EJN European Journal of Neuroscience FENS Federation of European Neuroscience Societies

European Journal of Neuroscience, Vol. 39, pp. 1508–1516, 2014 doi:10.1111/ejn.12513

COGNITIVE NEUROSCIENCE

Stimulus duration and diversity do not reverse the advantage for superordinate-level representations: the animal is seen before the bird

Marlène Poncet[1,2] and Michèle Fabre-Thorpe[1,2]
[1]Centre de Recherche Cerveau et Cognition, UPS, Université de Toulouse, Toulouse, France
[2]CNRS CERCO UMR 5549, Pavillon Baudot CHU Purpan, BP 25202, 31052 Toulouse Cedex, France

Keywords: basic-level categorization, natural scenes, presentation time, stimulus diversity, visual categorization

Abstract

Basic-level categorization has long been thought to be the entry level for object representations. However, this view is now challenged. In particular, Macé *et al.* [M.J.-M. Macé *et al.* (2009) *PLoS One*, **4**, e5927] showed that basic-level categorization (such as 'bird') requires a longer processing time than superordinate-level categorization (such as 'animal'). It has been argued that this result depends on the brief stimulus presentation times used in their study, which would degrade the visual information available. Here, we used a go/no-go paradigm to test whether the superordinate-level advantage could be observed with longer stimulus durations, and also investigated the impact of manipulating the target and distractor set heterogeneity. Our results clearly show that presentation time had no effect on categorization performance. Both target and distractor diversity influenced performance, but basic-level categories were never accessed faster or with higher accuracy than superordinate-level categories. These results argue in favor of coarse to fine visual processing to access perceptual representations.

Introduction

Since the late 1970s, our understanding of the temporal order in which humans access object categories has been dominated by the classic studies of Rosch *et al.* (1976) and others (Mervis & Rosch, 1981; Murphy & Smith, 1982). They reported that humans are faster at accessing object representations at the basic level (e.g. dog) than at the superordinate level (animal) or the subordinate level (e.g. poodle). This standard view implies a hierarchical processing scheme for visual stimuli, with the basic level as an entry step to reach a more abstract superordinate level of object recognition.

At odds with that theory, several studies have suggested that superordinate-level information might be available before the processing of more detailed information (Sugase *et al.*, 1999; Löw *et al.*, 2003; Large *et al.*, 2004; Martinovic *et al.*, 2008). Directly tackling the well-established basic-level entry point for object representation, Macé *et al.* (2009) used a go/no-go paradigm, and showed that participants were ~50 ms faster at categorizing a briefly flashed image as containing an animal than categorizing it as containing a bird or a dog. This superordinate-level advantage has been replicated in another study (Praß *et al.*, 2013), and also in scene gist categorization (Joubert *et al.*, 2007; Loschky & Larson, 2010; Kadar & Ben-Shahar, 2012).

Correspondence: Michèle Fabre-Thorpe, [2]CNRS, as above.
E-mail: michele.fabre-thorpe@cerco.ups-tlse

Received 12 November 2013, revised 30 December 2013, accepted 13 January 2014

In these experiments, images were masked or flashed very briefly. It has been argued that such fast presentations could emphasize coarse visual information over basic-level information (Mack & Palmeri, 2011). If the period of stimulus information uptake is interrupted, either because of masking or because of very short stimulus presentation, then perhaps only the features that can be extracted very rapidly can be used for further processing (Lamberts & Freeman, 1999; Lamberts, 2000). Another effect of brief presentation is that visual information gathered from the stimulus could be minimal and/or degraded (Pothos & Chater, 2002; Close & Pothos, 2012). Coarse representation might be relatively immune to such noise, whereas it could be deleterious for detailed representations, leading to a shift towards superordinate-level representations. With flashed stimuli, the superordinate-level advantage could thus be potentially a direct consequence of the restricted time available for the collection of information.

An alternative explanation might possibly account for the contradictory results for superordinate-level or basic-level advantages seen in different studies. It concerns the homogeneity vs. heterogeneity of the stimulus sets used as targets and distractors. Studies have shown that a 'dog' basic categorization is faster if the distractor category only includes exemplars from a different superordinate-level category (vehicle) than if the distractors include exemplars from the same animal superordinate-level category (Bowers & Jones, 2008; Macé *et al.*, 2009). Indeed, the similarity between and within categories might have a role in the speed of categorization (Mohan & Arun, 2012).

By varying the presentation time of the stimuli, the type of object to be categorized, and the similarity within and between categories, we investigated the robustness of the superordinate-level advantage observed in go/no-go rapid visual categorization tasks.

Experiment 1: Stimulus duration

To test how stimulus duration would influence response latencies at different levels of visual categorization, we used an ultra-rapid categorization task introduced by Thorpe *et al.* (1996). Fast responses were encouraged by presenting a stimulus very briefly and by requiring go/no-go responses to be produced in a constrained time window (1 s). With this protocol, we investigated the effect of increasing the stimulus presentation time from 25 to 250 ms and 500 ms. If short stimulus duration emphasizes coarse processing, we should recover the basic-level advantage at longer presentation times. To generalize the results, both natural object categories (Experiment 1a) and artificial objects (Experiment 1b) were used.

Methods

Participants

Ten volunteers participated in Experiment 1a and Experiment 1b (four women, one left-handed; mean age, 29 years). Half of the participants performed Experiment 1a first, and the other half performed Experiment 1b first, with an interval of 1–5 days between the two experiments. All participants had normal or corrected to normal acuity, and provided written informed consent. The experiments received the approval of the French Ethical Committee (comité de protection des personnes Sud-Ouest et Outre-Mer I). They conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki), printed in the *British Medical Journal* (18 July 1964).

