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Evidence for Response Membership in Stimulus Classes by Pigeons

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Abstract

Response membership in pigeons' stimulus class formation was evaluated using associative symmetry and class expansion tests. In Experiment 1, pigeons learned hue-hue (AA) and form-form (BB) successive matching plus a modified hue-form (AB) task in which reinforcement was contingent upon a left versus right side-key response after the positive AB sequences. On subsequent BA (symmetry) probe trials, pigeons responded more often to the comparisons on the reverse of the positive than negative AB sequences and, more importantly, preferentially pecked the side key consistent with symmetry after the reversed positive sequences. In Experiment 2, the original three baseline tasks were supplemented by dot-white (CC) successive matching in which reinforcement was contingent upon a left versus right side-key response after the positive CC sequences. Class expansion was then tested by presenting non-reinforced CA and CB successive matching probes. Comparison response rates were mostly non-differential on CA probes but were uniformly higher on CB probes that consisted of the C samples and B comparisons from the same, hypothesized class. Together, these results provide evidence that responses can become members of stimulus classes, as predicted by Urcuioli's (2008) theory of pigeons' stimulus-class formation and Sidman's (2000) theory of equivalence.

Keywords

stimulus classes; response membership; associative symmetry; successive matching; conditional discrimination; simple discrimination; pigeons; key peck

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In his theoretical analysis of equivalence classes, Sidman (1994, 2000) proposed that responses and reinforcers can become class members if the reinforcement contingencies during training do not create a conflict between establishing the n-term analytical units of behavior (Sidman, 1986) and class inclusion. In other words, as long as the baseline contingencies support discrimination learning, responses and reinforcers can enter into equivalence relations with the stimuli with which they have been associated. Sidman (1994, 2000) claims that equivalence relations consist of all pairs of events – conditional stimuli, discriminative stimuli, the

experimenter-defined responses, and the experimenter-defined reinforcers – specified by the reinforcement contingencies.

Consider, for example, conditional discrimination training consisting of two conditional (a.k.a. sample) stimuli (A1 and A2), two discriminative (a.k.a. comparison) stimuli (B1 and B2), two defined responses (Resp1 and Resp2), and two reinforcing outcomes (O1 and O2). Assume that O1 is presented only when the subject makes Resp1 to the B1 comparison stimulus in the context of the A1 sample, and that O2 is presented only when the subject makes Resp2 to the B2 comparison in the context of the A2 sample. According to Sidman (2000), these contingencies could generate two 4-member equivalence classes – [A1, B1, Resp1, O1] and [A2, B2, Resp2, O2] – and, with them, a variety of new or emergent relations. For example, subjects could preferentially select the A1 comparison over the A2 comparison if now presented with B1 as the sample and, conversely, select the A2 comparison over the A1 comparison if presented with B2 as the sample (associative symmetry). Furthermore, presentation of one of the reinforcing outcomes (O1 or O2) or emission of one of the responses (Resp1 or Resp2) might now occasion selection of the sample or comparison stimulus associated with that reinforcer or response in training.

The predicted inclusion of reinforcers in equivalence classes was confirmed by Dube, McIlvane, Mackay, and Stoddard (1987, Experiment 1). They trained two intellectually disabled adults on symbolic and identity matching-to-sample (MTS) tasks in which different foods (O1 and O2) served as reinforcers for correctly selecting different comparisons (B1 and B2) following different sample stimuli (A1 and A2). After baseline training to high levels of accuracy, Dube et al. conducted non-reinforced probe trials in which the samples were replaced by their associated foods, and found that both participants always selected the comparison stimulus that, in theory, belonged to the same class as the O1 or O2 reinforcer (see Dube & McIlvane, 1995; Hall, Mitchell, Graham, & Lavis, 2003; and Joseph, Overmier, & Thompson, 1997 for similar findings).

