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Rapid category selectivity for animals versus man-made objects: An N2pc study

Austin Moon [a,*], Chenxi He [b], Annie S. Ditta [a], Olivia S. Cheung [c,1], Rachel Wu [a,1]

[a] Department of Psychology, University of California, Riverside, United States of America
[b] INSERM, U992, Cognitive Neuroimaging Unit, Gif/Yvette, France
[c] Department of Psychology, Division of Science, New York University Abu Dhabi, United Arab Emirates

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ABSTRACT

Visual recognition occurs rapidly at multiple categorization levels, including the superordinate level (e.g., animal), basic level (e.g., cat), or exemplar level (e.g., my cat). Visual search for animals is faster than for man-made objects, even when the images from those categories have comparable gist statistics (i.e., low- or mid-level visual information), which suggests that higher-level, conceptual influences may support this search advantage for animals. However, it remains unclear whether the search advantage can be explained in part by early visual search processes via the N2pc ERP component, which emerges earlier than behavioral responses, across different categorization levels. Participants searched for 1) an exact image (e.g., a specific squirrel image, Exemplar-level Search), 2) any images of an item (e.g., any squirrels, Basic-level Search), or 3) any items in a category (e.g., any animals, Superordinate-level Search). In addition to Target Present trials, Foil trials measured involuntary attentional selection of task-irrelevant images related to the targets (e.g., other squirrel images when searching for a specific squirrel image, or other animals when searching for squirrels). ERP results revealed 1) a larger N2pc amplitude during Foil trials in Exemplar-level Search for animals than man-made objects, and 2) faster onset latencies for animal search than man-made object search across all categorization levels. These results suggest that the search advantage for animals over man-made objects emerges early, and that attentional selection is more biased toward the basic-level (e.g., squirrel) for animals than for man-made objects during visual search.

The ability to distinguish animals from man-made objects is foundational for the development of appropriate object representations. This fundamental difference requires humans to understand that animals can trigger events (e.g., Rakison and Poulin-Dubois, 2001), as animals are agents that can independently produce actions (e.g., voluntary movement) and possess mental processing capabilities driven by biological functions. In contrast, man-made objects require actions from humans and other animals to operate (e.g., phones can only make calls via a user's actions) and hold no mental state. The human understanding of this difference is thought to be evolutionarily adapted, as animals afforded higher survival values (either as a source of food or danger) than inanimate objects for human beings tens of thousands of years ago (e.g., Caramazza and Shelton, 1998; New et al., 2007).

The animal versus man-made object distinction has been well-established both in behavior and neural representations. Separate neural regions have been identified for processing animals versus man-made objects (e.g., Kiani et al., 2007; Khaligh-Razavi and Kriegeskorte, 2014; Kriegeskorte et al., 2008; Naselaris et al., 2012). EEG studies have found that differences in processing line-drawn images of animals versus man-made objects emerge around 150 ms after stimulus onset (Proverbio et al., 2007). In addition, prior behavioral studies have consistently observed faster performance (i.e., manual responses) when searching for animals compared with searching for man-made objects, even though both animals and man-made objects are easily recognizable (e.g., New et al., 2007; Wang et al., 2015). Eye tracking studies also have shown attentional biases toward animals over man-made objects (Yang et al., 2012). From these studies, it remains unclear how much of the differences are driven by visual features, such as specific shapes or colors (e.g., giraffes have long necks), or higher level, conceptual features, including relatively abstract or intrinsic properties about a category (e.g., warm-blooded). However, to understand the nature of the mental representations for the different categories, it is important to distinguish these

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[*] Corresponding author at: Department of Psychology, 900 University Ave., Riverside, CA 92521, United States of America.
E-mail address: smoon041@ucr.edu (A. Moon).

[1] These authors contributed equally.

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sources of influences for categorization and distinction.

Although both visual and conceptual differences may likely influence the processes for distinguishing and searching for animals versus man-made objects, their respective influences remain largely underexplored. Previous behavioral and fMRI studies have shown that it is possible to rely on only overall shapes or low- and mid-level visual features to distinguish between animals and man-made objects (e.g., gist statistics, Torralba and Oliva, 2003; Rice et al., 2014; Watson et al., 2014; curvilinear vs. graspable shapes, Almeida et al., 2014; mid-level texture and form, Long et al., 2017; Long et al., 2018; Zachariou et al., 2018; visual complexity, Tyler et al., 2003). It is also possible that different kinds of features may be utilized to represent visual inputs at multiple categorization levels, including the superordinate-, basic-, or exemplar-levels (e.g., Maxfield and Zelinsky, 2012). Representations for animals and man-made objects may be constrained differently across the categorization levels, depending on the visual or conceptual features that may be best for distinguishing between the categories or exemplars. While systematic differences in low- and mid-level visual features between animals and man-made objects can produce a search advantage for animals at the superordinate level, recent evidence shows that these visual differences alone cannot solely account for the search advantage. Specifically, diagnostic low- and mid-level visual differences between animals and man-made objects can be quantified using gist statistics (e.g., Torralba and Oliva, 2003), and careful control of the gist statistics across the categories allows for the investigation of influences from conceptual knowledge on visual search. Using a large image set of animals and man-made objects (with fruits/vegetables as filler distractors) that had comparable gist statistics across categories, a search advantage for animals over man-made objects remained robust (He and Cheung, 2019). Specifically, faster search performance was found when participants were asked to search for animals, compared with searching for man-made objects. This finding suggests that the search advantage for animals is likely facilitated by higher-level top-down processes (Wolfe and Horwitz, 2017), such as general conceptual knowledge about the categories (Cunningham and Wolfe, 2014). Using a similar set of images with comparable gist statistics across categories, neural selectivity for the categories in the animal- and tool-selective regions within occipitotemporal cortex was again observed using fMRI (He et al., 2020), which further suggests that the neural representations selective for animals and man-made objects can be driven by higher-level conceptual information independent of low- or mid-level visual properties.

Given behavioral evidence of the search advantage for animals over man-made objects when controlling for gist statistics, it is unclear how early this advantage emerges. The present study uses the N2pc ERP component to address this question, as the N2pc is the fastest and most robust neural marker of target selection. This component appears approximately 200-300 ms after stimulus onset, which is faster than behavioral responses (which often occur approximately 500 ms after stimulus onset). The N2pc is detected contralateral to the hemifield of the target location, and it indicates when attention has shifted to the target location in a hemifield (Eimer, 1996; Luck and Hillyard, 1994). Recent N2pc studies have demonstrated that the component emerges not only when participants search for a specific target item (e.g., the letter A), but also when searching for a whole category (e.g., any letter), even when the items are visually heterogeneous within the same target category (e.g., Nako et al., 2014; Wu et al., 2013; Wu et al., 2017). The robust N2pc findings from studies using superordinate-level categories (e.g., letters) suggest that the N2pc can reflect the use of categorical information alongside visual differences during visual search. If the N2pc component for superordinate-level search is present even when visual differences between categories are minimized, it would suggest that conceptual differences between categories may be utilized to distinguish the categories.