Apparatus and stimuli

Participants were seated in a dimly lit room, around 50 cm from a cathode ray tube screen (800 × 600 pixels; refresh rate, 120 Hz). Go response latencies were recorded via a response pad equipped with infrared diodes. The stimulus display and the response pad were synchronized with the refresh rate of the monitor.

All images used in the experiments were colored natural images chosen from the image sets used in previous studies (Macé *et al.*, 2009; Poncet *et al.*, 2012) and from the Internet. Objects were shown at various orientations, positions, and sizes (Fig. 1). The animal category included mammals, insects, birds, etc. The non-animal category included various vehicles and scenes without a specific foreground object (mountains, buildings, city, etc.). The content of each category is detailed in Table S1. Each participant saw the images (15° × 15° visual angle) only once. The level at which the image had to be categorized was randomly assigned, and the image status, target or distractor, depended on the level of categorization.

Procedure

Before the beginning of each 200-trial block, participants were told which category they had to respond to, and were trained on 20 images. To start a trial, subjects had to place their fingers on the response pad. A fixation square was then presented (600–1000 ms) at the center of a black screen, followed by the stimulus. Participants had to release their finger as quickly and as accurately as possible if the image contained a target object (they did not have to wait until the end of the stimulus presentation). Otherwise, they had to keep their finger on the response pad. The next trial started automatically after 1200 ms from stimulus onset. In each block, targets and distractors were equiprobable.

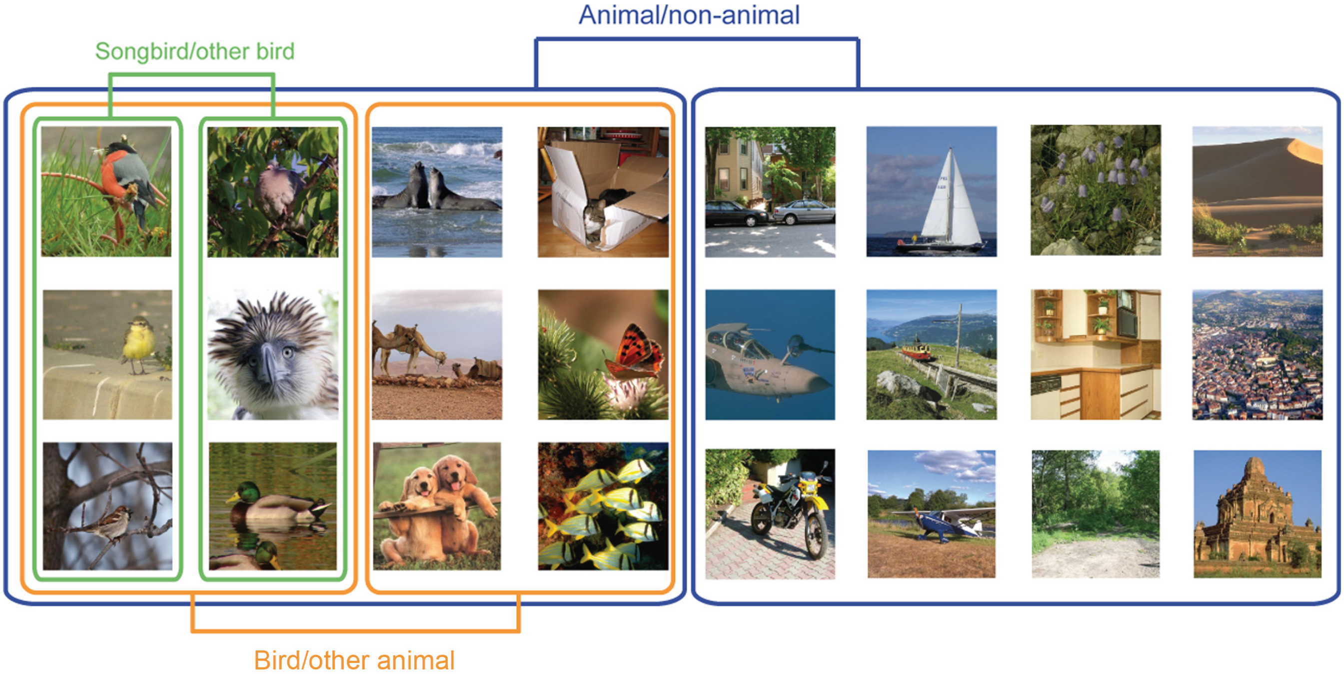

FIG. 1. Examples of images used in Experiment 1a. The three categorization tasks are framed according to the stimulus category: blue for the superordinate level; orange for the basic level; and green for the subordinate level. For each level of categorization, the target category is illustrated on the left and the distractor category on the right.

Experiment 1a. Participants had to categorize images of animals (vs. non-animals) at the superordinate level, birds (vs. other animals) at the basic level, and songbirds (vs. other birds) at the subordinate level. Each task was performed with three stimulus presentation times (25, 250, or 500 ms) for a total of nine blocks (three categorization levels × three presentation times). Block order was randomly assigned to the participants.

Experiment 1b. The same procedure was used with artificial objects: vehicles (vs. non-vehicles) at the superordinate level, motorcycles (vs. other vehicles) at the basic level, and Harley motorcycles (vs. other motorcycles) at the subordinate level.

Data analysis

For each participant, behavior was assessed by the use of median RT for correct go responses and d' [corrected by Snodgrass & Corwin (1988)]. Anticipatory responses (RT < 150 ms) and RTs that were > 1 s were rejected from the analysis (0.13% of the trials). Repeated measures ANOVAS (level of categorization × stimulus duration) were applied for each of the two experiments on median RT and d'. The same ANOVAS were performed without the subordinate-level results to enable a better comparison between superordinate-level and basic-level categorization performance. Sphericity of the data was assessed with Maulchy's sphericity test. Any violation was corrected with the Greenhouse–Geisser correction. When ANOVA results were significant for either the presentation time or the interaction factor, paired t-tests were applied to determine the relationship between the three presentation times. All t-test P-values reported in the article are those after Bonferroni correction. Results are given as average ± standard error of the mean (SEM).