Demonstrating emergent relations between the samples and comparisons of different MTS tasks that involve the same set of outcomes provides additional, indirect evidence for reinforcer class membership. For example, Maki, Overmier, Delos, and Gutmann (1995, Experiment 3) reported that young children trained on AB and CD MTS, each involving blue versus red poker-chips (later exchangeable for food vs. small toys) as reinforcers for correct choice, subsequently matched each D comparison to the A sample associated with same colored poker chip (i.e., AD matching). Presumably, stimulus classes containing these matching stimuli developed via the common reinforcers they shared during training (see also Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989; Schenk, 1994). Indeed, Maki et al. showed that the emergent AD effect did not occur in the absence of differential outcomes training.

Data obtained from non-human animals also indicate that stimuli associated with the same reinforcing outcome belong to the same stimulus class (Urcuioli, 2005; 2013). For instance, sample stimuli that share a common differential-outcome association during baseline training are interchangeable with one another in new contexts (e.g., Astley & Wasserman, 2001; Edwards, Jagielo, Zentall, & Hogan, 1982; Honig, Matheson, & Dodd, 1984; Meehan, 1999; see also Urcuioli & Zentall, 1992), and the same is true for comparison stimuli as well (Urcuioli & DeMarse, 1997).

In contrast to the reinforcer-membership findings, compelling evidence for response membership in stimulus classes has been relatively sparse. This is due partly to methodological difficulties in obtaining directly relevant data (e.g., how can Resp1 and Resp2 be “presented” as sample stimuli in testing?) and to the interpretive ambiguities of other findings. An example of the latter is the emergent differential sample responding effect reported by Manabe,

Kawashima, and Staddon (1995, Experiment 3). They initially trained budgerigars on hue-form MTS in which presentation of the form comparisons was contingent upon high- versus low-frequency vocal calls (Resp1 vs. Resp2) to the hue samples. Later, identity MTS trials in which the form stimuli appeared as both samples and comparisons were added to the hue-form trials in each session. On the form-form trials, either a high or a low vocal call to each form sample produced the comparisons. Despite these nondifferential sample-response contingencies, the budgerigars began to vocalize differentially to the form samples as their form-form MTS accuracy increased. Specifically, they made a high-frequency call (Resp1) to the form sample that occasioned the same form-comparison choice as the hue sample to which a high-frequency call was required, and they made a low-frequency call (Resp2) to the form sample that occasioned the same form-comparison choice as the hue sample to which a low-frequency call was required.

Manabe et al. (1995) interpreted their results as evidence that the explicitly trained [vocal call → form comparison] relations on the hue-form trials were symmetrical. In other words, that training purportedly yielded two stimulus classes each containing a specific hue, call, and form. Consequently, each form sample eventually occasioned the high- or low-frequency call in its respective class (see Sidman, 1994). Saunders and Williams (1999), however, argued that adventitious reinforcement of high- versus low-frequency calling on the added form-form MTS trials could equally well account for the findings. Moreover, Urcuioli and Vasconcelos (2008b), adapted Manabe et al.'s procedure for use with pigeons (cf. Urcuioli, Lionello-DeNolf, Friedrich, Fetterman, & Green, 2002) and found that differential responding to the added samples emerged only if those samples occasioned the same comparison selections as the originally trained samples. Nominal identity between the added samples and the comparisons from initial training was insufficient to yield the emergent effect, contrary to a symmetry account.

Urcuioli, Lionello-DeNolf, Michalek, and Vasconcelos (2006) sought direct evidence for response membership in pigeons using a transfer-of-control assessment following training on many-to-one MTS, a conditional discrimination known to reliably produce acquired sample equivalence (e.g., Lowe, Horne, & Hughes, 2005; Urcuioli, Zentall, & DeMarse, 1995; Wasserman, DeVolder, & Coppage, 1992). During many-to-one training, two patterns of center-key pecking (viz., rapid versus slow pecking generated by fixed-ratio versus differential-reinforcement-of-low-rates-of-responding schedules, respectively) served as “samples” that occasioned the same reinforced comparison selections as two other, visual sample stimuli. Pigeons then learned to match either the visual or the response-pattern samples to new comparison stimuli (reassignment training), and this was followed by a transfer test which assessed their ability to match the remaining samples to the new comparisons. If acquired equivalence between the response and visual samples had been established in many-to-one training (Urcuioli, DeMarse, & Zentall, 1994), then the new comparison choices learned to one set of samples during reassignment training should be immediately occasioned by the other set in testing. Three separate experiments (Urcuioli et al., 2006, Experiments 1, 2, and 4), however, failed to confirm this acquired equivalence prediction (although see Urcuioli & Vasconcelos, 2008a for another interpretation of the negative findings).

