial type was determined by whether the target category, not the image per se, was presented in the preceding trial. The hand to use for responding was determined by whether the category-oddball target was an open or closed container.

Object Selection and Categorization in the DPE

The present study used a task in which participants had to both locate and categorize a target object. We investigated both target selection and target categorization (associated with postselection processes) and their relationships, using a novel paradigm. Specifically, grayscale beverage images served as stimuli in the current study. Grayscale was used to eliminate potential differences in color salience (see Goolsby et al., 2005). Beverage pictures were used as stimuli because a beverage is an example of an object category (a) about which people learn perceptual and semantic characteristics throughout their lifetime, and therefore should have strong representations about them; (b) that is very familiar to college student participants; and (c) that can be used in other alcohol research, thereby extending the relevance of the current findings to the alcohol cue-reactivity literature (e.g., Bartholow, Lust, & Tragesser, 2010; Shin, Hopfinger, Lust, Henry, & Bartholow, 2010; Townshend & Duka, 2001). We used beverage stimuli that could be categorized orthogonally according to their relatedness to alcohol (alcohol related or alcohol unrelated) and their container type (closed with a lid or open without a lid). The first of these factors (alcohol relatedness) served as a target-defining category, and the second factor (container type) served as a response-defining category.

Figure 1 shows examples of the DP and TP conditions, differentiated by whether or not the target category was presented in the preceding trial. In the DP condition, the target-absent display shows alcohol-unrelated objects (albeit with perceptual differences among them), followed by the target-present display in which one alcohol-related object (i.e., target) is presented among alcohol-unrelated objects (i.e., distractors). In the TP condition, the target-absent display shows alcohol-related objects (again with perceptual differences among them), followed by the target-present display in which one alcohol-related object (i.e., target) is presented among alcohol-unrelated objects (i.e., distractors). Note that all distractor images in the target-present displays were identical and thus were perceptually separated from the target by dissimilarity (Wertheimer, 1923). Thus, this target selection process was perceptually driven, but the objects between the two consecutive displays were semantically related by the target-defining category (i.e., alcohol or not).

Posterior P1, Anterior P2, and Target Selection

In addition to target selection processes presumed to be reflected in the N2pc, other attention-related processes that might contribute to the DPE were investigated by examining the posterior P1 and anterior P2 components of the ERP. The posterior P1 is a visually evoked positive deflection peaking around 100 ms poststimulus and generated in extrastriate cortex (Di Russo, Martinez, Sereno, Pitzalis, & Hillyard, 2001; Hillyard & Anllo-Vento, 1998). This P1 is typically larger for stimuli shown in attended versus unattended locations (Eimer, 1994; Mangun & Hillyard, 1991), reflecting attention-related sensory gain control, a facilitatory mechanism contributing to the acuity of visual perception (Eimer 1993, 1994). The anterior P2 component, often labeled the frontal selection positivity (FSP, Kenemans, Kok, & Smulders, 1993; Ruijter, De Ruiter, & Snel, 2000; Smid, Jakob, & Heinze, 1999), occurs at 100–300 ms poststimulus and is maximal at frontal scalp locations. The FSP has been discussed in the context of selective attention to specific features (e.g., spatial frequency, color), and is thought to reflect early selection processes. However, given that little currently is known about its neural generator(s) and specific functions, in the current study we decided to use the more descriptive label "anterior P2" instead of FSP.

The P300 and Target Categorization

In the current task, perceptual characteristics of the target images—the container type—were used to force participants to process the targets further. The response-defining category indicated the hand with which participants were to respond. This postselection categorization process was investigated with the parietal P300 component. The P300 is sensitive to task-relevant categorization processes (Donchin, 1981; Fabiani et al., 2007; Kutas, McCarthy, & Donchin, 1977) and correlates with allocation of attentional resources (Donchin, 1981; Isreal, Chesney, Wickens, & Donchin, 1980; Kramer, Wickens, & Donchin, 1983). For example, the amplitude of the P300 elicited by a secondary task decreases as a primary task becomes perceptually more difficult (Donchin, 1981; Isreal et al., 1980; Kramer et al., 1983). According to one prominent theory (Polich, 2007, 2012), these attention-allocation effects on P300 reflects inhibition of extraneous neural activity to facilitate the transmission of information for encoding. Applying this logic to the current paradigm, we predicted that there should be a positive correlation between N2pc and P300 amplitudes because the resources allocated to target selection (shown in the N2pc) are more likely to be shared with or carried over to target categorization (shown in the P300). Furthermore, if this enhanced target categorization facilitates behavioral responses, we might also find that enhanced P300 amplitude is associated with shorter RTs (Verleger, Jaskowski, & Wascher, 2005).

In sum, the present study sought to test whether the DPE can emerge in a category-oddball task using object images that can be perceptually discriminated and semantically categorized. The role of attention allocation to target locations in producing the DPE was investigated using attention-related ERP components. We also investigated how selecting a target from distractors is associated with categorizing the selected target by having participants respond based on target characteristics. These features allow for examination of separate (pre)selection and postselection processes and their relevance in determining the DPE.

Method

Participants

Fifty-eight adults (ages 18 to 30) participated in the study and received either partial credit for an Introductory Psychology course or monetary compensation. Participants reported that they were in good health and had normal or corrected-to-normal vision. Participants also completed the Edinburgh Handedness Inventory (Oldfield, 1971) to determine their handedness; data from one left-handed participant were excluded. Data from a second participant were excluded because of poor task performance (accuracy at chance levels). Thus, the final sample included 56 participants (28 women).

Stimuli and Procedures

As shown in Figure 1, stimuli comprised combinations of four beverage-related images: a beer bottle, a pitcher of beer, a fruit juice bottle, and a teacup on a saucer. These images were rendered to grayscale, label free, and similar in size (subtending $0.5° \times 1.7°$ of visual angle). Target- and response-defining categories were orthogonal in that each image could be grouped by the two categories (e.g., relatedness to alcohol and container type) simultaneously. For example, a beer bottle was categorized as an alcohol-related object and as a closed container.

Participants (seated about 110 cm from the monitor) were asked to respond to category-oddball targets as quickly and accurately as possible by pressing one of two buttons on a response box. The container type of the target indicated the hand to use for responding, which was counterbalanced across participants. Participants were given 1,500 ms to respond. They were asked to fixate on the central fixation cross throughout the experiment and to limit their body movements.