Results

Accuracy

Accuracy was very high in all categorization tasks: approximately 90 ± 1% in Experiment 1a and 93 ± 1% in Experiment 1b. In Experiment 1a, increasing presentation times increased the accuracy of performance at all levels of animal categorization ($P = 0.003$, no interaction) (see detailed results and statistical comparisons in Fig. 2A and Table 1). On the other hand, presentation time had no effect on the categorization of vehicles, with the exception of the subordinate level of motorcycles (Experiment 1b, Harley), in which accuracy was lower at 25 ms than at 250 ms ($t_9 = 3.3$, $P = 0.03$) and 500 ms ($t_9 = 5.7$, $P = 1.4 \times 10^{-4}$).

Relative to basic-level categorization, accuracy at the superordinate level was either higher for natural objects ($P = 0.006$) or similar for artificial objects. For all experiments, subordinate-level categorization was performed with a lower d' than for the other levels of categorization, but still with very high accuracy scores (> 80%).

RTs

The main aim of the study was to determine the impact of stimulus presentation time on the response latency at the three different levels of categorization. The results were very clear in all three experiments: stimulus presentation time had no effect on RTs (Table 1).

Comparison of response latencies at the three levels of categorization showed that subordinate-level categorization was always performed most slowly ($P = 3.9 \times 10^{-11}$). Superordinate-level categorization was performed faster than basic-level categorization for animals as compared with birds (by 34 ± 3 ms; Experiment 1a; $P = 5.5 \times 10^{-7}$), but at similar speeds for vehicles as compared with motorcycles (Experiment 1b; 375 ± 14 ms and 373 ± 11 ms respectively; $P = 0.75$). As shown in Fig. 2B, the above results were valid for a large majority of the participants, and were not influenced by stimulus duration. The temporal advantage of superordinate-level over basic-level categorization for natural objects, and the absence of this for artificial objects, can be seen from the earliest responses. This is illustrated by the shift of RT distributions towards longer latencies for bird than for animal responses, and the overlap of RT distributions for vehicle and motorcycle responses (Fig. 3).

Discussion

Our results show no signs of a basic-level advantage that could appear with longer stimulus presentation times, which is at odds with many models of object recognition (Lamberts, 2000; Close & Pothos, 2012). Increasing presentation times increased accuracy for natural object categories, but response latencies remained unaffected.

One could argue that these results are the consequence of the restricted 1-s response time window that we used in our paradigm. It is very likely that, without time pressure, participants would slow down their responses to achieve higher accuracy for a 500-ms stimulus than for a 25-ms stimulus (accuracy trade-off). However, we show here that, with the same response criterion used in the different conditions, performance speed was not affected by the duration of the stimulus.

We found a superordinate-level advantage for animal over bird categorization but not for vehicle over motorcycle categorization. On the one hand, animals might be considered to constitute a very special category of biologically pertinent objects that rely on faster hard-wired neural mechanisms, possibly tuned by ancestral priorities (New *et al.*, 2007). On the other hand, animal and vehicle stimuli were categorized at the superordinate level with similar accuracies and RTs (RT, paired t-test $t_9 = 0.04$, $P = 0.9$; d', $t_9 = 0.97$, $P = 0.35$), a result that replicates the findings of a study by VanRullen & Thorpe (2001). It might, then, be possible that categorization performance for motorcycles reached the level of a superordinate-level categorization because this basic vehicle category is very homogeneous as compared with the bird category.

To test whether target heterogeneity could play a role in the results obtained, in Experiment 2 we used a more diverse basic category of vehicles (car). If categorization performance were similar for vehicles and cars, such as in Experiment 1b with vehicles and motorcycles, this would suggest special visual processing of animals. In contrast, if a superordinate-level advantage were observed, such as in Experiment 1a with animals and birds, this would indicate a role of stimulus diversity in categorization performance.

Experiment 2: Target category diversity

Methods

Experiment 2 was performed by 13 new volunteers (seven women, one left-handed; mean age, 25 years). The protocol was similar to that of Experiment 1, with cars (vs. other vehicles) at the basic level