To date, Shimizu (2006) has reported the most convincing demonstration of response membership in stimulus classes. Normal adults learned two three-alternative MTS tasks (AB and CD) in which reinforcement was contingent not only on correct comparison selections but also on the correct execution of one of three four-part computer-mouse movements (e.g., left, right, up, down). Thus, baseline training was actually ABR and CDR, where R refers to the different comparison-response movements. Subsequent testing revealed a large number of emergent relations (e.g., AC, BC, AD, and BD matching) consistent with the idea that the common responses across baseline tasks brought their respective samples and comparisons

together into the same classes. In addition, on some test trials, different mouse-movement sequences were “presented” as samples. These trials began with the appearance of a solid white square and subjects were asked to make one of the previously learned mouse movements; the correct movement was then followed by the comparisons. Shimizu found that on these RA and RC test trials, subjects also made class-consistent comparison selections.

Lionello-DeNolf and Braga-Kenyon (in press) have also reported evidence for response membership in adult humans. Subjects were trained to make two different response patterns (pressing a computer touch screen 10 times in rapid succession or two times spaced several seconds apart) to red and green stimuli. Next, they were trained on form-hue MTS in which the required response to each stimulus was a single touch. Finally, using a procedure similar to Urcuioli et al. (2006), the different response patterns served as samples in MTS and the comparisons were either the hue or form stimuli (in separate test sessions). Two participants made class-consistent comparison selections on their first exposure to the tests, and a third did so after repeated tests and additional training.

The positive results reported by Shimizu (2006) and by Lionello-DeNolf and Braga-Kenyon (in press) are theoretically important especially in view of the previous negative or ambiguous findings from the non-human animal literature. Encouraged by their results, the present study sought to demonstrate response membership in stimulus classes by pigeons, albeit with a different approach to the definition of responses. Given the likely difficulties of establishing different temporal patterns of comparison pecking and arranging valid emergent-relations tests (see, for example, Lionello & Urcuioli, 1998), we defined the responses as moving toward and pecking keys in different locations; namely, pecking a left key versus pecking a right key. These spatial responses were incorporated into successive MTS (e.g., Wasserman, 1976, cf. Konorski, 1959), a conditional discrimination in which samples and comparisons are presented sequentially on a single manipulandum and comparison responding is reinforced only when the comparison matches (physically or symbolically) the preceding sample. In our procedure, reinforcement on the positive sequences in symbolic (AB) successive matching was contingent upon different side-key responses following the comparison stimuli on those trials. In other words, a simple discrimination between the comparison stimuli (e.g., peck left after B1 and peck right after B2) was added to a conditional discrimination between those stimuli (i.e., peck the comparisons on A1B1 and A2B2 trials but not on A1B2 and A2B1 trials).

Given that pigeons exhibit a variety of emergent relations like associative symmetry (Frank & Wasserman, 2005; Urcuioli, 2008, Experiment 3) after successive matching training (see also Strasser, Ehrlinger, & Bingman, 2004; Sweeney & Urcuioli, 2010; Urcuioli, 2011; Urcuioli & Swisher, 2012), Experiment 1 asked whether combining this type of conditional discrimination training with simple (left- vs. right-response) discrimination training would provide evidence for response membership in stimulus classes. Specifically, would BAR symmetry, where R refers to different side-key responses, emerge from ABR training?