In addition to selection of a target item or a target category, the N2pc also detects involuntary activations of category representations via Foil trials. These trials display a non-target within the same category as the target while the target itself is absent. For example, when participants are asked to search for the letter T among non-letter distractors, the letter A would appear instead. A Foil effect refers to a significant N2pc during these types of trials, suggesting an involuntary activation of the broader category representation (e.g., any letter), as attention is shifted to these foils that are within the same category as the target. Prior N2pc studies have found N2pc Foil effects across a variety of real-world categories (e.g., letters/numbers, Nako et al., 2014; human and ape faces, Wu et al., 2015; food items, Wu et al., 2017). Therefore, an N2pc during Foil trials could provide further evidence for the robustness of a category representation, specifically the task-irrelevant activation of category representations. Prior N2pc studies investigating superordinate-level search typically do not rigorously match the stimuli across categories based on gist statistics (e.g., Nako et al., 2014; Wu et al., 2017). Therefore, there remains a potential reliance on visual differences between categories that might have resulted in the N2pc categorization effects.

1. The present study

Building on previous work showing a visual search advantage for animals, compared with man-made objects, after controlling for low- and mid-level visual differences between the categories (He and Cheung, 2019), the present study examined whether this search advantage might be detectable early in the visual search process by the N2pc component. While we expected that significant N2pc effects would be observed when participants searched for either animal or man-made object targets, a difference in the N2pc amplitude between the categories would suggest that the mental representations used to search for animals may be more robust or unified than those for man-made objects.

Furthermore, the present study also manipulated the categorization levels of the search targets. In previous studies (e.g., He and Cheung, 2019; see also New et al., 2007), participants were asked to search for the presence of any animals or man-made objects. A visual search advantage for animals might be due to relatively unified search templates, resulting from general knowledge about relational properties (e.g., a head, a body, and limbs for animals; Macé et al., 2010), compared with more variable relational properties of man-made objects. Searching for animals versus man-made objects also can occur at multiple levels differing in the specificity of the target representations (e.g., Maxfield and Zelinsky, 2012), including the superordinate level (e.g., animals vs. man-made objects), the basic-level (e.g., dolphins vs. water bottles), the exemplar-level (e.g., a specific image of a dolphin vs. a specific image of a water bottle). Investigating search at these different categorization levels provides insights into how specific to general representations give rise to the search advantage for animals compared with man-made objects.

Using a large set of images with comparable gist statistics across categories (He and Cheung, 2019; He et al., 2020), the present study used a visual search paradigm with targets at three categorization levels: 1) a specific exemplar image (Exemplar-level Search, e.g., a specific dolphin image), 2) any image of a basic-level item (Basic-level Search, e.g., any dolphin images), and 3) any image of items in the broader category (Superordinate-level Search, e.g., any animal images). Target specificity is highest when searching for a specific image (e.g., a specific dolphin) and lowest when searching for any item from a broader category (e.g., any animal). As target specificity decreases, search efficiency also decreases (i.e., smaller N2pc, Olivers et al., 2011; longer reaction time, Maxfield and Zelinsky, 2012), potentially because less specific visual or conceptual information can be used to identify the target. With comparable gist statistics across the broader categories, the present study also examined how the target specificity required for the search tasks at the different categorization levels might influence the search advantage for animals over man-made objects during both Target Present trials and Foil trials.

With the three categorization levels for Target Present trials, there were two types of Foil trials: Foil trials during Exemplar-level Search and during Basic-level Search. Foil trials during Exemplar-level Search included non-target exemplar images (e.g., other dolphin images) when the target exemplar image (e.g., a specific dolphin image) was absent. The N2pc amplitude in these trials would indicate the level of involuntary activation of a representation of a basic-level item (e.g., a dolphin) when searching for a specific image, possibly due to either or both conceptual and perceptual similarity among the exemplars. The influence of such similarity would be expected for both animals and man-made object target exemplars. Foil trials during Basic-level Search included non-target items within the same superordinate-level category as the target item (e.g., seahorse appeared when dolphins were the target), when the target item was absent. These Foil trials would reveal the involuntary activation of a representation of the superordinate-level category (e.g., any animals) when searching for a specific basic-level item (e.g., a dolphin) due to conceptual (but not visual) similarity among items within the same category. For the Superordinate-level Search task, there were no foil trials as all stimuli from the category (e.g., any animals) were potential targets.

In sum, the present study builds on four prior findings: 1) robust N2pc components for Target Present trials, but also Foil trials, during exemplar-level and basic-level search (e.g., Nako et al., 2014; Wu et al., 2015), 2) a behavioral advantage for searching for animals versus man-made objects at the superordinate level (e.g., He and Cheung, 2019), 3) enhanced search efficiency with increased target specificity (e.g., Maxfield and Zelinsky, 2012; Olivers et al., 2011), and 4) faster neural processing of animals versus man-made objects (e.g., Proverbio et al., 2007). From these findings, we expected the following N2pc results: 1) significant N2pc amplitudes at the standard 200-300 ms time window for both animals and man-made objects during Target Present and Foil trials, indicating attentional selection of targets at multiple categorization levels (Target Present trials), and distraction from foils related to the targets due to categorical attentional selection (Foil trials); 2) larger N2pc components during Target Present and Foil trials when searching for animals compared with man-made objects, suggesting a more unified representation of animals than man-made objects; 3) larger N2pc components with increased specificity of target candidates, with highest specificity for Exemplar-level Search, followed by Basic-level Search, and then Superordinate-level Search; 4) earlier N2pc onset latencies for animals than man-made objects.

In terms of the behavioral results, we predicted in the Target Present trials, a search advantage for animals compared with man-made objects at the superordinate level, replicating He and Cheung (2019). If the representations of animals are also more unified compared with man-made objects at either the basic- or exemplar-levels, a behavioral search advantage for animals also would be expected during Basic-level Search and Exemplar-level Search, with faster and more accurate search for animals compared with man-made objects.

2. Method

2.1. Participants

Fifteen adults ($M = 18.92$ years; $SD = 0.90$, range: 18–21 years; 9 females and 6 males) enrolled in University of California, Riverside participated in this study. All participants were recruited through the university's research participation system (SONA) for course credit. Six additional participants were excluded due to either low accuracy (less than 70% accuracy) or excessive eye movements (less than 50% of trials kept after artifact rejection). All participants self-reported normal or corrected-to-normal vision. The final fifteen participants included in the final analyses were 20% Hispanic or Latino and 80% non-Hispanic, with a racial breakdown of 20% Asian, 13% White, 7% Black or African American, 20% other, and 40% unidentified. Eleven out of the fifteen participants were right-handed. The sample size selection was based on prior N2pc studies that have been able to detect both behavioral and N2pc differences with a similar sample size (e.g., Wu et al., 2015; Wu et al., 2016). This study was approved by the university's Institutional Review Board.

