A Natural Bias For the Basic Level?

Annie Archambault (ANNIE@PSY.GLA.AC.UK)
Frédéric Gosselin (GOSSELIF@PSY.GLA.AC.UK)
Philippe G. Schyns (PHILIPPE@PSY.GLA.AC.UK)
Department of Psychology, University of Glasgow
58 Hillhead St., Glasgow G12 8QB UK

Abstract

It is well established that people can categorize the same objects at different levels of abstraction (i.e., superordinate, basic, and subordinate). Of these, the basic level is known to have a privileged status that is often attributed to the organization of categories in memory. Here, we argue that the bias could in part arise from the image formation process itself—i.e., the object properties for categorization that arise from the 2D retinal projections of distal 3D objects. In the real world, people do categorize objects from a variety of viewing distances and these modify the availability of object information on the retina. In two experiments, we tested the hypothesis that the information for basic categorizations is more resistant to changes in viewing distance than that of subordinate categorizations.

Casual observers would experience little difficulty to categorize the animals in Figure 1 as exemplars of *dog* and those of Figure 2 as exemplars of *whale*. If they were “experts”, they could categorize these animals as *Saint-Bernard dog*, *Doberman dog*, *Sperm whale*, and *Humpback whale*. People can similarly apply different levels of category abstraction to the 3D distal objects that impinge on their retina.

Rosch et al.’s (1976) seminal research isolated three “natural” levels of object categorization: the superordinate (*animal, vehicle, furniture*), the basic (*dog, car, chair*), and the subordinate (*Saint-Bernard dog, Porsche, Chippendale chair*). Of these, the basic and subordinate are thought to be closer to perception and we will focus on their main differences. The former level is superior to the later in a number of ways:

(1) Categories at the basic-level are verified fastest (see also Hoffmann & Ziessler, 1983; Jolicoeur, Gluck & Kosslyn, 1984; Murphy, 1991; Murphy & Smith, 1982; Murphy & Brownell, 1985; Tanaka & Taylor, 1991).

(2) Objects are named faster at the basic than at the subordinate level (Hoffmann & Ziessler, 1983; Jolicoeur, Gluck & Kosslyn, 1984; Murphy, 1991; Murphy & Smith, 1982; Murphy & Brownell, 1985; Rosch et al., 1976; Tanaka & Taylor, 1991; Johnson & Mervis, 1997).

(3) Objects are preferentially designated with their basic-level names (Berlin, 1992; Brown, 1958; Rosch et al., 1976; Tanaka & Taylor, 1991; Wisniewski & Murphy, 1989).

(4) Throughout development, basic names are learned before subordinate names (Anglin, 1977; Brown, 1958; Rosch et al., 1976; Horton & Markman, 1980; Markman, 1989; Markman and Hutchinson, 1984; Mervis and Crisafi, 1982).

(5) Basic names tend to be shorter (Brown, 1956; Rosch et al., 1976).

The origin of the bias to the basic level is still a matter of debate. In categorization, researchers have proposed that categories at the basic level are more *differentiated* that is, “... have the most attributes common to members of the category and the least attributes shared with members of other [contrasting] categories.” (Rosch et al., 1976, p. 435) The first component of this differentiation definition has been called the *specificity* (Murphy & Brownell, 1985), or the *informativeness* (Murphy, 1991) of a category, and the second component the *distinctiveness* of a category (Murphy & Brownell, 1985; Murphy, 1991). The difference between basic and subordinate categorizations would thus stem from distinct differentiations at these two levels. But the origin of these remain unspecified.