Experiment 1

The rationale for, and the design of, Experiment 1 were also based on Urcuioli's (2008) theory of stimulus-class formation in pigeons. The important theoretical assumptions from which predictions regarding response membership (see below) were derived are as follows. First, stimulus class formation is facilitated by continual juxtaposition of non-reinforcement for certain sample-comparison combinations with reinforcement for other sample-comparison combinations. Successive MTS (cf. Nelson & Wasserman, 1978; Wasserman, 1976), in which both samples and comparisons are presented individually, is ideal in this regard because half of all sample-comparison combinations end in non-reinforcement independently of the level of conditional discrimination accuracy. Second, the functional stimuli in successive matching

are compounds consisting of the nominal matching stimuli plus their ordinal positions within a trial. Thus, a red sample stimulus is functionally red-in-the-first-ordinal position (viz., R1), whereas a red comparison stimulus is functionally red-in-the-second-ordinal position (viz., R2). Third, class members are the elements of the reinforced sample-comparison combinations. For example, reinforced responding to a triangle comparison following a red sample will yield a [red sample, triangle comparison] class. Fourth, elements common to more than one stimulus class produce class union (e.g., Mackay, Wilkinson, Farrell, & Serna, 2011; Maki et al., 1995; see also Sidman, 1994). For example, if training involves multiple successive matching tasks – e.g., AB and BB matching – in which one reinforced AB combination consists of a red sample and a triangle comparison (R1 and T2) and one reinforced BB combination consists of a triangle sample and a triangle comparison (T1 and T2), the common T2 element should merge the [R1, T2] and [T1, T2] classes into one [R1, T1, T2] class.

For this experiment, pigeons were concurrently trained on three tasks: hue-form (AB), hue-hue (AA) and form-form (BB) successive matching using red and green hues, and triangle and horizontal-lines forms (see Table 1). AA and BB were identity tasks: Reinforcement occurred only after matching sample-comparison sequences – namely, red-red (R1-R2), green-green (G1-G2), triangle-triangle (T1-T2), and horizontal-horizontal (H1-H2). In the symbolic (AB) task, reinforcement also occurred only after certain sample-comparison sequences – e.g., red-triangle (R1-T2) and green-horizontal (G1-H2) – and only if pigeons made an experimenter-designated correct side-key response (viz., pecking a lit left key or pecking a lit right key) after comparison offset. An incorrect side-key response on these otherwise “positive” trials ended these trials without reinforcement. The remaining symbolic sequences – e.g., red-horizontal (R1-H2) and green-triangle (G1-T2) – were defined as “negative”: They involved no lighting of the side keys and no reinforcer delivery, ending automatically with comparison offset after a fixed time.

Figure 1 depicts the six stimulus classes hypothesized to result from baseline training (cf. Urcuioli, 2008). The bottom two rows show the classes arising from hue identity (AA) and form identity (BB) successive matching. Note that the identity classes contain the matching sample and comparison of each positive (reinforced) sequence (e.g., R1 and R2, and G1 and G2). The top row shows the corresponding classes arising from hue-form (AB) symbolic matching. These include not only the sample and comparison stimulus of each reinforced sequence (e.g., R1 and T2) but also the correct side-key responses for those sequences (e.g., the left response or Left3). The “3” denotes the third ordinal position because the reinforced side-key response on a positive symbolic matching trial follows the sample (ordinal position 1) and comparison (ordinal position 2).

The bolded italics are used to highlight elements common to more than one class – e.g., R1 (red sample) in both the symbolic and the hue identity classes. If common elements cause their respective classes to merge, as Urcuioli (2008) hypothesizes, then baseline training should yield the two five-member stimulus classes shown in Figure 2 – namely, [R1, R2, T1, T2, Left3] and [G1, G2, H1, H2, Right3]. The elements of these classes predict associative symmetry (Frank & Wasserman, 2005; Urcuioli, 2008) in pigeons’ performances on novel BA test trials. Specifically, their comparison-response rates should be higher on T1-R2 and H1-G2 test trials (viz., the reverse of the positive baseline trials) than on T1-G2 and H1-R2 test trials (viz., the reverse of the negative baseline trials). More importantly, when given a left versus right choice on the positive BA test trials, pigeons should make more left responses (Left3) than right responses on the novel T1-R2 test sequence and more right responses (Right3) than left responses on the novel H1-G2 test sequence. Such side-key preferences on the test sequences would constitute evidence for response membership in stimulus classes by pigeons.