Trial sequences were constructed such that a target-absent display (presented for 300 ms) always preceded a target-present display (presented for 250 ms and followed by a 1,250-ms response interval). An 850-ms interstimulus interval separated the two displays. As shown in Figure 1, target-absent displays consisted of four images whose target-defining category could be entirely alcohol related or unrelated. Because all of these images belonged to one category, there was no category oddball, and thus a response was not required. These four images were presented against a black background, one in each quadrant, with a constraint that at least one of the four images was a different object within the same target-defining category. All images were positioned on an imaginary 2.6° circle (centered on a fixation cross) at fixed locations (45°, 135°, 225°, 315° relative to the vertical meridian). Half of the trials used alcohol-related images; the other half used alcohol-unrelated images.

Target-present displays also consisted of four images, with one (the target) different from the other three according to the target-defining category. These four images also were placed around the imaginary circle, although their locations changed from trial to trial, with the constraint that images were 90° apart and that none fell within 5° of the horizontal and vertical meridians. Due to these location changes, a target could appear in one of 12 possible locations, making its location difficult to predict. The target category, container type, and hemifield of presentation were randomized and occurred with equal probability. A total of 27 40-trial blocks were run (1,080 trials), preceded by a 50-trial practice block.

ERP Recording and Analysis

The electroencephalogram (EEG) was recorded with tin electrodes from 23 scalp locations (modified 10–20 system; see Oostenveld & Praamstra, 2001) using an electrode cap. The right mastoid served as an online reference; an average reference was derived offline. The recording locations included 3 midline sites (Fz, Cz, and Pz), 10 lateral sites to the left of the midline (Fp1, F3, C3, T3, T5, P3, PO5, PO7, O1, and left mastoid), and their homologous sites to the right of the midline. Vertical and horizontal electrooculogram (EOG) was recorded bipolarly. Impedance was kept below 10 kΩ. All signals were amplified with NeuroScan SynAmps2 amplifiers (Compumedics USA, Charlotte, NC). A 0.05–30 Hz band-pass filter was used for all online recordings. EEG and EOG were sampled at 500 Hz, and were epoched starting 200 ms before the presentation of the target-present display and ending 1,400 ms poststimulus.

Blinks were corrected offline using a regression-based procedure (Semlitsch, Anderer, Schuster, & Presslich, 1986). We excluded epochs with horizontal eye movements exceeding ± 25 μV between the 200-ms prestimulus and 500-ms poststimulus within which the N2pc is typically observed. Also, epochs containing scalp and mastoid potentials exceeding 100 μV were excluded from further analyses. Average waveforms were obtained for each participant, electrode, and condition for correct trials only. The N2pc effects were derived by subtracting brain potentials at electrodes ipsilateral to the presentation side of the category-oddball target from the contralateral ones, separately for the DP and TP conditions.

Based on the findings of Shin et al. (2008), we expected the paradigm used in the current study to also elicit N2pc activity across participants. However, initial inspection of the ERP data suggested that a substantial number of the participants (~40%) showed no evidence of an N2pc at all. Some participants' ERPs showed very small negativity or even positivity during the N2pc epoch, and in some cases it was difficult to discern the N2 deflection in the posterior contralateral and ipsilateral waveforms. Thus, to better understand the importance of the attentional selection processes reflected in the N2pc for producing the DPE, we decided to split the sample into two groups on the basis of whether or not their ERPs showed an N2pc component. Including this grouping variable in our analyses permitted better understanding of whether, for example, the DPE can occur in this novel paradigm among participants who show no N2pc, as well as whether other attention-related processes reflected in other ERP components might also be informative concerning the magnitude of the DPE regardless of whether an N2pc is present. The N2pc-present group comprised 33 participants (17 women) who showed visually noticeable N2pc effects (peak amplitudes ≤ –0.4 μV 200–320 ms following onset of the target-present display). The N2pc-absent group comprised 23 participants (11 women) who showed no N2pc effects (peak amplitudes > –0.4 μV in the same time window).

N2pc amplitude was measured as the mean voltage 220–320 ms poststimulus. These means were submitted to one sample *t* tests in order to determine, first, whether the potentials were significantly lateralized from baseline in the DP and TP conditions—that is, whether there was a significant N2pc effect in each category-preview condition. For the category-preview conditions that elicited significant N2pc effects, we tested whether these conditions significantly differed from each other using within-subject *t* tests and repeated measures analyses of variance (ANOVAs). We also measured N2pc onset latencies by estimating the time at which the N2pc exceeded the absolute criterion –0.4 μV[3] for each condition between 200 and 400 ms poststimulus (Kiesel, Miller, Jolicœur, & Brisson, 2008). Statistical tests were performed using a jackknife-based method (Miller, Patterson, & Ulrich, 1998), involving the following steps for this data set: (a) averaging data from all participants except one was repeated by the number of participants, such that each participant was excluded from one of the averages; (b) the mean and standard error of the N2pc latency (assessed by the –0.4 μV criterion) between the DP and the TP conditions were computed; (c) the standard error was multiplied by (not divided by) the square root of the number of participants minus one, which is necessary to correct the redundancy of the individual observations (Miller et al., 1998).

To analyze the posterior P1 component, we obtained mean amplitudes from the posterior electrodes T5, T6, PO7, PO8, PO5, PO6, O1, and O2 between 106 and 154 ms poststimulus centering around the peaks of the component (see the posterior locations indicated by arrows in Figure 2). We then averaged these mean amplitudes separately for the left and the right scalp electrodes and submitted these values to a 2 N2pc Group (N2pc-present, N2pc-absent) × 2 Gender × 2 Hemisphere (left, right) × 2 Category-Preview condition (DP, TP) mixed factorial ANOVA. Unlike other ERP components, our initial assessment of gender effect indicated that gender influenced these measurements. Thus, we included gender in this analysis.

For the analysis of the anterior P2, we obtained mean amplitudes from the three frontal (F3, Fz, and F4) and three central (C3, Cz, and C4) electrode sites between 180 and 250 ms poststimulus (see the anterior locations indicated by the arrows in Figure 2). These measurements were averaged for the frontal and central locations, respectively, and then were submitted to a 2 N2pc Group (N2pc-present, N2pc-absent) × 2 Location (frontal, central) × 2 Category-Preview condition (DP, TP) mixed factorial ANOVA.