2.2. Stimuli

There were a total of 832 greyscale images used in the study. This image set was adapted from He and Cheung (2019) with replacement of several man-made object images. Because animals tend to have curvy shapes and man-made objects tend to be elongated, both elongated and round shapes were used to account for the possibility of merely using the overall shape to distinguish animals versus man-made objects (e.g., Almeida et al., 2014; Long et al., 2017; Long et al., 2018; Zachariou et al., 2018). There were 16 images of each animal, man-made object, or fruit/vegetable item (e.g., 16 images of dolphins, water bottles, or bananas). The animal and man-made object stimuli consisted of 384 images within four stimulus types: 6 items of elongated animals, 6 items of elongated man-made objects, 6 items of round animals, and 6 items of round man-made objects (Fig. 1). Additionally, 448 images of round (14 items) or elongated (14 items) fruits/vegetables were used as distractors. The images across all three categories were carefully matched in terms of gist statistics (see below) for elongated and round shapes, and image size, in order to minimize pop-out effects. For the elongated items (e.g., cucumbers), all of the images had a vertical orientation. All images were presented on a gray background (RGB: 128, 128, 128) in a 2-item search array. Each image subtended 3.37°×3.37° and was presented 3.13° to the left and right of the central fixation dot. Note that each image pair was presented nearly foveal, as opposed to a peripheral presentation, since the near edge of each of the two images was 1.45° from the central fixation point.

2.2.1. Gist statistics

Similar to the image set used in He and Cheung (2019), the gist statistics of the current image set were significantly different between elongated and round stimuli, but the images within each shape shared comparable gist statistics across the three categories. Specifically, the visual shape properties of the images were quantified by gist statistics (Oliva and Torralba, 2001), with Gabor filters across four spatial frequency scales and eight orientations (32 values) applied to each raw image. The resulting filtered images were then divided into 4 by 4 grids with the values averaged within each cell, making up a vector with a total of 512 [$32 \times 4 \times 4$] values. Those values were then averaged across the 16 exemplars for each item. The dissimilarity of gist statistics was then calculated using the squared Euclidean distance between item pairs (Fig. 2). We compared the dissimilarity between same-shaped items

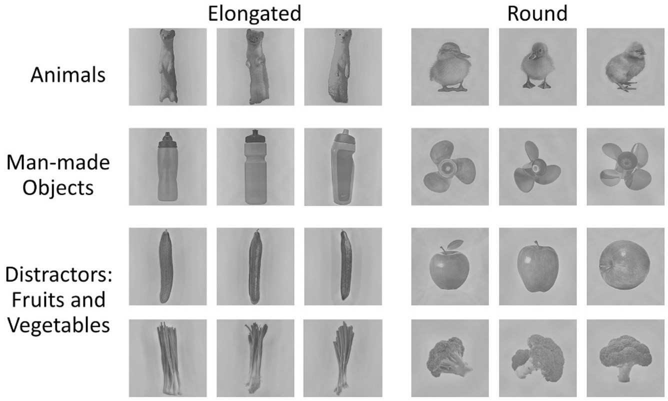

Fig. 1. Example stimuli of elongated and round animals (e.g., weasels and ducklings), man-made objects (e.g., water bottles and propellers), and fruits/vegetables (e.g., cucumbers, sugarcane, apples, and broccoli). For the animals, man-made objects, and fruits/vegetables, 16 exemplar images were used for each item (e.g., 16 dolphins, 16 water bottles, 16 bananas, etc.)

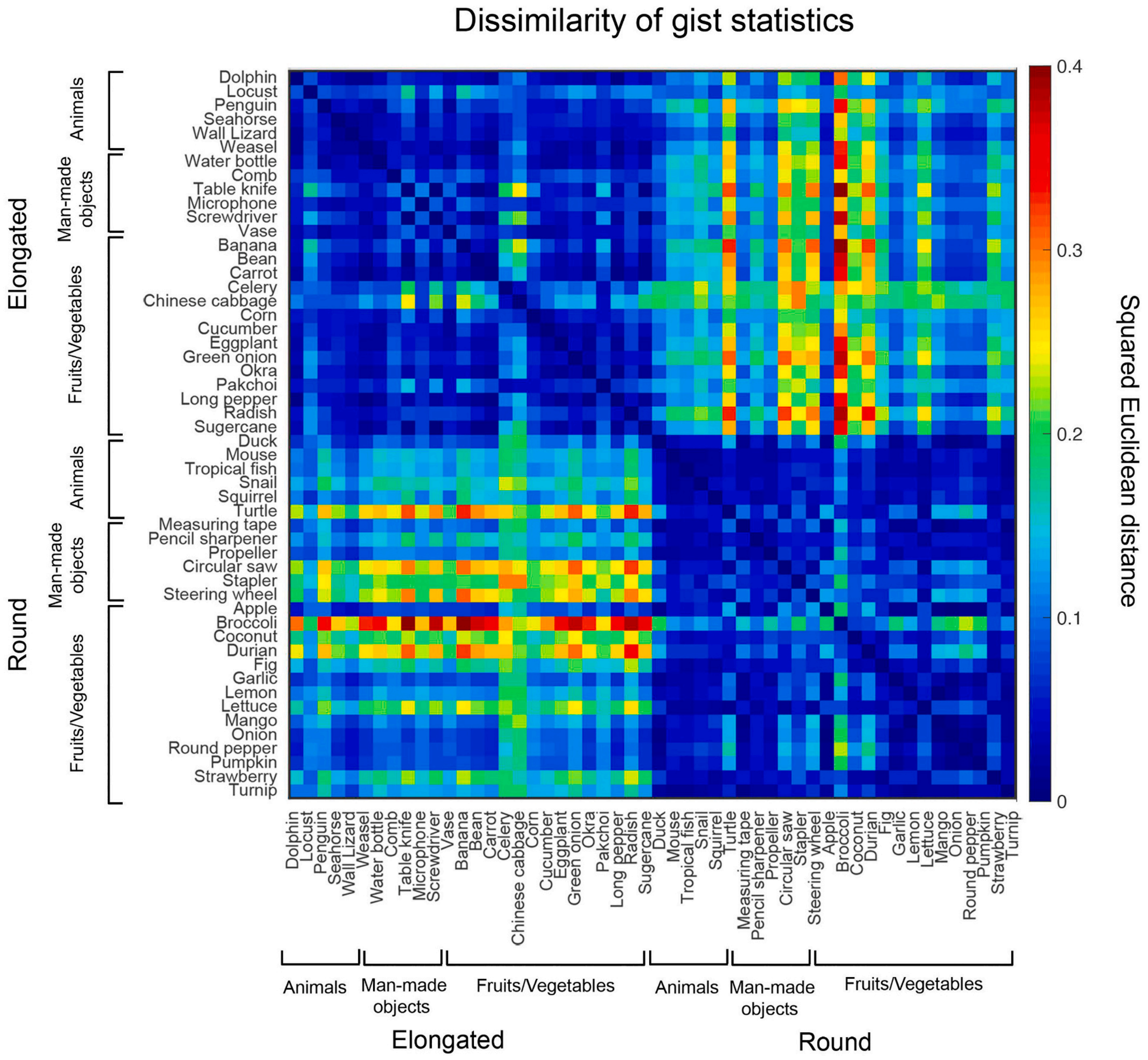

Fig. 2. Pairwise dissimilarity of gist statistics across all pairs of animals, man-made objects, and fruits/vegetables, measured in terms of squared Euclidean distance, showed no significant differences across the categories within either round or elongated shapes (adapted from He and Cheung, 2019).