In recognition, researchers have sought to ground the basic level advantage on object properties (i.e., feature content). Rosch et al. (1976) found that basic-level categories are the most inclusive categories at which objects look alike. This suggests that shape is an important factor in the advantage of the basic over the subordinate level. One determinant of shape is part structure. Tversky and Hemenway (1984) found–for a broad range of natural categories including objects and organisms–a little increase in the number of listed parts from the basic to the subordinate level. Parts could therefore be a main determinant of basic-levelness. Jolicoeur, Gluck, & Kosslyn (1984) proposed that objects are initially recognized at the basic level on the basis of their parts, but also that these parts index the entry point to recognition. Entry point categories are usually at the basic-level but not always. To access categories below the entry point, such as Rosch’s subordinates, *additional perceptual information* is required (see also Biederman, 1987). This additional information was, however, left unspecified. Reflecting on the state of the art in object recognition, it is fair to say that the relationships between the basic level preference and its perceptual determinants are at a standstill.

From this brief review of the literature, two main stances emerge regarding the advantage of basic level over the subordinate categorizations:

(1) Categorization researchers have argued that the organization of categories in memory produces the faster access to the basic level (e.g. Murphy, 1991).

(2) Recognition researchers have proposed that categorization is faster at the basic level because the visual system is geared to extract parts from the input, and parts represented categories at the basic level (e.g. Biederman, 1987).

We will here present and test a third, and possibly simpler alternative: The bias for the basic level could arise from natural constraints on the image formation process that modifies the perceptual availability of object cues with changes of viewing distance.

People who recognize common objects tend to do so over a wide range of viewing distances. For example, you need to recognize your car at a distance in a parking lot, but you also need to recognize it from a closer range, when you are about to unlock its door.

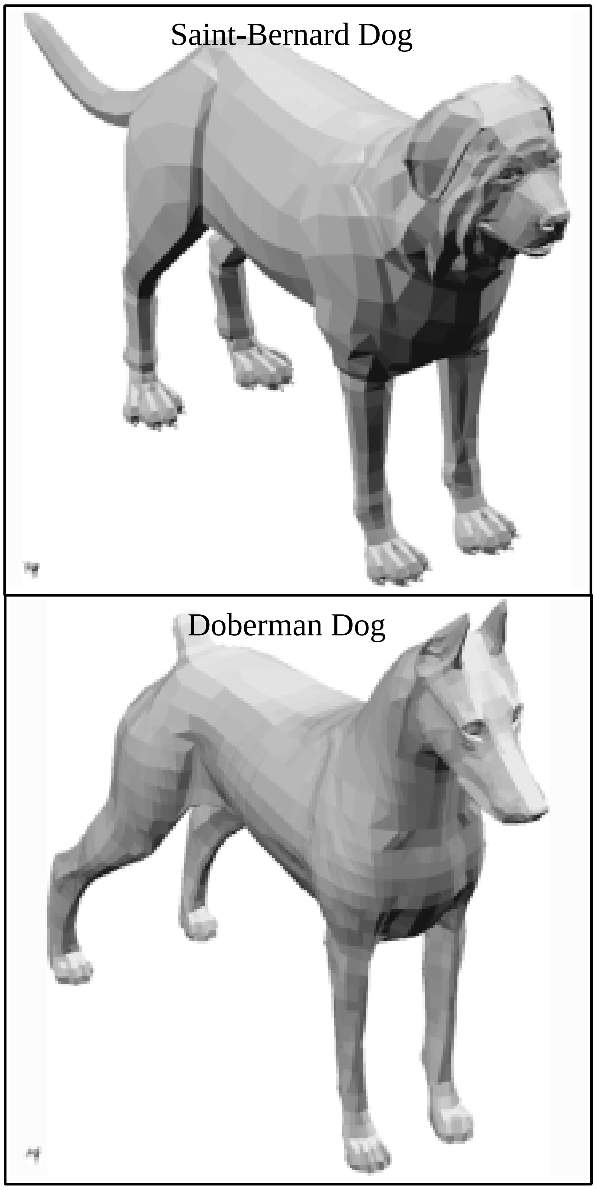

Figure 1. Three-quarter right views of the Saint-Bernard and the Doberman Dogs used in experiments 1 and 2. T The figure respects the proportions of the stimuli, not their absolute sizes: the large animals occupied 12 deg of visual angle; the small ones (see dark spots at the bottom-left of each large animal) .38 deg.

