Learning Features of Representation in Conceptual Context

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Abstract

When people categorize an object, they often encode a certain number of its properties for later classification. In Schyns and Murphy (in press), we suggested that the way people group objects into categories could induce the learning of new dimensions of categorization--i.e., dimensions that did not exist prior to the experience with the categorization system. In this research, we examine whether the context of known concepts can influence feature extraction. The first experiment simply tested whether the context of different object categories could change the perception of the same target stimuli. The second experiment examined whether learning category *B* given the concept of category *A* may result in different features being learned that learning *A* given *B*. The results showed that the context of known concepts influence the features people learn to represent object categories.

Introduction

When people identify an object, they often encode a certain number of its properties for later classification. For example, an orange is commonly perceived as a round object of orange color with an orange-peel texture. These properties are then input to categorization processes which output "orange" instead of "lemon" or "apple." Many theories of object recognition and categorization assume this simple division of labor: Low-level perception encodes the input object along a *fixed set* of dimensions which are the input of categorization processes.

Presumably, the reason why people preferentially use shape, texture and color to describe fruits is that these properties are particularly informative to distinguish fruit categories. Category learning is often thought of as the process which groups into concepts the most informative properties among a fixed set of possible properties (e.g., Bruner, Goodnow & Austin, 1956; Bourne, 1986; Estes, 1986, among many others). From a developmental perspective the notion of a fixed set poses difficulties as it now seems clear that infants and young children are not aware of all the stimulus dimensions that become important in later category learning--in fact, the acquisition of new dimensions has often been used to explain discrepancies between children's and adults' word usage (e.g. Clark, 1983; Mervis, 1987). Similarly, when adults engage in tasks such as reading x-ray films, classifying pre-cambrian organisms or chicken sexing, they do not become experts overnight. Only extensive perceptual learning allows novices to notice the structures experts see (Biederman, 1987; Gibson, 1969; Lesgold, 1984).

Schyns and Murphy (1991, in press) suggested that the way people organize their world could influence their perception of objects (see also Goldstone, in press; Medin and Wisnieski, in press, Schyns, 1991). Specifically, the grouping of objects into categori es could induce the learning of new dimensions of cat egorization--i.e., dimensions that did not exist prior to the experience with the categorization system. Schyns and Murphy gave a functional definition of features that attributes an important role to perceptual *and* categorical structures. The Functionality Principle summarizes this view (Schyns & Murphy, in press): If a fragment of stimulus categorizes objects (distinguishes members from nonmembers) the fragment is instantiated as a unit in the vocabulary of object concepts. The Functionality Principle claims that the vocabulary of categorization is not necessarily fixed, but rather expandable--i.e., not independent of the process of category formation, but intertwined with it. The aim of this research is to investigate further the constraints a categorical context imposes on feature extraction.

An important implication of the Functionality Principle is that the vocabulary of representation not only characterizes members of a category, but also distinguishes members of contrast categories. Thus, contrast categories could influence feature extraction. To illustrate how this might work, imagine you were a Martian with no experience of Earth objects. The first objects you learn about are a bunch of glasses which, as we know, have a cylindrical shape. However, your Martian vocabulary does not possess *cylinder* as a feature. So, you encode the cylindrical shape of glasses with the new *cylinder* unit in your vocabulary. From now on, you can use the unit *cylinder* to categorize objects. On your second day of Earth life, you learn about mugs. Mugs have a cylindrical part, so they look like glasses, except that another fragment is systematically attached to

mugs. Because this fragment distinguishes the concept of *glass* from the new category *mug*, *handle* is added to your vocabulary, and *mug* is represented in memory with the units *cylinder* and *handle*.

The Martian example illustrates how concepts influences the learning of new units. When the vocabulary is not sufficient to distinguish a new category from known concepts, the fragment allowing the discrimination (*handle* in the previous example) is incorporated in the vocabulary as a new conceptual unit. Note that feature learning is not always reversible. That is, two categories *A* and *B* presented in a different order could induce people to extract different features. This occurs because learning category *B* given *A* may set different constraints for feature extraction than learning *A* given *B* . To illustrate, assume arrow's time goes backwards for our Martian: He learns about mugs before learning about glasses. Supposing his perceptual structures were roughly like ours, he could describe the mugs by mentioning that something seems to break the regularity of the surface. However, he needs not encode this fact to ide tify the mugs--perhaps they are the only small objects of that sort he has ever observed. The Martian may represent *mug* with a holistic, single unit (the shape of a mug as a chunk) in the vocabulary. It is not necessary to learn two units of representation when one unit performs the relevant categorization. When the Martian experiences glasses, the chunk *mug* is not a component of glasses as *cylinder* was of mugs. To distinguish the two categories, the Martian could simply instantiate *cylinder* as a new unit in his vocabulary. Thus, although the two Martians would categorize glasses and mugs equivalently well, different features and concepts would cause this behavior.

