

Learning and transfer of relational matching-to-sample by pigeons

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We trained pigeons on a relational matching-to-sample task to see whether a nonprimate species can discriminate higher-order “relations between relations.” We required the birds to relationally match arrays of 16 items that were chosen from five nonoverlapping sets of 20 colored computer icons. On each trial, randomly selected icons from one set were placed into a 4×4 grid to form a sample; on *same* trials, all 16 icons were identical to each other, whereas on *different* trials, all 16 icons were different from each other. After 10–20 pecks, 16-item *same* and *different* testing arrays were presented that were created from an entirely different icon set. Because no icons were common to the sample and testing arrays, discriminating higher-order relations was required for success on the tests. As have primates in similar tasks, pigeons successfully learned and transferred this relational discrimination, suggesting that both birds and mammals possess the cognitive antecedents of analogical reasoning.

The ability to understand analogies underscores the power and flexibility of human cognition. Analogical thinking runs from simple acts of recognizing similar objects to complex linguistic mappings of one relation onto another. As French (1995) suggested, comprehending analogies not only requires understanding the relations *within* each domain, it also demands the slippage and transport of the derived common relations *between* domains. Increasing attention is being paid to how humans process higher-order relational similarities, metaphors, and analogies, because of this ability’s foundational importance to cognition (see, e.g., Gentner, Holyoak, & Kokinov, 2001).

The laboratories of the two authors share the similar goal of elucidating how nonhuman animals discriminate stimulus relations, because we believe that a comparative perspective is required in order to reveal the basic mechanisms of animal cognition and the origins of human thought. Using diverse methods and stimuli, our work has strongly suggested that pigeons can discriminate *first-order* same/different (S/D) relations—that is, whether two or more stimuli are identical ($A=A$ or $B=B$) or nonidentical ($A \neq B$ or $B \neq A$) (Cook & Wasserman, 2006).

Research on an even more advanced type of S/D discrimination focuses on whether an organism can process *higher-order* relations between multiple first-order relations. Specifically, can an animal discriminate stimulus groups that entail the *same* higher-order relations ($[A=A] = [B=B]$ or $[A \neq B] = [C \neq D]$; i.e., both same or

both different) from stimulus groups that entail *different* higher-order relations ($[A=A] \neq [C \neq D]$; i.e., one same and one different)? Such higher-order relations share similarities with human analogical reasoning. For French (1995), the perception of sameness in all of its subtlety “sets human cognition apart from any other on our planet.” For others, the essence of human reasoning and intelligence rests on such analogical thinking (Gentner et al., 2001; Holyoak & Thagard, 1997; Sternberg, 1977).

Even if we grant the truth of these proposals, such analogical thinking must not have emerged full-blown in hominids without any phylogenetic or cognitive antecedents. Hence, comparative study should elucidate the evolutionary origins of analogical thinking. Premack (1983) hypothesized that only symbol-using animals (humans and “language”-trained chimps) can solve such higher-order relational tasks. Adopting less exclusive assumptions, Thompson and his colleagues have proposed that only apes, but not monkeys or nonprimates, can appreciate such higher-order relations (Thompson & Oden, 2000).

Contrary to these proposals, Fagot, Wasserman, and Young (2001) found that baboons can discriminate higher-order S/D relations in a matching-to-sample (MTS) task. The baboons matched a sample relation to the same type of relation in the testing stimuli. The 4×4 grids of black-and-white computer icons in the sample array could either be all same or all different; following the sample, two testing stimuli appeared, one all same and the other all different, and the animal had to pick the relation among the test

elements that was in the sample. Because the icons in the sample and testing arrays did not overlap, this task critically required processing the higher-order relations *between* the sample and testing arrays, beyond the first-order relations *within* the two arrays. The results of this study suggested that language or symbol training is not necessary in order to appreciate higher-order relations and that perhaps primates as an order can solve such problems.

Here, we explore for the first time whether a nonprimate species, the pigeon, can master relational MTS (see Figure 1). If pigeons could learn and transfer this relational discrimination, the capacity to detect and discriminate higher-order relations would appear to be more

widespread, and perhaps phylogenetically older, than is commonly believed.