within the same category (e.g., dolphins and lizards for elongated animals) and across categories (e.g., between elongated animals and elongated man-made objects, such as dolphins and water bottles). Critically, we found no significant differences between within-category dissimilarity and cross-category dissimilarity among all categories for each shape: animals versus man-made objects (elongated: $t(64) = 0.53$, $p = .60$, round: $t(64) = 0.20$, $p = .85$), animals vs. fruits/vegetables (elongated: $t(188) = 0.48$, $p = .64$, round: $t(188) = 0.93$, $p = .35$), and man-made objects vs. fruits/vegetables (elongated: $t(188) = 0.15$, $p = .88$, round: $t(188) = 0.72$, $p = .47$). Furthermore, low-level visual features including mean luminance, contrast and power spectrum (averaged across different orientations at each spatial frequency) were also balanced across the three categories using the SHINE toolbox (Willenbockel et al., 2010).

2.3. Design and procedure

Participants completed visual search tasks at three categorization levels. For each participant, the target image from Exemplar-level Search was removed for Basic-level Search, and the target images from Basic-level Search were removed for Superordinate-level Search to eliminate familiarity effects related to previous targets. Each of the search tasks had different numbers of targets: one specific image in Exemplar-level Search (e.g., search for an exact image, such as dolphin image #1), any of the 15 images of an item in Basic-level Search (e.g., search for any dolphins; image #2–16), and any of the 16 images from 5 items of the same shape (elongated or round) in Superordinate-level Search (e.g., search for any elongated animals) (see Fig. 3). Within each categorization level, participants were assigned to search for a specific target exemplar (Exemplar-level Search: only one specific dolphin and not any other dolphins), a specific basic-level target (Basic-level: only dolphins and not any other animals), or a target category (Superordinate-level: only animals and not man-made objects). All trials displayed two images, one in each hemifield. The targets could appear either on the left or right side from the fixation. Within the three categorization levels, Target Present trials displayed a target image and a distractor image (fruits/vegetables). The Target Present trials were referred to as Exemplar-level Match trials for Exemplar-level Search, Basic-level Match trials for Basic-level Search, and Superordinate-level Match trials for Superordinate-level Search. Foil trials displayed a non-target image related to the target and a distractor image (fruits/vegetables). For Exemplar-level Search, Foils were non-target images of the

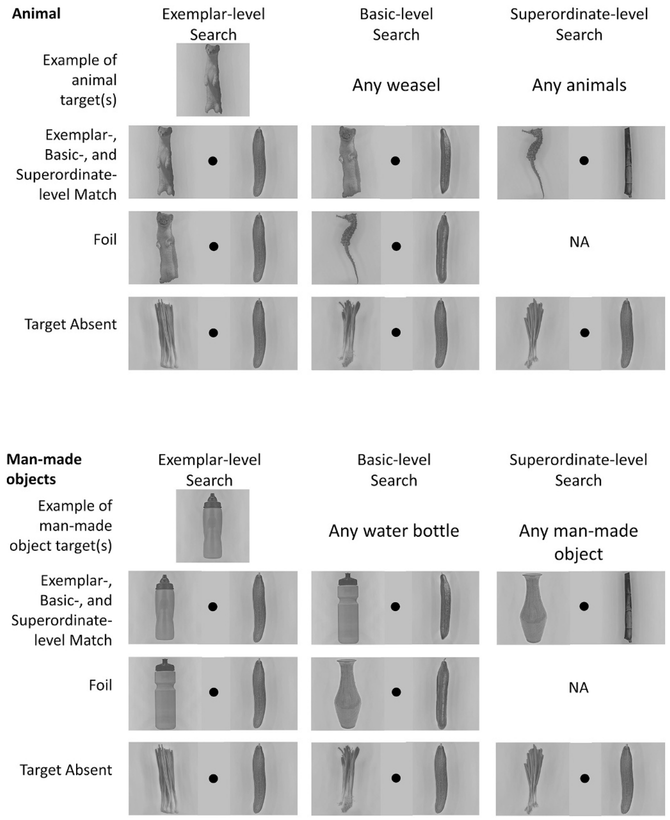

Fig. 3. Examples of targets and displays for Target Present, Foil, and Target Absent trials (rows) across the three categorization levels: Exemplar-level Search, Basic-level Search, and Superordinate-level Search (columns).

same basic-level item as the exemplar target (e.g., dolphin #2–16 when searching for dolphin #1). For Basic-level Search, Foils were non-target items from the target superordinate-level category (e.g., other animals such as lizards when searching for dolphins). Superordinate-level Search did not include any Foil trials because all items of the same category were targets. Target Absent trials displayed two images of different fruits/vegetables items (e.g., banana and celery).

Each of the search tasks at the three categorization levels involved animals or man-made objects of either elongated or round shapes in separate blocks. Therefore, there were a total of 12 conditions (3 categorization levels: exemplar, basic, or superordinate × 2 categories: animals or man-made objects × 2 shapes: elongated or round). In order to maximize trial numbers for each condition, while minimizing participant fatigue from one experimental session, for each of the four category-by-shape conditions (i.e., elongated animals, round animals, elongated man-made objects, round man-made objects), participants completed three blocks of Exemplar-level Search, two blocks of Basic-level Search, and two blocks of Superordinate-level Search, resulting in a total of 28 blocks (4 category-by-shape conditions × 7 blocks across the three categorization levels). Note that to ensure that there would be sufficient numbers of usable trials for the Exemplar-level Search, one extra block was included because of the potential low accuracy in performance due to higher visual similarity between the target and foils, compared with the other two search tasks. Each block of Exemplar-level Search or Basic-level Search consisted of a total of 28 Target Present trials, 28 Foil trials, and 4 Target Absent trials. Each block of Superordinate-level Search consisted of a total of 30 Match trials and 30 Target Absent trials. Target Present, Foil, and Target Absent trials were randomized within each block. The presentation order of the search tasks based on category-by-shape conditions was counterbalanced using a Latin square design.