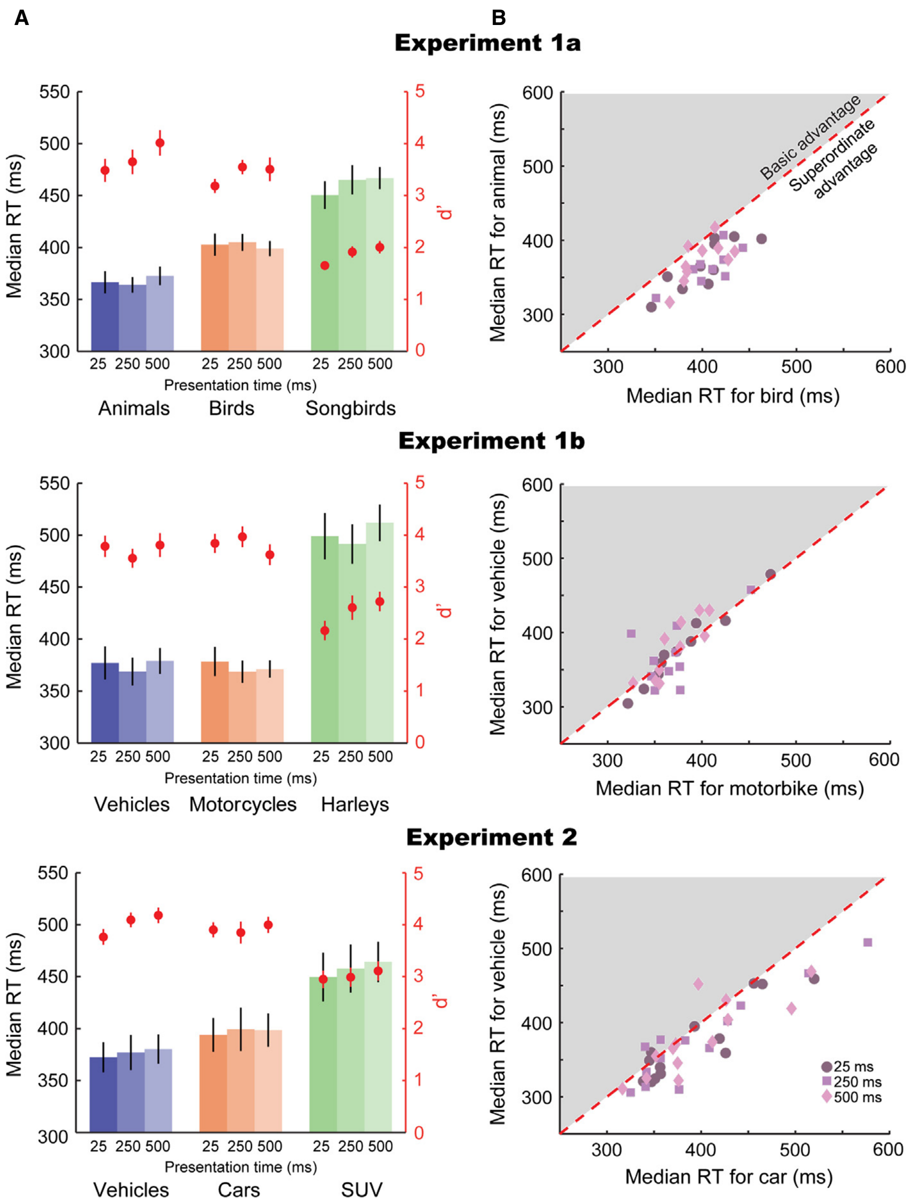

FIG. 2. Results of Experiments 1 and 2 with animal (Experiment 1a) or vehicle (Experiments 1b and 2) categories. (A) Bars illustrate the median RT at each presentation time for superordinate-level (blue), basic-level (orange) and subordinate-level (green) categorization. Red circles denote accuracy (d', see right y-axis). Error bars represent the SEM. (B) The median RT in the basic-level categorization is compared with the median RT in the superordinate-level categorization. Each symbol represents the performance of an individual participant for presentation times of 25 ms (dark circles), 250 ms (squares), and 500 ms (light diamonds). Symbols falling in the shaded area indicate a basic-level advantage.

and sport utility vehicles (SUVs) (vs. other cars) at the subordinate level.

Results

As observed in Experiment 1, accuracy was very high in all categorization tasks (94 ± 3%). Participants' accuracy (d') was similar for all presentation times (Fig. 2; Table 1), but lower for the subordinate-level categorization (SUV) than for other levels of categorization (vehicle and car). Thus, the pattern of d' results was very similar to that found in Experiment 1b, but that of RT results was not. SUVs were categorized more slowly than cars and vehicles, but, more importantly, cars were also categorized more slowly than vehicles (by 21 ± 6 ms; $P = 0.004$). Thus, we found a superordinate-level advantage with vehicles/cars as categories of artificial object. This effect was not affected by presentation time ($P = 0.65$), and was found in most of the participants (Fig. 2B).

Discussion

In this experiment, we tested whether we could replicate the results obtained in Experiment 1b when using a less homogeneous basic category of vehicle. As in Experiment 1b, our results showed no effect of presentation time. However, whereas vehicles and motorcycles were categorized with similar speed and accuracy in Experiment 1b, vehicles were categorized faster than cars in Experiment 2. This

TABLE 1. Statistical results of experiments 1 and 2. Repeated measures ANOVA between different levels of categorization were applied to median RT and d'