METHOD

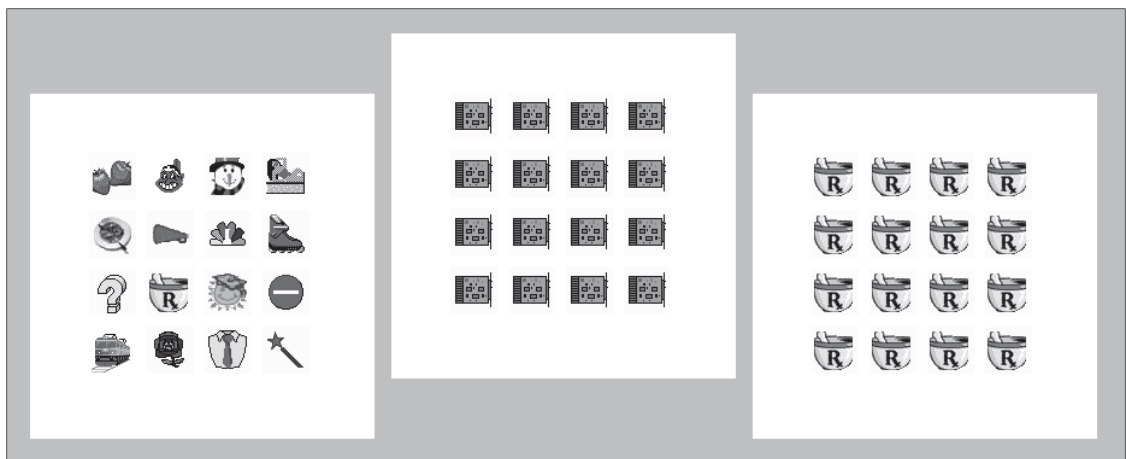
Animals

We studied 4 male pigeons at 80%–85% of their free-feeding weights. All had had prior first-order visual S/D training in a successive S/D task very similar to the one used by Cook, Kelly, and Katz (2003).

Apparatus

We conducted testing in an illuminated black operant chamber. Stimuli were presented on a color monitor (800 × 600) visible through a touch-screen window in the middle of the front panel.

Same Sample Display



Correct Choice

Different Sample Display



Correct Choice

Figure 1. Representative examples of *same* and *different* displays. The top panel shows in the center a typical example of a *same* sample made from one set of icons, with *same* and *different* testing stimuli made from a second set of icons on either side. The bottom panel shows an example of a *different* sample trial. The 16 icons in each display were drawn at random from the 20 icons that comprised each set.

Table 1
Icon Combinations (Sample/Testing Stimuli)
Trained and Tested in Each Phase

	Training	Probe Tests
Phase 1	Set 1/Set 2	Set 2/Set 1
Phase 2	Set 1/Set 2	Set 3/Set 1
	Set 2/Set 1	Set 3/Set 2
		Set 4/Set 1
Phase 3	Set 1/Set 2	Set 4/Set 2
	Set 2/Set 1	Set 3/Set 1
	Set 3/Set 4	Set 3/Set 2
	Set 4/Set 3	Set 4/Set 1
		Set 4/Set 2
		Set 1/Set 3
		Set 1/Set 4
Phase 4	Set 2/Set 3	Set 2/Set 3
	Set 2/Set 4	Set 2/Set 4
	Set 1/Set 2	Set 5/Set 1
	Set 2/Set 1	Set 5/Set 2
	Set 3/Set 4	Set 5/Set 3
	Set 4/Set 3	Set 5/Set 4
	Set 3/Set 1	
	Set 4/Set 2	
	Set 3/Set 1	
	Set 4/Set 2	
	Set 1/Set 3	
	Set 1/Set 4	
	Set 2/Set 3	
Set 2/Set 4		

Pecks to the monitor were detected by an infrared LED touch screen (CarrollTouch), and correct responses were reinforced via a food hopper (see Cook, Levison, Gillett, & Blaisdell, 2005).

Stimulus Materials

Five sets of 20 icons (Sets 1, 2, 3, 4, and 5) allowed us to construct the sample and testing stimuli. Each sample or testing stimulus consisted of a white 8.2 × 8.2 cm background square containing a 4 × 4 (5 × 5 cm) grid of colored icons. For every stimulus and trial, these 16 icons were randomly selected from the 20 available in each set. For *same* displays, all 16 icons were identical; for *different* displays, all 16 icons were nonidentical (sampled without replacement).

Discrimination

Each trial started with a peck to a white ready signal, which was replaced by a centrally located *same* or *different* sample. After 10–20 sample pecks (variable-ratio-15 schedule), *same* and *different* testing stimuli appeared 1 cm to the left or to the right of the sample and 1.8 cm lower. These testing stimuli were counterbalanced across left/right positions and, crucially, came from a different icon set than had the sample stimuli. Correct choices (consisting of one peck to the test stimulus with a relation that matched that of the sample) received 2.5 sec of mixed grain; incorrect choices (one peck to the test stimulus with a relation that did not match that of the sample) were punished with a 10-sec dark time-out. Trials were separated by a 10-sec intertrial interval. A correction procedure was used in which the entire trial was repeated until a correct response was recorded. Only the *first* time a trial was presented was scored for analysis.