Participants were instructed to maintain their gaze on the central fixation dot (Fig. 4). For Exemplar-level Search, targets were indicated via an instruction screen at the beginning of the experiment that displayed the exact target image. For Basic-level and Superordinate-level Search, experimenters provided a printout to the participants of all possible target images. The participants were allowed to study the images for as long as they wanted, typically for a few minutes. For each trial, the stimuli were presented in a 2-item search array for 200 ms, followed by a 1600 response window displaying a gray screen with only the central fixation dot. During this time window, participants indicated the presence of the target by pressing the left arrow key, or the absence of the target participants with the right arrow key. Afterwards, a brief inter-trial interval of 20 ms was presented with just the fixation dot.

For the analyses, the focus was on the two categories and the three categorization levels, with the data collapsed across round and elongated shapes. Although all participants had sufficient numbers of trials for each condition for the analyses, a small subset of data from five participants in the final sample of 15 had to be excluded. Specifically, for three of the five participants, EEG data for the Superordinate-level Search with round man-made objects were excluded due to a coding error. For another participant, EEG data across all categorization levels with elongated man-made objects were excluded due to technical and administrative errors. For the last participant, EEG data for Basic-level Search with round man-made objects and Basic-level Search with elongated animals were excluded due to equipment failure. All remaining data from these five participants were included in the final analyses. Since the final analyses averaged across elongated and round shapes for animals and man-made objects at each categorization level, all analyses included all 15 participants, allowing the degrees of freedom to be consistent across the conditions.

2.4. EEG recording and processing

With a sampling rate of 500 Hz, the EEG data were DC-recorded from 32 scalp electrodes following the extended 10/20 system. We used an offline 40 Hz Butterworth zero phase IIR low-pass filter (48 dB/octave), a 0.1 Hz high pass filter (12 dB/octave), and a 60 Hz notch filter after re-referencing to averaged earlobes. Epochs were time locked between 100 ms prior to and 500 ms after stimulus onset. The criteria for artifact rejection were horizontal EOG exceeding ±25 μV (0 to 300 ms), vertical EOG exceeding ±60 μV (0 to 300 ms), and all channels exceeding ±80 μV for the whole epoch. Note that electrode Cz was manually removed for one of the 15 participants due to excessive eye movement, but this electrode was not critical for the final N2pc analyses. The average N2pc amplitude based only on correct trials was calculated at lateral posterior electrodes PO7 and PO8, using the standard N2pc time window of 200-

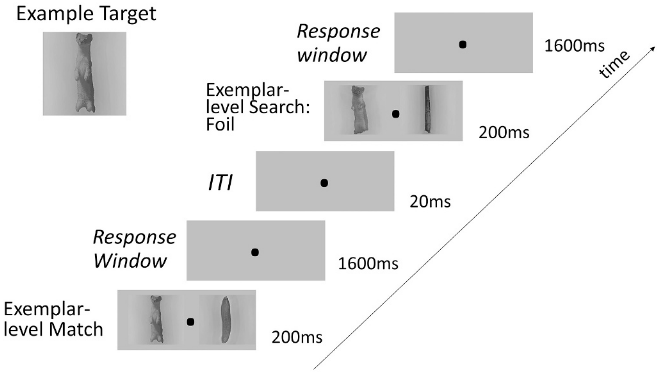

Fig. 4. Example trial sequence from the Exemplar-level Search (e.g., search for the exact image of a weasel; the target is shown on the top left as reference) with a Target Present trial (Exemplar-level Match) and a Foil trial (non-target weasel). ITI refers to inter-trial intervals.

300 ms after stimulus onset. As with the behavioral analysis, the EEG data were averaged across shapes for animals and man-made objects. Therefore, an average N2pc waveform was computed for all categories (animals/man-made objects) by categorization level (Target Present: Exemplar-/Basic-/Superordinate-level search; Foil: Exemplar-/Basic-level search) separately for each participant. There were no missing cells in the final analyses.

For the five participants with partial data, 72% (SD = 16%) of the correct trials were retained after artifact rejection, compared with the 10 participants with complete data who retained 80% (SD = 14%) of the correct trials. The waveforms, which were collapsed across shape (round and elongated) were based on the following total number of correct trials across all 15 participants included in the final sample: 1) Target Present trials with animals: 99 trials (SD = 38) for Exemplar-level Search, 67 trials (SD = 22) for Basic-level Search, and 86 trials (SD = 12) for Superordinate-level Search, 2) Target Present trials with man-made objects: 96 trials (SD = 38) for Exemplar-level Search, 63 trials (SD = 28) for Basic-level Search, and 67 trials (SD = 26) for Superordinate-level Search, 3) Foil trials with animals: 94 trials (SD = 41) for Exemplar-level Search and 66 trials (SD = 22) for Basic-level Search, and 4) Foil trials with man-made objects: 92 trials (SD = 38) for Exemplar-level Search and 61 trials (SD = 27) for Basic-level Search.

3. Results

We examined the N2pc amplitudes using correct trials for animal and man-made object search during the 200-300 ms time window after stimulus onset. For the N2pc analyses, only Target Present and Foil trials were included, as Target Absent trials did not contain markers for either targets or foils. Grand-averaged contralateral and ipsilateral waveforms (Fig. 5) and difference waveforms (Fig. 6) for Target Present and Foil trials were measured for animals and man-made objects at the three categorization levels at posterior electrodes PO7 and PO8. Pairwise comparisons between animals and man-made objects at the different categorization levels were not corrected because they were planned comparisons, whereas pairwise comparisons among categorization levels were Bonferroni-corrected.

3.1. *N2pc amplitude (200-300 ms)*

3.1.1. *Presence of the N2pc*

When searching for animal or man-made objects at the various categorization levels (Fig. 5), one-sample *t*-tests (0 μV test value) revealed significant N2pc components for animals and man-made objects in all Target Present and Foil trials, $|t|(14) > 2.82$, $p < .014$, $|d| > 0.73$.

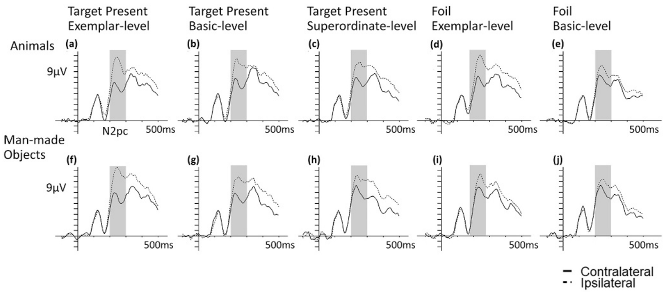

Fig. 5. Grand-average contralateral and ipsilateral N2pc ERPs recorded from electrodes PO7 and PO8 between categories (animals and man-made objects; top and bottom rows) and across categorization levels (Target Present trials: Exemplar-level Search, Basic-level Search, Superordinate-level Search; Foil trials: Exemplar-level Search, and Basic-level Search). The gray bar represents the 200-300 ms time window.

