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Associative symmetry in a spatial sample-response paradigm

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Abstract

Symmetry has been difficult to observe in nonhumans mainly because they seem to perceive stimuli as a conjunction of visual, spatial, and temporal characteristics. When such characteristics are controlled, symmetry does emerge in nonhumans (cf. Frank and Wasserman 2005; Urcuioli 2008). Recently, however, Garcia and Benjumea (2006) reported symmetry in pigeons without controlling for temporal order. The present experiments explored their paradigm and the ingredients for their success. Experiments 1 and 2 sought to replicate their findings and to examine different symmetry measures. We found evidence for symmetry using non-reinforced choice probe tests, a latency-based test, and a reinforced consistent versus inconsistent manipulation. Experiment 3 adapted their procedure to successive matching to evaluate their contention that a choice between at least two comparisons is necessary for symmetry to emerge. Contrary to their prediction, symmetry was observed following go/no-go training. Our results confirm Garcia and Benjumea's findings, extend them to other test and training procedures, and once again demonstrate symmetry in the absence of language.

Keywords

choice; matching-to-sample; associative symmetry; pigeons; latency

1. Introduction

The ability to exhibit untrained symmetrical associations has been a long-standing research issue in psychology. In simple terms, if an organism learns the association between non-identical stimuli A and B in which A always precedes B ($A \rightarrow B$), the ability to spontaneously report (or behave consistently with) $B \rightarrow A$ is evidence for symmetry.

Despite theoretical disagreements over how and when symmetrical associations emerge, the empirical evidence establishes that the phenomenon of associative asymmetry is a reliable one in humans (e.g., Asch and Ebenholtz 1962; Kahana 2002; Murdock 1966; Lazar, Davis-Lang, and Sanchez 1984; Rehfeldt 2003; Tomanari et al. 2006). The data are quite different, however, for other animals.

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Despite evidence for bidirectional associations in Pavlovian conditioning (e.g., Arcediano, Escobar, and Miller 2003; Matzel, Held, and Miller 1988; Hearst 1989), most operant conditioning studies insuring that any test for symmetry is uncompromised by the continued presence of reinforced baseline relations have returned null findings (for a thorough review, see Lionello-DeNolf 2009). A sample of these null-effect studies are Hogan and Zentall (1977), Lionello-DeNolf and Urcuioli (2002), and Lipkens, Kop, and Matthijs (1988), with pigeons; D'Amato, Salmon, Loukas, and Tomie (1985), and Sidman et al. (1982) with monkeys; Dugdale and Lowe (2000) with chimpanzees; and Sidman et al. (1982) with baboons.

Does the typical failure to observe symmetry in non-human animals indicate that human-unique processes are required for this phenomenon? The answer to this question is important not only for the narrower question just posed but also because it bears directly upon broader issues concerning the origins of equivalence relations, of which symmetry is one behavioral index (cf., Sidman and Tailby 1982; Sidman 2008).

It turns out that one of the reasons researchers have so often failed to demonstrate symmetry in non-human animals is that their tests mistakenly assumed that the functional stimuli for the animals were simply the nominal stimuli themselves. Specifically, two-choice arbitrary matching-to-sample (MTS), a common paradigm for investigating symmetry, presents sample and comparison stimuli in different spatial locations—e.g., samples on the center of three horizontally aligned keys and the comparisons on the two adjacent side keys. This common training procedure does not yield a valid symmetry test (i.e., a test to see if animals can later match the former comparisons to their associated, former sample stimuli) if the functional matching stimuli include where each stimulus is seen. In other words, if animals learn to match “A-on-the-center to B-on-the-side” during training (cf. Iversen 1997; Iversen, Sidman, and Carrigan 1986; Lionello and Urcuioli 1998), this precludes symmetry because testing assesses the ability to match “B-on-the-center” to “A-on-the-side”. If “A-on-the-center” is not the same stimulus as “A-on-the-side” and, likewise, “B-on-the-side” is not the same stimulus as “B-on-the-center”, the test essentially requires the animal to match two novel stimuli to one another. A similar concern arises in regards to the ordinal position of each matching stimulus: Is a stimulus appearing first in a trial (i.e., as a sample) functionally the same as the same nominal stimulus appearing second (i.e., as a comparison)?

Interestingly, compelling evidence demonstrating associative symmetry in pigeons has recently appeared precisely because researchers have taken into account these ostensibly incidental but consequential features of samples and comparisons. For example, Frank and Wasserman (2005) and Urcuioli (2008) trained pigeons on successive (“go/no-go”) matching in which the samples and comparisons are presented singly at the same spatial location. Responding to the comparisons on one half of the sample-comparison combinations is reinforced, whereas comparison responding on the other half is not. In these studies, symbolic ($A \rightarrow B$) successive matching was supplemented by concurrent training on identity ($A \rightarrow A$ and $B \rightarrow B$) successive matching ostensibly to control for temporal order (i.e., to accustom pigeons to seeing each stimulus in both the first and second ordinal positions in a matching trial). When later tested with non-reinforced $B \rightarrow A$ (symmetry) probe trials, most pigeons pecked more to comparisons on probes that reversed the reinforced $A \rightarrow B$ symbolic baseline relations than to comparisons on probes that reversed the non-reinforced $A \rightarrow B$ relations. In other words, they showed associative symmetry.

Interestingly, Garcia and Benjumea (2006) recently reported a symmetry effect in pigeons using a choice procedure which did not control for the temporal order of the matching stimuli although it did maintain the spatial location of the test stimuli used to assess symmetry. In their Experiment 1, each matching trial began with a white stimulus appearing

simultaneously on both the left and right keys. Only one key, however, was “active” (the sample). Specifically, five consecutive pecks to the active location (viz., sample) turned off both keys followed 2 s later by red and green comparisons on those same keys (counterbalanced in their left-right positions across trials). Any peck to the “inactive” key location during the sample phase reset the peck counter. Thus, the comparisons only and always appeared after 5 consecutive pecks to the active (sample) location. For some pigeons, choosing the red comparison after pecking the left sample and the green comparison after pecking the right sample were reinforced, whereas the opposite choices were non-reinforced. (For other pigeons, these contingencies were reversed.) After these conditional relations were learned to high levels of accuracy, the possibility that the reinforced [Left key peck → red choice] and [Right key peck → green choice] relations were symmetrical was assessed by presenting infrequent, non-reinforced probe trials in which only one color (red or green) was presented on both side keys. These symmetry probes ended with 10 pecks (not necessarily on the same key). Garcia and Benjumea found that pigeons pecked the left key more often on these probes when the color presented on both keys was the one reinforced after the left sample in training and, likewise, pecked the right key more often when the color presented on both keys was the one reinforced after the right sample in training. Continuing with the specific example, pigeons pecked more to the left key when red appeared on both side keys, and pecked more to the right key when green appeared on both, in testing. This finding was replicated in a follow-up experiment in which baseline training required five consecutive pecks to the designated correct comparison for reinforcement and in which only the “active” key (left or right) was lit at the beginning of each matching trial.