Training and Testing

Phase 1. Table 1 summarizes training and testing in each phase. During initial training in Phase 1, the sample stimuli were created from Set 1 and testing stimuli from Set 2. Because the birds started at different times, pigeons 4A and 3R received 160 Set 1/Set 2 trials (80S/80D) per session, whereas 1H and 2L received 120 Set 1/Set 2 trials per session.

Following acquisition, discriminative symmetry was tested using probe trials in which the sample stimuli were from Set 2 and the

testing stimuli from Set 1. These reversed Set 2/Set 1 probes were exactly like the training trials, except that nondifferential reinforcement was delivered for any choice, and correction trials were not given. Twelve Set 2/Set 1 probe trials (6S/6D) were randomly mixed into daily training trials. Three probe sessions were conducted.

Phase 2. Training here consisted of Set 1/Set 2 and Set 2/Set 1 trials, now equally intermixed, with all of the trials being differentially reinforced. Each session contained equal numbers of counterbalanced *same* and *different* trials from each set. Pigeon 4A was dropped because of illness. At least 60 sessions of Phase 2 training were given.

Following acquisition, novel transfer probe trials using sample icons from Sets 3 and 4 were conducted. Only novel sample icons were given in order to minimize the expected disruptive effects of showing novel testing icons; this is the same plan that was followed in the baboon project of Fagot et al. (2001). Two rounds of 20 sessions were given; each session had 12 (6S/6D) probe trials randomly added among the training trials. The first 10 sessions tested Set 3 sample stimuli with Set 1 testing stimuli, followed by 10 sessions of Set 3 sample stimuli with Set 2 testing stimuli. The second round tested 10 sessions with Set 4 samples and Set 1 tests, followed by 10 sessions with Set 4 samples and Set 2 tests.

Phase 3. Sixty training sessions randomly intermixing Set 1/ Set 2, Set 2/Set 1, Set 3/Set 4, and Set 4/Set 3 trials were given (Set 1 or 2 vs. Set 3 or 4 was *not* tested). All trials were differentially reinforced, and the sessions contained 96 trials apiece (12S/12D of each combination).

Following acquisition, novel transfer sessions with Set 3 and 4 samples and Set 1 and 2 tests were again conducted. Six sessions were given, with 16 probe trials (4 of each combination) randomly added to each session (112 total trials). Then novel transfer sessions with Set 1 and 2 samples and Set 3 and 4 tests were given for the first time, using the identical procedure.

Phase 4. Training consisted of sessions involving all sample/test arrangements of the four icon sets, except for the identity relation (Set 1/Set 1, etc.). Each 96-trial session contained equal numbers of counterbalanced *same* and *different* trials, with each set shown equally often. This training continued for 13 sessions. Novel probe transfer tests were then conducted in which Set 5 samples were tested using stimuli from each of the four other sets. Twenty sessions were given, with 16 probe trials (4 with each icon set) randomly added to the 96 training trials.

Stimulus-analytic tests. In this phase, a series of modified samples (staggered, delay, blurred, and mixed orientations and sizes) were presented in order to assess the contributions of different visual features to the discrimination (see Figure 2). To examine the role of icon alignment, staggered displays were introduced, in which each icon’s location was staggered within a 20 × 20 pixel area. Sessions in which half of the trials (48) involved staggered displays were continuously conducted. To examine whether having the sample and test stimuli overlap in time played any role, zero-delay trials were introduced, in which the sample ended prior to onset of the test stimuli. Sessions in which half of the trials (48) involved delayed testing were continuously conducted. After this test, only staggered displays were tested. To examine the contribution of icon detail and high spatial frequencies, blurred displays were tested, in which each sample icon was Gaussian blurred via software. Eight probe trials with blurred samples were randomly intermixed within eight sessions of 96 training trials apiece. To examine the role of icon orientation and size, mixture displays were also created. On orientation mixture trials, the sample’s icons randomly appeared in any of four orientations (0°, 90°, 180°, or 270°); in size mixture trials, the sample’s icons randomly appeared in any of four sizes (60%, 80%, 100%, or 120% of normal). In separate orientation and size tests, eight probe trials of each mixture type were randomly intermixed among 96 training trials, for six sessions. To familiarize the birds with all orientations and sizes prior to these tests, sessions were conducted in which the pigeons were given training trials consisting exclusively of the four orientations or sizes presented separately (i.e., never mixed).