Method

Subjects—Six White Carneau retired breeders obtained from the Palmetto Pigeon Plant (Sumter, SC) began the experiment. One pigeon's participation was discontinued for health reasons and another's because it did not achieve the required baseline matching accuracies after 85 training sessions; their data are not reported. Of the remaining four pigeons, one (CHC1) was experimentally naïve and three (CHC3, CHC4, and CHC6) had previously participated in an unrelated experiment and in a successive matching experiment with differential-reinforcement-of-other-behavior contingencies (Urcuioli, 2010). All were maintained at 80% of their free-feeding body weights by restricting feeding to the experimental sessions and providing a reduced amount of Purina ProGrains in the home cages on the days they were not run. Water and grit were freely available in their stainless steel, wire-mesh home cages. All were housed in a colony room that was on a 14h–10h light-dark cycle (lights on at 07:00).

Apparatus—Pigeons were run in BRS/LVE (Laurel, MD) pigeon chambers (Model PIP-016 three-key panel inside a Model SEC-002 enclosure). The three response keys were 2.5 cm in diameter, 5.7 cm apart center to center, and aligned horizontally in a row 7.5 cm from the top of the panel. Mounted behind each key was a BRS/LVE Model IC-901-IDD stimulus projector that was equipped with films and filters for displaying red (R), green (G), and white (W) homogeneous fields, and three white horizontal lines (H), a solid white inverted triangle (T), and three small white circular dots (D) oriented 45° counter-clockwise from vertical, all on black backgrounds (BRS/LVE Pattern No. 692). The rear-mounted food hopper could be accessed via a 5.8-cm-square opening located 13 cm below the center key. When the hopper was raised, it was illuminated by a small miniature bulb (ESB-28) in the surrounding metal housing. A GE #1829 bulb located 7.6 cm above the center key provided general chamber illumination. The opening in the metal shield surrounding the bulb directed its light toward the ceiling. Ventilation and masking noise was provided by a constantly running blower fan attached to the chambers. All experimental events were controlled by customized programs written in GW-Basic Version 3.20 and running on an IBM-compatible computer.

Procedure

Preliminary training—All pigeons were initially trained to peck a key displaying the stimuli that would later appear in the successive matching tasks. In the first and second sessions, 30 presentations each of the triangle and horizontal lines, and red and green, respectively, appeared in randomized order on the center key, and a single key peck to the lit key was followed immediately by food. In the third and fourth sessions, there were 10 center-key presentations of triangle and horizontal, and red and green, respectively, plus 20 presentations each of white on the left and right side keys, again in random order and with single key pecks to the lit keys reinforced. Successive stimulus presentations were separated by a 15-s intertrial interval (ITI) with the house light remaining on throughout each session.

Next, pecking the center-key stimuli was reinforced on fixed-interval (FI) schedules. The first seven FI sessions contained 30 randomized presentations each of red and green, and the following seven sessions contained 30 randomized presentations each of the triangle and horizontal lines. Within a 7-session block, the FI value was increased from 2 to 5 s over the initial four sessions. For the last three sessions, completion of a FI 5-s requirement ended with food on a random 50% of occasions. Successive stimulus presentations (trials) within a session were again separated by a 15-s ITI, the first 14 s of which were spent in darkness. The house light came on for the last 1 s of the ITI and remained on until the end of a trial. The duration of food access per delivery was constant within a session but varied individually from 1.8 – 6.0 s across sessions to maintain a pigeon's 80% body weight.