However, a simple computational argument can be made that changing the size of the retinal projection also changes the information available in the image for identification. Simply put, reducing the retinal projection of an object by a factor of two reduces its sampling frequency by the same factor. Simplifying a little, if one starts with a 512x512 original image, the reduction samples one pixel every other pixel to produce a 256x256 image.

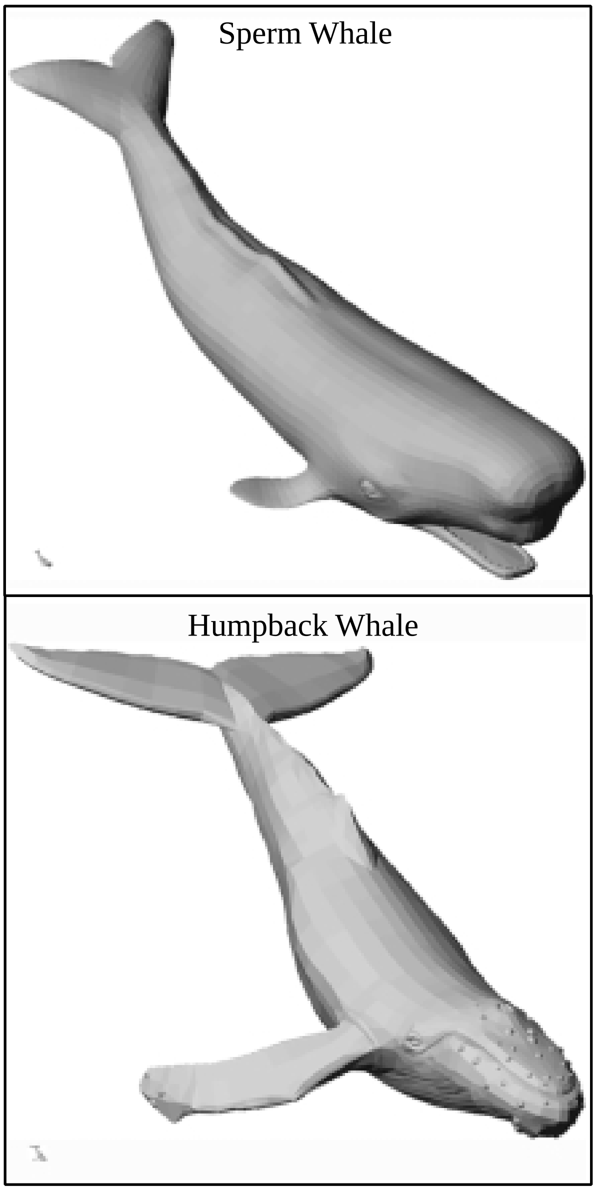

Figure 2. Three-quarter right views of the Sperm and Humpback Whales used in experiments 1 and 2. The figure respects the proportions of the stimuli, not their absolute sizes: the large animals occupied 12 deg of visual angle; the small ones (see dark spots at the bottom-left of each large animal) .38 deg.

Any variation that was expressed between any two adjacent pixels of the original image (e.g. a black and white contrast) is lost in the reduced image. (Technically, shrinking an image eliminates its high spatial frequency information). This produces a marked loss in information for visual categorization.

If we hypothesize that different basic and subordinate categorizations require visual information that resides at different scales of the stimulus, changing the scale of one stimulus could produce markedly different patterns of categorization performance. For example, removing large-scale information by reducing the size of objects could selectively impair the categorization level requiring the most specific details—i.e. the subordinate level. If this were the case, a bias to the basic level could arise from the statistics of categorization attributes over a wide range of viewing distances. Specifically, the attributes that access the basic level could have a greater resilience over scale changes than those accessing the subordinate level. This natural bias on the availability of perceptual cues would shed a new light on the structure of the basic level. We would still not know exactly what is this “additional information” required for the subordinate, but we would know that it is resistant to scale changes.