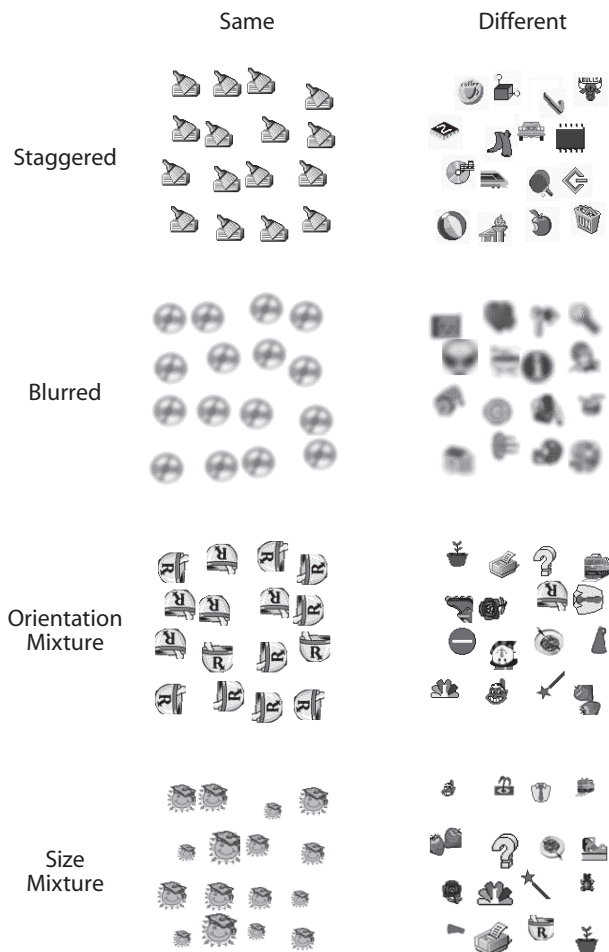


Figure 2. Representative examples of *same* and *different* sample displays used in the stimulus-analytic tests.

RESULTS

Overall, our pigeons (1) learned the relational MTS task, (2) showed reliable transfer of discriminative responding to novel sample displays, (3) exhibited increased savings when incorporating novel sample displays into their discriminative repertoire, and (4) showed discriminative invariance across changes in the orientation and size of the sample icons.

Acquisition

All 4 pigeons successfully learned the relational MTS task (see Figure 3). A repeated measures ANOVA (factors: two-session block \times sample) confirmed the significant improvement over sessions [$F(19,57) = 9.8$] and revealed a significant block \times S/D interaction [$F(19,59) = 7.1$] due to slightly faster learning on *same* than on *different* trials. This disparity persisted, with mean accuracy on *same* trials (74.3%) being significantly higher than accuracy on *different* trials (63.0%) [$F(1,3) = 14.1$] over Blocks 15–20. (All statistical significance was judged using an alpha level of .05.)

Transfer

Overall, the pigeons exhibited increasing transfer across phases, suggesting that they were responding to the generalized *same* and *different* relations among the sample and testing stimuli. The results from the two symmetry tests and the three novel sample transfer tests over the four phases are summarized in Figure 4 and are detailed below.

Phase 1. The 4 pigeons did not respond discriminatively in the first symmetry test, which involved reversal of the sample/test assignments. Accuracy was 79.1% in the baseline condition (Set 1 samples/Set 2 tests), but only 45.3% in the symmetry condition (Set 2 samples/Set 1 tests).

Phase 2. After they had also learned to match Set 2 samples and Set 1 tests (see the Savings section below), all of the remaining pigeons showed significant discrimination transfer to the novel Set 3 and 4 samples (Set 3, 60.8%; Set 4, 59.2%); the corresponding baseline accuracy (Sets 1 and 2) was 81.8%. Pigeon 2L transferred best (62.5%), with 1H (59.4%) and 3R (57.6%) performing slightly less accurately. Single-mean *t* tests using transfer accuracy over the 20 testing sessions (grouped into two-session blocks) confirmed that all 3 birds responded significantly above chance with Set 3 [1H, $t(9) = 3.4$; 2L, $t(9) = 6.2$; 3R, $t(9) = 2.8$] and Set 4 [1H, $t(9) = 3.1$; 2L, $t(9) = 4.3$; 3R, $t(9) = 3.9$] samples.

Phase 3. Following segregated training with Sets 1/2 and 3/4, the transfer tests from Phase 2 were conducted again, since these combinations had not been differentially reinforced in the immediately previous exposure. The pigeons exhibited reliable transfer on this retest, with the Set 3 and 4 samples now matched with Set 1 and 2 tests (70.1%); the corresponding baseline accuracy was 75.7% (sample/test Sets 1/2, 2/1, 3/4, and 4/3 combined). Pigeons 1H [80.2%, $t(5) = 5.6$] and 2L [72.9%, $t(5) = 3.5$] showed significant transfer performance, but 3R transferred less well [57.2%, $t(5) = 1.5$].