Successive matching acquisition—Table 1 summarizes the reinforcement contingencies for the baseline successive matching tasks. All pigeons were concurrently trained on hue-form symbolic, hue-hue identity, and form-form identity matching. The hue-hue and form-form identity tasks involved typical successive matching contingencies (Nelson & Wasserman, 1978; Wasserman, 1976). Here, a 5-s sample stimulus presented on the center key was followed, after a 1-s dark interval, by a 5-s comparison stimulus presented on the same key. The trial ended in reinforcement if the comparison physically matched the preceding sample (positive trial), but without reinforcement if the comparison did not match the preceding sample (negative trial). More specifically, the first key peck to the sample on a trial initiated a fixed-interval (FI) 5-s schedule that ended with the sample turned off, a 1-s dark interval and the onset of a comparison stimulus. On positive trials, the first comparison key peck after a 5-s interval timed from the first peck turned off the comparison and produced food. On negative trials, the comparison stimulus and the house light went off after 5 s independent of any key pecking.

The sequence of events on negative hue-form symbolic matching trials (viz., R1-H2 and G1-T2) was the same as the sequence described above for negative identity matching trials. However, on positive hue-form trials (viz., R1-T2 and G1-H2), comparison offset was accompanied by the simultaneous illumination of white on the left and right side keys. A single peck to either side key within 3 s turned off both side-key stimuli and produced either food if the side-key response was designated “correct” or a short blackout if the response was designated “incorrect”. For three pigeons (CHC1, CHC4, and CHC6), a left response was correct after the R1-T2 sequence and a right response was correct after the G1-H2 sequence. For the remaining pigeon (CHC3), a right response was correct after the R1-T2 sequence and a left response was correct after the G1-H2 sequence. For all pigeons, incorrect side-key responses turned off the house light for a period equal to the reinforcement duration for that session, as did the absence of any side-key peck within 3 s. Due to experimenter error, the left- and right-response contingencies were also in effect on the positive identity trials for the first 10 sessions for two pigeons (CHC4 and CHC6), but were removed thereafter.

Each training session consisted of an equal number (32) of hue-form, hue-hue and form-form matching trials presented in random order except that no sample-comparison sequence could occur on more than two consecutive trials. Successive trials were separated by a 15-s ITI, the first 14 s of which was spent in darkness. The house light came on for the last 1 s of the ITI and remained on until the end of the food-hopper cycle on reinforced trials or comparison offset on non-reinforced trials. Reinforcement duration (1.8 – 6 s) was again adjusted as needed on a session-by-session basis for each pigeon in order to maintain its 80% body weight as closely as possible.

Conditional discrimination learning was assessed by calculating a discrimination ratio (DR) in which the total number of comparison pecks on the positive trials of each baseline task was divided by the total number of comparison pecks on both positive and negative trials of that task. Only pecks occurring within the first 5 s of comparison-stimulus onset entered into these computations. Simple discrimination learning on the hue-form trials was assessed by calculating the percentage of all side-key responses designated as “correct”. Baseline training for each pigeon continued until it achieved a DR of 0.80 or higher on each successive matching task, and at least 13 correct side-key responses on the 16 positive hue-form trials (81.3% correct), for five of six consecutive sessions (“criterion”). This was followed by a minimum of 10 overtraining sessions, the last six of which had to meet the aforementioned performance levels.

Symmetry testing—Following overtraining, eight test sessions, run in four two-session blocks separated by at least five baseline sessions at criterion, were conducted to determine

whether the hue-form baseline relations were symmetrical. Each test session contained 96 baseline trials divided equally among the three baseline tasks (hue-form, hue-hue and form-form) plus eight non-reinforced probe trials in which the sample was either the triangle or horizontal lines and the comparison was either red or green. The four possible form-hue probes (T1-R2, T1-G2, H1-R2, and H1-G2) were each presented twice in each test session. The first probe trial did not occur until at least one of each possible baseline trial was presented, and successive probes were separated by at least six baseline trials. Probe trials that were the reverse of the negative baseline trials (viz., T1-G2 and H1-R2) ended automatically (comparison stimulus and the house light off) 5 s after comparison onset. For probe trials that were the reverse of the positive baseline trials (viz., T1-R2 and H1-G2), comparison offset after 5 s was accompanied by the simultaneous illumination of white on the left and right side keys. A single peck to either side key turned both off without food delivery, although the house light remained on for a period equal to the session's reinforcement duration. All other procedural details were identical to those previously described. These probe trials permitted two assessments of associative symmetry: 1) a DR based on the number of comparison pecks on "positive" probe trials (viz., on the reverse of the positive baseline trials) divided by the number of comparison pecks on both "positive" and "negative" probe trials (viz., on the reverse of the positive and negative baseline trials), and 2) the percentage of side-key responses to the same (left or right) side key as that designated correct on the positive hue-form baseline trials.

