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Item and Category-Based Attentional Control During Search for Real-World Objects: Can You Find the Pants Among the Pans?

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To compare the speed and efficiency of item-based and category-based attentional control during visual search for real-world objects, we measured N2pc components as electrophysiological markers of attentional target selection. In different blocks, participants searched for 1 or 2 specific target objects or for any object in a target category (items of clothing or kitchen objects). Search displays contained 6 line drawings of different objects, and targets always appeared together with 5 distractors from the other object category. The presence of N2pc components to categorically defined targets demonstrated that category-based search can operate at visuoperceptual processing stages. In contrast to previous findings for letter/digit search (Nako, Wu, & Eimer, 2014), target N2pc components were delayed by 40 ms during category-guided search relative to single-target search. This suggests that for objects and object categories that are less familiar than alphanumerical stimuli, category-guided target selection operates less efficiently than selection that is based on a physical match with an attentional template.

Keywords: attentional selection, N2pc, visual search, category search

Visual search for known target objects is controlled by representations of task-relevant information in working memory (attentional templates), which can guide attention toward specific features, objects, or target categories (Desimone & Duncan, 1995; Olivers, Peters, Houtkamp, & Roelfsema, 2011). When searching for something to wear in the morning, we may try to find a specific object (e.g., the blue sweater), a particular color (e.g., anything blue), or just any item of clothing. Research into the control of visual search has mainly focused on feature- or object-based selection, and less on category-guided search. Feature-based search is more efficient than category-defined search for target objects (e.g., Malcolm & Henderson, 2009; Yang & Zelinsky, 2009), but this does not imply that object categories play no role in the guidance of attentional target selection. Behavioral evidence has shown that nontarget objects that are physically dissimilar but semantically linked to current targets can attract attention during visual search (e.g., Moores, Laiti, & Chelazzi, 2003; Belke, Humphreys, Watson, Meyer, & Telling, 2008; see also Telling, Kumar, Meyer, & Humphreys, 2010, for corresponding electrophysiological evidence), suggesting that category-based selection mechanisms are involved in the control of visual attention.

Two recent event-related potential (ERP) experiments from our lab (Wu et al., 2013; Nako, Wu, & Eimer, 2014) have identified electrophysiological correlates of category-based control in visual search. In these studies, participants searched for specific digits among letters, or vice versa, and N2pc components were measured as online markers of attentional target selection. The N2pc is an enhanced negativity at posterior electrodes contralateral to the side of targets in visual search displays that emerges between 180 and 220 ms after stimulus onset, is generated in ventral visual cortex (Hopf et al., 2000), and reflects spatially selective processing of candidate target objects among distractors (e.g., Luck & Hillyard, 1994; Eimer, 1996). In our studies, N2pc components were triggered not only during search for one specific object (e.g., the letter A), which can be based on a physical match with a stored attentional template, but also when targets were categorically defined (i.e., any letter). This demonstrates that category-based attentional control can have spatially selective effects at relatively early perceptual stages of visual processing. Target N2pc onset latencies did not differ between search for one specific target and search for category-defined targets. N2pc components to nontarget foil objects that belonged to the current target category (e.g., an R during search for the letter A) emerged at the same time as target N2pcs (180 ms after search display onset; Nako et al., 2014). These observations suggest that category-based attentional control might even precede item-based control during search for alphanumeric targets. The fact that targets were detected faster and target N2pc components were larger during single-letter compared with category-based search in both studies (Wu et al., 2013; Nako et al.,

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2014), demonstrates that feature-guided target selection was still more efficient than category-guided selection.