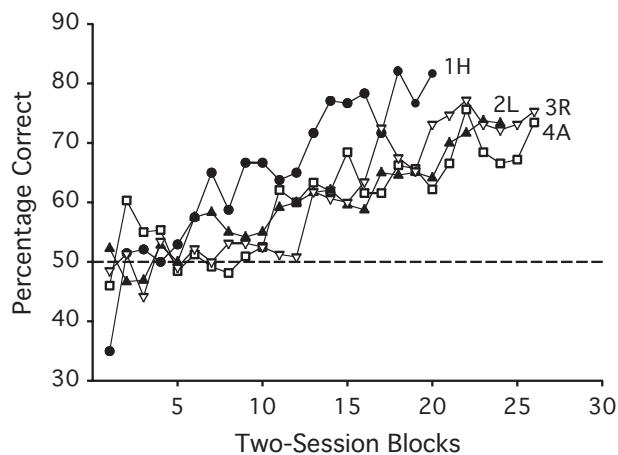


Figure 3. Mean choice accuracy for each of the 4 pigeons throughout the training sessions of Phase 1. The dotted reference line depicts 50% chance responding.

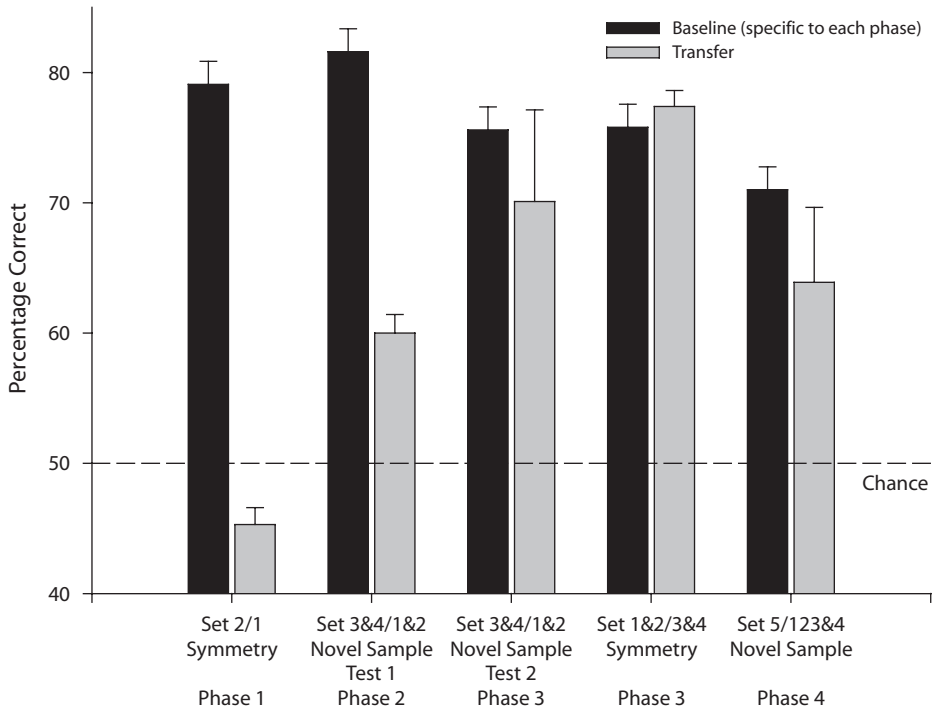


Figure 4. Mean choice accuracy across pigeons in the five transfer tests conducted during the four experimental phases. Black bars show the baseline data from the testing sessions, and gray bars show the transfer results. The first line of the bottom labels describes the transfer test items (sample/test); the middle line or lines define the nature of the test; and the last line specifies the phase in which the test occurred. The error bars represent the standard error of the mean for each condition, and the dashed line shows chance responding.

All pigeons showed reliable transfer in the second symmetry test, reversing Set 1 and 2 samples with Set 3 and 4 tests. Mean transfer accuracy was 77.4%, not significantly different from baseline accuracy (75.8%). Pigeons 1H [78.1%, $t(5) = 10.5$], 2L [75%, $t(5) = 5.8$], and 3R [79.1%, $t(5) = 6.4$] all exhibited significantly above-chance transfer.

Phase 4. Two of the 3 pigeons showed reliable transfer to the novel fifth set. Birds 1H [72.7%, $t(9) = 7.0$] and 2L [66%, $t(9) = 6.7$] exhibited significantly above-chance performance; 3R did not reliably transfer to the fifth set [53.1%, $t(9) = 0.6$], but it did improve slightly, scoring 60% on transfer trials during the last 10 test sessions.

