Behavioural Processes 93 (2013) 98–110

Contents lists available at SciVerse ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

Categorization of birds, mammals, and chimeras by pigeons

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ARTICLE INFO

Article history:
Received 27 June 2012
Received in revised form 31 October 2012
Accepted 4 November 2012

Keywords:
Pigeons
Categorization
Chimeras
Vision
Feature learning

ABSTRACT

Identifying critical features that control categorization of complex polymorphous pictures by animals remains a challenging and important problem. Toward this goal, experiments were conducted to isolate the properties controlling the categorization of two pictorial categories by pigeons. Pigeons were trained in a go/no-go task to categorize black and white line drawings of birds and mammals. They were then tested with a variety of familiar and novel exemplars of these categories to examine the features controlling this categorization. These tests suggested the pigeons were segregating and using the principal axis of orientation of the animal figures as the primary means of discriminating each category, although other categorical and item-specific cues were likely involved. This perceptual/cognitive reduction of the categorical stimulus space to a few visual features or dimensions is likely a characteristic of this species' processing of complex pictorial discrimination problems and is a critical property for theoretical accounts of this behavior.

It is well established that a number of animals can learn to discriminate and categorize a wide variety of ill-defined, open-ended, natural categories. Pigeons, for example, have learned to discriminate "natural" polymorphous noun categories such as flowers, cars, trees, chairs, cats, dogs, and people (Aust and Huber, 2001; Ghosh et al., 2004; Herrnstein, 1979; Herrnstein and Loveland, 1964; Wasserman et al., 1988). Besides supporting rapid learning, these types of categorical discriminations have been established to support transfer to novel exemplars similar to human conceptual behavior. Because of this similarity and its implications for the evolution of cognition, visual discriminations of this type have generated considerable interest since their inception.

One important issue in the analysis of visual categorization centers on what properties control discrimination and transfer performance. A shortcoming in many categorization experiments has been the scarcity of information about the nature of the cues regulating such discriminations. Without knowing what cues or features are being used by the animals, however, it is difficult to make inferences about the representation of these categories, their underlying computational mechanisms, or their similarity to human conceptual behavior (Cerella, 1986; Cook, 1993; Huber, 2001; Lea et al., 2006a). With these issues in mind, this paper describes experiments focused on identifying the visual properties controlling the discrimination by pigeons of two representative pictorial noun categories – birds and mammals.

Research on natural categories has relied on photographs as the primary medium for testing such discrimination. A major limitation with this type of complex stimulus is that it is not easily manipulated. While this photographic complexity may be a key element in the formation of such discriminations, they correspondingly make it difficult to isolate the controlling cues. The availability of modern software for manipulating such images has resulted, however, in some progress. The most in-depth analysis of this type has been the series of experiments conducted by Aust and Huber (2001, 2002, 2003) examining the controlling properties involved with categorizing pictures of people from non-people by pigeons. Using a variety of different transformations (e.g., image scrambling and inversion, part deletion, gray scale) the results of these tests highlight the complexity of this analytic goal. Initial tests involving the scrambling of the entire image suggested that local cues associated with the people and image color were particularly critical (Aust and Huber, 2001). Subsequent research suggested that some portions of the human body (heads, hands) were more important than others (Aust and Huber, 2002) and that the spatial configuration of these parts may be at least partially encoded (Aust and Huber, 2003). The importance of the head has also been confirmed by the pecking and tracking of this part in a people-present/people-absent discrimination (Dittrich et al., 2010). Finally, their results suggested that both item-specific information about the individual exemplars and category-specific information about the class of items were both being encoded by the pigeons as

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0376-6357/$ – see front matter © 2012 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.beproc.2012.11.006

determined by their different responses to tests with familiar and novel exemplars. Using a similar approach to examining the visual categorization of people, flowers, chairs and cars by pigeons, Lazareva et al. (2006b) found that different visual attributes controlled them. From tests involving stimulus inversion, blurring and scrambling, their results suggested that the categorization of flowers and people were controlled by the overall contour of the images, while cars and chairs were determined by local features.

The analysis of visual categorization by pigeons in this article has its origins in the research of Cook et al. (1990) using stimuli consisting of black and white line drawings of birds and mammals as the discriminative classes. These stimuli were drawn from edited collections (Harter, 1979; Iyari, 1979) of wood cuts and drawings from 19th century scientific journals and popular magazines. These images have the complex characteristics of photographed natural categories, but have several advantages as a medium. First, because of their original scientific and educational purposes, they capture the animals with considerable detail including, key visual features, characteristic or canonical poses and postures, and often include surrounding habitat for each animal. Combined with the considerable irrelevant variation produced by differences in perspective, subjective distance, and the number of animals depicted, these stimuli seemed well suited for the study of categorization. Second, because each image is a simple collection of individual pen strokes, each line can be independently altered allowing for easy manipulation of their features. Third, their black-and-white nature excludes color information. This is valuable because color often overshadows the processing of other features and dimensions of complex stimuli by pigeons. Thus, these stimuli provided an excellent mixture of the featural richness and variation of photographs, with the capacity for easy manipulation.