Such effects of category-based attentional control at early stages of visual processing may only be observed for visual search tasks with letter targets and digit distractors, or vice versa. This type of category search is very efficient (e.g., Egeth, Jonides, & Wall, 1972), which has led to the suggestion that letters and digits are identified and categorized in parallel at preattentive processing stages (Duncan, 1980). The goal of the current experiment was to compare item-based and category-based attentional control mechanisms in a task where stimuli were more complex (line drawings of real-world visual objects) and object categories less well practiced. Participants searched for items of clothing among kitchen objects, or vice versa (see Figure 1). In some blocks, one particular object (that could appear either in one constant view or in two mirror-image views) served as the target. In other blocks, participants searched for either of two possible target objects. These blocks also included foil trials where a nontarget object from the task-relevant category was shown (e.g., a T-shirt during search for pants). Critically, there were also blocks where the target could be any object in one category. N2pc components were measured to target and foil objects in these different task conditions. If category-based control affects modality-specific stages of visual processing in search tasks with real-world visual objects and object categories, N2pc components should be elicited by category-defined target objects. The presence of N2pc components to foils during single-object search would demonstrate that, even when item-based control is available, object categories still affect the allocation of attention. We also compared target N2pc components between blocks with constant and mirror-image views of a target object, and between blocks with one and two target objects, to assess the view-dependence of attentional templates for real-world visual objects, and their capacity limitations.

Method

Participants

Twelve paid participants with normal or corrected vision (age range: 24–39 years, 7 females) were tested.

Stimuli, Design, and Procedure

Stimuli were black line drawings (11 clothes and 11 kitchen objects; angular size: 2.02° × 3.14°; see Figure 1) from the Bank of Standardized Stimuli stimulus set (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010). Circular search arrays contained six different equidistant objects presented at a radial distance of 3.4° from central fixation against a white background (39.4 cd/m^2) on a 100-Hz 24-in. LCD monitor at a viewing distance of 100 cm. Search arrays remained on the screen until a response was re-

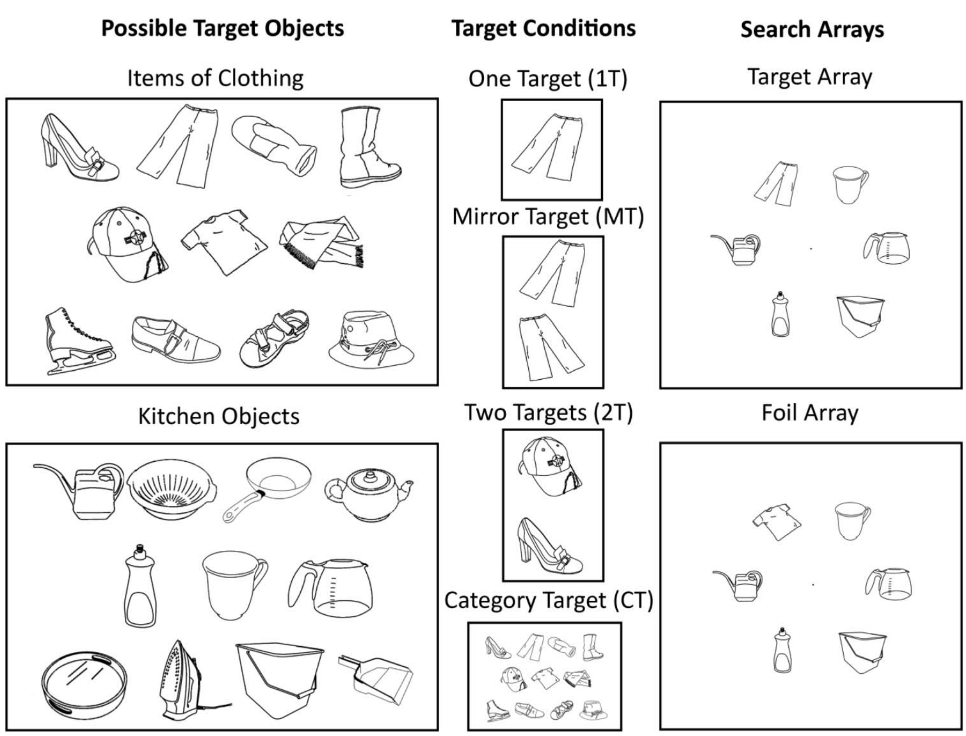

Figure 1. Individual objects used in this experiment (left panel). There were two stimulus categories (line drawings of items of clothing and of kitchen objects), each including 11 objects. Examples of target definitions used in the four different search tasks (middle panel). In different blocks, participants searched for one specific target (1T), one target object that could appear in two mirror-image view (MT), two targets (2T), or category-defined targets (CT). Example search arrays for a block where pants served as search target (top) and any other item of clothing such as a T-shirt (bottom) could appear as foil (right panel).

corded. The search array on the next trial was presented 1,500 ms after display offset.