The P300 analysis was restricted to the electrode Pz at which the P300 was most evident and was largest. The mean amplitudes of the P300 were measured between 400 and 1,400 ms poststimulus, and these measurements were submitted to a 2 N2pc Group (N2pc-present, N2pc-absent) × 2 Category-Preview condition (DP, TP) mixed factorial ANOVA. In addition, P300 latencies were compared between the two groups, within which the amplitudes from the DP and TP trials were collapsed. The latencies for the N2pc-present and the N2pc-absent group were estimated using the jackknife-based method combined with the relative criterion 50% of peak amplitude in each group (Kiesel et al., 2008) and were tested using a *t* test.

Results

Behavioral Data

RT and Fisher-transformed accuracy rates were submitted to separate 2 N2pc Group (N2pc-present, N2pc-absent) × 2 Category-Preview condition (DP, TP) mixed factorial ANOVAs with repeated measures on the second factor. RTs were significantly shorter for the DP (655 ms) than for the TP trials (662 ms), $F(1,54) = 19.77$,

3. We chose –0.4 μV as a criterion to measure onset latencies because the N2pc-present and N2pc-absent groups have been divided on this value.

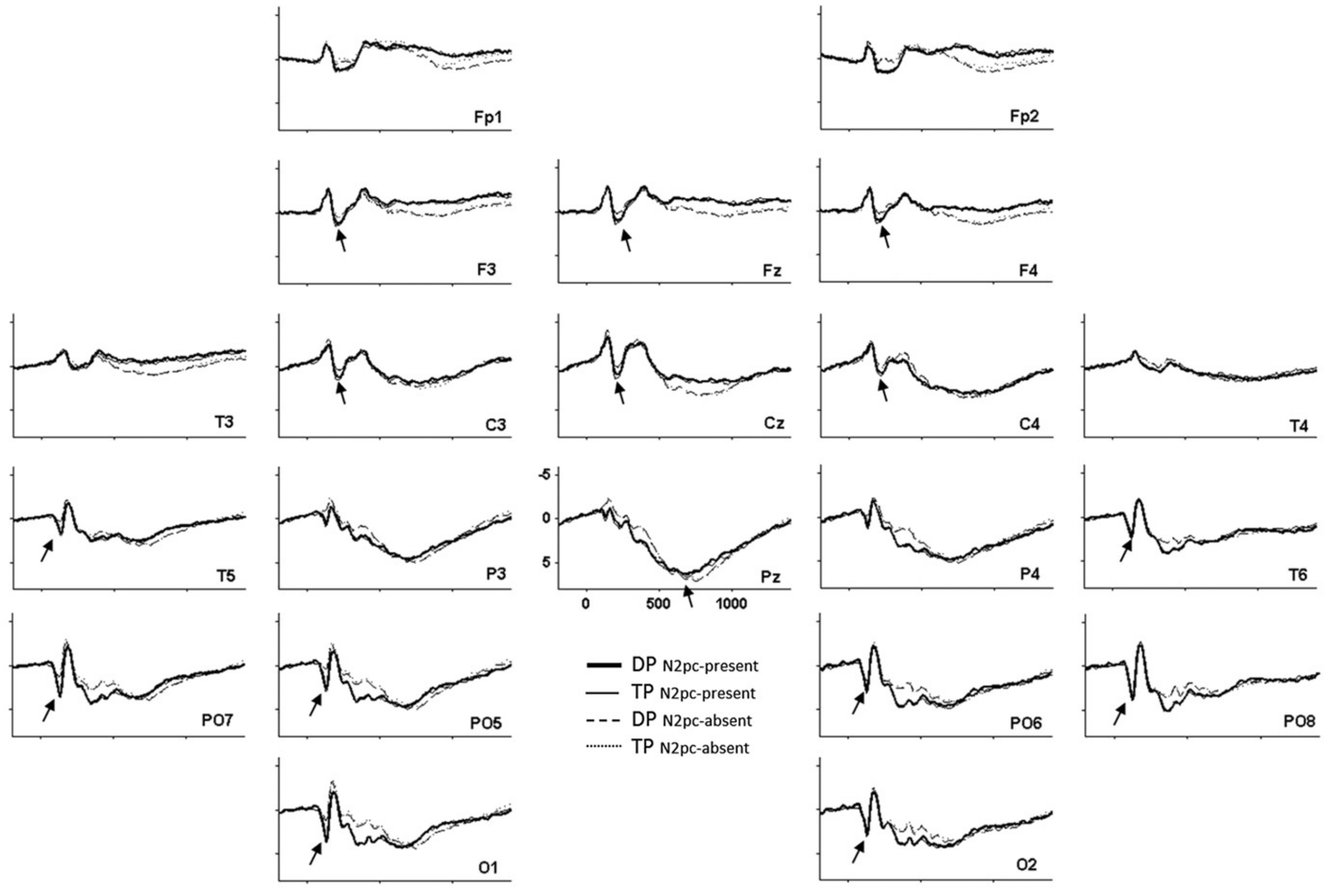

Figure 2. Grand-average ERP waveforms obtained at all scalp locations for the distractor-category previewing (DP) and target-category previewing (TP) trials comparing the N2pc-present and N2pc-absent groups. The arrows indicate the electrode sites that were used for the assessments of the posterior P1 (T5, PO5, PO7, O1, and their homologous locations), anterior P2 (F3, Fz, F4, C3, Cz, C4), P300 (Pz), and N2pc (PO7, PO8) components.

$p < .001$, $\eta_p^2 = 0.27$, and accuracy was significantly higher for the DP (92.3%) than for the TP trials (91.7%), $F(1,52) = 4.69$, $p < .05$, $\eta_p^2 = 0.08$. Neither the group effect nor the interaction was significant for either measure, RT: Fs(1,54) < 1.35, *ns*; accuracy: Fs(1,54) < 0.61, *ns*. Specifically for the N2pc-present group, responses were significantly faster in the DP ($M = 642$ ms) than in the TP condition ($M = 649$ ms), $F(1,32) = 8.87$, $p < .01$, $\eta_p^2 = 0.22$. Accuracy also was significantly higher in the DP condition (92.3%) than in the TP condition (91.5%), $F(1,32) = 5.40$, $p < .05$, $\eta_p^2 = 0.14$. Participants in the N2pc-absent group also responded more quickly in the DP ($M = 674$ ms) than in the TP condition ($M = 682$ ms), $F(1,21) = 12.15$, $p < .01$, $\eta_p^2 = 0.36$. However, their accuracy rates did not differ significantly between the two conditions, $F(1,21) = 0.79$, *ns*. Note that our initial assessment of gender effect did not yield any significant results in the behavioral data (all Fs < 3.84, *ns*), and therefore gender was excluded in the main analyses.