Experiment 1

Experiment 1 was designed to investigate the interaction between the scale of objects and their levels of categorization. Stimuli were three-dimensional (3D) gray-level computer synthesized animal categories (*bird*, *cow*, *dog*, *horse*, *frog*, *turtle*, *spider* and *whale*) (e.g., see figures 1 and 2). A similarity judgment task required participants to establish whether two simultaneously presented animals were the same either at the BASIC level (e.g., are both pictures *cow* exemplars?) or at the SUBORDINATE level (e. g., are the two pictures the same cow?). The animal pairs represented either two identical individuals (e. g., the same cow), two members of the same animal category (e.g., two different cows) or two members of a different animal categories (e.g. a cow and a bird). Animal pairs could appear in one of six possible different sizes. Each pair stayed on the screen as long as participants deemed it necessary (self-paced judgments). If the perceptual cues needed for BASIC and SUBORDINATE judgments are available regardless of the scale of the objects, participants should not differ in performing basic and subordinate similarity judgments. However, if information differs for BASIC and subordinate categorizations, a reduction in stimulus size might differently affect performance.

It is important to stress that this task involves absolute levels of information. That is, participants can use all the information present in a stimulus pair, as the two animals remained on the screen until a similarity judgment was made. Failure to notice a difference in these conditions would imply that the required information had vanished.

Participants

Twenty Glasgow University students with normal or corrected vision were paid to participate in the experiment.

Stimuli

Stimuli were computer-synthesized 3D animals. The set of animals was composed of 8 different animal categories (*bird*, *cow*, *dog*, *horse*, *frog*, *turtle*, *spider* and *whale*), each comprising 2 different exemplars. All animals were presented at one of six different sizes. The largest size corresponded to 512 square pixels and the smallest one to 16 square pixels. Successive divisions (by 2) of the largest pictures produced all intermediate sizes. These sizes were 256, 128, 64, and 32 square pixels. They corresponded to about 12, 6, 3, 1.5, .75 and .38 degrees of visual angle, respectively. In total, 96 stimuli were created (8 animal categories * 2 individuals * 6 sizes). In addition, each object could be presented from two different viewpoints (separated by 95 degrees of rotation in depth), so that when two objects appeared in a pair they would never be strictly identical pictures and people would need to recognize the represented animals to judge their similarity.

Procedure

Before starting the experiment, each participant was instructed that they needed to make two different types of similarity judgments. To the question “Same animal category?” participants had to judge whether the two presented animals belonged to the same animal category (e. g., are both animals dogs?). To the question “Same individual?” the task was to decide whether both animals were the same exemplar (e. g., are both dogs the same individual?). Participants were told to take as long as they wished and to look very carefully at each animal pair before making a decision.

A trial started with the apparition of one animal pair on the computer monitor. The two animals appeared simultaneously and were always pictured from a different viewpoint. Participants could observe the animal pair for as long as they wished. A keypress would substitute that animal pair with a question of the screen. The question was either “Same animal category?”, "Different animal categories?", “Same individual?” or "Different individuals?". They then entered their judgment by pressing “yes” and “no” keys on the computer keyboard.

Experiment 1 comprised 4 main classes of trials depending on whether there was a match (vs. non-match) at the BASIC (vs. SUBORDINATE) level. Match trials at the BASIC level represented different animals from the same animal categories (e.g., two different dogs), whereas non-match trials represented animals from different animal categories (e.g., a dog and a cow). Match trials at the SUBORDINATE level represented 2 pictures of the same individual from a different viewpoint whereas non-match trials presented pictures of different individuals. With these specifications, BASIC-match and SUBORDINATE-non-match trials comprised the same animal-pairs. The experiment included 768 trials and lasted for about forty minutes. The order of trials was randomized across participants.