There were four different search tasks (see Figure 1). In one-target (1T) blocks, participants searched for one prespecified target object (e.g., pants). In mirror-target (MT) blocks, a single target object could appear in two different orientations (e.g., two mirror images of the pants). Two-target (2T) blocks included two different target objects from the same category (e.g., hat or shoe). In category-target (CT) blocks, any of the 11 objects in the target category could appear as the target. Participants searched for different target objects in 1T, MT, and 2T blocks. On target trials, a target object was accompanied by five distractor objects from the nontarget category. Distractor-only trials included six non-target-category objects. In 1T, MT, and 2T blocks, there were also foil trials, which included one nontarget object that was randomly chosen on each trial from the task-relevant category. There were no foil trials in CT blocks, because all objects in one category were potential targets. Targets or foils (when present) randomly appeared at one of the six possible stimulus locations. Participants reported the presence or absence of a target by pressing a corresponding response button with their right index or middle finger. Six participants searched for items of clothing, and six others for kitchen utensils.

Twenty blocks were run (five successive blocks for each search task, each preceded by one training block). Task order was pseudorandomized across participants. Each 1T, MT, and 2T block included 36 target trials, 18 foil trials and 18 distractor-only trials. Each CT block included 36 target and 18 distractor-only trials.

EEG Recording and Data Analysis

Electroencephalography (EEG) was DC-recorded from 23 scalp electrodes at standard positions using the extended 10/20 system (sampling rate, 500 Hz; low-pass filter, 40 Hz) against a left-earlobe reference, and was re-referenced offline to averaged earlobes. The continuous EEG recording was segmented from −100 to 500 ms relative to search array onset. Trials with artifacts (horizontal EOG exceeding ±30 V, vertical EOG exceeding ±60 V, all other channels exceeding ±80 V) were removed. Residual horizontal EOG deflections were below ± 2 μV during the first 300 ms poststimulus. Averaged waveforms for trials with correct responses were computed for target and foil trials, separately for each task. N2pc amplitudes were measured at lateral posterior electrodes PO7 and PO8 as ERP mean amplitudes between 200 and 300 ms poststimulus. Jackknife-based analyses were used to compare target and foil N2pc onset latencies across tasks (Miller, Patterson, & Ulrich, 1998), with *F* and *t* values corrected as prescribed, and N2pc onset defined relative to an amplitude criterion of −1 μV. All multiple comparisons were Bonferroni-corrected.

Results

Behavioral Results

Figure 2 shows correct reaction times (RTs) on target, foil, and distractor-only trials in each task condition. There were main effects of task for target RTs, $F(3, 33) = 10.43$, $p < .001$, $\eta^2 = .487$, foil RTs, $F(2, 22) = 25.448$, $p < .001$, $\eta^2 = .698$, and distractor-only RTs, $F(3, 33) = 25.45$, $p < .001$, $\eta^2 = .698$. RTs to targets were faster in 1T and MT blocks (505 and 508 ms, respectively) than in 2T and CT blocks (591 and 562 ms, respectively; $ps < .021$), and the target RT difference between 2T and CT blocks approached significance ($p = .054$). Target-absent responses on foil trials were slower in 2T blocks (665 ms) relative to 1T and MT blocks (536 and 542 ms, respectively; $ps < .001$). Target-absent RTs on distractor-only trials were slower in 2T and CT blocks (625 and 731 ms, respectively) relative to 1T and MT blocks (507 and 522 ms, respectively; $ps < .001$), and slower in CT relative to 2T blocks ($p < .001$). There were no reliable RT differences between 1T and MT blocks for target, foil, or distractor-only trials. Target-absent responses were delayed in foil trials relative to distractor-only trials in 1T, MT, and CT blocks ($ps < .001$). Accuracy was above 95%, and did not differ between tasks.