In short, we want to argue that the context of known concepts constrains the learning of new features. At any state of conceptual development, a set of features defines a repertoire of possible concepts--the set of all possible combinations of the features of the set, or more technically, the *closure* on the feature set. Known concepts are always a subset of this repertoire. Learning a new category either means finding a new combination of features within the conceptual repertoire, or expanding the repertoire by adding a new feature to the vocabulary. Which strategy applies depends on the similarities and contrasts between known concepts and the new category. Known concepts constitute a *categorical context* , they fix contrasts and similarities for concept learning and feature extraction processes.

The following experiments test a few predictions of feature learning in categorical context. The first experiment was a simple test of the idea that the context of different object categories could change the interpretation of the same target stimuli. The second experiment examined whether categorical context could induce the representation of two categories *A* and *B* with different features, depending on which category is the context of the other.

Experiment 1

The following experiments used unfamiliar categories of grey-level "Martian cells" similar to cells observed in a microscope. The rationale of Experiment 1 was to present two groups of subjects (the *A-BC* group and the *AB-C* group) with the context of two categories (respectively categories *A* and *BC* and categories *AB* and *C*) composed of different groupings of the same *a*, *b*, and *c* components. We expected the acquisition of a new vocabulary to be context dependent and to determine the parsing of test objects.

Methods

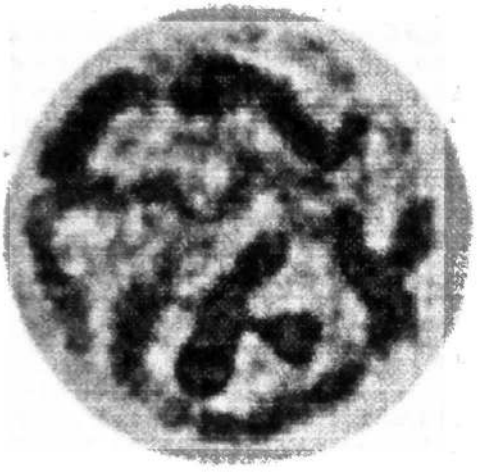
Subjects and Stimuli. Twenty-four Grenoble University students were randomly assigned to experimental conditions *AB-C* or *A-BC* with the constraint that the number of subjects be equal in each condition. We synthesized categories of "Martian cells" with 2D-graphics software on an Apple Macintosh computer. A Martian cell was created from a uniformly grey circle, by adding black parts (cell bodies) at random locations within the circle. Some parts defined the categories, other parts were distractors. A Gaussian filter was then applied to each cell to blend together the background circle and the organites (see Figure 1 for example of Martian cells). We synthesized a total of 4 learning categories, each composed of 5 Martian cells. Categories *A* and *C* were *simple* categories because a single component (respectively part *a* and part *b*) defined them. Categories *AB* and *BC* were *composed* categories because two components (respectively *ab* and *bc*) were adjacent to one another in the cells. Note that the adjacent components were always connected at loci of local minima of curvature, the perceptual constraint on part segmentation of Hoffman and Richards (1985). Testing cells *A*, *C*, *AB*, *BC* and *ABC* (see Figure 1) were named according to the simple or composed part they tested. Testing cells included the subcomponents *a* , *b* , *c* of the learning categories plus distractor components.

Procedure. In a learning phase, subjects were told that they would see 10 Martian cells, one at a time. Subjects were instructed to observe the pictures carefully (each on a separate page). In the *A-BC* (vs. *AB-C*) condition, subjects experienced the *A* (vs. *AB*) category and the *BC* (vs. *C*) category. (The order of presentation of the categories was counterbalanced.) Subjects were *not* instructed that the 10 stimuli formed two categories; categories were presented a maximum of 3 times, depending on subjects' self-assesment of their learning.

