

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.

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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 addi-

tionally 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 acquisition 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

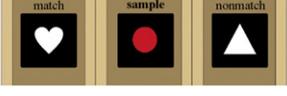
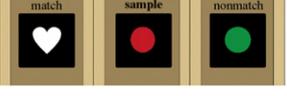
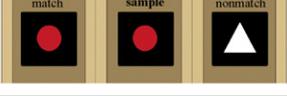
Trialtype	Nonmatch:shape	Nonmatch:color
S-S (same) Match-shape-to-same-shape		
S-S (group) Match-shape-to-group-shape		
S-C (group) Match-shape-to-color		
C-S (group) Match-color-to-shape		
C-C (same) Match-color-to-color		

Fig. 1. Examples for the five different trial types 1. Match-shape-to-same-shape (S–S (same)), match-shape-to-group-shape (S–S (group)), match-shape-to-color (S–C (group)), match-color-to-shape (C–S (group)), match-color-to-color (C–C (same)) for samples of group 1. These trial types were further subdivided in the quality of the nonmatch: in the first column the nonmatch is a shape and in the second column the nonmatch is a color.

upwards arrow in Table 1, first column) This pigeon preferentially chose the left comparison key, irrespective of stimulus and thus did not even learn to avoid the white square.

Three birds reached criterion in the SMG-BLOCK phase after 12–29 sessions (Table 1, second column). These birds did not show any side preference. In contrast, bird 806 displayed a strong bias to the right side with start of the SMG-BLOCK phase. This bias did not vanish after 24 sessions without reaching criterion (indicated by the upwards arrow in Table 1, second column); the bird was dismissed and named “slow learner” in the following.

One bird (808) reached criterion in the SMG-RANDOM phase after only five sessions (Table 1, third column). This bird was named “fast learner” in the following. Although the two remaining birds (807 and 805) successfully finished the SMG-BLOCK phase, this was not the case for the SMG-RANDOM phase. After 21 (807) and 13 (805) sessions without reaching criterion they were dismissed and named “average learners” in the following.

Fig. 2 shows the performances of the fast, average, and slow learners. The fast learner performed about 80% correct in all trial types and subtypes. The average learners performed at chance

level (min. 46.8%, max. 50.6%) in S–S-trials and even below chance level (41.2% and 43.1%) in S–C-trials, but only when the nonmatch was a shape. When the color was the nonmatch, average learners’ performance was between 68.7% and 78.7% correct in S–S-trials, and between 63.7% and 67.5% correct in S–C-trials. In contrast, average learners performed at 70% and 75% correct in C–S-trials with shape as nonmatch and even better (95% and 96.2%) with color as nonmatch. Best performances were reached in C–C-trials (86.2% and 76% with shape as nonmatch; 100% and 92.5% with color as nonmatch). Noteworthy, average performers even outperformed the fast learner in C–C-trials with color as nonmatch. Likewise, the slow learner performed poorly in S–S-trials (56% and 58%) and in S–C-trials (61%) both with shape as nonmatch. With color as nonmatch performance increased to 75% and 74% (S–S-trials) and 80% (S–C-trials). In contrast to the average performers the slow performer performed also poorly in C–S-trials with shape as nonmatch (61%), but likewise increased performance in C–S-trials with color as nonmatch (76%). In C–C trials the slow performer reached 74% (shape as nonmatch) and 78% (color as nonmatch) but did not outperform the fast learner.

In S–S- and S–C-trials with shape as nonmatch the average performers did not exhibit a response bias in those trials ($t = -1.4$ and -1.5 , respectively; $p = 0.2$ and 0.18 , respectively) but the slow performer showed a strong bias to the right pecking key in those trials ($t = -10.2$; $p < 0.001$).

4. Discussion

The aim of the present study was to investigate (1) whether pigeons can learn a simultaneous matching-to-group task, (2)

Table 1
Amount of sessions needed to reach criterion in the different phases of acquisition