Garcia and Benjumea (2006) claimed that they were able to obtain symmetry from the explicitly reinforced ([Left key peck → Red] and [Right key peck → Green] baseline relations because the functional sample stimuli were proprioceptive rather than exteroceptive (see also Garcia and Benjumea 2007; Garcia, Gómez, and Benjumea 2007). In other words, they argued that the pigeons’ own differential behavior provided the conditional cue for comparison choice in training (cf. Urcuioli and Honig 1980). Note that this assumes that pecking to one spatial location versus pecking to a different spatial location represents different behavior as opposed to different exteroceptive stimuli associated with those locations. Furthermore, it also assumes that the conditional cue is only the 5 consecutive left- or right-key pecks immediately preceding the appearance of the comparisons.

Be these as they may, their findings are important empirically and theoretically. For one, they potentially represent another example of the traditionally elusive symmetry effect in non-human animals. For another, they are not predicted by Urcuioli’s (2008) recent theory of pigeons’ equivalence-class formation which predicts symmetry between sample and comparison stimuli (A and B) only when baseline training generates a class containing the nominal matching stimuli in each of their two possible ordinal positions within a trial (i.e., as samples, A1 and B1, and as comparisons, A2 and B2). Such a class could not have developed in Garcia and Benjumea’s experiments according to Urcuioli’s theory because red and green never appeared in the first ordinal position of a trial during training. Consequently, these results disconfirm theoretical predictions and indicate another way in which symmetry might emerge from conditional discrimination training.

Presently, Garcia and Benjumea’s (2006) results stand almost by themselves in the non-human literature on symmetry (although see Schusterman & Kastak, 1993) because they were obtained in the typically problematic two-choice procedure. Thus, given their theoretical and empirical ramifications, a replication and fuller evaluation of these results are in order. In the present experiments, we aimed to (a) replicate the Garcia and Benjumea (2006) findings (b) examine other measures of symmetry in their paradigm, and (c) assess the necessity of the simultaneous presentation of the comparisons (viz., choice) as opposed

to a successive presentation of an individual comparison on each matching trial (cf. Frank and Wasserman 2005; Urcuioli 2008).

2. Experiment 1

Experiment 1 was primarily designed to assess the reliability of Garcia and Benjumea's (2006) findings (cf. Vasconcelos, Urcuioli, and Lionello-DeNolf 2007). A secondary purpose was to evaluate their symmetry claim using a slightly different test procedure and another dependent measure. Specifically, we ran probe tests in which red appeared on one side key and green on the other and the latency of the first keypeck to either stimulus was recorded. We reasoned that if choosing red had been reinforced after pecking a white-left sample and choosing green had been reinforced after pecking a white-right sample in training, then pigeons should respond relatively quickly (i.e., exhibit relatively short first-peck latencies) with red on the left key and green on the right key in testing because these locations are consistent with the hypothesized symmetrical versions of the baseline contingencies. Conversely, latencies should be relatively long when red and green appear in the opposite spatial locations.

2.1. Materials and Method

2.1.1. Subjects—Six adult White Carneau (*Columba livia*) retired breeders obtained from the Palmetto Pigeon Plant (Sumter, SC) participated in the experiment. All had limited experience unrelated to the present contingencies. Upon arrival in the lab, all had continuous access to Purina Pro-Grains in order to determine their free-feeding body weights. Each pigeon's weight was then gradually reduced to and maintained at 80% of its free-feeding value by restricted feeding. During experimental participation, food was provided in the home cage only when food intake in a session was insufficient to maintain the 80% body weight and on days on which the experiment was not run.

Pigeons were housed individually in stainless-steel, wire-mesh cages in a temperature- and humidity-controlled colony room on a 14:10 day-night cycle. The light portion of the cycle began at 07:00 hours. Grit and water were always available in the home cage.

2.1.2. Apparatus—A single BRS/LVE (Laurel, MD) experimental chamber, consisting of a three-key panel (Model PIP-016) inside a Model SEC-002 enclosure with an aluminum grid floor, was used in this experiment. The pigeon's compartment was 36.8 cm high $\times$ 30.5 cm wide $\times$ 34.3 cm deep. Stimuli were displayed via in-line projectors (Model IC-901-IDD) mounted behind the keys, each 2.5 cm in diameter, spaced 8.3 cm apart center-to-center, and positioned approximately 25 cm from the grid floor. The center-key projector could display an inverted white triangle on a black background (BRS/LVE Pattern No. 692). The side-key projectors could display red, green, and white homogeneous fields. A partially covered GE #1829 bulb 5.7 cm above the center key directed light toward the ceiling of the enclosure to provide general chamber illumination. Food (Purina ProGrains) could be accessed through a 5.8 $\times$ 5.8 cm opening centered approximately 13 cm below the center key. The metal housing in back of this opening was lit by a miniature bulb (ESB-28) when the food hopper was raised. A constantly running blower fan attached to the enclosure provided ventilation and masking noise. An IBM-compatible 386 computer in an adjacent room controlled the presentation and recording of all events via an interface connected to the experimental apparatus.

2.1.3. Procedure

2.1.3.1. Preliminary Training: Each pigeon learned to obtain food by pecking red, green, and white side-key stimuli on a fixed-ratio (FR) schedule, the parameter of which was

gradually raised from 2 to 10 over seven sessions. The 60 trials in each preliminary training session were divided equally among all stimuli scheduled to appear in a session, with successive trials separated by a 10-s inter-trial interval (ITI). Reinforcement duration was constant within a session but varied between 1.5 – 6 s across sessions to maintain the 80% body weights. The house light remained on continuously.