	Effect	RT F	RT P	RT η^2	d' F	d' P	d' η^2
Superordinate-level vs. basic-level categorization							
Experiment 1a: animal, bird	Category	$\mathbf{F_{1,9} = 155.69}$	$\mathbf{5.5 \times 10^{-7}}$	**0.94**	$\mathbf{F_{1,9} = 12.60}$	**0.006**	**0.58**
	Presentation time	$F_{2,18} = 0.06$	0.94	0.01	$\mathbf{F_{2,18} = 5.11}$	**0.02**	**0.36**
	Interaction	$F_{2,18} = 1.25$	0.31	0.12	$F_{2,18} = 1.03$	0.38	0.10
Experiment 1b: vehicle, motorcycle	Category	$F_{1,9} = 0.11$	0.75	0.01	$F_{1,9} = 1.85$	0.21	0.17
	Presentation time	$F_{2,18} = 0.87$	0.44	0.09	$F_{2,18} = 0.32$	0.73	0.03
	Interaction	$F_{2,18} = 0.87$	0.43	0.09	$F_{2,18} = 3.21$	0.06	0.26
Experiment 2: vehicle, car	Category	$\mathbf{F_{1,12} = 12.52}$	**0.004**	**0.51**	$F_{1,12} = 1.83$	0.20	0.13
	Presentation time	$F_{2,24} = 0.44$	0.65	0.04	$F_{1,17} = 2.08$	0.16	0.15
	Interaction	$F_{2,24} = 0.10$	0.90	0.01	$F_{2,24} = 1.88$	0.17	0.13
Superordinate-level vs. basic-level vs. subordinate-level categorization							
Experiment 1a: animal, bird, songbird	Category	$\mathbf{F_{1,17} = 120.00}$	$\mathbf{1.6 \times 10^{-7}}$	**0.93**	$\mathbf{F_{1,12} = 137.59}$	$\mathbf{3.0 \times 10^{-8}}$	**0.94**
	Presentation time	$F_{2,18} = 0.99$	0.39	0.10	$\mathbf{F_{2,18} = 8.32}$	**0.003**	**0.48**
	Interaction	$F_{4,36} = 1.57$	0.20	0.15	$F_{4,36} = 0.78$	0.54	0.08
Experiment 1b: vehicle, motorcycle, Harley	Category	$\mathbf{F_{2,18} = 130.64c}$	$\mathbf{1.9 \times 10^{-11}}$	**0.94**	$\mathbf{F_{2,18} = 77.29}$	$\mathbf{1.5 \times 10^{-9}}$	**0.90**
	Presentation time	$F_{2,18} = 1.37$	0.29	0.13	$F_{2,18} = 1.32$	0.29	0.13
	Interaction	$F_{4,36} = 1.71$	0.17	0.16	$\mathbf{F_{4,36} = 4.41}$	**0.005**	**0.33**
Experiment 2: vehicle, car, SUV	Category	$\mathbf{F_{1,11} = 35.28}$	$\mathbf{4.3 \times 10^{-6}}$	**0.75**	$\mathbf{F_{2,44} = 40.21}$	$\mathbf{2.2 \times 10^{-8}}$	**0.77**
	Presentation time	$F_{2,24} = 1.34$	0.28	0.10	$F_{2,44} = 2.83$	0.08	0.19
	Interaction	$F_{4,48} = 0.28$	0.89	0.02	$F_{4,48} = 1.21$	0.32	0.09

Significant values are in bold.

superordinate-level advantage replicates the results observed with animal and bird categories in Experiment 1a, albeit with a weaker effect. As already suggested, the difference between motorcycle and car categorization performance could be explained by the diversity of exemplars in the target category (cars are more diverse than motorcycles). Furthermore, the perceptual distance between targets and distractors might also have an effect on processing time (Mohan & Arun, 2012). The stronger superordinate-level advantage observed in Experiment 1a could thus result from the very large stimulus diversity in the animal kingdom and in each animal basic category. In contrast, the vehicle category is less diverse, and basic categories such as car and motorcycle are easily distinguishable from other vehicles. In Experiment 3, we further tested the influence of increasing and decreasing exemplar similarity on basic-level categorization performance. To this end, we manipulated the homogeneity of the animal image set, as this category is more diverse than the vehicle category.

Experiment 3: Image set homogeneity

Methods

Fourteen participants (11 women, one left-handed; mean age, 25 years) categorized images in a go/no-go paradigm similar to the one used in Experiment 1, but with stimuli always displayed for 250 ms. The stimulus diversity in the target and distractor sets was manipulated for basic-level categorization while instructions were kept the same (release your finger as quickly and as accurately as possible when you see a bird). The target category 'bird' could be restricted to birds of prey or could include different bird species. The distractor category 'non-bird animal' could be restricted to dogs or include any kind of animal. Therefore, basic-level categorization could be performed in three different conditions. Target and distractor categories could both be restricted (condition RR: bird of prey vs. dog), the target category could be broadly open with a restricted distractor category (condition BR: bird vs. dog), or both target and distractor categories could be broadly opened (condition BB: bird vs. non-bird animal). Participants were not told about the differences in the experimental design. They were also tested at the superordinate level (animal) and subordinate level (with bird of prey as target). The distractor category was restricted to vehicle at the superordinate level, and to songbird at the subordinate level. Participants performed a total of five blocks of 200 trials (three blocks at the basic level, RR-BR-BB; one block at the superordinate level; and one block at the subordinate level).

The median RT for correct go responses and d' were calculated for each participant. Paired t-test comparisons between the different types of categorization were applied (four comparisons in total: superordinate vs. BB condition, BB vs. BR condition, BR vs. RR condition, and RR vs. subordinate condition). All t-test P-values reported are those after Bonferroni correction. In order to determine the effect of restricting the distractor set at each level of categorization, we conducted an ANOVA on the results of Experiment 1a (when stimuli were presented for 250 ms) and Experiment 3 (with the BR condition at the basic level), using the level of categorization as a within-subject factor and the group of participants as a between-subject factor.

Results

The central manipulation of Experiment 3 was modulation of the homogeneity of the target and distractor sets when subjects were asked to perform the same basic-level categorization task. Increasing the diversity of the target set while keeping the distractor set restricted (comparison RR vs. BR) induced a significant 21-ms RT increase ($t_{13} = 3.3$, $P = 0.02$), but had no effect on d' ($t_{13} = 1.7$, $P = 0.46$) (Fig. 4). A further increase in stimulus diversity in the distractor set (comparison BR vs. BB) decreased d' by 0.7 ($t_{13} = 3.9$, $P = 0.007$), and had a tendency to increase RT ($t_{13} = 2.6$, $P = 0.09$).