Results and Discussion

Remember that Experiment 1 sought to assess the interaction between the scale of objects and the level of categorization (basic vs. subordinate). Specifically, we tested that participants were equally good at assessing similarity judgments when they were required to do it at the basic level (e.g. same animal category?) and at the subordinate level (e.g., same individual?) when the scale of objects was large. A d’ measure, which includes both Hit (H) rate (saying that two animals are different when they are different) and False Alarm (FA) rate (saying that two animals are different when they are identical), was used as our dependent variable. The top of Figure 3 shows the average *d’*s across all subjects at the different scales and categorization levels.

A two-way, within-subjects ANOVA revealed significant main effects of size (512, 256, 128, 64, 32, 16 square pixels) $F(5, 95) = 38.59$, $p < .01$, level of categorization (Basic vs. Subordinate), $F(1, 19) = 66.29$, $p < .01$, and a significant interaction between these factors, $F(5, 95) = 5.80$, $p < .01$. Further analysis revealed that differences between levels of categorization were true for 16 square pixels, $F(1, 19) = 119.73$, $p < .01$, 32 square pixels, $F(1, 19) = 87.38$, $p < .01$, 64 square pixels, $F(1, 19) = 6.52$, $p < .01$, 128 square pixels, $F(1, 19) = 41.44$, $p < .01$ and 256 square pixels, $F(1, 19) = 13.11$, $p < .01$, but not for 512 square pixels, $F(1, 19) = 7.14$, *ns*.

Furthermore, the slope of the best subordinate linear predictor in Figure 2, top, is about twice as much as that of the basic (see continuous lines in Figure 3, top; R^2 = .63 and .81 for the best basic and subordinate fits).

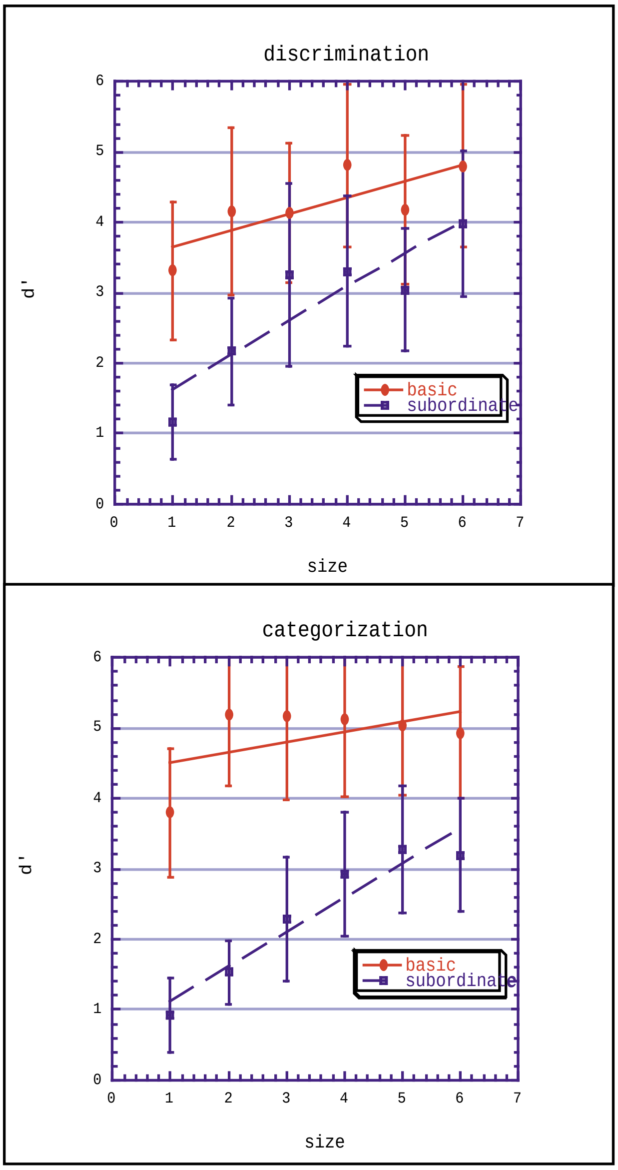

Figure 3. Average d's with standard deviations for Experiments 1 and 2 at the basic and subordinate categorization levels. The continuous lines are the best linear predictors. (Note that size 1 = .38 deg and that size 6 = 12 deg.)