2.1.3.2. Baseline Training: Next, all pigeons learned to match white on the left and right side keys to red and green comparisons. At the beginning of each trial, both side keys were lit but only one was active. Five consecutive pecks (FR 5) to the active key (the sample) turned off both keys and initiated a 2-s delay. A single peck to the inactive key reset the peck counter to zero. After the 2-s delay had elapsed, red and green comparisons were presented on the side keys. Five consecutive pecks to the designated “correct” comparison turned off both stimuli and produced food, whereas a single peck to the designated “incorrect” comparison turned off both stimuli and initiated the ITI. For three birds, pecking the red comparison after a white-left sample and pecking the green comparison after a white-right sample were correct whereas for the remaining birds, the opposite was true. The four possible sample-comparison combinations (2 samples $\times$ 2 left-right positions of the comparisons) in each 80-trial session were randomized with the constraints that each trial type occur equally often and that none occur more than 3 times in a row. Successive trials were separated by a 10-s ITI. As before, reinforcement duration was adjusted on a session-by-session basis for each bird to maintain its 80% body weight as closely as possible. The house light remained on throughout the entire session.

After 12 sessions on this procedure, pigeons had not met a pre-set performance criterion of 3 consecutive sessions with at least 90% overall accuracy and at least 85% choice accuracy with each sample. At this point a correction procedure was added in which an incorrect choice on any trial repeated that trial after the usual ITI but with the house light off. However, this change also failed to produce the desired levels of performance after 30 additional training sessions because pigeons tended to peck the (dark) sample location throughout the 2-s post-sample delay and into the comparison period. Consequently, the 2-s delay was replaced by a center-key triangle that appeared immediately after sample offset. A single peck to the triangle turned it off and produced the comparisons on the left and right keys. When run with the correction contingencies, this modified procedure was effective in generating criterion levels of performance.

2.1.3.3. Red-Red/Green-Green Tests: After meeting criteria, pigeons received two 84-trial test sessions separated by a baseline training session. Each test session consisted of 4 non-reinforced probe trials interspersed among 80 baseline training trials. Probe trials consisted of the simultaneous presentation of either the red or the green comparison on both side keys at trial onset (cf. Garcia & Benjumea, 2006). Ten pecks, not necessarily at the same key, turned both keys off and initiated the 10-s ITI.

2.1.3.4. Red-Green Tests: After 3 baseline refresher sessions, five additional 84-trial test sessions were run, each separated from the next by a single baseline session. The four non-reinforced probe trials in each of these test sessions involved the presentation of red on one side key and green on the other, with side allocation counterbalanced across trials. On half of the probe trials, the color comparisons were presented at locations consistent with symmetry; on the other half, they were presented at locations inconsistent with symmetry. For example, if pecking red after the white-left sample and pecking green after the white-right sample were reinforced in training, a consistent probe trial involved presenting red on the left key and green on the right key, whereas an inconsistent probe trial involved the opposite color-location combinations. All other procedural details for these probes and for

the baseline trials were identical to those for the red-red/green-green test. The primary dependent measure for the Red-Green tests was the latency to the first probe-trial peck.

2.2. Results

2.2.1. Baseline Performances—All pigeons exhibited a strong side bias during sample presentation: They consistently pecked five times to the white-left sample first 97.6% of the time, switching to the white-right sample only when the left key was not active for that particular trial.

As mentioned before, no bird met the performance criterion during the initial training phase, averaging only 81% correct choices by the end of that phase. All pigeons met criterion, however, within 5 sessions following the introduction of the center key peck requirement. Average accuracies for the white-left and white-right samples were 96.9%, and 96.8% correct, respectively [$F(1, 5) = 0.01$], for the 3 criterion sessions.

2.2.2. Red-Red/Green-Green Tests—Figure 1 shows the proportion of “symmetrical” pecks across the two test sessions during which probes consisted of either red on both side keys or green on both side keys. Symmetrical probe-trial pecks were those made to the same location as the white sample that had occasioned reinforced pecking to the red or green comparison in training. On average, birds pecked 72.9% (range: 55.0 – 93.8%) of the time to the “symmetrical” side key. T -tests showed that this overall preference was significantly different from chance [$t(5) = 3.41$, $p = .02$], and this was true for the first test session as well (77.5%; range: 50 – 100%; not shown; $t(5) = 2.96$, $p = .03$). Analyses of individual performances for just the first test session (to avoid accumulating deleterious effects of probe-trial non-reinforcement) showed that four pigeons (S1, S3, S5, and S6) significantly preferred the “symmetrical” comparison location, largest binomial $p < .001$.

2.2.3. Red-Green Tests—Figure 2 plots the average first-peck latencies on consistent and inconsistent trials for the 5 tests during which the non-reinforced probe trials consisted of red on one side key and green on the other. Not surprisingly, overall probe-trial latencies increased across test sessions. More importantly, average first-session latencies were shorter on consistent than on inconsistent probe trials: 1.76 s and 3.38 s, respectively [$t(5) = -2.60$, $p = .048$], and this difference was observed in every pigeon (not shown; binomial $p = .03$). This effect quickly dissipated, however: Average latencies did not differ significantly on any of the last 4 test sessions [all $t(5) \geq -1.21$ and ≤ 1.15], and this was true for each pigeon as well (smallest binomial $p = .22$).

2.3. Discussion

Our Red-Red/Green-Green test results replicated those of Garcia and Benjumea (2006). When presented with the same color comparison on both side keys, pigeons pecked significantly more to the side key they had pecked in order to produce that reinforced comparison during baseline training. Experiment 1 also provided another index of symmetry by showing that pigeons were faster to peck either side key when red and green appeared together in a probe-trial display consistent with symmetrical baseline relations.

It was unfortunate that none of our 6 pigeons reached criterion levels of performance after 42 training sessions (30 with a correction procedure) using the same procedure as Garcia and Benjumea (2006, Experiment 2), although they reported only a 50% success rate in this regard. Introducing a mandatory center-key peck following each sample, however, produced an immediate jump in baseline accuracy suggesting that the below-criteria accuracy levels without this added contingency represented a performance deficit rather than a learning deficit (Blodgett 1929; Hearst 1987; Tolman and Honzik 1930). In any event, after the

necessary procedural modifications for training our pigeons, our test data provide both a systematic and a conceptual replication of Garcia and Benjumea (2006).

3. Experiment 2

Using the aforementioned “successful” training procedure, Experiment 2 assessed symmetry after training with either one white side-key stimulus (Group 1S) or two (Group 2S) at the beginning of each matching trial. These conditions were comparable to those run by Garcia and Benjumea (2006, Experiment 2) for which they found evidence of symmetry in both. We also trained a third group (Group 1SI) with one side-key sample using Garcia and Benjumea’s (2006) exact procedure to see if a single-sample procedure might support criterion levels of baseline accuracy without an intervening center peck requirement.