Our results showed the same temporal dynamics for accessing the three levels of object representation as in Experiment 1. The

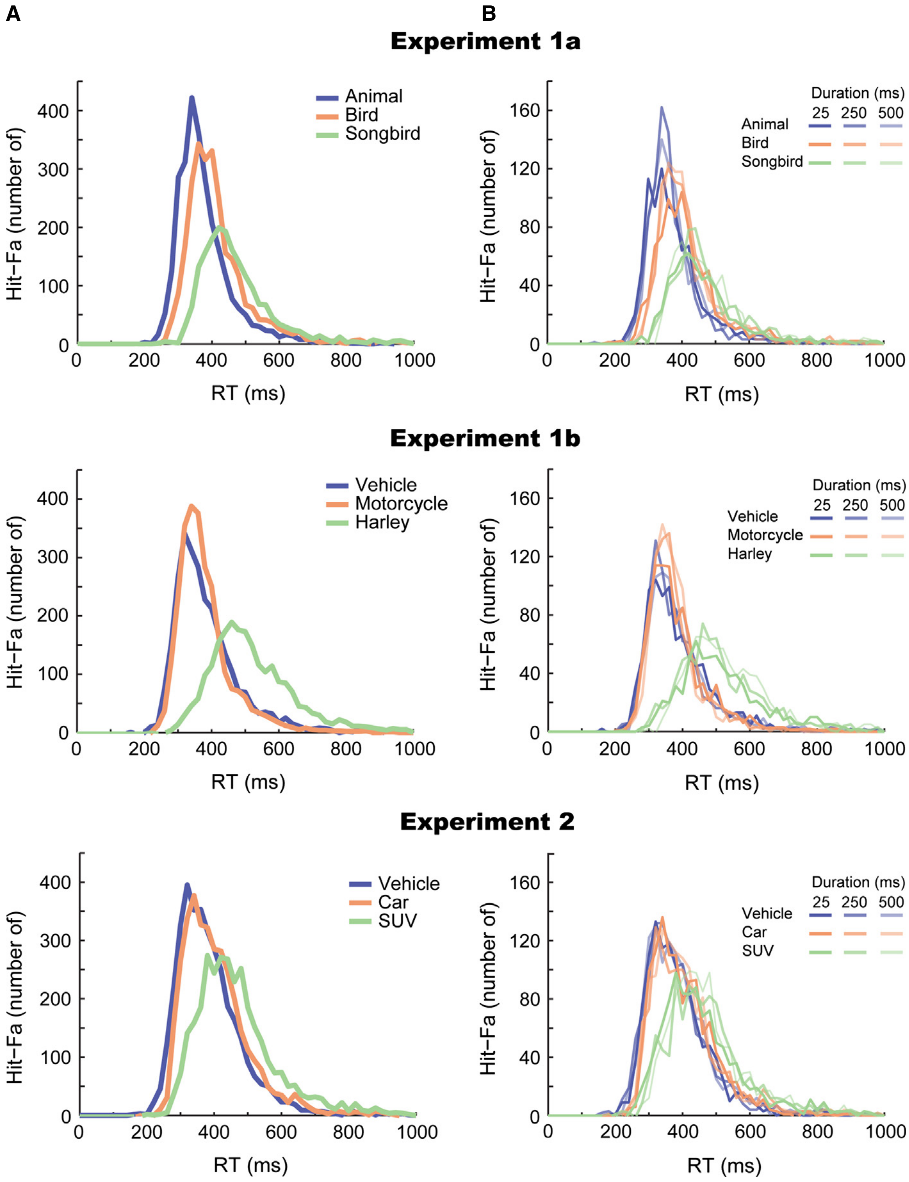

FIG. 3. RT distribution in Experiments 1a, 1b and 2 for superordinate-level (blue), basic-level (orange) and subordinate-level (green) categorization. Each RT distribution was obtained by subtracting the number of false alarms (Fa) from the number of Hits (Hit) in a 20-ms bin. The RT distribution is shown for three presentation times separately (B) or pooled (A). The longer the presentation time of the stimulus, the lighter the color of the curve.

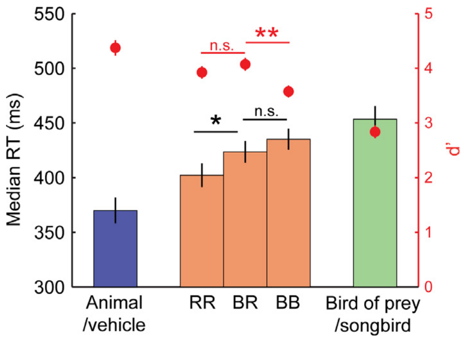

FIG. 4. RT (bars) and d' (red circles) in Experiment 3 for superordinate-level (blue), basic-level (orange) and subordinate-level (green) categorization. The stimulus diversity at the basic level was either: restricted for the target and distractor sets (RR); broad for the target and restricted for the distractor set (BR); or broad for the target and distractor sets (BB). Error bars represent the SEM. n.s., not significant. *$P < 0.05$, **$P < 0.01$.

superordinate-level advantage was still present even when basic-level categorization was made easier by restricting the diversity of the targets and distractors (comparison with RR condition). Participants were 32 ± 8 ms faster ($t_{13} = 3.78$, $P = 0.009$) and more accurate ($t_{13} = 3.35$, $P = 0.02$) in categorizing animals vs. vehicles than in categorizing birds of prey vs. dogs. In accordance with the results of Experiment 1, subordinate-level categorization was always performed less accurately than basic-level categorization. Participants performed bird of prey vs. songbird categorization with similar RTs ($t_{13} = 2.19$, $P = 0.19$) but with much lower d' values ($t_{13} = 8.86$, $P = 2.9 \times 10^{-6}$) than bird vs. animal categorization (BB condition).