N2pc Results

Target trials. Figure 3 shows ERPs at electrodes PO7/8 contralateral and ipsilateral to the target in 1T, MT, 2T, and CT blocks, and difference waveforms obtained by subtracting ipsilateral from contralateral ERPs. A repeated-measures analysis of variance on ERP mean amplitudes in the 200–300 ms poststimulus time window for task (1T, MT, 2T, and CT) and laterality (elec-

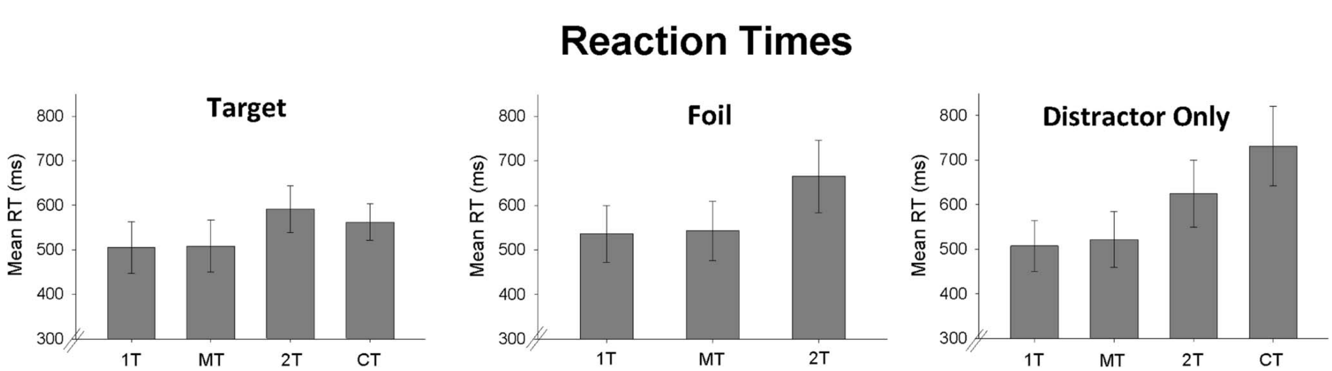

Figure 2. Mean reaction times on correct trials on target, foil, and distractor-only trials, shown separately for the four different search tasks. Error bars indicate ± 2 *SEM*. RT = reaction time; 1T = one target; MT = mirror target; 2T = two target; CT = category target.