All groups received 3 symmetry tests after acquisition to criterion. The first two tests were identical to those in Experiment 1. The third test was a differentially reinforced version of the previously described red-red/green-green test in which the first 5 consecutive pecks to one side key turned both keys off and yielded either food with a 50% probability or no food. In one test condition, reinforcement was contingent upon left- versus right-key pecking consistent with the symmetrical versions of the baseline relations. Thus, if [Left key peck→Red] and [Right key peck→Green] were the reinforced baseline relations, then pecking left when both side keys were red and pecking right when both were green were reinforced on a 50% schedule in testing and the opposite choices were non-reinforced. In the other test condition, reinforcement was contingent upon left- versus right-key pecking inconsistent with the symmetrical versions of the baseline relations. Continuing with the same baseline contingencies just described, pecking right when both side keys were red and pecking left with both were green were reinforced on a 50% schedule, and the opposite choices were non-reinforced, in this test condition. For this differentially reinforced test, symmetry should yield (a) above- and below-chance levels of accuracy in the consistent and inconsistent conditions, respectively, at the outset of testing, (b) faster probe-trial acquisition over repeated test sessions in the consistent condition, and/or (c) a temporary deterioration in baseline performances in the inconsistent condition given that the explicitly reinforced non-symmetrical test relations conflict with the baseline relations.

3.1. Materials and Method

3.1.1. Subjects and Apparatus—Sixteen experimentally naïve White Carneau retired breeders housed and maintained as previously described participated in this experiment. Six pigeons each were randomly assigned to Groups 1S and 2S and 4 to Group 1SI. The experiment was run in two operant chambers similar to the one used in Experiment 1.

3.1.2. Procedure

3.1.2.1. Preliminary Training: After food magazine training and shaping the key peck response to a white triangle on the center key, each pigeon underwent preliminary training similar to that in Experiment 1.

3.1.2.2. Baseline Training: At the beginning of each baseline matching trial, a white stimulus appeared on either the left or right side key for Groups 1S and 1SI but on both sides keys for Group 2S. Five consecutive pecks to the solely lit key (Groups 1S and 1SI) or to the active key (Group 2S) terminated the white side key(s) and produced either a center-key triangle (Groups 1S and 2S) or a 2-s delay interval with all keys off (Group 1SI). The red and green side-key comparisons were then presented after either a single peck to the triangle (Groups 1S and 2S) or the end of the 2-s delay (Group 1SI). The comparison-response

requirement and reinforced sample-comparison contingencies were identical to those described in Experiment 1 as were all other procedural details (including counterbalancing).

Three pigeons in Group 1SI were unable to reach criterion levels of accuracy because their pecking to the location of the single white sample carried over into and through the delay interval. To eliminate this behavior, the procedure for this group was eventually changed such that pecking more than once to the dark sample location during the 2-s delay produced a 4-s time-out with the house light off, after which the trial was reinitiated.

Each pigeon was trained to a criterion of three consecutive sessions in which their overall accuracy was 90% correct or higher with a minimum of 85% correct for each sample, after which they received 20 overtraining sessions.

3.1.2.3. Red-Red/Green-Green Tests: These 84-trial test sessions were identical to those in Experiment 1. The first two red-red/green-green tests were given consecutively prior to baseline training and without a correction procedure in effect in order to assess any side-key preferences for the red and green displays before pigeons had learned the matching contingencies. The final two red-red/green-green tests were given after baseline training was completed with the correction procedure in effect for baseline trials. The latter tests were separated by one baseline session.

3.1.2.4. Red-Green Tests: After 15 additional baseline refresher sessions, pigeons received four red-green latency tests, each containing 4 probe trials interspersed among 80 baseline training and alternated with continued training on the pigeons' respective baseline tasks. Procedural details were identical to those for the corresponding tests in Experiment 1.

3.1.2.5. Consistent versus Inconsistent Tests: After 15 more baseline refresher sessions without a correction procedure, 36 consecutive test sessions were run, each consisting of 80 non-correction baseline trials plus 8 differentially reinforced red-red/green-green probe trials. On each probe trial, 5 consecutive pecks to either side-key stimulus turned both off and either produced food with a probability of .5 or nothing. (Any alternation between side keys reset the FR 5 requirement.) For half of the pigeons in each group, the reinforced fifth peck was consistent with the symmetrical [Sample location – Reinforced Color] versions of the baseline relations; for the remaining birds, the reinforced fifth peck was inconsistent with these relations. All other procedural details were as previously described.

3.2. Results

3.2.1. Baseline Performances—The average numbers of training sessions to reach criterion were 5.2, 5.4, and 31.0 for Groups 2S, 1S, and 1SI, respectively. One-way ANOVA on these data showed a statistically significant group difference [$F(2, 15) = 10.49, p = .002$] with post-hoc Scheffé tests showing that Group 1SI took significantly more sessions to reach criterion than Groups 2S and 1S [largest $p < .01$]. As in Experiment 1, the pigeons in Group 2S exhibited a strong sample side bias, consistently pecking either the white-left or white-right key 87.0% of the time at trial onset.

At criterion and subsequent to it, average matching accuracies for the left- and right-key samples were uniformly high. For example, left- and right-key sample accuracies averaged over the last 3 overtraining sessions were 99.2% and 99.0% correct for Group 2S [$F(1, 5) = .12$], 99.4% and 99.2% correct for Group 1S [$F(1, 5) = .46$], and 95.2% and 90.1% correct for Group 1SI [$F(1, 3) = 2.17$].

3.2.2. Red-Red/Green-Green Tests—Figure 3 shows individual results for the red-red/green-green tests in each group. The bars in each panel show performances on the two post-

acquisition test sessions; the connected points show performances on the initial (pre-acquisition) test sessions. On average, the pigeons in Group 2S (top panel) pecked at the symmetrical location 43.1% of the time (range: 33.8 – 52.5%) in the pre-acquisition tests and 65% of the time (range: 42.5 – 78.6%) in the post-acquisition tests. T -tests showed that the former preference was not significantly different from chance [$t(5) = -1.96$], but the latter preference and the shift in preference from pre- to post-acquisition testing were significant [$t(5) = 2.90$, $p = .034$ and $t(5) = -4.90$, $p = .004$, respectively]. The average percentage of symmetrical pecks on the first post-acquisition test session (not shown) was also significantly above chance [$t(5) = 2.74$, $p = .041$].

For Group 1S (middle panel), the average percentages of symmetrical pecks on the pre- and post-acquisition test sessions were 62.1% (range: 47.5 – 75%) and 58.3% (range: 46.3 – 75%), respectively. Neither deviated significantly from chance [$t(5) = 2.09$ and 1.95 , respectively] nor did the slight downward shift in preference from pre- to post testing [$t(5) = -.42$].