N2pc

The largest N2pc was observed at the electrode pair PO7 and PO8, consistent with previous work (Luck et al., 1997; Shin et al., 2008). Thus, analyses were restricted to this electrode pair (e.g., Akyürek, Dinkelbach, Schubö, & Müller, 2010; Woodman & Luck, 2003). Figure 3 shows N2pc effects in the two groups, including both the contralateral/ipsilateral grand average and the difference waveforms obtained in the DP and TP conditions averaged across the PO7/PO8 electrode pair. Figure 4 shows the differences in N2pc amplitudes between the two conditions for the N2pc-absent and N2pc-present groups. The data depicted in Figure 4 were submitted to a 2 N2pc Group × 2 Category-Preview condition mixed ANOVA. Unsurprisingly, the N2pc was significantly larger in the N2pc-present group ($M = -0.76$ µV) than in the N2pc-absent group ($M = 0.16$ µV), $F(1,54) = 80.56$, $p < .001$, $\eta_p^2 = 0.60$. Also, there was a marginally significant Group × Category-Preview interaction, $F(1,54) = 3.92$, $p = .053$, $\eta_p^2 = 0.07$, which resulted from a larger difference between the DP and TP conditions in the N2pc-present group ($M = -0.51$ µV) compared to the N2pc-absent group ($M = 0.01$ µV).

Within the N2pc-present group, the N2pc was significantly different from baseline for the DP (−1.01 µV; $t(32) = -7.73$, $p < .001$; Cohen's $d = 1.35$) and TP (−0.50 µV; $t(32) = -5.28$, $p < .001$; Cohen's $d = 0.92$) trials, indicating the presence of the N2pc in both conditions. However, the N2pc was significantly larger, $t(32) = 2.74$, $p < .01$; Cohen's $d = 0.79$, and rose reliably earlier, $t(32) = 4.15$, $p < .01$; Cohen's $d = 0.58$, in the DP (210 ms) than in the TP (258 ms) condition, indicating that attention was differentially deployed to the category-oddball target depending upon which category was previewed in the preceding target-absent display. For those in the N2pc-absent group, N2pc amplitudes did

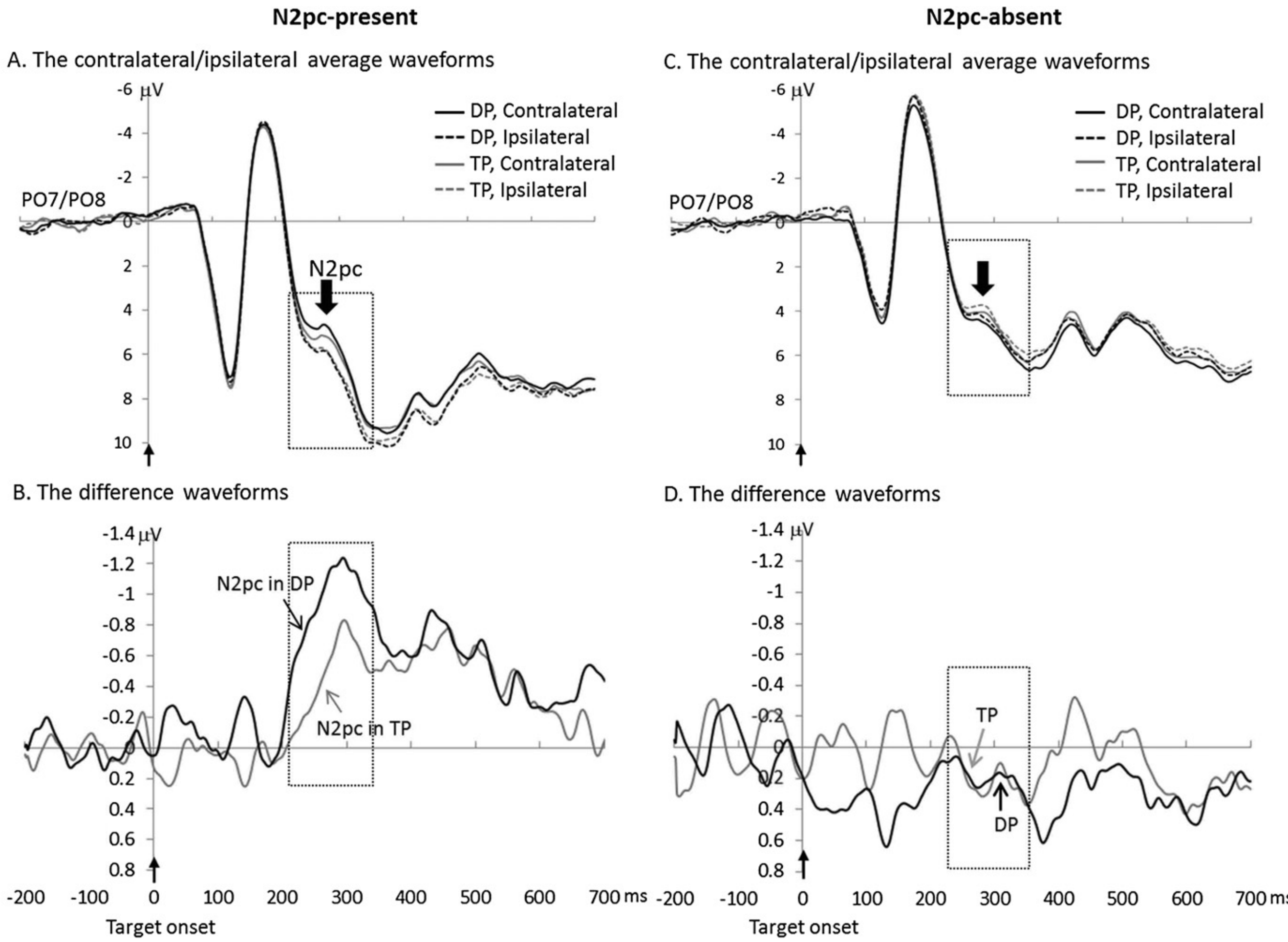

Figure 3. A: The N2pc-present group's contralateral/ipsilateral averaged waveforms measured at the temporooccipital sites (PO7/PO8). B: The N2pc-present group's difference waveforms at PO7/PO8. C: The N2pc-absent group's contralateral/ipsilateral averaged waveforms measured at PO7/PO8. D: The N2pc-absent group's difference waveforms at PO7/PO8. Note that DP and TP represent the distractor-category and target-category previewing conditions, respectively. Also, the N2pc waveforms resulting from differences between the contralateral and the ipsilateral waveforms in each condition are shown in the lower panel. The dotted rectangles indicate the time windows in which the N2pc is typically observed.