Savings

Because the pigeons showed imperfect but reliable transfer, their lowered accuracy allowed us to look for savings during subsequent learning with the novel sets. To compare these learning effects across all four phases, we computed the mean number of trials that it took to reach the second session over 70% correct with any introduced condition. Figure 5 shows that pigeons became progressively faster at incorporating each new condition into their relational matching repertoire; indeed, by Phase 4, this incorporation was virtually immediate (detailed below). This significant savings may reflect the increasing use of a generalized discrimination rule or strategy.

Phase 2. The absence of transfer in the first symmetry test suggests that the birds had learned the sample- and/

or test-specific properties of each set. After training with the reversed arrangement (Set 2 samples/Set 1 tests), pigeons' accuracy improved (Figure 6A). A repeated measures ANOVA (two-session block \times set \times S/D) found a significant block \times set interaction [$F(29,58) = 1.97$], confirming the convergence of Set 2 and Set 1 accuracy. There was also a significant block \times set \times S/D triple in-

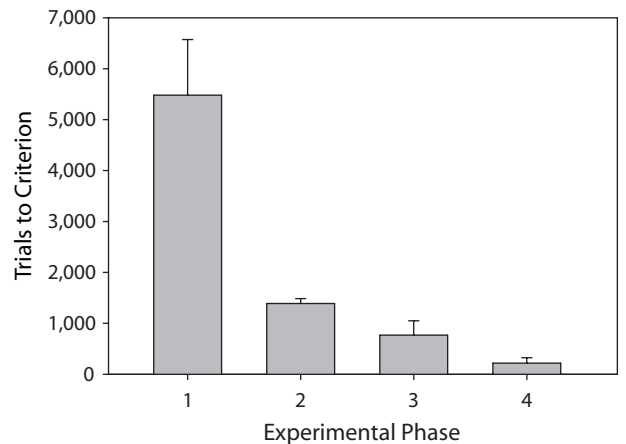


Figure 5. Mean number of trials to criterion (i.e., two sessions at $\geq 70\%$) for the novel conditions introduced into each phase. Error bars show the standard error of the mean for each condition.

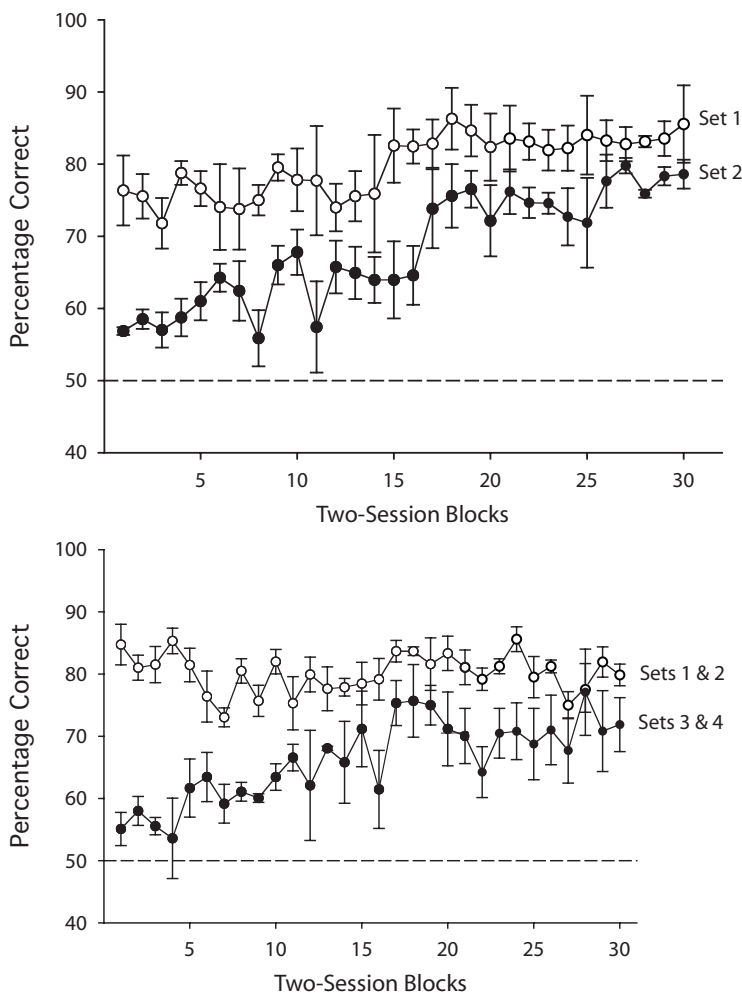


Figure 6. The top panel shows mean choice accuracy during the first 60 training sessions of Phase 2 with each sample/test mapping (“Set 1” = Set 1 samples/Set 2 tests; “Set 2” = Set 2 samples/Set 1 tests). The bottom panel shows mean choice accuracy during the first 60 training sessions of Phase 3 with each sample/test mapping. Performance with Set 1 and 2 samples and with Set 3 and 4 samples has been combined. The dashed reference lines depict chance responding. Error bars show the standard error of the mean for each condition.

teraction [$F(29,58) = 1.7$], due to the different rates at which the S/D disparity of Phase 1 decreased for each set. This disparity remained for each set (for Set 1, same = 85.6%, different = 81.6%; for Set 2, same = 79.8%, different = 76.2%), but it lessened with experience.