For Group 1SI (bottom panel), the average percentages of symmetrical pecks on the pre- and post-acquisition test sessions were 42.5% (range: 25 – 70%) and 46.9% (range: 25 – 61.3%), respectively. The pre- and post-acquisition test performances did not deviate significantly from one another [$t(3) = -.29$] nor from chance [$t(3) = -.69$ and $-.40$, respectively].

3.2.3. Red-Green Tests—Figure 4 shows each group's average first-peck latencies on consistent and inconsistent trials on its first red-green test session. These latencies were uniformly shorter on consistent than on inconsistent trials: 0.91 s versus 2.37 s, respectively, for Group 2S; 0.69 s versus 1.49 s, respectively, for Group 1S; and 0.61 s versus 0.91 s, respectively, for Group 1SI. Although these numerical differences were in the direction predicted by symmetry, none was statistically significant [$t(5) = -1.73$, $t(5) = -1.26$, and $t(3) = -1.84$, respectively]. However, binomial tests revealed that the number of subjects exhibiting shorter latencies on consistent trials was significantly greater than chance in Groups 2S and 1S (all 6 pigeons in both; both $ps = .03$) although not in Group 1SI (3 pigeons; $p = .63$).

3.2.4. Consistent versus Inconsistent Tests—Contrary to prediction, an above-versus below-chance accuracy pattern was not observed in the symmetry-consistent versus symmetry-inconsistent conditions in initial testing. For example, in Group 2S, average first-session accuracies were below chance in both test conditions: 37.5% (range: 25 – 50%) versus 33.3% correct (range: 25 – 37.5%), respectively. In Group 1S, average first-session accuracy was below chance in the consistent test condition, 45.8% correct (range 25 – 62.5%), and above chance in the inconsistent test condition, 62.5% correct (range: 37.5 – 87.5%). In Group 1SI, corresponding accuracies were above chance in both conditions: 56.6% (range: 50 – 62.5%) versus 68.8 % correct (range: 50 – 87.5%), respectively. There were no significant deviations from chance [all $ts \geq -4.00$ and ≤ 1.00].

Figure 5 plots test-trial accuracies for each group over blocks of 3 successive test sessions. In general, birds in the consistent test conditions learned their probe-trial discrimination task faster than birds in the inconsistent test conditions (compare filled circles versus unfilled circles). Despite this numerical difference throughout testing for Group 2S (top panel), a mixed ANOVA with block and reinforced relations (consistent vs. inconsistent) as factors yielded only a main effect of block [$F(11, 44) = 14.94$, $p < .001$]. There was no main effect of reinforced relations [$F(1, 4) = 1.48$] and no interaction between reinforced relations and test block [$F(11, 44) = .20$]. Analyzing just the first 3 or the first 6 blocks of test sessions yielded the same pattern of statistical results.

Similarly a mixed ANOVA on all of the test data for Group 1S (middle panel) yielded a significant effect of block [$F(11, 44) = 6.62, p < .001$], a marginal effect of reinforced relations [$F(1, 4) = 6.96, p = .058$], and no interaction [$F(11, 44) = 1.22$]. However, the overall consistent versus inconsistent difference was significant in this group when the analysis was restricted to the first 6 blocks [$F(1, 4) = 21.18, p = .01$]. For Group 1SI (bottom panel), there was no significant effect of reinforced relations [$F(1, 2) = 2.11$] or its interaction with session block [$F(11, 22) = .73$] when all test blocks were included in the analysis but, as for Group 1S, there was a significant effect of reinforced relations [$F(1, 2) = 21.73, p = .043$] over just the first 6 blocks of test sessions.

Despite the nonsignificant effect of trained relations in Group 2S, a mixed ANOVA including the 3 groups yielded a significant effect of trained relations over the first 6 blocks of test sessions [$F(1, 10) = 14.16, p = .004$] and a significant effect of block [$F(5, 50) = 8.51, p < .001$]. The effect of group [$F(2, 10) = 3.18$] and all interactions were nonsignificant [all $F_s < 1.09$].

Figure 5 also shows that baseline accuracies remained uniformly high in both the consistent and inconsistent conditions (filled and unfilled triangles, respectively). ANOVA confirmed that there was no significant between-condition difference in any group. Obviously, baseline performance did not deteriorate with probe-trial contingencies that were incompatible (inconsistent) with the symmetrical versions of the baseline relations.

3.3. Discussion

This experiment partially corroborated the findings of Experiment 1. Using the test procedure of Garcia and Benjumea (2006), we found evidence for symmetry in a non-reinforced red-red/green-green test when two samples were presented at the outset of each baseline trial (Group 2S). By contrast, the one-sample training procedures did not yield evidence of symmetry using this same test. The first-session latency results from the red-green test showed that pigeons in each group were faster to peck stimuli presented at locations consistent with symmetry than at locations inconsistent with symmetry, although none of the differences was significant. Nevertheless, significantly more pigeons showed the predicted difference than not in Groups 2S and 1S.

In the differentially reinforced tests, peck-left versus peck-right accuracies to red-red versus green-green displays were numerically higher when the reinforced peck locations were consistent with symmetry than inconsistent with it, although the difference was significant only for Groups 1S and 1SI and only over the first half of their testing. Across groups, however, the effect was significant. Ideally, the difference would have been apparent early in testing. The fact that it was not might have been due in part to the fact that responding to these probe-trial displays had been routinely non-reinforced in 4 earlier red-red/green-green tests.

These results together with those of Experiment 1 indicate that under some conditions of training, the baseline relations used by Garcia and Benjumea (2006) appear to be symmetrical. Evidence for symmetry was obtained in the Red-Red/Green-Green tests for Group 2S, in the Red-Green latency tests for Groups 2S and 1S, and in the consistent versus inconsistent tests for Groups 1S and 1SI. Interestingly, Group 1SI provided the weakest evidence for symmetry despite training which most closely resembled that used by Garcia and Benjumea.

4. Experiment 3

Besides their one- and two-sample conditions, Garcia and Benjumea (2006; Experiment 2) ran two other groups in which only the reinforced comparison appeared after the sample(s). Neither of these groups (their Groups 1S1C and 2S1C) showed evidence for symmetry. Garcia and Benjumea concluded that explicit choice during training is crucial for the emergence of symmetry because only in this way can animals effectively “label” their prior (sample) behavior. However, their comparison of choice with no-choice training confounded this variable with the presence versus absence of differential reinforcement (cf. Frank and Wasserman 2005; Urcuioli 2008). Consequently, it is possible that the absence of symmetry in their single-comparison groups may have been due to the fact that neither group received discrimination training prior to testing.

