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Research report

Grouping of artificial objects in pigeons: An inquiry into the cognitive architecture of an avian mind

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Abstract

How does a pigeon see the world? Although pigeons are known to be adept at learning large numbers of figures, colors, and natural images, various experiments show that their visual cognitive specialization is more geared towards seeing colors and textures instead of shapes. They also excel in the analysis of local features instead of shapes that can only be differentiated by their outline. We therefore embarked into a detailed analysis of the relative weight of colors versus shapes in an object grouping task. At the same time we used a design that gave us information on the question of the relative importance of the S+ and S− in cognitive tests. Our strategy was to use the classic matching to sample task in which pigeons have to associate a sample with another stimulus (S+), which belongs to the same arbitrary group while at the same time avoiding choosing another stimulus (S−), which is part of another arbitrary group. Our results clearly reveal that color is, relative to shape, the primary cue that pigeons use to guide their decisions. Although they are in principle able to use shape information, they utilize shape as the last cognitive resort. Our data further reveal that pigeons guide their decisions in a matching to sample task primarily by focusing on the S+, although they also utilize information from the S−, albeit to a smaller extent. They are flexibly able to use cognitive match- or nonmatch-strategies depending on the presence or absence of color- or shape-cues.

Keywords: Pigeon; Common coding; Strategy; Matching-to-sample; Object grouping

1. Introduction

Our perception of the environment is not a faithful registration of its physical attributes. Instead, we carve the world into meaningful groupings or categories. This process of abstracting and storing the commonalities among like-themed attributes is fundamental to cognitive processing because it imparts knowledge [8]. Categorization is regarded as a process of determining which things "belong together", and a category is a group of stimuli or events that so cohere [28]. For primates it has been shown, that perceptual categories are mainly processed by neurons in the prefrontal cortex [7,8,19]. However, this ability seems not to require a mammalian neocortex [10], since pigeons also are able to form perceptual categories [11–13,25,26]. The aim of this study is to understand which cognitive processes lead to a grouping of stimuli within the avian brain. In the following the term 'grouping' is used to describe a classification of different looking objects into a group. Usually, in the cognitive sciences literature 'perceptual grouping' or 'binding' refers to the early visual processing mechanisms underlying segmentation of visual scenes, which is, at least in mammals, done in the visual cortex [15,23]. We consider the term 'categorization' to be too strong, because it gives the impression that generalization to new objects is possible. Since this is not the case and goal in the present study the term 'grouping' is used as a softer/moderate form of 'categorization'. Former studies have shown that there are many features of the cognitive architecture that are important for object grouping. In most of these categorization studies pigeons were trained in many-to-one matching tasks [16,22,27,29,31,32] where the association between two stimuli is formed unidirectionally. This means that two or more different sample stimuli require the choice of one out of two alternative comparison stimuli, whereas the comparison stimuli never serve as samples. The authors discovered that samples could be either represented as compound samples (each sample would be capable of eliciting the same compound representation) or one of the samples could be represented in terms

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of the other sample [20,30]. Additionally, it has been shown that in delayed matching-to-sample tasks pigeons store intermediate information primarily in a retrospective, but not prospective, manner [22,30,32]. Furthermore, there is evidence that hues are remembered better than line orientations [6], and, consequently, association from hue samples to line orientation comparisons were acquired more rapidly than from line orientation samples to hue comparisons [20]. Although pigeons are known to be adept at learning large numbers of figures, colors, and natural images, there is recent evidence that their visual cognitive specialization is more geared towards seeing colors and textures instead of shapes [17].

In the present study we therefore investigated which of these features of cognitive architecture are important in a many-to-many matching task in which associations between stimuli should be formed symmetrically. Therefore, we embarked into a detailed analysis of the relative weight of colors versus shapes. At the same time we used a design that gave us information on the question of the relative importance of the S+ and the S− in cognitive tests.