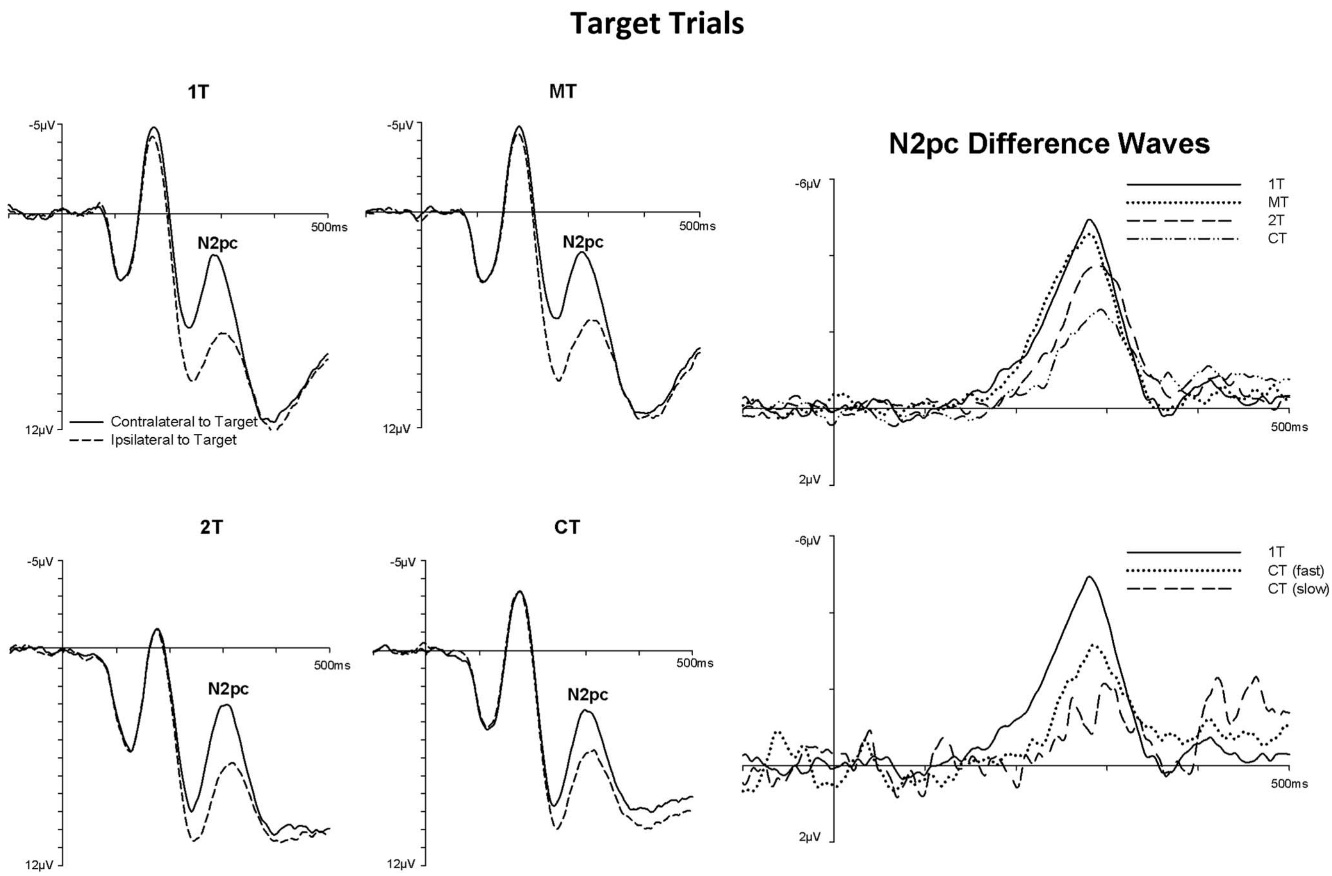

Figure 3. Grand-average event-related potentials (ERPs) elicited in response to search arrays on target trials at posterior electrodes PO7/8 contralateral and ipsilateral to a target item, shown separately for the four search tasks (left panel). N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERP waveforms at PO7/8 for each search task (right top panel). N2pc difference waveforms for the one target task, and for fast and slow trials in the category target (CT) task (right bottom panel). Fast and slow CT trials were classified on the basis of reaction time median splits for each participant. 1T = one target; MT = mirror target; 2T = two target.

trode contralateral vs. ipsilateral to the target) revealed a main effect of laterality, $F(1, 11) = 45.86$, $p < .001$, $\eta^2 = .807$, and a Task × Laterality interaction, $F(3, 33) = 8.28$, $p < .001$, $\eta^2 = .430$. The *t* tests comparing contralateral and ipsilateral ERP mean amplitudes confirmed the presence of target N2pc components in all tasks, all $t(11) > 5.1$, $ps < .001$. N2pc amplitudes did not differ between 1T and MT blocks, $t(11) < 1$. Relative to these two tasks, the N2pc was reliably reduced in 2T and CT blocks, both $t(11) > 2.25$, $ps < .05$. The N2pc amplitude difference between 2T and CT blocks was marginally significant, $p = .051$. During the 300–500 ms poststimulus interval, a main effect of laterality, $F(1, 11) = 15.24$, $p = .013$, $\eta^2 = .440$, indicated that a residual contralateral negativity remained present beyond the N2pc time window (see Figure 3). This late negativity did not differ between 1T, MT, 2T, and CT blocks, $F(3, 33) < 1$.

N2pc components emerged earlier in 1T and MT blocks (192 and 200 ms, respectively) relative to 2T (223 ms) and CT blocks (240 ms), confirmed by a main effect of task, $F_c(3, 33) = 5.46$ $p = .013$, for N2pc onset latencies. Paired comparisons showed that the target N2pc was delayed in the CT task relative to the other three tasks ($ps < .03$), and in the 2T task relative to the 1T and MT tasks ($ps < .05$). This N2pc onset delay in the CT task was observed both for trials with fast and with slow responses (see Figure 3, bottom right panel), indicating that it cannot be attributed to an increased trial-by-trial variability of target selection speed in this task.