An interesting comparison can be performed between the results obtained in Experiment 1a at 250 ms and Experiment 3. In Experiment 1a, whatever the level of categorization, the target and distractor sets were always broadly open. On the other hand, in Experiment 3, performance was investigated at all levels in the BR condition (distractors were restricted to vehicles at the superordinate

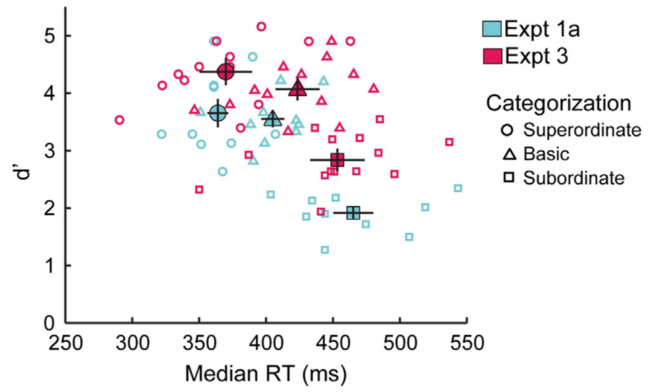

FIG. 5. Individual median RT as a function of d' in Experiment 1a (blue) and Experiment 3 (red) for categorizations at the superordinate level (circles), basic level (triangles), and subordinate level (squares). Filled shapes represent the average of performance in each condition. The distractor set diversity was broad in Experiment 1a but restricted in Experiment 3.

level and to songbirds at the subordinate level). Therefore, we could compare Experiment 1a and Experiment 3 to investigate the effect of restricting the distractor set at the three levels of categorization (Fig. 5). We found an effect of the level of categorization for both RT ($F_{2,44}$ = 109.2, $P = 8.7 \times 10^{-18}$, $\eta^2 = 0.85$) and d' ($F_{2,44}$ = 123.3, $P = 9.2 \times 10^{-19}$, $\eta^2 = 0.85$). These results were expected because, in both experiments, we found a superordinate-level advantage (therefore, no further *post hoc* analyses were performed). As observed at the basic level, increasing the diversity in the distractor set had no effect on RT ($F_{1,22}$ = 0.1, $P = 0.77$; no interaction, $F_{2,44}$ = 3.0, $P = 0.06$). However, d' values were significantly higher in Experiment 2 than in Experiment 1a ($F_{1,22}$ = 25.7, $P = 4.4 \times 10^{-5}$, $\eta^2 = 0.54$) at all levels of categorization (no interaction, $F_{2,44}$ = 0.9, $P = 0.39$).

Discussion

In this experiment, we again found that categorization at the superordinate level was performed faster and more accurately than categorization at the basic level or subordinate level. Increasing heterogeneity in the target or distractor sets had different behavioral effects: large target diversity increased RT, whereas large distractor diversity decreased d'.

In our results, the speed of categorization was mostly driven by modulation of the target set but not by modulation of the distractor set. One could argue that this is attributable to the paradigm used. In a go/no-go procedure, participants are more focused on the target category than on the distractor category, whereas in a yes/no paradigm, RTs could be adjusted for both target and distractor sets, making it more likely that a basic-level advantage could emerge. We tested this hypothesis in Experiment 4.

Experiment 4: Type of response

Methods

Nine participants (two women, one left-handed; mean age, 26 years) performed Experiment 4 in a procedure similar to that used in Experiment 1. Participants were tested in a go/no-go task and in a yes/no task on superordinate-level (animal vs. non-animal) and basic-level (bird vs. non-bird animal) categorization. Stimuli were always displayed for 250 ms (as in Experiment 3), and in both response conditions participants reported their responses on a keyboard. They had to keep their finger on the space bar and release it in the go/no-go condition, whereas in the yes/no condition they had to press the ‘c’ or the ‘n’ key for a ‘yes’ or a ‘no’ response, respectively. Median RTs for correct go and yes responses, as well as d', were calculated for each participant. Repeated measures ANOVAS (level of categorization × type of response) were then applied.

Results

Animal categorization was performed faster ($F_{1,8}$ = 39.5, $P = 2.4 \times 10^{-04}$, $\eta^2 = 0.83$) than bird categorization, but with similar d' ($F_{1,8}$ = 1.56, $P = 0.25$) (Fig. 6). Performance (RT and d') was lower with yes/no responses than with go/no-go responses (RT, $F_{1,8}$ = 25.5, $P = 0.001$, $\eta_2 = 0.76$; d', $F_{1,8}$ = 23.7, $P = 2.3 \times 10^{-4}$, $\eta^2 = 0.83$), as found previously (Bacon-Macé *et al.*, 2007), but this difference was the same for superordinate-level and basic-level categorization (no interaction: RT, $F_{1,8} = 1.4 \times 10^{-6}$, $P = 1.00$; d', $F_{1,8}$ = 0.01, $P = 0.93$), and was present from the earliest responses (Fig. S1).

Discussion

We found a 32 ± 6-ms superordinate-level advantage for both go and yes correct responses. Therefore, the adjustment of response thresholds for the target category does not depend on a specific type of response.

General discussion

The first goal of the study was to investigate alternative explanations that have been put forward to explain the superordinate-level advantage found in fast visual categorization tasks. According to Mack & Palmeri (2011), ‘with limited exposure, it is likely that only relatively coarse and potentially salient visual properties of an image are encoded … additional exposure would be necessary to encode more detailed features required for fast and accurate basic- or subordinate-level categorization’. Thus, superordinate-level representations would be favored because of the brief presentation of stimuli, which imposes temporal constraints on the collection of visual information. Our results showed that increasing stimulus duration did not prevent the superordinate-level advantage. Superordinate-level categories were always accessed with shorter processing times than other levels of category (except for the motorcycle category; but see late).

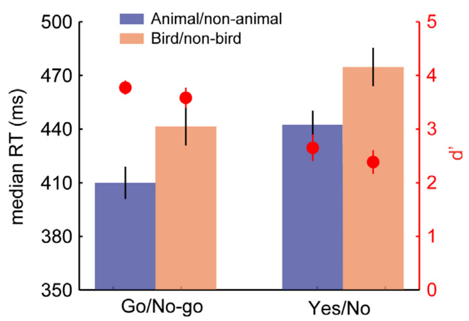

FIG. 6. Results of Experiment 4. Participants performed superordinate-level (blue) and basic-level (orange) categorizations in either a go/no-go (left side) or a yes/no (right side) task. Bars represent median RT and red circles d'. Error bars represent the SEM.