Results reveal that at smaller scales (256 to 16 square pixels) identical animals pairs were easier to distinguish at the basic level than at the subordinate level (see Figure 3, top).

Experiment 2

Experiment 1 revealed that the information of SUBORDINATE-level judgments was less resilient to changes of scale than BASIC-level judgments. This is interesting because participants could use all the information available in the stimuli to resolve the task. It therefore suggests that the information for subordinate categorization vanished before that of basic categorizations.

However, one could oppose that the matching task of Experiment 1 might solicit representations and processes that are atypical of everyday categorizations. For instance, it is conceivable that participants relied simply on local one feature-difference to decide that two stimuli differed—e.g., if one of the two stimuli had a tail. Of course, this would not explain how they did when the stimuli did not differ, but it still triggers the more basic problem of generalizing from the results of Experiment 1 to realistic categorizations.

Experiment 2 was designed to directly probe everyday categorization processes. One criticism that is often leveled at experiments studying the nature of visual information in categorization tasks is that they use tachistoscopic conditions of stimulus presentation. Here, we made sure that the stimuli stayed on the screen for as long as the subjects felt necessary. This approach allows a measure of categorization performance in conditions of absolute information—i.e. information availability is not relative to speed of presentation.

Experiment 2 was a free categorization task. In a learning phase, participants learned to identify each of the sixteen animals at the basic and subordinate levels. They were then transferred to a categorization task where an animal (e.g., a whale) would appear on the screen (at one of 6 possible scales). After a self-paced scrutiny of the picture, participants were asked a question about the membership of the input to either a basic-level (is this a whale?), or a subordinate category (is this a sperm whale?). If the results of Experiment 1 tapped into the absolute levels categorization information then we expect the categorization results of Experiment 2 to follow a similar trend—i.e., a faster decrease of subordinate categorization accuracy with decrease in stimulus scale.

Participants

Twenty Glasgow University students with normal or corrected vision were paid to participate in the experiment.

Stimuli

The training set comprised gray-scale pictures of the 16 different individual animals. For each animal two pictures (showing the animals from two different view points–95 degrees apart in depth) were printed onto a white sheet of paper side by side. Pictures measured in total 10 x 10 cm. Each individual was identified by a sentence printed underneath the pictures. For example the two whales were identified as *sperm whale* and *humpback whale* (see Figure 2).

The stimuli used for the categorization task were the ones of Experiment 1 (e.g., see figures 1 and 2). The set consisted again of the 8 animal categories (2 individuals per animal category), the six different sizes and the two different viewpoints.

Procedure

During the training phase, participants learned to identify each of the sixteen animals at the basic and subordinate levels. We tested their knowledge by presenting them with the pictures alone, one at the time, and asking them to name the animal at the basic and subordinate levels. *Perfect naming* performance was required before going on to the categorization task. Corrective feedback was provided.

In the categorization task, participants were shown an animal on a computer monitor. Animals were presented from one of the two possible viewpoints and were displayed at one of the six different sizes. Participants were told that they could look at the animals for as long as they wanted. Once they were ready, a key press would initiate the disappearance of the animal and would display a question on the computer monitor. The question could either be basic ("Is it a cow?") or subordinate ("Is it a Fresian cow?"). Participants responded by pressing the appropriate key on the keyboard. The experiment included 768 randomized trials and lasted for about 50 minutes.