Phase 3. Following the introduction of Sets 3 and 4, accuracy again converged toward baseline (Sets 1 and 2; see Figure 6B). A repeated measures ANOVA (two-session block \times Sets 1 and 2 combined vs. Sets 3 and 4 combined) confirmed this trend with a significant block \times combined set interaction [$F(29,58) = 2.13$].

Phase 4. Consistent with the reliable transfer exhibited during the novel stimulus and symmetry tests in Phase 3, the introduction of reinforced training with all set combinations (except for identity combinations) went smoothly. Over sessions, there was no significant effect of session for either familiar or novel icon arrangements (session \times

familiar vs. new). Over the last five sessions, mean accuracy was 71.4% for all set combinations (73.3% for 1H, 73.1% for 2L, and 67.9% for 3R), with *same* performance (73.4%) slightly higher than *different* performance (69.4%). There were no significant differences as a function of set or role (sample or test). Mean accuracy for Sets 1, 2, 3, and 4 as samples was 73.5%, 72.2%, 69.4%, and 70.8%, respectively; mean accuracy for Sets 1, 2, 3, and 4 as tests was 71.6%, 71.9%, 72.7%, and 69.4%, respectively. By the end of Phase 4, pigeons were reliably discriminating all sets, despite the numerous permutations involved.

Stimulus-Analytic Tests

The results of the five stimulus-analytic tests are summarized in Table 2, which presents mean accuracy on baseline and test trials for each condition. Overall,

Table 2
Results of Stimulus-Analytic Tests

	Baseline (%)	Test (%)
1. Staggered displays	78.4	76.4 ⁺
2. Delayed testing	72.3	71.3 ⁺
3. Blurred displays (simultaneous)	70.7	53.5 [*]
3. Blurred displays (zero delay)	69.7	53.0 [*]
4. Orientation mixture (simultaneous)	71.0	70.8 ⁺
4. Orientation mixture (zero delay)	69.2	69.4 ⁺
5. Size mixture (simultaneous)	72.2	52.7 ⁺⁺
5. Size mixture (zero delay)	69.6	76.3 ⁺

*Baseline versus test; *t* tests, $p \leq .05$ for all birds. ⁺Test accuracy greater than chance (50%); binomial tests, $p < .05$ for all birds. ⁺⁺Test accuracy greater than chance (50%); binomial tests, $p < .05$ for only 1 bird.

changes in the sample produced little disruption in choice accuracy, with performance significantly above chance in the test conditions (binomial test) and not significantly different from baseline (*t* tests based on sessions for each pigeon). The two exceptions were the blurred displays, for which performance was not significantly different from chance and was significantly below baseline for all 3 pigeons [$ts(7) > 2.9$], and the simultaneous (but not the zero-delay) size mixture condition, which was not significantly different from chance for 2 of the 3 birds, whereas the third bird showed no difference from its zero-delay performance.

DISCUSSION

These results suggest that pigeons can learn and transfer higher-order relational MTS. To our knowledge, this is the first demonstration of this important ability in a nonprimate species. Two birds consistently transferred discriminative responding at above-chance levels of accuracy to novel sample displays and temporal arrangements, and a third bird transferred a majority of the time. Transfer performance improved over testing (Figure 3), as did the savings in mastering new conditions after their introduction into training (Figure 6). The significant transfer and savings observed after Phase 1 suggest that pigeons came to use higher-order relational codes to process and compare the first-order S/D relations in the sample and testing arrays. It is not known whether this abstract code emerged from mere experience with the task or from the increasing demands of processing the ever-expanding numbers of icons and set relations (Cook et al., 2005; Katz & Wright, 2006). Over training, our findings are similar to Fagot et al.'s (2001) baboon results in documenting successful acquisition and transfer of relational MTS. As such, pigeons, and perhaps birds in general, resemble primates in processing higher-order S/D relations. If so, the hypothesis that only humans or language-trained apes can learn about higher-order S/D relations is too limited (Premack, 1983; Thompson & Oden, 2000).