not differ significantly from baseline, 0.16 μV for the DP and 0.15 μV for the TP, $ts(22) < 1.65$, *ns*. Main effects and interactions involving gender were not significant (Fs < 1).

Posterior P1

As indicated in Figure 5, the amplitude of the posterior P1 (indicated by the shaded areas) was larger overall in the N2pc-present group compared to the N2pc-absent group, $F(1,52) = 4.06$, $p < .05$, $\eta_p^2 = 0.07$. This effect was particularly pronounced at left hemisphere electrodes, as indicated by a significant Group × Hemisphere interaction, $F(1,52) = 5.78$, $p < .05$, $\eta_p^2 = 0.10$. The posterior P1 was also larger overall on the left compared to the right, $F(1,52) = 4.27$, $p < .05$, $\eta_p^2 = 0.08$. The analysis also showed a significant Category-Preview × Gender interaction, $F(1,52) = 5.42$, $p < .05$, $\eta_p^2 = 0.09$. However, this effect is irrelevant to current predictions and therefore will not be discussed.

Anterior P2

Figure 6 shows grand average waveforms for the two groups and category-preview conditions as measured at anterior electrode

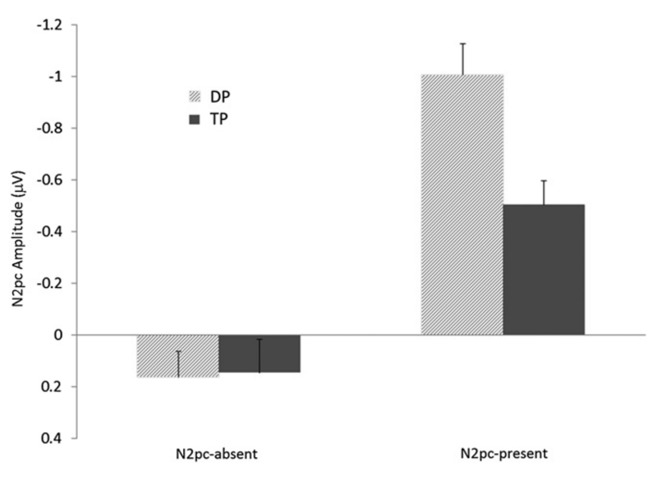

Figure 4. Mean amplitudes of the N2pc obtained at PO7/PO8 between 200 and 320 ms poststimulus between the distractor-category previewing (DP) and target-category previewing (TP) conditions in the N2pc-absent and the N2pc-present group. Note that negative values are plotted up as ERP waveforms are displayed in this paper. The error bars represent standard errors.

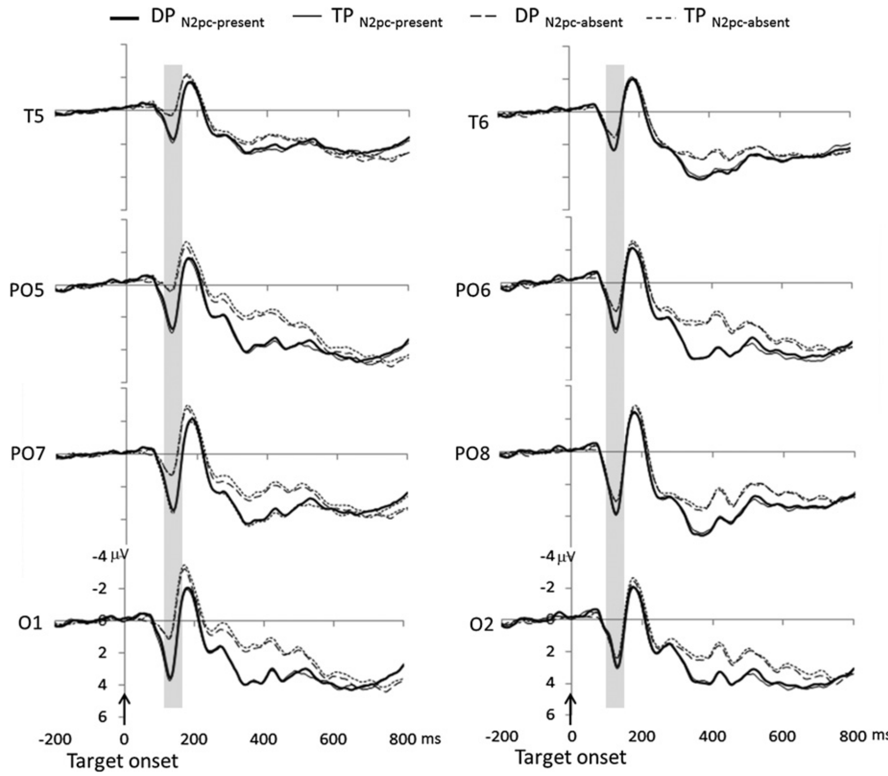

Figure 5. Enlarged grand-average waveforms at the posterior electrode sites. The shaded areas indicate the time window (106–154 ms) at which the posterior P1 effect was analyzed. DP represents distractor-category preview. TP represents target-category preview.

sites. The time window of the anterior P2 component, reflecting initial attention selection, is indicated by the shaded areas. The ANOVA on the anterior P2 amplitudes measured at these locations indicated significant main effects of category-preview condition, $F(1,54) = 33.43$, $p < .001$, $\eta_p^2 = 0.38$, and group, $F(1,54) = 12.37$, $p < .001$, $\eta_p^2 = 0.19$, which were qualified by a significant Category-Preview condition × Group interaction, $F(1,54) = 34.47$, $p < .001$, $\eta_p^2 = 0.39$. Evidently, this significant interaction was driven by the presence of larger anterior P2 amplitude in the TP than the DP conditions for the N2pc- present group, whereas anterior P2 amplitudes in the TP and DP conditions were indistinguishable in the N2pc-absent group. The anterior P2 was larger at frontal