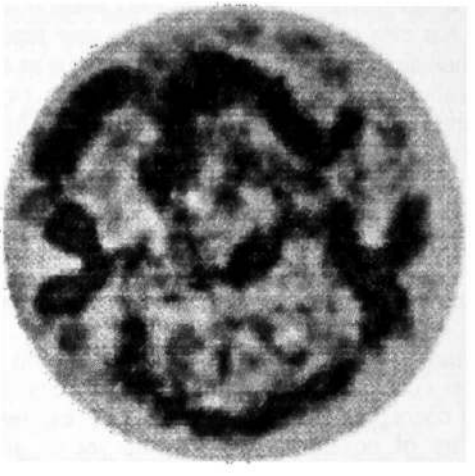
In a testing phase, subjects saw the five test stimuli in a random order, one at a time, on a CRT screen. Subjects were instructed to circle the parts of the cells by delineating them using a computer mouse (see Schyns and Murphy, 1991, 1993).

ABC cell

AB cell



C cell



A cell

BC cell

Figure 1 : This figure illustrates the exemplars of Martian cells used in the testing phase of Experiment 1. The simple *A* and *C* cells are respectively defined by the *a* and *c* components. Composed *AB*, *BC*, and *ABC* cells are defined by various combinations of the *a*, *b* and *c* components.

Results and Discussion.

If the context of different objects results in different units being learned, subjects should interpret the same test stimuli quite differently. *A-BC* subjects should analyze the new *ABC* test cell as a composition of *a* and *bc* , but *AB-C* subjects should perceive *ab* and *c*. We scored subjects on whether their segmentations of *ABC* was compatible with the *a* and *bc*, or with the *ab* and *c* vocabulary. A Chi-square test of association revealed a significant association between group (*A-BC* vs. *AB-C*) and type of delineation (*a* and *bc* vs. *ab* and *c*), $X^2(1) = 10.37, p < .01$.

To test further the hypothesis that subjects had extracted different vocabularies of object representation, we compared the delineations of the composed test stimuli. Our hypothesis was that *A-BC* subjects should segment *AB* in two parts (because *a* was a unit allowing the segmentation) but they should systematically delineate *BC* as a chunk. *AB-C* subjects should do the opposite (i.e., segment *BC* because of *c*, but delineate *AB* as a chunk). We scored each subject on whether they segmented *AB* or *BC*. A Chi-square test of association revealed a significant association between group (*A-BC*, vs. *AB-C*) and segmentation or no segmentation of each chunk, $X^2(1) = 12.44, p < .001$. This indicates that what one group perceived as an indecomposable unit was perceived by the other group as a composition.

As indicated by the previous analysis, the simple parts *a* and *c* may have a different status in both groups. Specifically, the *A-BC* (vs. *AB-C*) group should perceive *a* (vs. *c*) as a unit of categorization, but *a* (vs. *c*) should not be a unit in *AB-C* (vs. *A-BC*). We scored each subject on whether they circled *a* or *c* in the *A* and *C* stimuli. A Chi-square test of association showed a significant association of group and delineation, $X^2(1) = 7.19, p < .01$. Each group was aware of its simple unit but was unaware of the simple unit of the other group. This provides further evidence that composed parts were perceived as a holistic single unit unless its components were themselves units (see also Schyns & Murphy, in press).

Experiment 2

Experiment 1 suggests that the context of different objects causes the learning of different units which influence people's perception of stimuli. The goal of Experiment 2 was to demonstrate that the context of known concepts determines which features are chosen to encode a new object category. We set up a very simple situation of categorization. Two groups of subjects had to learn a simple category *X* and a composed *XY* category of Martian cells, but the learning order was different in each group (*X* before *XY*, or *XY* before *X*). We wanted to show that despite equivalent categorizations of *X* and *XY* stimuli the groups used different features.

Methods

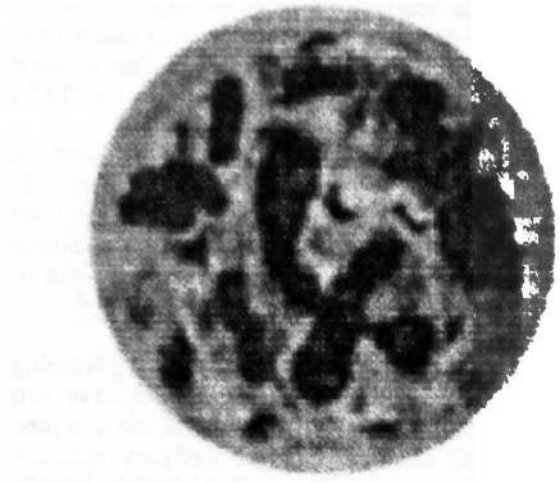
Subjects and stimuli. Twenty Grenoble University students participated in the experiment; they were assigned randomly to conditions. Stimuli were Martian cells constructed as explained earlier. We synthesized three categories of Martian cells for the learning phase of the experiment. The composed part *ab* defined the *AB* category (*a* and *b* were adjacent on each exemplar of the category). The *A* and *B* categories were simple categories defined respectively by the subcomponent *a* and the subcomponent *b*.