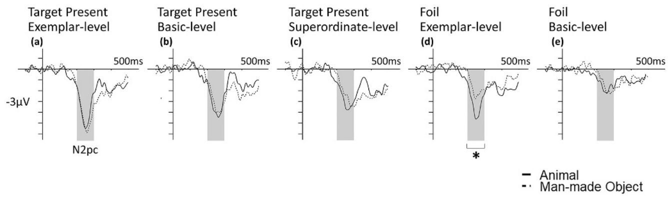

Fig. 6. N2pc difference waveforms recorded from contralateral and ipsilateral electrodes PO7 and PO8 for animal and man-made object search across categorization levels. The gray bar represents the 200-300 ms N2pc time window. *$p < .05$.

3.1.2. *ANOVA with Target Present trials*

To compare attentional selection to animal or man-made object targets across categorization levels, a 2 (category)×3 (categorization level: Exemplar-level Match trials, Basic-level Match trials, Superordinate-level Match trials) ANOVA revealed a main effect of categorization level, $F(2,28) = 6.20$, $p = .006$, $\eta^2_p = 0.31$. There was no main effect of category, $F(1,14) = 1.29$, $p = .275$, $\eta^2_p = 0.08$, nor an interaction between category and categorization level, $F(2,28) = 0.60$, $p = .555$, $\eta^2_p = 0.04$. Bonferroni-corrected pairwise comparisons ($\alpha = 0.017$) revealed a larger N2pc component for Exemplar-level Match ($M = -4.01$, $SD = 2.12$) than for both Superordinate-level Match ($M = -2.51$, $SD = 1.91$), $t(14) = -4.49$, $p = .002$, $|d| = 1.16$ and Basic-level Match ($M = -1.70$, $SD = 1.63$), $t(14) = -2.80$, $p = .043$, $|d| = 0.72$. There was no difference in N2pc amplitudes between Basic-level Match trials and Superordinate-level Match trials, $t(14) = -0.69$, $p > .99$, $|d| = 0.18$.

3.1.3. *ANOVA with Foil trials*

To compare the attentional capture of animal and man-made object Foils across categorization levels, a 2 (category) × 2 (categorization level: Foil trials from Exemplar-level Search and Foil trials from Basic-level Search) ANOVA revealed a main effect of categorization level, $F(1,14) = 9.54$, $p = .008$, $\eta^2_p = 0.41$. Pairwise comparison revealed a larger N2pc component during Foil trials from Exemplar-level Search (non-target images of the target item type, $M = -2.71$, $SD = 2.47$) compared with Foil trials from Basic-level Search (non-target items from the category, $M = -1.70$, $SD = 1.63$), $t(14) = -3.09$, $p = .008$, $|d| = 0.80$. There was no main effect of category, $F(1,14) = 3.79$, $p = .072$, $\eta^2_p = 0.21$. However, there was an interaction between category and categorization level, $F(1,14) = 7.11$, $p = .018$, $\eta^2_p = 0.34$. Pairwise comparisons between animal versus man-made objects for Foil trials revealed that during Exemplar-level Search, the N2pc amplitude was larger when searching for a specific animal image ($M = -3.73$, $SD = 2.68$) than when searching for a specific man-made object image ($M = -1.70$, $SD = 1.82$), $t(14) = -2.62$, $p = .020$, $|d| = 0.68$ (Fig. 7). There was no significant difference in N2pc amplitudes between animals and man-made objects for Foil trials during Basic-level Search, $t(14) =$

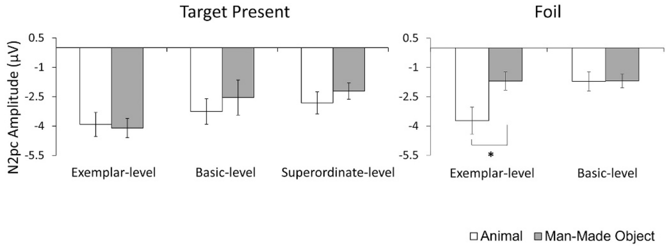

Fig. 7. Mean N2pc amplitudes for animal and man-made object search across the categorization levels (Target Present trials: Exemplar-level Search, Basic-level Search, and Superordinate-level Search; Foil trials: Exemplar-level Search, and Basic-level Search) for the 200-300 ms time window. Error bars represent ±1 SE. *$p < .05$.

-0.05, $p = .959$, $|d| = 0.01$.

3.2. N2pc onset latencies

N2pc onset latencies were analyzed separately for correct Target Present and Foil trials, using a jackknife-based approach (see Miller et al., 1998) with a standard amplitude threshold of -1 μV.

3.2.1. Latencies for Target Present trials

To examine potential temporal differences in attentional selection between animals and man-made objects, a 2 (category) × 3 (categorization level) ANOVA revealed a significant main effect of category, $F(1,14) = 454.46$, $p < .001$, $\eta^2_p = 0.97$, with faster onset latencies for animals ($M = 174.49$ ms, $SD = 5.03$) than for man-made objects ($M = 207.64$, $SD = 3.61$). There was a main effect of categorization level, $F(2,28) = 112.82$, $p < .001$, $\eta^2_p = 0.89$. Bonferroni-corrected pairwise comparisons ($\alpha = 0.017$) revealed a faster N2pc onset latency for Exemplar-level Match ($M = 176.20$, $SD = 6.16$) than for both Superordinate-level Match ($M = 200.33$, $SD = 1.63$), $t(14) = -17.72$, $p < .001$, $|d| = 4.57$, and Basic-level Match ($M = 196.67$, $SD = 5.89$), $t(14) = -9.15$, $p < .001$, $|d| = 2.36$. There was no difference in latency between Basic-level Match trials and Superordinate-level trials, $t(14) = -2.51$, $p = .075$, $|d| = 0.65$. There was an interaction between category and categorization level, $F(2,28) = 3.71$, $p = .04$, $\eta^2_p = 0.21$. Pairwise comparisons of Target Present trials between animals and man-made objects across different categorization levels revealed faster onset latency for animals over man-made objects for Exemplar-level Match (animals: $M = 160.53$, $SD = 12.20$; man-made objects: $M = 191.87$, $SD = 1.41$), $t(14) = -9.91$, $p < .001$, $|d| = 2.56$, for Basic-level Match (animals: $M = 177.47$, $SD = 1.77$; man-made objects: $M = 215.87$, $SD = 11.17$), $t(14) = -13.73$, $p < .001$, $|d| = 3.55$, and for Superordinate-level Match (animals: $M = 185.47$, $SD = 3.25$; man-made objects: $M = 215.20$, $SD = 1.27$), $t(14) = -31.18$, $p < .001$, $|d| = 8.05$.