Pigeon #	PRE-SMG	SMG-BLOCK	SMG-RANDOM
808	17	12	5
807	26	14	21 (↑)
805	19	29	13 (↑)
806	23	24 (↑)	–
804	61 (↑)	–	–

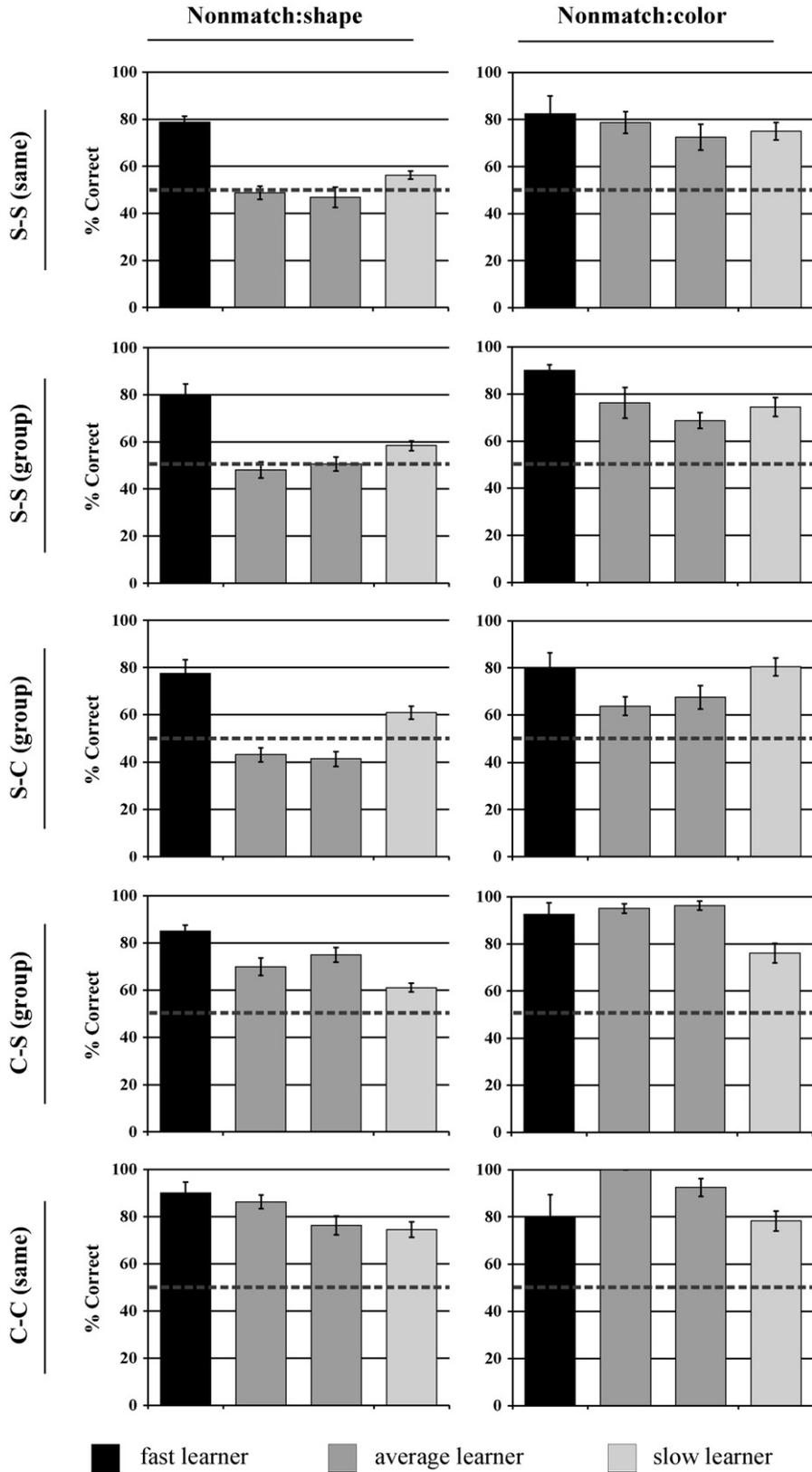


Fig. 2. Performance \pm standard error of four pigeons (fast, average and slow learners) in the five different trial types (rows) and subtypes (columns). The dotted black line represents chance level.

whether they acquire a common coding of stimuli within one group, (3) which strategies pigeons develop to solve the task, and (4) to what extent exclusion of the nonmatch plays a role in their decisions. The results of the experiment show that pigeons can form functional equivalence classes of three stimuli belonging together. Comparable results have been obtained in a recent study [9], which nicely shows that pigeons develop a four-member class in a hybrid one-to-one/many-to-one matching task. However, in this study pigeons had to form only one group of four members (and one group consisting of one member), whereas in the present study two groups of three members each had to be established.

Did the training lead to a common coding of the related stimuli? Due to the fact that in our design each of the stimuli served as samples and comparisons, a single-response/default strategy [3] is not a useful strategy to solve the task with less cognitive demand. Since the stimuli within the same group are associated with one another, common coding of these three stimuli seems to be the only strategy with which the task could be solved perfectly. Since not all pigeons performed perfectly in this task there must have been other strategies the pigeons used to at least partly solve the task.

Four of the five pigeons trained in this task did not fully understand the emergent relations between the stimuli within the groups and thus, most likely did not establish a common coding among group members. The strategy of the pigeon (804) that had failed in the PRE-SMG phase was simply to choose only one side, thereby obtaining reward in 50% of all trials.