Foil trials. Figure 4 (left panel) shows ERPs triggered contralateral and ipsilateral to foil objects. A main effect of laterality, $F(1, 11) = 41.60$, $p < .001$, $\eta^2 = .791$, on N2pc mean amplitudes demonstrated the presence of a reliable foil N2pc. There was no difference in foil N2pc amplitude between the 1T, MT, and 2T tasks, $F(2, 22) < 1$, and foil N2pcs were reliably present in all three tasks ($ps < .02$). Foil N2pc amplitudes were strongly attenuated relative to target N2pcs (see Figure 4, right panel), as reflected by the Trial Type (target vs. foil, collapsed across 1T, MT, and 2T tasks) × Laterality interaction, $F(2, 22) = 27.20$, $p < .001$, $\eta^2 = .71$.

Discussion

Our findings showed that attentional task sets for real-world object categories produce spatially specific visual processing mod-

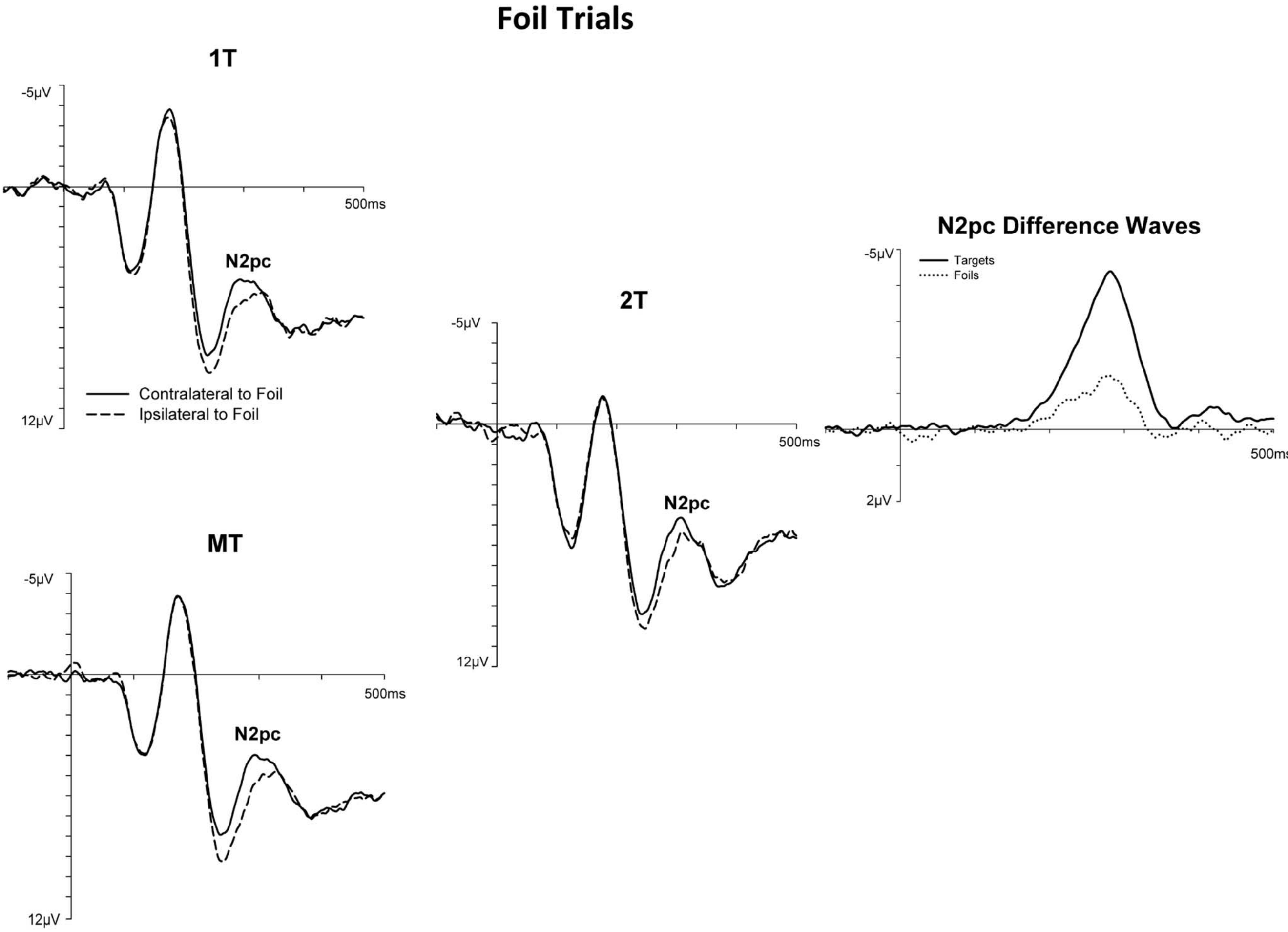

Figure 4. Grand-average event-related potentials elicited in response to search arrays on foil trials at posterior electrodes PO7/8 contralateral and ipsilateral to a foil item, shown separately for the one-target (1T), mirror-target (MT), and two-target (2T) tasks (left panel). N2pc difference waveforms for target and foil trials, collapsed across the 1T, MT, and 2T conditions (right panel).

ulations at relatively short poststimulus latencies. When observers searched for line drawings of kitchen objects among items of clothing, or vice versa, category-defined targets triggered N2pc components that emerged around 240 ms poststimulus. Extending our observations for letter/digit search (Wu et al., 2013; Nako et al., 2014), this result demonstrates rapid category-based attentional guidance with more complex objects and less well trained objects and object categories.

The results obtained on foil trials provide further evidence for category-based attentional control. When participants searched for one or two specific target objects, nontarget foils that matched the target category elicited reliable N2pc components. Even though foil N2pcs were smaller than target N2pc components (see Figure 4), their presence suggests that foil objects attracted attention even when search could have been based exclusively on item-specific attentional templates. Target-absent RTs were slower on foil relative to distractor-only trials, which shows that the presence of a category-matching foil in a search display made it harder to confirm the absence of a target.

Although category-guided attentional control processes were active in the present experiment, they were not as efficient as item-based control. Target RTs were faster and target N2pc components were larger and emerged earlier when participants searched for one specific target object relative to blocks where category-based search was required. This demonstrates that target selection operated more rapidly and efficiently when it could be