Furthermore, the superordinate-level advantage was not reversed by manipulating the diversity of exemplars in the target and the distractor sets (Experiment 3) or by using a new response mode (Experiment 4, yes/no). Thus, our results show that the superordinate-level advantage seen in rapid visual categorization tasks is robust, and is not a result of the coarser information quality associated with briefly flashed stimuli; the animal is seen earlier than the bird, whatever the quality of the gathered information.

The results of Experiment 3 showed that, whereas higher target heterogeneity induced longer RTs, higher heterogeneity among distractors decreased accuracy. When the target set is restricted, the number of relevant features may be smaller and more reliable than with a large diversity of target exemplars. One possibility is that the areas engaged in category decisions change their read-out of the visual cortical responses, and only focus on these relevant features (Li *et al.*, 2009). A non-exclusive alternative is that object-based attention could modulate bottom-up visual processing (Reynolds & Heeger, 2009; Miller *et al.*, 2011). The neuronal threshold could be adjusted to pertinent features, depending on the goal (look for the bird) and the context (target and distractor heterogeneity) of the task. After a correct trial, the amount of information required to reach the decision threshold will be reduced, until it increases again when an incorrect response is produced. These fluctuations will quickly stabilize, and the resulting decision threshold could be lower for a homogeneous set than for a heterogeneous set. This hypothesis might also explain why RTs for motorcycles and vehicles were similar in Experiment 1b. The shorter RTs for motorcycles than for other basic-level object categories might be explained by higher homogeneity in the motorcycle set of images: different motorcycles are perceptually more similar than different cars. Thus, at a given level of categorization (e.g. basic), increased homogeneity in the target set (while the same distractor set is kept) could correlate with shorter RTs. These assumptions could be tested in a computational model.

On the other hand, it seems that accuracy scores depend mostly on the number of features shared between targets and distractors. When the distractor category is large, the probability of finding a relevant feature in a distractor image increases, which could lead to more false alarms. This result fits with the study of Macé *et al.* (2009), where they found that false alarms were mostly seen with distractors that were similar to the target category. When participants were performing a dog categorization task, false alarms often occurred for wolves and foxes, whereas when participants were performing a bird categorization task, false alarms occurred for fish and insects.

It should be noted that the stimuli were unmasked in the present study, as the goal was to reproduce the experimental conditions used in most ultra-rapid categorization studies. Indeed, a mask would have interrupted, disturbed and/or limited the processing of the stimulus, when our goal was to allow maximal processing of the information collected with longer stimulus presentation time (using situations close to normal viewing conditions). Although we cannot draw any conclusions about whether the superordinate-level categorization is a necessary stage in reaching basic-level representations (Mack *et al.*, 2009), we clearly show that superordinate-level representations can be accessed faster than basic-level ones, which is at odds with the basic-level advantage often reported.

The go/no-go paradigm used in the present study appears to be a good protocol with which to study the time course of perceptual categorization. In contrast, the verification tasks typically used in experiments where a basic-level advantage has been reported (e.g. Rosch *et al.*, 1976) might not reflect the steps of pure visual processing. For each trial, the name of the target category was presented before the stimulus, meaning that the task also involves reading and language areas. The instruction probably triggers iterative loops between the different cortical areas, in order to prepare and modulate the threshold of the neurons involved in the task, which could favor basic-level over superordinate-level responses. However, in a go/no-go paradigm, the instruction is only given at the beginning of the block. Object processing might be independent from language areas, as the neuronal threshold in the visual system will be adjusted following correct and incorrect responses. Indeed, RTs in ultra-rapid categorization tasks are much faster than in any verification task, and these ultra-rapid categorization tasks can be performed by monkeys that do not have access to language and have performance levels very similar to those of humans (Macé *et al.*, 2010; Fize *et al.*, 2011). Whatever the level of categorization, the system is in an optimal state to process upcoming visual information, and our results clearly show faster access to superordinate-level representations. Moreover, they also show that this superordinate-level advantage does not result from degraded information that would favor coarse representations, as it is very robust to increasing stimulus duration.

Another explanation for the superordinate-level advantage comes from electrophysiological and functional magnetic resonance imaging results. It has been shown that the brain activity elicited in the infero-temporal cortex by a visual object is most dissimilar between animate and inanimate objects (Kiani *et al.*, 2007; Kriegeskorte *et al.*, 2008). Superordinate-level categorization tasks, which compare animate and inanimate object categories, might directly rely on this brain organization, and would thus be performed faster than basic-level categorization tasks, which compare different animate exemplars.

To conclude, this study shows that the advantage of the superordinate level of categorization over basic-level representations revealed by rapid categorization tasks persists even when long stimulus durations up to 500 ms are used. It also reveals that increasing exemplar diversity in the target and distractor exemplar sets does not reverse the superordinate-level advantage but has differential effects on performance. Our results are in favor of the idea that visual processing first accesses coarse representations, before allowing finer differentiation. This might be supported by the clear difference between the brain activities elicited by animate and inanimate objects.

Supporting Information

Additional supporting information can be found in the online version of this article:

Table S1. Description of the content of each target and distractor images set in Experiment 1a, Experiment 1b and Experiment 2 for the three categorization tasks.

Fig. S1. RT distributions (20-ms bins) in Experiment 4 for superordinate-level (blue) and basic-level (red) categorization in either a go/no-go task (darker curves) or a yes/no task (lighter curves).

Acknowledgements

We thank Simon Thorpe for helpful comments on the manuscript. The authors declare no conflict of interests.

Abbreviations

RT, reaction time; SEM, standard error of the mean; SUV, sport utility vehicle.

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