According to Zentall et al. [29], a missing transfer in many-to-one matching probably indicates an absence of a common representation of two samples. Concerning the strategies of the average and slow learners in the present study it is likely that the pigeons relied mainly on rote learning for those trial types where the sample was a colored disc but mostly failed in trials with shape as cue for the group they had to choose. Accordingly, Zentall et al. could show that although fast and slow learners acquired the hue sample-comparison associations at about the same rate, the fast learners acquired the line-orientations-sample trial types significantly faster than the slow learners. Thus, one cannot conclude simply that smarter pigeons generally learn faster and develop emergent relations [29,31].

Moreover, the average and slow learners in the present study indeed performed well and sometimes even better than the fast learner, when they had the opportunity to exclude the nonmatch. This was only the case when the nonmatch was a color. In accord with this result, there is evidence from the literature [4] that pigeons are able to base their decision in a matching-task not only by selecting the match but also, when given the opportunity, by excluding the nonmatch. This raises the question, however, as to why in the task of the present study pigeons only were able to exclude the nonmatch when it was the color. A possible explanation is based on the finding that in matching-to-sample task pigeons retain a retrospective representation of the sample rather than a prospective representation of the correct comparison [22,30,32]. Such a representation could consist of a compound involving the three samples associated with each other. Thus, each sample would be capable of eliciting

the same compound representation (red/heart/lightning). Alternatively, two of the samples could be represented in terms of the other, e.g., the red sample would be represented as red and the heart and lightning samples would also be represented as red. Given the case that the pigeon sees the heart sample and this sample elicits the representation “RED”, subsequently the two comparisons appearing on the pecking keys were heart (match) and triangle (nonmatch), the pigeons have problems in either selecting the match or excluding the nonmatch. When the nonmatch is green, however, they easily can recognize that red and green never match and therefore the heart must be the correct choice. This explanation is supported by evidence that lines, and thereby probably also shapes, are less discriminable than colors [6,17]. We therefore argue that the average and slow learners acquired a strategy which mostly relies on color information and that they additionally guide their behavior by excluding the nonmatch.

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. Due to this fact fast learning animals also are able to utilize shape information, while slow learners rely on color information. This points to the fact that their strategy of local analysis is geared towards surface aspects of visual stimuli without combining the outline of stimuli as full shapes. 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. Detailed information about comparative literature of categorization and conceptualization is given in chapters 16–21 of Wasserman and Zentall's [24] and in chapters 5–8 of Heyes and Huber's [14]. Moreover, developmental studies of human infants have shown, that similarities in hue are one of the earliest criteria used by young children to categorize objects [18] albeit the propensity to categorize objects by hue may owe its origin more to perceptual than to cognitive processes [1]. Additionally, infants tend to prefer hue information over shape information in visual categorization processes [2].

Finally, this study for the first time shows that the task used is well suited to force pigeons to establish equivalence classes as requested by Sidman's definition, because it incorporates reflexivity, symmetry and transitivity features [5,21].

Acknowledgement

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References

- [1] M.H. Bornstein, A descriptive taxonomy of psychological categories used by infants, in: C. Sophian (Ed.), *Origins of Cognitive Skills* Hillsdale, Erlbaum, NJ, 1984, pp. 313–338.
- [2] D. Catherwood, B. Crassini, K. Freiberg, Infant response to stimuli of similar hue and dissimilar shape: tracing the origins of the categorization of objects by hue, *Child Dev.* 60 (1989) 752–762.