In Experiment 3, we modified their single-comparison procedure to include explicit discrimination training. Pigeons were trained on successive (“go/no-go”) matching (Nelson and Wasserman 1978; Urcuioli and Zentall 1990; Wasserman 1976) in which either the correct or incorrect comparison appeared after pecking the left or right side-key sample (see Table 1). For example, following a white-left sample, pecking red was reinforced no matter where it appeared (i.e., on the left or right key), but pecking a green comparison was never reinforced. Conversely, following a white-right sample, pecking green was reinforced no matter where it appeared, but pecking a red comparison was never reinforced. Accurate discrimination performances are evident when subjects respond frequently to the reinforced comparisons and little, if at all, to the non-reinforced comparisons.

If discrete choices in training are necessary to yield symmetry in the Garcia and Benjumea (2006) paradigm, then this emergent effect should not occur after successive matching training. On the other hand, if differential reinforcement of comparison responding is key, symmetry should be apparent in testing. Indeed, Urcuioli’s (2008) theory of pigeon’s equivalence-class formation predicts that successive matching should be especially conducive to symmetry because the continual juxtaposition of non-reinforcement of certain baseline relations with reinforcement of other baseline relations throughout training should facilitate class formation.

4.1. Materials and Method

4.1.1. Subjects and Apparatus—Fourteen White Carneau pigeons, 10 experimentally naïve and 4 with limited experience unrelated to the present contingencies, participated in this experiment. They were randomly divided into two groups with the constraint that naïve and experienced birds were equally distributed between them. Preliminary analyses revealed no effect of experience either on successive matching acquisition or testing. Housing, maintenance conditions, and the two operant chambers were identical to those previously described.

4.1.2. Procedure

4.1.2.1. Preliminary Training: The experimentally naïve pigeons initially received food magazine training and shaping by the method of successive approximations to peck a white triangle on the center key. They then received a series of sessions during which single pecks to white, red, and green side-key stimuli were reinforced with food.

Next, all pigeons were trained to peck red, green, and white side-key stimuli on a fixed-interval (FI) schedule of reinforcement, the parameter of which was gradually raised from 2 to 5 s over the course of 3 sessions. The first peck after the interval elapsed immediately turned the stimulus off and produced food. The 60 trials in each preliminary training session

were divided equally among all of the stimuli scheduled to appear in a session, with successive trials separated by a 10-s ITI. All other procedural details were identical to those for preliminary training in the preceding experiments.

4.1.2.2. Baseline Training: During successive matching that began immediately upon completion of preliminary training, each matching trial began with white either on the left or the right side key (Group 1S) or white on both side keys (Group 2S). Completing a FR 5 response requirement to the single sample (Group 1S) or 5 consecutive pecks to the active sample (Group 2S) turned off the sample(s) and lit a center-key triangle which, when pecked, was replaced by a red or green comparison on either the left or right side key. (For Group 2S, a single peck to the “inactive” white key reset the peck requirement.) The first comparison peck after 5 s turned off the comparison and produced food on reinforced trials, whereas the comparison stimulus went off automatically after 5 s on non-reinforced trials. For half of the pigeons in each group, pecking the red comparison no matter where it appeared was reinforced on left-sample trials and pecking the green comparison no matter where it appear was reinforced on right-sample trials; the opposite combinations were non-reinforced. For the remaining pigeons, these contingencies were reversed. Each training session contained 96 trials divided equally among the 8 possible trial types (2 samples $\times$ 2 hue comparisons $\times$ 2 comparison locations) which were presented in random order with the constraint that none occur more than three times in a row. The ITI was 10 s and daily reinforcement durations were adjusted as previously described.

A discrimination ratio (DR) was computed for each sample by dividing the total number of comparison pecks on reinforced trials by the total number of comparison pecks on all trials. Only pecks during the first 5 s of comparison onset entered into this computation. Each pigeon was trained until it achieved a DR of 0.80 or higher for each sample for 3 consecutive sessions, after which it received 15 additional overtraining sessions.

4.1.2.3. Red-Red/Green-Green Tests: These 100-trial test sessions consisted of 4 non-reinforced probe trials interspersed among 96 baseline training trials. Probes involved presenting the same (red or green) comparison on both side keys at trial outset. Ten pecks, not necessarily to the same side key, terminated the trial without reinforcement. Two successive tests were given prior to baseline training (pre-acquisition) and 2 more tests, separated by a session of baseline training, were given after overtraining (post-acquisition). All other details of these tests were the same as those previously described.

4.2. Results and Discussion

4.2.1. Baseline Performances—The average numbers of training sessions to reach criterion levels of performance were 30.3 (range: 19 – 49) and 23.4 (range: 15 – 49) for Groups 2S and 1S, respectively [$F(1,13) = 1.04$]. At criterion, the average DRs for the left- and right-key samples were comparably high in both groups: .95 for both samples in Group 2S [$F(1, 6) = 0.13$] and .94 for both samples in Group 1S [$F(1, 6) = 0.02$]. For the three overtraining sessions preceding the first post-acquisition symmetry tests, the average DRs were .98 and .96 for the left- and right-key samples for Group 2S [$F(1, 6) = 2.05$] and .97 for both samples for Group 1S [$F(1, 6) = 0.08$].

4.2.2. Red-Red and Green-Green Symmetry Tests—Individual subject data averaged over sessions are shown in Figure 6. Bars represent performance for the two post-acquisition tests and the line represents performance on the two pre-acquisition tests. On average, birds in Group 2S (top panel) pecked at the location corresponding to the sample that preceded the reinforced comparison in training 42.8% of the time (range: 25.0 – 62.5%) in the pre-acquisition tests and 57% of the time (range: 42.5 – 70%) in the post-acquisition

tests. The difference was non-significant [$t(6) = -2.08$, $p = .082$]. Moreover, neither the pre- nor post-acquisition percentages deviated significantly from chance [$ts(6) = -1.55$ and 1.95 , respectively].

However, the corresponding percentage of symmetrical pecks did differ significantly from chance when only the first five pecks on each probe trial were considered [$M = 57.5\%$; range: $47.5 - 65\%$; $t(6) = 3.14$, $p = .02$]. Across the post-acquisition test sessions, two pigeons (S5 and S7) showed a significant deviation from chance (largest binomial $p = .018$), one (S4) showed a marginally significant deviation (binomial $p = .057$) and the remaining four performed at chance (smallest binomial $p = .093$).