3.2.2. Latencies for Foil trials

To test the latency of attentional capture of animal or man-made object foils, a 2 (category) x 2 (categorization level) ANOVA revealed a main effect of category, $F(1,14) = 349.07$, $p < .001$, $\eta^2_p = 0.96$, with faster onset latencies for animals ($M = 195.80$ ms, $SD = 2.91$) than for man-made objects ($M = 220.80$, $SD = 4.06$). There was a main effect of categorization level, $F(1,14) = 65.30$, $p < .001$, $\eta^2_p = 0.82$. Specifically, there was a faster N2pc onset latency for Foil trials during Exemplar-level Search ($M = 202.87$, $SD = 3.34$) than during Basic-level Search ($M = 213.73$, $SD = 3.73$). There was an interaction between category and categorization level, $F(1,14) = 7.99$, $p = .01$, $\eta^2_p = 0.36$. Pairwise comparisons revealed faster onset latencies for animals over man-made object foils during both Exemplar-level Search (animals: $M = 189.07$, $SD = 5.39$; man-made objects: $M = 216.67$, $SD = 2.09$), $t(14) = -22.59$, $p < .001$, $|d| = 5.83$, and Basic-level Search (animals: $M = 202.53$, $SD = 1.41$; man-made objects: $M = 224.93$, $SD = 7.36$), $t(14) = -11.52$, $p < .001$, $|d| = 2.98$, with a larger difference between the latencies for animals than man-made objects during Exemplar-level than Basic-level Search.

3.3. Behavioral results

Accuracy and reaction time (RT) on correct trials for Exemplar-, Basic-, and Superordinate-level Search for animals and man-made objects are illustrated in Fig. 8. As with the EEG data, the behavioral data were also averaged across elongated and round shapes within each category. The behavioral data for Target Present versus Foil/Target Absent trials were analyzed separately because different behavioral responses were required. For the five participants with partial EEG data, only one of them did not have the full behavioral dataset for the analyses. As with the EEG analyses, pairwise comparisons among categorization levels were Bonferroni-corrected, whereas pairwise comparisons between animals and man-made objects were not corrected because they were planned comparisons.

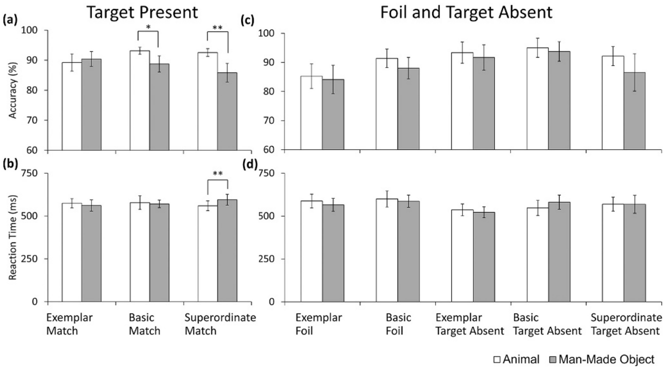

Fig. 8. Mean accuracy and reaction time for correct trials for animal and man-made object search for the Target Present trials across Exemplar-level Search (Exemplar Match), Basic-level Search (Basic Match), and Superordinate-level Search (Superordinate Match; Fig. 8a, b), and for the Foil trials during Exemplar-level Search (Exemplar Foil) and Basic-level Search (Basic Foil), and Target Absent trials (Fig. 8c, d). Error bars represent ±1 SE. $^{*}p < .05$, $^{**}p < .01$.

3.3.1. Target Present trials

A 2 (category: animal and man-made objects) × 3 (categorization level: Exemplar-level Match, Basic-level Match, and Superordinate-level Match) ANOVA was conducted on accuracy and RT, respectively. There was a significant main effect of category for accuracy, $F(1,14) = 8.82$, $p = .010$, $\eta^2_p = 0.39$ but not for RT: $F(1,14) = 0.42$, $p = .529$, $\eta^2_p = 0.03$. Accuracy was higher when searching for animals ($M = 91.64$, $SE = 7.51$) than for man-made objects ($M = 88.33$, $SE = 10.69$). There was no main effect of categorization level for accuracy, $F(2,28) = 0.77$, $p = .473$, $\eta^2_p = 0.05$, or for RT, $F(2,28) = 0.60$, $p = .555$, $\eta^2_p = 0.04$. However, there was an interaction between category and categorization level for accuracy, $F(2,28) = 4.87$, $p = .015$, $\eta^2_p = 0.26$, but not for RT, $F(2,28) = 1.62$, $p = .217$, $\eta^2_p = 0.10$. Planned pairwise comparisons revealed that during Basic-level Search, accuracy was higher when searching for an animal ($M = 93.13$, $SD = 4.53$) than for a man-made object ($M = 88.77$, $SD = 10.47$), $t(14) = 2.16$, $p = .048$, $d = 0.56$. Additionally, as expected, during Superordinate-level Search, accuracy was higher and RT was faster when searching for any animals (accuracy: $M = 92.55$, $SD = 4.99$; RT: $M = 559.77$, $SD = 110.18$) than for any man-made objects (accuracy: $M = 85.83$, $SD = 12.05$; RT: $M = 595.32$, $SD = 123.69$), accuracy: $t(14) = 3.38$, $p = .004$, $d = 0.87$ (Fig. 8a), RT: $t(14) = -3.29$, $p = .005$, $|d| = 0.85$ (Fig. 8b). There were no other significant results.

3.3.2. Foil and Target Absent trials

A 2 (category) × 5 (categorization level) ANOVA was conducted on accuracy and RT, respectively. There was a significant main effect of categorization level for accuracy, $F(4,56) = 8.54$, $p < .001$, $\eta^2_p = 0.38$, and for RT: $F(4,56) = 5.67$, $p = .001$, $\eta^2_p = 0.29$. Bonferroni-corrected pairwise comparisons among the 5 categorization levels ($\alpha = 0.01$) revealed that during Exemplar-level Search, performance was worse and slower for Foil trials (accuracy: $M = 84.69$, $SD = 17.33$; RT: $M = 576.50$, $SD = 148.37$) than Target Absent trials (accuracy: $M = 92.50$, $SD = 15.37$; RT: $M = 529.27$, $SD = 127.70$), accuracy: $t(14) = -6.86$, $p < .001$, $|d| = 1.77$, RT: $t(14) = 4.55$, $p = .005$, $d = 1.18$. During Basic-level Search, accuracy for Foil trials ($M = 89.69$, $SD = 13.21$) was also lower than for Target Absent trials ($M = 94.38$, $SD = 12.75$), $t(14) = -4.53$, $p = .005$, $|d| = 1.17$. In addition, accuracy in Foil trials during Exemplar-level Search was worse than in Target Absent trials during Basic-level Search, $t(14) = -5.31$, $p = .001$, $|d| = 1.37$. The main effect of category was marginally significant for accuracy $F(1,14) = 3.90$, $p = .068$, $\eta^2_p = 0.22$, but not for RT: $F(1,14) = 0.17$, $p = .689$, $\eta^2_p = 0.01$. There was no interaction for either accuracy, $F(4,56) = 0.50$, $p = .734$, $\eta^2_p =$

0.04, or RT, $F(4,56) = 1.33$, $p = .270$, $\eta^2_p = 0.09$. Planned pairwise comparisons did not reveal significant differences between animal or man-made object search across the categorization levels for accuracy, $t < 1.62$ (Fig. 8c), nor for RT, $t < 1.49$, (Fig. 8d).