Cook et al. (1990) established that these line drawings were effective at creating categorical behavior. They found that these line drawings were easy to discriminate, produced robust transfer to novel exemplars of each category, and that speed of learning and degree of transfer varied with the number of training exemplars. Importantly, they also found that the degree of transfer appeared to be sensitive to the similarity of the items within each category as judged from human prototypicality ratings.

The goal of the present research was to identify the controlling features involved in the discrimination of these bird and mammal categories. We used a partitioning strategy to search the possible feature space involving a series of different image manipulations. These manipulations were tested as a pair of tests. The first test involved the manipulation of familiar exemplars while the second tested novel exemplars. This allowed us to assess both item-specific and category-specific information in the pigeons' reaction to the altered stimuli. The pigeons were trained and tested in a go/no-go discrimination task in which they had to discriminate between the categories by pecking at pictures of birds to be reinforced with food, while inhibiting pecking to pictures of mammals that were presented in extinction. Using this established discrimination, we then conducted a series of tests manipulating different aspects of the stimuli. The background, logic and rationale for these tests are described in the next section.

1. Stimulus analytic tests: background, rationale and logic

The purpose of Test 1 was to examine the degree to which the figure of an animal and/or the contextual natural backgrounds/habitats controlled the discrimination. This was important to determine because it has become established that pigeons can memorize the visual content of a very large numbers of pictorial items (Cook et al., 2005; Fagot and Cook, 2006; Vaughan and Greene, 1984). Further, earlier studies had suggested that small differences in the background of photographic images could also be detected and used by the birds (Greene, 1983). Cook et al. (1990) eliminated backgrounds from some of the training stimuli and showed that pigeons had little trouble continuing to discriminate these animal figures without the background, a finding consistent with the hypothesis that the pictured animals were of primary importance to the categorical discrimination. In those experiments, however, the pigeons were not tested with stimuli in which the figures were removed to evaluate how the background itself contributed to the discrimination. In the test conducted here, we removed the background from a larger set of familiar images, and included conditions where the animal in the drawing was removed, leaving only the background. This allowed us to determine whether or not the redundant contextual information contributed to the discrimination.

As detailed below, the results of the first test will show that the animal figure was indeed most important, so we next divided the animal figures into parts, examining the independent contributions of the head, body and legs. Tests 2A and 2B involved using chimera animals involving mixtures of these parts within and across the categories. By mixing and crossing together different portions of each category into a single "chimera" test animal, it was possible to judge which portions of the animal figures were making the greatest contribution to the pigeons' discrimination. Cook et al. (1990) had pilot-tested a few limited examples of such chimera stimuli. The results from three of the four exemplars tested suggested that the body of the animal, rather than features associated with the head, were most important. In the present study, we employ the same strategy but tested greater numbers of chimeras, constructed from a greater variety of animals, to better test and strengthen the conclusions from that earlier study. One set of tests involved exchanging the head and body of the animals from the two categories. The second set of tests involved manipulating the type and number of legs across the two categories.

The next two tests were designed to evaluate the relative contributions and roles of the global organization and local features of the animal figures. In Test 3A the animal figures were divided into three parts involving the head, trunk, and rear sections of the animals. To manipulate global information, conditions were tested in which these different parts were separated from each other by a spatial gap or simultaneously scrambled or inverted from their normal order of appearance. If the order and continuous nature of these different parts were critical, then these alterations to the global organization should be disruptive to the pigeons' performance.

In Test 3B the interior texture was replaced by a solid area of single brightness. This removed local information primarily leaving global shape as the basis for any discrimination. These test stimuli were presented over a range of brightness values, from complete silhouettes, through intermediate brightness values, to exclusively outlined contours. If the global form was exclusively controlling the discrimination, then the pigeons should have little difficulty with these altered forms. On the other hand, if local details in the interior of the animals were also a part of their representation of the categories, then this manipulation should disrupt performance.

Finally, Test 4 examined how the orientation of animal figures influenced the discrimination. Cook et al. (1990) had found that the pigeons were insensitive to either reflections or 180° rotations of the categories, suggesting that orientation was not particularly important. However, both tests had retained the primarily diagonal orientation of the birds and the basic horizontal orientation of the mammals. In Test 4, we included a more extensive and diagnostic set of figural orientations to reexamine the contribution of this global factor to the discrimination of both familiar and novel members of each category.

For purposes of economy, the general methods outline the shared elements of the procedures for the different tests. This is