2. Method

2.1. Subjects

Five experimentally naive pigeons (*Columba livia*) served as subjects. All birds were housed individually in wire mesh cages, had free access to water and grit, and were maintained on a 12-h light–dark cycle, with lights on at 8:00 h. Before training pigeons were food deprived until they reached a weight of 75–80% of their free-feeding body weights. All procedures were in compliance with the guidelines of the National Institutes of Health for the care and use of laboratory animals and were approved by a national committee (North Rhine-Westphalia, Germany).

2.2. Apparatus

All training and testing was conducted in a standard pigeon operant chamber. Situated on the front panel of the chamber were three rectangular transparent plastic keys, each 5 cm × 5 cm. The midpoint of the keys was located 20 cm above the chamber floor, and the keys were 9.5 cm apart from center to center. Behind the keys a 15′ TFT-monitor delivered the visual stimuli. Below the center key a food magazine delivered the wheat food reward. The experiment was controlled via an IO-warrior (Frank Buschmann Investigations, Bochum) attached to the operant chamber. Stimuli consisted of two colored disks (red and green) and four white shapes on black background (heart, lightning, triangle and cross) of identical area. These stimuli were arbitrarily divided in two groups (G1: heart, lightning, red disk; G2: triangle, cross, green disk).

2.3. Behavioral procedure

After a 10-s intertrial interval (ITI), where the houselight was switched on, a sample stimulus appeared on the center key. Following 15 pecks to the center key, the side keys were additionally illuminated with the comparison stimuli. Five pecks to the comparison stimulus that matched the group (G1 or G2) of the sample stimulus turned all three stimuli off and resulted in 3-s access to a reward, followed by the ITI. A peck to the nonmatch comparison resulted in a 10-s time-out period (punishment), followed by the ITI. The location of the match was counterbalanced. A session consisted of 108 trials, with each sample-comparison configuration occurring pseudorandomly.

2.4. Shaping

Birds were first autoshaped and then trained to peck 15 times the white illuminated center key. Then they were exposed to a training version of the simultaneous-match-to-group (SMG) task: after pecking the sample 15 times only the match was presented on one of the side keys. Pecking the match was rewarded. A peck to the unlit side key had no consequences. As soon as the birds reliably pecked to sample and match, the pecking requirement to the comparison was set to FR5. Training continued until the subject performed >80% in three consecutive training sessions.

2.5. Acquisition

In the first acquisition phase (PRE-SMG) a nonmatch (white square on black background) that did not belong to either group was added. Pecks on this nonmatch were punished; pecks to the match were rewarded. This was conducted until the pigeons performed >80% correct in 10 consecutive training sessions. In the second acquisition phase (SMG-BLOCK) the nonmatches were also selected out of the three stimuli of the prevailing group, but the samples were selected blockwise, i.e., in the first half of the session only samples of, e.g., G1 and in the second half only samples of G2 were used. This order was randomized. When pigeons performed at more than 80% in three consecutive training sessions, the third acqusition phase followed (SMG-RANDOM), in which also the groups were presented randomly.

This design contained five different trial types: (1) match shape-to-same-shape, (2) match shape-to-group-shape, (3) match shape-to-color, (4) match color-to-shape, and (5) match color-to-color. Each of those trial types could furthermore be divided in subtypes with A shape as nonmatch and B color as nonmatch. Examples of these trial types and subtypes are illustrated in Fig. 1 for “heart” and “red” as samples. For quantitative analysis percentage of correct responses for the five trial types and subtypes were calculated separately. Additionally, the *t*-test was used to test for preference of the pigeons to choose comparison stimuli mainly of one side.

3. Results

Learning speed was determined by the number of sessions needed to reach criterion in three training steps (Table 1): (1) PRE-SMG, (2) SMG-BLOCK, and (3) SMG-RANDOM.

Four birds reached criterion in the PRE-SMG phase after 17–26 sessions (Table 1, first column). Bird 804 was dismissed after 61 sessions without reaching criterion (indicated by the