Group 1S (bottom panel) showed an average of 30.5% (range: $12.5 - 50\%$) and 62.7% (range: $50 - 83.8\%$) symmetrical pecks in its pre- and post-acquisition tests, respectively. Both percentages deviated significantly from chance: Pigeons preferentially pecked the side key inconsistent with symmetry during pre-acquisition testing [$t(6) = -3.42$, $p = .014$] and preferentially pecked the side key consistent with symmetry during post-acquisition testing [$t(6) = 2.63$, $p = .039$]. The difference was also significant [$t(6) = -3.74$, $p = .010$]. Across post-acquisition test sessions, four pigeons (S1, S2, S3, and S6) showed a distribution of pecks significantly different from that expected from chance and in the direction predicted by symmetry (largest binomial $p = .033$), whereas the remaining three did not (smallest binomial $p = .434$).

In contrast to our preceding experiments which showed evidence of symmetry after two- but not after one-sample training, the opposite pattern was observed here. We have no ready explanation for this incongruity, although the varied test results across experiments brings into question the robustness of the Garcia and Benjumea (2006) effect.

Nevertheless, the results from Group 1S suggest that symmetry in the Garcia and Benjumea (2006) paradigm does not depend on choice between simultaneously presented comparisons during baseline training. Garcia and Benjumea's analogy between an explicit "labeling" choice response after a preceding sample behavior (or sample location) and the naming hypothesis (e.g., Dugdale and Lowe 1990; Horne and Lowe 1996) may be apt, but it is not crucial for obtaining symmetry in this paradigm. Instead, a more important variable appears to be differential reinforcement for comparison responding. In other words, symmetry can emerge when only one comparison appears on each baseline training trials if an explicit discrimination is required across trials.

5. General Discussion

Since Sidman and colleagues' seminal papers (Sidman et al. 1982; Sidman and Tailby 1982), the search for symmetry in nonhuman animals has been extensive and proven much more challenging than initially expected. Nevertheless, recent studies by Frank and Wasserman (2005) and Urcuioli (2008, Experiment 3) using successive (go/no-go) matching rather than the more typical n -alternative choice matching paradigm have yielded compelling evidence for this emergent effect in pigeons. The results reported by Garcia and Benjumea (2006) are noteworthy in this context not only because they represent another example of symmetry in non-human animals but also because the positive results were obtained in a normally "unforgiving" two-choice procedure.

Furthermore, their data challenge the view that a valid symmetry test requires that temporal/ordinal variables associated with sample and comparison presentation be controlled or, indeed, be considered as integral components of the functional matching stimuli (cf., Frank and Wasserman 2005; Urcuioli 2008). For instance, Urcuioli (2008) has hypothesized that such stimuli are compounds consisting of the nominal matching stimuli plus their spatial and

ordinal positions, and that symmetry and other emergent relations (Sweeney and Urcuioli 2010) reflect the formation of stimulus classes arising from the continual juxtaposition of non-reinforced with reinforced sample-comparison combinations during training. For symmetry to emerge, all of the matching stimuli must appear as both samples and comparisons during training in order to generate the requisite classes. Clearly, these conditions were not met in the Garcia and Benjumea (2006) experiments, yet symmetry was observed.

Considering, then, the empirical and theoretical implications of the Garcia and Benjumea (2006) findings, the present experiments were designed to evaluate both their reliability and validity. In the experiment most closely related to ours, Garcia and Benjumea (2006, Experiment 2) reported that 2 of 4 pigeons trained on a two-sample, two-choice procedure with a 2-s inter-stimulus interval acquired the baseline discrimination to high levels of accuracy within 40 sessions. These pigeons later made 88% and 75% symmetry-consistent pecks in a subsequent red-red/green-green preference test. One of the remaining pigeons eventually achieved high levels of baseline accuracy with additional training and subsequently made 75% symmetry-consistent pecks during its preference test. Thus, the average symmetry-consistent preference for the 3 pigeons that learned this two-sample, two-choice baseline task was 79.3%.

By contrast, none of our pigeons achieved high and stable baseline levels of accuracy with the Garcia and Benjumea (2006, Experiment 2) procedure. The problem we encountered was that our pigeons persisted in pecking the location of the formerly active sample key throughout the inter-stimulus interval and into the comparison period. Not surprisingly, then, baseline choice accuracies suffered because pigeons often pecked the non-reinforced (“incorrect”) comparison alternative just as it appeared. Consequently, we do not have the desired direct comparison between our results and those obtained by Garcia and Benjumea. However, by modifying our training procedure such that a single center-key peck was required following each sample or that dark side-key responding was punished during the inter-stimulus interval, we did obtain high and stable levels of baseline accuracy. After such modified training in the two-sample, two-choice conditions of Experiments 1 and 2, the average percentage of symmetry-consistent pecks in a subsequent red-red/green-green test was approximately 69%. In our view, this compares favorably with the average score in Garcia and Benjumea (2006, Experiment 2) and attests to the reliability of those findings.

Additionally, we showed that pigeons’ probe-trial choices between red and green comparisons were generally faster when those comparisons appeared at locations consistent with the symmetrical version of the baseline relations than when they appeared at locations inconsistent with the symmetrical version of the baseline relation. Although this latency difference was statistically significant only in Experiment 1, the number of pigeons showing shorter location-consistent latencies was significantly greater than that expected by chance in both Experiments 1 and 2 (except for Group 1SI). These data help to establish the validity of Garcia and Benjumea’s (2006) interpretation. Likewise, Experiment 2 showed that for two groups, differential reinforcement of red-red/green-green probe-trial responding yielded significantly higher levels of accuracy when the reinforced left versus right responses on these trials were consistent with symmetry than when they were inconsistent with symmetry, at least over the first half of testing.

Finally, Experiment 3 addressed the necessity of simultaneously presented comparisons (i.e., discrete comparison choice) during training. According to Garcia and Benjumea (2006), discrete choice permits pigeons to “label” each previously observed sample stimulus. Consequently, we removed the discrete choice aspect of training by using successive matching as the baseline task. In this task, only one comparison appears on each matching

trial with half of all trials ending in reinforcement for comparison responding and the half in non-reinforcement. When both side keys were lit at the start of each successive matching trial (i.e., in the two-sample procedure), the test results supported Garcia and Benjumea's position – there was little evidence of symmetry. However, when only one side key was lit at the start of each successive matching trial (i.e., in the one-sample procedure), 4 of 7 pigeons pecked the symmetry-consistent location significantly more often than chance during testing. These data, then, indicate that a discrete “labeling” choice during baseline training is not necessary to observe symmetry.