4. Discussion

The present study investigated whether and how the behavioral advantage of searching for animals compared with searching for man-made objects manifests early in visual search processes via the N2pc ERP component. Similar to He and Cheung (2019), we used images of animals and man-made objects (as well as fruits/vegetables as filler distractors) that were of comparable gist statistics to investigate the impact of higher-level, conceptual knowledge, instead of low- or mid-level visual properties, on visual search performance for the two categories. We also included visual search tasks at three different levels of categorization (exemplar, basic, superordinate) to measure differences in search efficiency based on the specificity of the target(s). We replicated a behavioral advantage for animals over man-made objects at the superordinate-level (animals versus man-made objects, He and Cheung, 2019), as well as observing the advantage for animals over man-made objects at the basic-level (e.g., squirrels, water bottles), but not at the exemplar-level.

For all search tasks, there was a significant N2pc component during the standard time window of 200-300 ms after stimulus onset, suggesting that both attentional selection during Target Present trials and Foil effects occurred across the categorization levels for the two categories. If the search advantage for animals over man-made objects occurs at the early stages of processing at all categorization levels, a larger N2pc component would be expected for animal targets compared with man-made object targets across all levels. Interestingly, although the N2pc amplitudes were large when either animal or man-made object targets appeared, the amplitude was larger for animal foils than for man-made object foils, but not with Target Present trials. Specifically, the effect with Foil trials was present only at the Exemplar-level. Perhaps, during Target Present trials, attentional selection in the presence of the target occurred the same way for both animals and man-made objects, whereas during Foil trials, the involuntary capture depended on the level of the category representation. It is important to note that although the Foil N2pc components during Exemplar-level Search were stronger for animals than for man-made objects, the behavioral results did not show significant differences between the two categories. Therefore, it is possible that the attentional capture of task-irrelevant stimuli may have been suppressed relatively quickly to minimize any interference later in the search process. Future studies should tease apart potential downstream effects driven by early processes that may influence overt attention or recognition.

In addition to the main effect of category, we observed some differences in the N2pc amplitude across the three categorization levels (Exemplar-level, Basic-level, and Superordinate-level). Previous studies have used the N2pc component to measure task-relevant attentional selection of either an exact exemplar (e.g., the letter A) or a whole category (e.g., any letters) and involuntary attentional selection of non-target items related to the target (Foil trials, e.g., Nako et al., 2014; Wu et al., 2015). The present study expanded this approach to include an Exemplar-level and Basic-level Search task. Because the degree of target specificity of animals and man-made objects was highest when searching for a specific image (Exemplar-level Search), we predicted that search efficiency would decrease when searching for multiple images of the same item (i.e., Basic-level Search) and even more so for multiple items within the animal or man-made object category. As expected, we found that target selection was better for Exemplar-level Match trials compared with Superordinate-level Match trials. Interestingly, the N2pc amplitude between Basic-level Match and Superordinate-level Match did not differ, despite Superordinate-level Search requiring a larger number of possible targets than Basic-level Match. The N2pc component during Exemplar-level Match trials was also larger than the N2pc during Basic-level Match trials. It is possible that the strong N2pc during Exemplar-level Match trials might be due to a priming effect of targets (Eimer et al., 2010), since there was only one target image for Exemplar-level Match trials, whereas multiple possible target images were used during Basic and Superordinate-level Match trials. However, it is unlikely that priming effects induced differences between animal and man-made object categories, given that priming effects would exist for both categories. Finally, we found a significant Foil N2pc during Exemplar-level Search for both animals and man-made objects, suggesting that when searching for specific images of items, participants exhibited involuntary activations of representations for multiple exemplars of the same basic-level item to guide their search (e.g., activating other dolphin images when searching for a specific target dolphin image). This result aligns with previous work demonstrating behavioral advantages for basic-level categorization (Jolicoeur et al., 1984; Maxfield and Zelinsky, 2012; Rosch et al., 1976). In addition, we found that the N2pc amplitude during Foil trials from Exemplar-level Search was larger than Foil trials from Basic-level Search, suggesting a stronger activation of task-irrelevant templates at the basic level (e.g., any dolphin images), presumably because basic-level representations are highly robust (Rosch et al., 1976), compared with the superordinate level representations (e.g., any animal images).

To further examine the potential differences in the precision of attentional templates (e.g., Eimer, 2014; Olivers et al., 2011) across categorization levels, the N2pc onset latency differences between the two categories were also examined. Indeed, we found that for both Target Present and Foil trials, the N2pc onset latencies were faster for animals than for man-made objects. Interestingly for Target Present trials, there was a faster onset latency for animals than for man-made objects but no difference in mean N2pc amplitude between the two categories. One possibility for this discrepancy is that attentional templates between animals and man-made objects, as measured by the N2pc amplitude, contain representations of the targets sufficient for attentional guidance, but the attentional template may be deployed faster when searching for animals compared with man-made objects. However, this would only be the case for trials in which the targets were present. When foils were present, N2pc components were larger for animals versus man-made objects during Exemplar-level Search, suggesting the activation of an attentional template of a basic-level representation. Overall, our finding that the N2pc components emerged faster for animals over man-made objects aligns with the argument that differences in the processing of the two categories emerge early during visual search, and that such differences are unlikely explained by low- or mid-level visual factors because the stimuli had comparable gist statistics.

Our findings build on and extend prior research exploring the nature and temporal dynamics of the search advantage for animals over man-made objects. While we acknowledge that the gist statistics and low-level visual features such as luminance, contrast, and power spectrum may not have exhausted all types of visual features, our findings suggest that the animate-inanimate distinction in visual search may not be solely driven by low- or mid-level visual features, but rather also by high-level complex categorical information (He and Cheung, 2019). One possibility that could account for our findings is that the higher-level feature space and feature overlap (e.g., eyes, heads) between different types of animals may be more homogeneous compared with man-made objects, potentially making it easier to search for animals than man-made objects. Another possibility is that the mental representations of animals and man-made objects may be informed by prior experiences with animals and man-made objects. Prior studies suggest that category representations that are used to guide search can depend on real-world experience (Hoemann et al., 2020; Mack and Palmeri, 2011; Tanaka, 2001; Tanaka and Taylor, 1991; Wu et al., 2015; Wu et al., 2017). Therefore, future research should consider how the search advantage for animals over man-made objects at the different categorization levels may be influenced by the amount and nature of real-world experience with the categories.

In conclusion, the present study provides evidence for an early search advantage for animals over man-made objects across multiple categorization levels from 200 ms after stimulus onset. Moreover, involuntary, task-irrelevant activation of related exemplars is also found to be consistently stronger when searching for a specific animal than a specific man-made object. These results cannot be explained by differences in low- or mid-level visual differences between the two categories, but rather may be driven by higher-level features (e.g., conceptual information about the categories). Investigating the relationship between categorization and visual search affords insights into the nature and the temporal dynamics of the representations used to identify and interact with animate and inanimate objects.

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