Results and Discussion

Remember that Experiment 2 was designed to replicate results of Experiment 1 with a categorization task. We were thus interested mainly in the proportion of correct responses. For each subject, we computed d’s for all sizes and categorization levels. The bottom portion of Figure 3 shows the mean *d*’s across subjects for the different sizes and categorization levels.

A two-way, within-subjects ANOVA revealed significant main effects of size (512, 256, 128, 64, 32, 16 square pixels) $F(5, 95) = 36.79$, $p < .01$, level of categorization (Basic vs. Subordinate), $F(1, 19) = 418.62$, $p < .01$, and a significant interaction between these factors, $F(5, 95) = 5.75$, $p < .01$. Further analyses revealed that differences between levels of categorization were true for 16 square pixels, $F(1, 19) = 174.53$, $p < .01$, 32 square pixels, $F(1, 19) = 379.61$, $p < .01$, 64 square pixels, $F(1, 19) = 119.23$, $p < .01$, 128 square pixels, $F(1, 19) = 68.95$, $p < .01$ and 256 square pixels, $F(1, 19) = 39.41$, $p < .01$, and for 512 square pixels, $F(1, 19) = 47.91$, $p < .01$.

The continuous lines on Figure 3, bottom, are the best linear predictors for the basic and subordinate *d*’s ($R^2 = .26$ and $R^2 = .92$, respectively). The slope of the subordinate line is more than three times that of the basic one.

Results thus reveal that, animals were easier to categorize at the basic level than at the subordinate level (see Figure 3, bottom).

General Discussion

This article tested the prediction that the preference for basic level categorizations could arise from a natural source of biases. When the retinal projection of one object shrinks in size (as happens when the object is moved further away from the observer), scale-specific visual information is lost. We tested the hypothesis that the basic and subordinate categorizations of identical objects require information that resides at different scales of the same distal stimulus. Two experiments tested these predictions.

In Experiment 1, participants in a similarity task were asked to judge whether two simultaneously presented objects had the same basic level, or the same subordinate category. We found that even though subjects could take *as long as they wanted* to inspect the object pairs, subordinate judgments were significantly more affected by a reduction in stimulus size than basic judgments. The unconstrained inspection licenses the conclusion that we are tapping into the absolute level of information required for basic and subordinate categorizations.

Experiment 2 addressed the objection that a similarity task might trigger processes and representations that are atypical of everyday categorizations. In a categorization task, subjects had to confirm that the input belonged to a basic, or to a subordinate category. Even though subjects could again scrutinize the stimuli without any time constraint, we found that subordinate categorizations were much less resilient to changes of stimulus size.

In sum, the two experiments reported here converge on the idea that the perceptual shape cues required to resolve subordinate categorizations are more sensitive to scale changes than those required of basic categorizations. This has a number of implications for theories of basic and subordinate level categorization and recognition that we consider in turn.

Remember that we hypothesized a natural bias for the shape cues that access the basic level because these might be more resilient to variations in viewing distances. The results confirmed the hypothesis. Our results predict that the more robust default categorization strategy is to categorize objects at the basic, not the subordinate level. It is important to stress that we do not know precisely what the important basic and subordinate cues were in our experiments. However, to the extent that basic categorizations were not much affected by changes in size, we can propose that the cues present at all sizes (i.e. coarse scale cues) supported basic categorizations. For example, silhouettes were clearly present at all sizes and they could very well subtend basic categorizations—at least in the tasks considered here. An alternative could be that different cues residing at different scales can independently index the basic level, a hypothesis that has never been explored. If part extraction relies on the fine-grain edge description outlined in Biederman (1987), it seems unlikely that a part description of the objects subtended basic categorizations in our experiments, because Biederman’s (1987) part description process is sensitive to scale.

Concluding Remarks

We have shown here that size matters for subordinate categorization. One possibility for the basic level bias results from the greater resilience of basic level cues over a range of viewing distances. Future research will need to be conducted to isolate what the scale-independent and the scale-dependent cues are that support basic and subordinate categorizations.

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