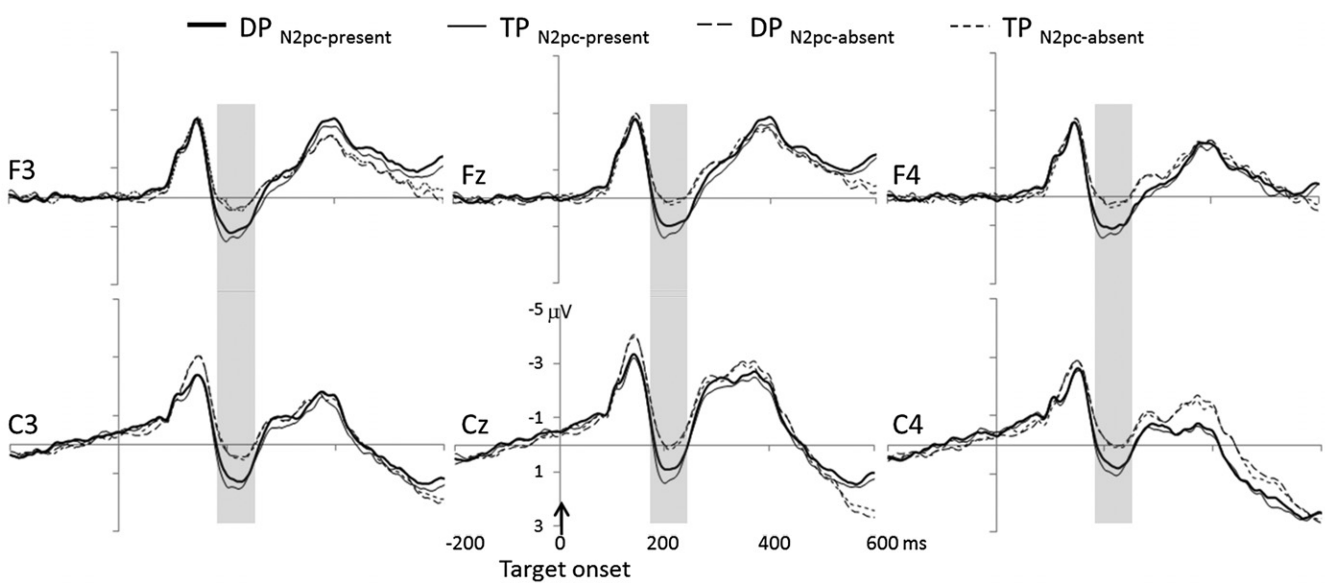

Figure 6. Enlarged grand-average waveforms at the frontal and central electrode sites. The shaded areas indicate the time window (180–250 ms) at which the anterior P2 effect was analyzed. DP represents distractor-category preview. TP represents target-category preview.

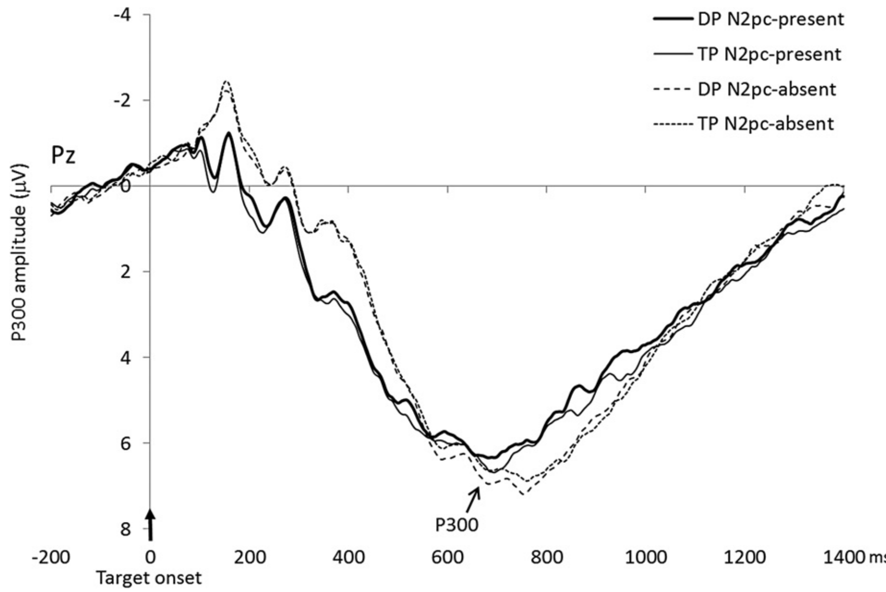

Figure 7. Enlarged grand-average waveforms at the Pz location. DP represents distractor-category preview. TP represents target-category preview.

than at central electrodes, as indicated by a significant main effect of location, $F(1,54) = 15.42$, $p < .001$, $\eta_p^2 = 0.22$.

P300

Figure 7 displays enlarged grand average waveforms at Pz. As is evident in Figure 7, the DP and TP conditions did not differ significantly in either group (*t*s < 1.11, *ns*), and the groups did not differ from each other, $F(1,54) = 0.29$, *ns*. The P300 appeared to peak earlier for those in the N2pc-present group than those in the N2pc-absent group (peak latencies 694 ms and 756 ms, respectively), but this difference was not significant, $t(54) = 0.27$, *ns*.

We hypothesized that the more attentional resources allocated to target categorization, the more target processing might be facilitated, which in turn led us to expect that larger P300 amplitudes would be associated with shorter RTs. Consistent with this prediction, P300 amplitude and RT were significantly negatively correlated, $r = -0.29$, $p = .05$. Moreover, as shown in Figure 8, this association was much stronger in the N2pc-present group ($r = -0.44$, $p < .05$) than in the N2pc-absent group ($r = -0.05$, *ns*), implying that posttarget selection processing was facilitated in the N2pc-present group, but not in the N2pc-absent group. However, despite the apparent group difference in the magnitude of this association, Fisher's z test analysis indicated that the correlation was not significantly larger in the N2pc-present group ($z = -1.42$, $p = .07$, one-tailed).