- [3] T.S. Clement, T.R. Zentall, Development of a single-code/default coding strategy in pigeons, *Psychol. Sci.* 11 (2000) 261–264.
- [4] T.S. Clement, T.R. Zentall, Choice based on exclusion in pigeons, *Psychon. Bull. Rev.* 10 (2003) 959–964.
- [5] J.D. Delius, M. Jitsumori, M. Siemann, Stimulus equivalencies through discrimination reversals, in: C. Heyes, L. Huber (Eds.), *The Evolution of Cognition*, The MIT Press, Cambridge, 2000, pp. 103–122.
- [6] G.W. Farthing, J.W. Wagner, S. Gilmour, H.M. Waxman, Short-term memory and information processing in pigeons, *Learn. Motiv.* 8 (1977) 520–532.
- [7] D.J. Freedman, M. Riesenhuber, T. Poggio, E.K. Miller, Categorical representation of visual stimuli in the primate prefrontal cortex, *Science* 291 (2001) 312–316.
- [8] D.J. Freedman, M. Riesenhuber, T. Poggio, E.K. Miller, Visual categorization and the primate prefrontal cortex: neurophysiology and behavior, *J. Neurophys.* 88 (2002) 929–941.
- [9] A.M. Friedrich, T.S. Clement, T.R. Zentall, Functional equivalence in pigeons involving a four-member class, *Behav. Process.* 67 (2004) 395–403.
- [10] O. Güntürkün, The avian ‘prefrontal cortex’ and cognition, *Curr. Opin. Neurobiol.* 15 (2005) 686–693.
- [11] R.J. Herrnstein, P.A. de Villiers, Fish as a natural category for people and pigeons, in: G.H. Bower (Ed.), *The Psychology of Learning and Motivation: Advances in Research and Theory*, vol. 14, Academic Press, San Diego, 1980, pp. 60–97.
- [12] R.J. Herrnstein, D.H. Loveland, Complex visual concept in the pigeon, *Science* 146 (1964) 549–551.
- [13] R.J. Herrnstein, D.H. Loveland, C. Cable, Natural concepts in pigeons, *J. Exp. Psychol.: Anim. Behav. Process.* 2 (1976) 285–302.
- [14] C. Heyes, L. Huber, *The Evolution of Cognition*, The MIT Press, Cambridge, London, 2000.
- [15] M. Jitsumori, Category structure and typicality effects, in: E.A. Wasserman, T.R. Zentall (Eds.), *Comparative Cognition: Experimental Explorations of Animal Intelligence*, University Press, Oxford, 2006, pp. 343–362.
- [16] D.H. Kaiser, L.M. Sherburne, J.N. Steirn, T.R. Zentall, Perceptual learning in pigeons: decreased ability to discriminate samples mapped onto the same comparison in many-to-one matching, *Psychon. Bull. Rev.* 4 (1997) 378–381.
- [17] O.F. Lazareva, P.S. Vecera, J. Levin, E.A. Wasserman, Object discrimination by pigeons: effects of object color and shape, *Behav. Process.* 69 (2005) 17–31.
- [18] R. Melkman, B. Tversky, D. Baratz, Developmental trends in the use of perceptual and conceptual attributes in grouping, clustering and retrieval, *J. Exp. Child Psychol.* 31 (1981) 470–486.
- [19] E.K. Miller, D.J. Freedman, J.D. Wallis, The prefrontal cortex: categories, concepts and cognition, *Phil. Trans. R. Soc.* 357 (2002) 1123–1136.
- [20] E. Neiman, T.R. Zentall, Common coding of samples associated with the same comparison: the nature of the common representation, *Learn. Motiv.* 32 (2001) 367–382.
- [21] M. Sidman, *Equivalence Relations and Behavior: A Research Story*, Authors Cooperative, Boston, 1992.
- [22] P.J. Urcuioli, T.R. Zentall, P. Jackson-Smith, J.N. Steirn, Evidence for common coding in many-to-one matching: retention, intertrial interference, and transfer, *J. Exp. Psychol.: Anim. Behav. Process.* 15 (1989) 264–273.
- [23] G. Vallortigara, The cognitive chicken: visual and spatial cognition in a non-mammalian brain, in: E.A. Wasserman, T.R. Zentall (Eds.), *Comparative Cognition: Experimental Explorations of Animal Intelligence*, University Press, Oxford, 2006, pp. 53–70.
- [24] E.A. Wasserman, T.R. Zentall, *Comparative Cognition: Experimental Explorations of Animal Intelligence*, University Press, Oxford, 2006.
- [25] Watanabe, S. Van Gogh, Chagall and pigeons: picture discrimination in pigeons and humans, *Anim. Cogn.* 4 (2001) 151.
- [26] Y. Yamazaki, U. Aust, L. Huber, M. Hausmann, O. Güntürkün, Lateralized cognition: asymmetrical and complementary strategies of pigeons during discrimination of the “human concept”, *Cognition* 104 (2007) 315–344.
- [27] T.R. Zentall, The case for a cognitive approach to animal learning and behavior, *Behav. Process.* 54 (2001) 65–78.
- [28] T.R. Zentall, M. Galizio, T.S. Critchfield, Categorization, concept learning, and behavior analysis: an introduction, *J. Exp. Anal. Behav.* 78 (2002) 237–248.
- [29] T.R. Zentall, L.M. Sherburne, P.J. Urcuioli, Common coding by pigeons in a many-to-one delayed matching task as evidenced by facilitation and interference effects, *Anim. Learn. Behav.* 21 (1993) 233–237.
- [30] T.R. Zentall, L.M. Sherburne, P.J. Urcuioli, Coding of hedonic and nonhedonic samples by pigeons in many-to-one delayed matching, *Anim. Learn. Behav.* 23 (1995) 189–196.
- [31] T.R. Zentall, J.N. Steirn, L.M. Sherburne, P.J. Urcuioli, Common coding in pigeons assessed through partial versus total reversals of many-to-one conditional and simple discriminations, *J. Exp. Psychol.: Anim. Behav. Process.* 17 (1991) 194–201.
- [32] T.R. Zentall, P.J. Urcuioli, J.A. Jagielo, P. Jackson-Smith, Interaction of sample dimension and sample-comparison mapping on pigeons’ performance of delayed conditional discriminations, *Anim. Learn. Behav.* 17 (1989) 172–178.