Although having language, learning a symbol system, or being a primate may not be preconditions for mastering relational MTS, our pigeons were not naive; each had had some form of S/D training prior to the present tests (as had Fagot et al.'s [2001] baboons). Perhaps first learning to attend to simpler *first-order* relations is prerequisite to

our pigeons' success in processing *higher-order* relations. Future tests with naive birds should prove informative.

As with all studies of concept learning in animals, one must consider whether "simpler" perceptual alternatives might account for the results. Although there was *never* any explicit perceptual identity between the icons of the sample and testing stimuli, concerns might be raised about whether performance with these multielement arrays might be mediated by lower-level visual mechanisms (e.g., edge alignment, symmetry, or spatial frequency signature). We explicitly explored these possibilities in our stimulus-analytic tests.

The pigeons robustly transferred to new conditions in which the alignment of the icons, their orientation, and their size were varied and mixed. Despite these changes in alignment, orientation, and size, pigeons reliably reported *higher-order* S/D relations between the sample and testing arrays, similar to their discrimination behavior in *first-order* S/D tasks (see, e.g., Young & Wasserman, 2001). Significantly, the test condition that gave pigeons the greatest difficulty involved blurring, which removed icon detail and likely prevented comparisons of icon identity within each array.

This pattern of results argues against the possibility that the pigeons' discrimination behavior was exclusively mediated by icon alignment, the presence of low-spatial-frequency signatures, or other large-scale perceptual regularities (e.g., symmetry) tied to our multielement stimuli. The pigeons' failure with blurred displays and the decrements relative to baseline recorded at the introduction of new icons specifically indicate that icon detail is needed to perform stimulus comparisons both within and between displays. The large class of perceptual accounts that rely only on global factors cannot account for the latter identity results.

Furthermore, any purely perceptual accounts do not explain the observed improvements in transfer and savings in the different experimental phases; rather, these improvements are more consistent with the idea that pigeons initially learn the task by using item-specific information (Cook et al., 2005), but increasingly shift to a higher-order relational strategy with the growing demands of the task.

Finally, perceptual accounts might also predict a drop in accuracy when the sample and testing stimuli are presented successively, thereby precluding any direct perceptual comparison. No such drop was observed, however, when our pigeons were switched from simultaneous to delayed MTS (cf. Fagot et al., 2001, who used delayed MTS from the outset of training and in all phases of transfer testing). In sum, the pattern of results from across the stimulus-analytic tests poses strong challenges for any purely perceptual interpretation.

Still, our use of multielement sample and testing stimuli has aspects that vex a complete conceptual interpretation. A central fact is that humans can learn S/D discriminations and analogies by comparing only two items; in contrast, baboons' performance dramatically declines as the number of sample icons is reduced in higher-order relational MTS (Fagot et al., 2001; Wasserman, Fagot, & Young, 2001). Wasserman and his colleagues also found

that pigeons' performance declines in a first-order S/D task as the number of icons is reduced (Young, Wasserman, & Garner, 1997). We suspect that pigeons' relational performance will similarly fall when we reduce the number of icons in the present relational task (but see Cook et al., 2003). Why pigeons and baboons, but not humans, require so much redundant information in a visual array in order to compute first- or higher-order S/D relations is not known. Having multiple elements may decrease search demands, or it may also reflect an important species difference in how stimulus relations are computed. Here, the possibility exists that the amount of variability or entropy in the sample and testing displays lies at the root of relational MTS behavior, but that humans are less controlled by that factor because they can verbally code the task stimuli (Fagot et al., 2001).

Thompson and Oden (2000) proposed that relational MTS captures the essence of analogy, in which all of the logical arguments are visually provided. Our results suggest that pigeons may have at least the rudimentary elements for analogical thinking, since they can report whether two visual arrays exemplify similar stimulus relations. Given that the last common ancestor of pigeons and people lived over 200 million years ago, the visual roots of understanding higher-order stimulus relations may run deep. Alternatively, this type of analogical behavior may represent a more recent cognitive advance that has independently evolved in both mammals and avians.

What is at issue is not an arcane point, but the very distinction between the minds of humans and nonhuman animals. We do not claim that pigeons can reason about analogies; we do suggest, however, that the perceptual and cognitive foundations for doing so may exist in the avian brain (Cook, 2001) and may have provided the visual building blocks that allowed for the later development of analogous symbolic representations, with the advent of more advanced abstract thought and language in hominids.

AUTHOR NOTE

This research was supported by a grant from the National Science Foundation (0316016) to R.G.C. We thank Dan Brooks, Angie Koban, and Taylor Johnson for their comments on an earlier draft. Correspondence relating to this article may be sent to R. G. Cook, Department

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Note—Accepted by David A. Balota's editorial team.

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(Manuscript received September 12, 2005;
revision accepted for publication June 23, 2006.)