Five types of stimuli were used for testing: *AB* cells, *A* cells, *B* cells, *A-B* cells and distractors. *A-B* cells were cells in which the components *a* and *b* were not adjacent to one another but randomly disposed in the cell with the constraint that they did not overlap. Distractor cells were only made of components of random shapes (see Figure 2).

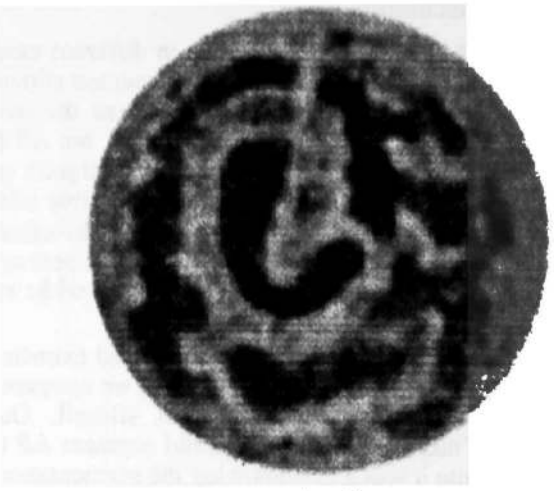
Procedure. Initial Learning Phase. In an initial learning stage, subjects were instructed to carefully observe two categories of 10 cells. Stimuli were presented one at a time for 1 sec. on a CRT screen. After each category, subjects' learning was tested with 4 cells (two new exemplars and two distractors). Subjects' task was to categorize the cells. Perfect categorization was the criterion to learn the second category, or to complete the initial learning phase. We defined four groups of subjects according to order of presentation of the categories. In th *A-AB*group and the *B-AB* groups, the simple category (either *A* or *B*) was learned before the composed *AB* category. This order was reversed in the *AB-A* and the *AB-B* groups. For ease of presentation, we will call the first two groups the *X-XY* learning condition and the other groups the *XY-X* learning condition.

Verification Phase. To insure that the memory of the second category did not interfere with the memory of the first category, we tested subjects' memory of the categories after completion of the initial learning phase. The test was a simple categorization of 6 new cells (two simple, two composed, and two distractors cells). Subjects had to indicate the categorical membership of each exemplar (possible responses were *X*, *XY* and *none*) by pressing the appropriate key of a computer keyboard. A single mistake would eliminate a subject from the experiment.

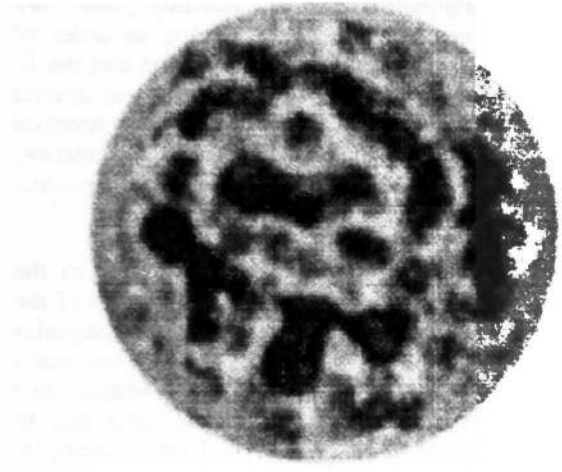
Testing Phase. In the testing phase, subjects were asked to categorize 20 new cells: 4 *X*, 4 *XY*, 4 *X-Y* and 8 distractors cells. To ensure that subjects would categorize *after* (instead of during) their exploration of the cells, we simulated the effect of looking at cells through the aperture of a microscope. That is, subjects saw successively 2 snapshots of different portions of the cells. For the *X* and *XY* cells, one portion showed the relevant component (*x* or *xy*) and the other portion revealed a distractor part. For *X-Y* cells, *x* was presented in one portion, and *y* in the other. For distractor cells, both portions showed distractor parts. (Order of snapshot presentation and of assignment of features to portions was randomized.) Subjects had to categorize each cell by pressing the appropriate keyboard key.