based on a physical match with an attentional template. Interestingly, there were no behavioral or N2pc differences between blocks where the target always appeared in the same view and blocks with two mirror-image views of the target object, suggesting that item-based attentional control processes may operate in a largely view-independent fashion. In blocks with two different possible targets, target RTs were slower and the N2pc was delayed and attenuated relative to single-target blocks. This demonstrates that attentional target selection was less efficient during multiple-object search compared with single-object search, in line with the hypothesis that attentional templates are strongly capacity-limited (Olivers, Peters, Houtkamp, & Roelfsema, 2011; see also Grubert & Eimer, 2013). Although the N2pc emerged earlier in 2T relative to CT blocks, target RTs tended to be slower in 2T blocks. This difference may reflect the additional time required to identify selected objects as targets in the 2T task, because no withincategory object discrimination was required after target selection in the CT task.

In our previous study of letter/digit search (Nako et al., 2014), target N2pc components to targets started around 180 ms poststimulus, whether participants searched for one, two, or three particular items, or for any letter or digit, and foil N2pcs emerged at the same point in time. These findings were interpreted as evidence that attentional guidance by alphanumeric category might operate more rapidly than the item-based selection of specific letters or digits. A different pattern of results was observed in the present experiment. N2pc components to category-defined targets emerged only around 240 ms after search display onset, and were delayed about 40 ms relative to target N2pcs measured during single-object search, and about 20 ms relative to the N2pc in blocks where two different objects served as targets (see Figure 3). This demonstrates that, in search tasks with line drawings of real-world objects, category-based attentional guidance operates more slowly than item-based attentional control. It also operates more slowly than category-based control during letter/digit search (Nako et al., 2014), presumably because the objects employed in the present experiment were more complex and the relevant categories less familiar than letters and digits. Under such conditions, the attentional selection of target objects is faster when it can be based on a physical match with an attentional template than when targets are only defined by their category. Whether extended perceptual training with specific real-world visual object categories might establish a temporal precedence of category-based over item-based attentional control is a question that should be addressed in future research.

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