Discussion

The attention-based account of the DPE (Lleras et al., 2008, 2009) suggests that differential selection of attention between the DP and TP conditions occurring for the target is an important factor in producing the DPE. The current study expanded units of attentional selection from features to objects (Duncan, 1984; Egly et al., 1994; He & Nakayama, 1995; Martinez-Trujillo & Treue, 2004; O'Craven et al., 1999; Schoenfeld et al., 2007; Treisman, 1969) and investigated whether the DPE occurs in a category-oddball search task in which perceptual salience via color was excluded. We also examined both target-selection processes, reflected in the posterior P1 and anterior P2 components and the N2pc, and subsequent postselection processes as reflected in the later P300 component, to provide broader coverage of attention-related processes that might contribute to the DPE.

The current study introduced an oddball task different from those used in previous studies. In the current task, the base of attentional selection was an object (truly an ordinary object that people learn through their lifetime), not a feature, and target categorization had to follow target selection. With this task, we found (a) that the DPE occurred even when no featural salience is involved; (b) that the DPE occurred at an object-categorization level; and (c) that the DPE did not always correspond with the N2pc effect.

Overall, the size of the behavioral DPE effect in the current study was smaller than those reported in previous studies (e.g.,

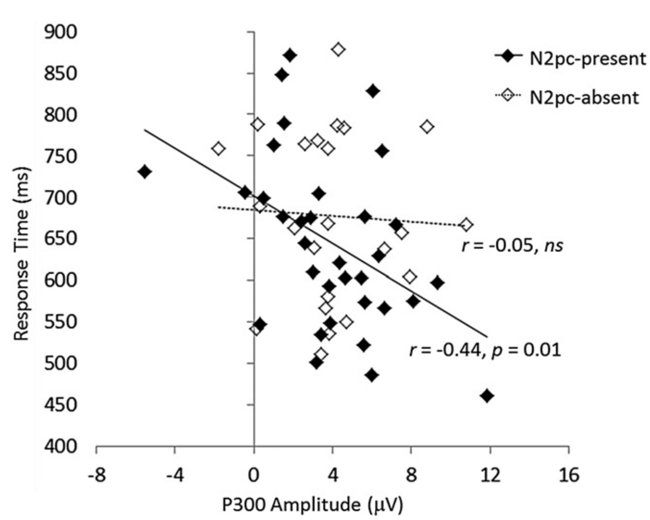

Figure 8. A scatter plot showing the relationship between P300 amplitude and RT in the N2pc-present and N2pc-absent groups.

Ariga & Kawahara, 2004; Lleras et al., 2009; Shin et al., 2008). The N2pc difference between the DP and TP conditions was also small overall, and was not observed for some participants. We postulate that these small effects might have been due to the relative difficulty of the current task, suggested by the fact that participants in the current study generally made more errors (around 8%) than participants in previous studies (e.g., < 5% in Ariga & Kawahara, 2004). Three elements of the current task likely contributed to its difficulty. First, in contrast to previous studies (Ariga & Kawahara, 2004; Lleras et al., 2009) that have used self-paced tasks with much longer display durations, the current task was much faster paced with response deadline forced. Second, whereas four items were used for each trial in the current task, previous studies only used three items for each trial. Third, participants were required to both locate and categorize targets before making a behavioral response; in previous studies simply locating a target was sufficient. This point implies that thorough visual analysis to categorize a target is not always necessary for the occurrence of the DPE. Either of these difficulties could have contributed to the fact that some participants did not show the expected N2pc effect. It could be that experiencing the task as particularly difficult would impede the development of processing strategies, such as dynamically shifting attention to possible targets, which would facilitate task performance. The N2pc-absent group did not show significant accuracy difference between the DP and TP conditions. This could be the reflection of this difficulty that individuals experienced.

It is important to note that the ERP findings in the current study suggest limitations to current attention-based accounts of the DPE. In particular, and contrary to our expectations, a significant number of participants did not demonstrate the expected pattern of enhanced N2pc amplitude and earlier N2pc latency on DP compared to TP trials; indeed, many individuals showed no discernible N2pc at all, despite showing a reliable DPE. Thus, in contrast to previous work suggesting that the DPE occurs due to a shift in attentional set to visual features in the current target-present trial (Lleras et al., 2008, 2009), the current results indicate a somewhat more complex picture, in that the DPE apparently can occur even in the absence of certain target selection processes reflected in the N2pc. In what follows, we consider a number of factors that theoretically could contribute to the DPE, some of which also differentiated subjects who showed the predicted N2pc effect from those who did not, and conclude by suggesting some reconciliation of the current findings with current attention-based accounts of the DPE.

Visual Sensory Gain, Target Selection, and the N2pc

In addition to the predicted N2pc effect, we also investigated early attention-related ERP components (i.e., the posterior P1 and anterior P2 components) to look for differences in early target processing that might have contributed to the presence or absence of those effects. The posterior P1 peaking about 130 ms poststimulus was significantly larger in the N2pc-present than in the N2pc-absent group (see Figure 4), indicating that early sensory gain control was enhanced and thus visual processing may have been facilitated among the individuals with significant N2pc activity relative to those with no N2pc activity. The anterior P2, occurring slightly later (180–250 ms), showed a significant interaction between the category-preview conditions and the groups. As shown in Figure 5, the DP and TP waveforms were differentiated in the N2pc-present group but were almost identical in the N2pc-absent group. Given that the anterior P2 reflects early selection processes (Hillyard & Anllo-Vento, 1998; Kenemans et al., 1993; Ruijter et al., 2000), we postulate that the participants in the N2pc-present group might have begun engaging in target selection around the time of the posterior P1 effect, which in turn may have guided the location to which attention should be allocated (indicated by the N2pc effect). In contrast, the N2pc-absent group did not show any signs of enhanced visual acuity and target selection in these early stages, which in turn could have contributed to the lack of systematic allocation of attention in the N2pc.

Because alcohol-related and alcohol-unrelated objects were used for stimuli, and given considerable research characterizing ERP differences as a function of alcohol use and risk for alcohol-related problems (e.g., see Polich, Pollock, & Bloom, 1994), it is reasonable to suspect that the differences between the N2pc-present and the N2pc-absent group may have resulted from individual differences in alcohol consumption, alcohol-related problems, or familial alcoholism risk. We in fact administered several self-report measures asking individual alcohol sensitivity (O'Neill, Sher, & Bartholow, 2002; see also Bartholow, Henry, & Lust, 2007; Bartholow et al., 2010; Shin et al., 2010), alcohol use and problems, and family history of alcoholism (Mann, Sobell, Sobell, & Pavin, 1985). None of these measures differentiated these two groups (Fs < 1). Thus, we think that the N2pc differences may have diverged from individual differences that begin in the very early visual processing, which are unrelated to the specific alcohol-related stimuli we used.

