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Comparing performance of humans and pigeons in rule-based visual categorization tasks

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ABSTRACT

We report two experiments which compare performance of pigeons and humans in rule-based categorization tasks with Gabor stimuli that varied in frequency and orientation. For different tasks, accurate responding depended on frequency while orientation varied but was non-relevant; or on orientation while frequency varied but was non-relevant. Results showed that humans learned both tasks faster than pigeons, with abrupt increases in accuracy that were indicative of rule-based responding, while pigeons learned the tasks gradually. In the frequency-relevant task, humans responded at near-optimal levels whereas accuracy for pigeons decreased when orientation was near vertical. These results suggest that humans are more adept than pigeons at solving categorization tasks that are facilitated by selective attention. However, both species responded suboptimally in the orientation-relevant task, with decreased levels of accuracy for exemplars with frequencies that were outside the middle of the range. Some processes mediating visual categorization of Gabor stimuli by humans and pigeons may be similar, despite functional and neuroanatomical differences.

How organisms learn to categorize stimuli that vary on multiple dimensions has been a major topic for research with both humans and nonhumans (Cook & Smith, 2006; Herrnstein, Loveland, & Cable, 1976; Jitsumori, 1994; Lazareva & Wasserman, 2009; Maddox & Ashby, 2004; Smith & Minda, 1998; Wasserman, Kiedinger, & Bhatt, 1988). A popular method for studying categorization with stimuli that vary quantitatively along two dimensions, known as the randomization procedure, was developed by Ashby and Gott (1988).

For category exemplars, studies with the randomization procedure often use Gabor stimuli – computer-generated, sinusoidal wave gratings that are defined by frequency and orientation (see Ashby & Maddox, 2005, for review). Two types of category tasks are commonly used: 'information integration' (II; Massaro & Friedman, 1990), in which accuracy depends on both orientation and frequency, and participants are typically unable to verbalize their response strategy; and 'rule based' (RB), in which accuracy depends only on a single dimension and participants are often able to describe their performance in terms of a verbal rule. The major finding from this research is that humans appear to have at least two different systems for category learning. An implicit or procedural learning system that depends on reinforcement feedback is based in midbrain structures and mediates performance on the II task. An explicit system that involves hypothesis testing is based in frontal

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cortex and is important for RB performance (Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Ashby & Ell, 2001; Ashby, Ennis, & Spiering, 2007; Erickson & Kruschke, 1998; E. E. Smith & Grossman, 2008).

The difference between the II and RB categorization tasks may also be described in terms of attention: The II task requires participants to attend to both dimensions, whereas participants can selectively attend to the relevant dimension and respond accurately in the RB task. Typically, humans show differences in performance on II and RB tasks, with II tasks acquired more slowly and with lower asymptotic levels of accuracy whereas RB tasks are acquired more quickly and to higher levels of accuracy (Smith, Beran, Crossley, Boomer, & Ashby, 2010). The advantage in learning RB tasks supports the view that humans have multiple systems for category learning.

An important question for comparative research is whether nonhumans also show superior performance on RB tasks. Smith et al. (2010) found that rhesus macaques (*Macaca mulatta*) required more training to reach comparable levels of accuracy as humans in the RB task, but also were more accurate than when they responded on the II task. Smith et al. (2012a) reported similar results with Capuchins (*Cebus apella*), a New World primate which has a substantially different evolutionary lineage from Old World primates like macaques. By contrast, Smith et al. (2011) compared performance of pigeons ($N = 17$) from different laboratories in the USA and NZ and found that results on RB and II tasks were similar both in terms of overall accuracy and rate of acquisition. Smith et al. (2012b) argued that these results suggested that a separate category learning system favoring dimensionalization and selective attention had evolved in the primate lineage, thus yielding better performance on RB tasks, whereas pigeons had only a single system for category learning and thus performed similarly on II and RB tasks. In contrast with primates, pigeons may represent a species whose category learning is not strongly dimensionalized; that is, pigeons tend to process stimuli holistically rather than analytically in terms of component dimensions.

Berg and Grace (2011) reported a detailed analysis of pigeons' responding in both II and RB tasks with Gabor stimuli. Forty exemplars were generated for each category using the same distributional parameters (bivariate normal) as Maddox, Ashby, and Bohil (2003). By using a fixed number of exemplars per category rather than sampling from larger distributions of stimuli (cf. Ashby & Gott, 1988; Herbranson, Fremouw, & Shimp, 1999), Berg and Grace were able to examine performance for individual exemplars in detail. They found that pigeons learned to respond accurately in both tasks, but that performance deviated from optimality in systematic ways. In the II task, accuracy for one category was higher for mid-range orientation values, whereas in the RB task, in which frequency was the relevant dimension, they found a significant trend for accuracy to decrease for stimuli with orientation values close to vertical (i.e., 90° counterclockwise from horizontal) compared to horizontal. Berg and Grace noted that results from the RB condition suggested an interaction between frequency and orientation, such that control by frequency was better for stimuli with orientation values close to horizontal rather than vertical. Their results show that there was some control by orientation over responding and are consistent with Smith et al.'s (2011, 2012b) proposal that pigeons do not process stimuli in terms of separate dimensions.

Although Smith et al. (2010, 2011, 2012a) have identified differences in how pigeons and non-human primates respond in visual categorization tasks with Gabor stimuli, they have not compared species' performance in detail at the level of individual exemplars. Thus in the present research we studied performances of pigeons (Experiment 1) and humans (Experiment 2) in RB tasks using identical category stimuli. Our primary interest was not speed of acquisition – we expected that humans would learn the tasks more rapidly – but to evaluate the extent to which asymptotic performances were optimal, and if not, whether patterns of suboptimal responding were similar or different across species. For this we planned to assess whether performance varied systematically with the non-relevant dimension in each RB task, similar to Berg and Grace (2011).

Experiment 1

In Experiment 1 we trained pigeons on RB – Frequency and RB – Orientation tasks. We planned to test whether the interaction reported by Berg and Grace (2011) for the RB – Frequency task could be replicated with a different group of pigeons, as well as testing whether similar results would be obtained in a similar RB task with orientation as the relevant dimension. To have two categorization tasks of comparable difficulty, we used a procedure (described below) for generating stimuli which ensured that the standardized difference between category means, measured as an effect size on the relevant dimension, was equal for both conditions, and that the range and standard deviation of the non-relevant dimension was proportional to the mean category difference in the condition in which the dimension was relevant. In this way, the categorization tasks should have been of comparable difficulty, even though the relevant dimensions are measured in different units.

Method

Subjects

Three pigeons, designated H5, H6, and H8, participated as subjects and were maintained at 85% of free-feeding weight ± 15 g by post-session feedings. They were housed individually and allowed free access to water and grit, in a vivarium with a 12:12 hour light/dark cycle (lights on at 7:00 a.m.). H5 and H8 had previously responded in visual categorization tasks using similar apparatus and stimuli (Berg & Grace, 2011) and in an unpublished experiment (with H6) prior to the current study.