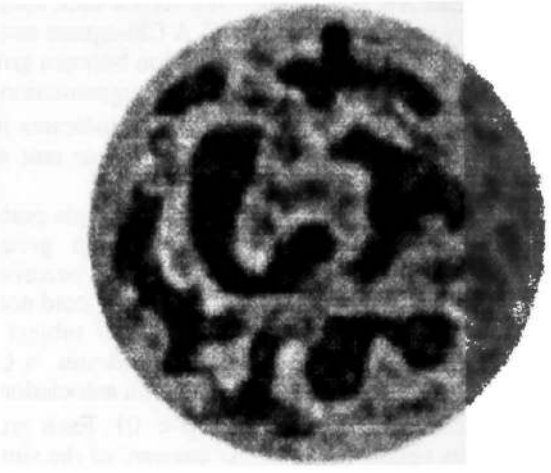
AB cell



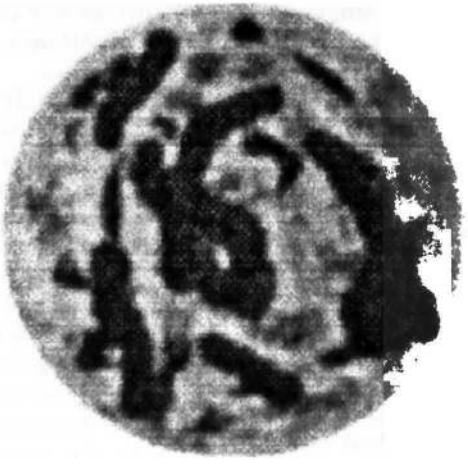
A cell



B cell



A-B cell



distractor cell

Figure 2 : This figure illustrates exemplars of the test stimuli. The simple *A* and *B* cells are respectively defined by the *a* and *b* components. *AB* and *A-B* cells are defined by the *a* and *b* components, but the components are not adjacent to one another in *A-B* cells.

Delineation Phase. To assess the units used in the testing phase, we simply asked subjects to circle the parts they saw during the experiment on five new cells (1 *X*, 1 *Y* and 3 distractors presented one at a time.)

Results and Discussion.

Both groups categorized equally well the *X* and *XY* cells (respectively, *X*= 97%, *XY*= 81% for the *X-XY* group and *X*= 94%, *XY*= 81% for the *XY-X* group). To understand better which units of representation were responsible of the categorical judgments we must turn to the categorizations of *X-Y* cells. Remember that *X-Y* cells are composed of the *x* and *y* components, but the components are not adjacent to one another (see the *A-B* cell on Figure 2). Since the categorical structure is *exactly* the same in both groups (namely, *y* distinguishes *X* and *XY*), *X-XY* and *XY-X* subjects should categorize *X-Y* cells in the same way.

We scored subjects on whether they categorized *X-Y* cells as *X* or *XY* cells. A t-test on the difference scores of *X* and *XY* categorizations of *X-Y* cells revealed a significant difference between *X-XY* and *XY-X*, $t(7) = 2.23$, $p < .05$. In other words, *X-XY* subjects preferentially categorized *X-Y* cells as *XY* while *XY-X* subjects categorized the same cells as *X*. This is counterintuitive because both groups categorized equivalently well *X* and *XY* stimuli! This suggests that the groups use different concepts to categorize the cells. Specifically, *X-XY* subjects seem to combine the features *x*and *y* to recognize *X-Y* cells, while *XY-X* subjects notice *x* and disregard *y*.

To test this hypothesis, we looked at whether subjects delineated the *x* and the *y* parts in *X* cells and *Y* cells during the delineation phase. A Chi-square test of association revealed a significant association between group and the delineations made (circling *x*and circling *y*), $X^2(1) = 4{,}267$, $p < .05$. If the *X-XY* subjects delineated *x* and *y*, *XY-X* subjects mostly delineated *x*, disregarding *Y* cells as distractors.

In summary, Experiment 2 demonstrated that the context of one concept influences which features are learned to encode a new category. Althought both groups experienced the same categories, each group represented the categories with a different features set. This ocurs because categorization influences features extraction. Specifically, in Experiment 2 learning the *X* concept forced *X-XY* subjects to instanciate *y* to represent the contrast between the known *X* category and the new *XY* category. Because *XY-X* subjects learned *xy* as a single holistic unit, the *XY* concept imposed different contrast for the encoding of the *X* category, resulting in *x* being added as an independant feature to the vocabulary of object concepts.

The results of Experiment 1 and Experiment 2 suggest that the way people organize their world determine their vocabularies of object representation. We think feature learning in conceptual context has far reaching implications for theories of perceptual learning and developement. Conceptual context extends concept learning to the development of a vocabulary of functional features -- features useful to categorize objects. Conceptual context offered a framework to study the grounding of functional fetaures on perception.

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