Target Categorization, P300, and Response Times

Target categorization processes (i.e., postselection processes) were investigated using the P300. We expected that participants with significant N2pc activity should show a larger P300 than participants with negligible N2pc activity because the resources allocated to target selection (shown in the N2pc) are more likely to be shared with or carried over to target categorization (shown in the P300). However, P300 amplitudes did not differ as a function of N2pc activity. Instead, P300 amplitudes were significantly correlated with faster responses (especially among participants with significant N2pc activity). This pattern of results makes sense when one considers the independent categorization of the target according to the target-defining category and to the response-defining category. Even if the target-defining category may have been an important base of target selection, selected targets had to be categorized according to the response-defining category, determining the hand to use for responding. Therefore, target categorization reflected in the P300 may have been linked to response-related processes more tightly than target selection processes. Moreover, some investigators (Verleger et al., 2005) have suggested that the P300 represents a process mediating between perceptual analysis and response initiation, in contrast to the traditional notion that the P300 reflects stimulus- (and not response-) related processes (Kutas et al., 1977; McCarthy & Donchin, 1981). Our data appear to fit well with this perspective on the P300. Neurophysiologically, the view that the P300 reflects the inhibition of extraneous neural activity (Polich, 2007, 2012) is consistent with this pattern of results. In particular, the participants in the N2pc-present group appear able to suppress extraneous neural activity in order to focus on the selected target to categorize, which appears to have downstream benefits in terms of the ability to enhance visual processing signals to facilitate target selection and allocation of attention to the target object. The ultimate result is more efficient target processing at multiple levels, resulting in accelerated behavioral responses.

Reconciling the Current Findings with Attention-Based Accounts of the DPE

Extant understanding of the role of attention processes in the DPE (see Lleras et al., 2008, 2009; Shin et al., 2008) holds that people tend to respond faster on DP compared to TP trials because attention is allocated to the target side earlier, and more attentional resources are deployed following a distractor-category preview than following a target-category preview. Among current participants with visible N2pc components (N2pc-present group), this model seems to have held: these individuals showed earlier developing and significantly larger N2pc amplitude for DP than for TP trials. These results are consistent with the idea that the DPE reflects a trial-by-trial, primarily top-down biasing of attentional set. The biasing of attentional set elicits shifting attention from rejected features associated with the previous target-absent trial to the features not associated with that trial. Hence, we postulate that the N2pc-present participants shifted attention effectively away from a previewed category to a novel (i.e., nonpreviewed) category in the target-present displays, and thus their target selection processes were facilitated.

In contrast, the N2pc-absent group did not show any significant N2pc effects, indicating the lack of any consistent shifting or biasing of attention for the target-present trials as a function of the relationship between the target-distractor categories in the two consecutive displays. Note that a subject-level N2pc may occur in either of two circumstances: (1) when attention is deployed preferentially to one hemifield over the other on every trial; and (2) when attention deployment to one hemifield over the other is systematic, resulting in the attention effect in the average waveform. For example, in the present study we hypothesized attentional bias toward a novel category, unrelated to a previewed category. However, if attention is deployed to both the target-present and the target-absent hemifield with approximately equal frequency in each category-preview condition, the participant may not show the N2pc effect. Due to practical difficulty discerning an N2pc in a single trial, it is unclear which of these scenarios is represented by participants in the N2pc-absent group. In either case, we can conclude that these participants did not engage in the kind of (presumably adaptive and strategic) systematic attention shifts that were evident among participants in the N2pc-present group.

Moreover, participants in the N2pc-absent group also seemed to show a relative disadvantage in terms of early deployment of attentional gain, as indicated by smaller amplitude of the posterior P1 and anterior P2 components and lack of any category-preview condition effect in the anterior P2 relative to the N2pc-present group. Together, these patterns suggest that some participants adopt a strategy in which they distribute attention broadly across stimulus arrays, possibly due to less effective attention gain control early in stimulus processing. While arguably less efficient in terms of distribution of attentional resources, this strategy appears effective in terms of facilitating responses on DP relative to TP trials. However, these participants did not demonstrate a DPE in accuracy, which could belie a performance decrement relative to those in the N2pc-present group. In any case, it is difficult to reconcile these findings with current accounts of the DPE. Therefore, these results point out that the DPE may not have a strong relationship with attention-related effects in some paradigms.

One implication of this finding is that the DPE might not reflect fully top-down processes as has been postulated (Lleras et al., 2008, 2009; Shin et al., 2008). Thus, it is important to consider any potential influence of stimulus-driven bottom-up factors (e.g., abrupt onset or feature salience; Theeuwes, 2004; Yantis & Jonides, 1984) that could have occurred in the current study. However, although we do not rule out such an influence, it is difficult to explain the DPE found in this study as a bottom-up phenomenon. Stimuli were rendered in grayscale to eliminate possible influences of color as a salient feature. Also, the extent to which the same stimuli were repeatedly presented across the two consecutive displays varied. Thus, we do not expect systematic influences of the repetition of a particular object(s) to have contributed to facilitation or slowing of response times.

Conclusions

In conclusion, the present findings strengthen the idea that dynamic attention shifts are contingent on previous successes or failures in searching for targets, favoring the ideas that intertrial inhibition effects reflect the dynamic and adaptive nature of attention allocation, and that these intertrial effects are optimized by setting priority for information that could lead to achieving the current goals in the task. More specifically, these effects may depend on whether or not information from a previous visual scene can help observers to prevent more failures and promote more efficient searches in the future—that is, whether or not previewed features are relevant to a current search (see Levinthal & Lleras, 2008). However, the present findings also point to the idea that such intertrial inhibition of attention may not explain all behavioral effects of the DPE, in particular when targets are not easy to find on the basis of a perceptual feature and require further visual processing to categorize. Future research should continue to systematically examine conditions under which these intertrial effects vary or do not occur, which in turn could reveal core components involved in dynamic attention shifts.

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