A notable difference between our results and those reported by Garcia and Benjumea (2006) is that we rarely found a significant difference between performances in the pre- and post-acquisition tests, a difference that formed the basis of their claim of symmetry. Perhaps our requirement that pigeons peck a common center-key stimulus after pecking the left or right (sample) keys diminished the chances of observing symmetry between peck location and the subsequently reinforced comparison choice by altering the important baseline relations from which symmetry might emerge. For example, the red-red/green-green symmetry test trials are predicated on functional baseline relations of the form [Left sample location – Red comparison] and [Right sample location – Green comparison]. But if the functional baseline relations were, instead, [Left sample location – Center-key peck – Red comparison] and [Right sample location – Center-key peck – Green comparison], those tests would not straightforwardly predict a left versus right choice; indeed, one could argue that they predict a common but unavailable center-key “choice”.

As mentioned before, Garcia and Benjumea's (2006) procedure seems atypical because it appears, at first glance, that the symmetry tests did not involve presentation of the former comparisons as samples and the former samples as comparisons (viz., an explicit reversal of the sample-comparison baseline relations). But a closer look suggests that perhaps their test procedure did incorporate such a reversal. Specifically, each symmetry test trial began with one of the former comparisons appearing on both side keys (i.e., as a “sample”). Upon seeing them, pigeons chose the left or right spatial location. If differential visual feedback afforded by the left and right locations are the functional samples in the baseline task, these locations can be thought of as “appearing” in the second ordinal position (i.e., as “comparisons”) on the test trials.

On the other hand, this interpretation of the nature of the symmetrical sample-comparison relations leads to question: Why wasn't the level of the symmetrical preferences higher than what we observed? Statistically, we certainly obtained significant preference effects indicative of symmetry. But why weren't the size of those effects larger and/or more consistent across subjects? We've just indicated a possible answer in the center-key peck requirement between sample offset and comparison onset. Another reason may be that this paradigm doesn't fully capture the conditions necessary for observing symmetry. For instance, an alternative (and perhaps more complete) characterization of the functional baseline relations in the Garcia and Benjumea (2006) procedure would be [Peck White on the Left Key → Peck Red (on either side key)] and [Peck White on the Right Key → Peck Green (on either side key)]. Obviously, then, the symmetrical relations would be [Peck Red (on either side key) → Peck White on the Left Key] and [Peck Green (on either side key) → Peck White on the Right Key]. But these were *not* the tested relations. Instead, the red-red/green-green probe trials tested [See Red (on either side key) → Peck Left] and [See Green (on either side key) → Peck Right] relations. From this perspective, the fact that we obtained any significant preferences indicative of symmetry is impressive.

In any event, the present findings once again underscore the point that the discrepancy between humans and other animals in demonstrating the behavioral effects of stimulus

equivalence (Hayes 1989) may be more a matter of procedural issues, inadequate understanding of the functional stimulus control, or both than of the presence versus absence of language. After all, both the Naming Hypothesis (Horne and Lowe 1996/1997) and Relational Frame Theory (e.g., Hayes 1991) assert that language is a (if not the) critical prerequisite for stimulus equivalence. Obviously, both imply that non-human animals and humans lacking language skills should not show symmetry. Our data and those of others (Frank and Wasserman 2005; Urcuioli 2008; Velasco et al. 2010; see also Schusterman and Kastak, 1993) are clearly contradictory and, instead, are consistent with an alternative position (Sidman 1990, 1992, 1994, 2000) that equivalence is a natural consequence of reinforcement contingencies and, thus, should be observable even in the absence of language.

Of course, these different views regarding the origins of equivalence have focused on proximate mechanisms. Proximate explanations are important as they illuminate both the causation and the development of such abilities, but optimally they should be complemented by other levels of analysis focusing on the function and evolution of equivalence relations (Tinbergen 1963; see also Sherman, 1988).

For now, the previously noted discrepancy between human and non-human animals in their ability to show symmetry seems more apparent than real. Language does not seem to be a necessary prerequisite. Whether or not the same will hold true for the other aspects of equivalence is an empirical question awaiting future research, but the current outlook looks promising for an answer in the affirmative (Sweeney and Urcuioli 2010).

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Figure 1. Percentage of symmetrical pecks for each pigeon averaged across both test sessions in Experiment 1. The horizontal dotted line indicates performance expected by chance.

Figure 2. Average latency (± 1 SEM) to make the first peck on consistent and inconsistent trials over the five latency-based test sessions of Experiment 1.

Figure 3.

Percentage of symmetrical pecks for each pigeon averaged across test sessions in Experiment 2. Columns represent data obtained after training and lines represent data obtained at the outset of training. Data from Groups 2S, 1S, and 1SI are presented in the top, middle, and bottom panels, respectively. The horizontal dotted lines indicate performance expected by chance.

Figure 4. Average latency (± 1 SEM) to make the first peck on consistent and inconsistent trials on the first latency-based test session of Experiment 2. Data from Groups 2S, 1S, and 1SI are presented in the top, middle, and bottom panels, respectively.

Figure 5.

Average accuracy (± 1 SEM) on baseline matching trials (triangles) and on test trials (circles) across blocks of 3 sessions in Experiment 2. On test trials, birds were tested with contingencies either consistent (filled symbols) or inconsistent (unfilled symbols) with the symmetrical associations reportedly learned during the baseline matching task. The top, middle, and bottom panels plot data from Groups 2S, 1S, and 1SI, respectively.

Figure 6. Percentage of symmetrical pecks for each pigeon averaged across test sessions in Experiment 3. Columns represent data obtained after training and lines represent data obtained at the outset of training. Data from Groups 2S and 1S are presented in the top and bottom panels, respectively. The horizontal dotted lines indicate performance expected by chance.

Table 1

Design of Experiment 3

Successive Matching Training	Testing
W. Left → R. Left +	
W. Left → R. Right +	
W. Left → G. Left –	
W. Left → G. Right –	R. Left vs. R. Right
W. Right → R. Left –	G. Left vs. G. Right
W. Right → R. Right –	
W. Right → G. Left +	
W. Right → G. Right +	

Note. W. Left = white on the left, W. Right = white on the right, R. Left = red on the left, R. Right = red on the right, G. Right = green on the right, G. Left = green on the left, + = reinforced trial, - = non-reinforced trial. Half of the birds experienced these contingencies and for the other half the opposite contingencies were in effect.