Because all four pigeons continued to respond at appreciable rates to the comparisons on the non-reinforced probe trials after eight test sessions, eight additional test sessions were run after baseline recovery to criterion performance levels. These latter test sessions were also run in four blocks of two sessions with a minimum of five baseline sessions at criterion separating each block.

For all statistical analyses reported in this paper, Type I error rate was set at 0.05 using the tabled F values reported by Rodger (1975) for controlling error rates on a per decision basis.

Results

Successive matching acquisition—Figure 3 plots discrimination ratios (DRs) for each pigeon on each baseline task (solid symbols) for the first 40 training sessions (in blocks of two sessions) and the percentages of correct choice on the symbolic (hue-form) task (open triangles). Discrimination ratios (DRs) reached criterion levels most rapidly on hue identity matching for three of the four pigeons (CHC1, CHC3, and CHC6), but most slowly for the remaining pigeon (CHC4). Nevertheless, all pigeons were performing at criterion levels (DR at or above .80) on all tasks within 40 training sessions. Choice accuracy on the hue-form (symbolic) trials was around chance (50% correct) at the beginning of training, but quickly rose to its criterion level (81.2% or above) within 8–10 sessions, stabilizing at nearly 100% by the end of training.

The average hue-identity DR over the last five overtraining sessions preceding testing was 0.94 (range: 0.91 – 0.97). The corresponding DRs for form identity and hue-form matching were 0.94 (range: 0.91 – 0.95) and 0.93 (range: 0.86 – 0.98), respectively. The average percentage of correct left versus right responses on the hue-form (symbolic) task over these five sessions was 98.5% (range: 96.3 – 100%).

Symmetry testing—The panels shown in the top two rows of Figure 4 plot the number of comparison pecks/s averaged over the first eight test sessions on the hue-form baseline trials (open circles) and on the non-reinforced form-hue symmetry probe trials (filled circles). The corresponding panels of Figure 5 plot the corresponding data averaged over the second set of eight test sessions. For the baseline trials, "positive" and "negative" refer to the (potentially) reinforced (R1-T2 and G1-H2) and the non-reinforced (R1-H2 and G1-T2) sample-comparison

sequences, respectively. For the symmetry probes, “positive” and “negative” refer to the reverse of the potentially reinforced and the non-reinforced baseline sequences (viz., T1-R2 and H1-G2, and H1-R2 and T1-G2), respectively. Each positive baseline datum point represents the average number of pecks on four randomly selected positive trials (two of each positive hue-form combination) from each test session within an eight-session block. Similarly, each negative baseline datum point is the average number of pecks on four randomly selected negative trials (two of each negative hue-form combination) from each of these test sessions. Each probe-trial datum point is the average of the four positive, or four negative, test trials from each test session across an eight-session block.

Throughout testing, pigeons pecked the comparisons at much higher rates on positive than on negative baseline trials, just as they did at the end of the acquisition phase. In short, the hue-form baseline conditional discriminations remained intact during testing. More importantly, probe-trial comparison-response rates were numerically higher on the symmetrical versions of the positive than on the negative baseline trials for all pigeons. For the first eight test sessions, this difference in probe-trial response rates was statistically significant in analysis of variance (ANOVA) only for pigeons CHC1 and CHC3, $F_s(1, 62) = 6.14$ and 18.96 , respectively. For the second set of eight test sessions, the difference was statistically significant for all four pigeons, $F_s(1, 62) = 3.95, 15.80, 4.44$, and 3.90 for pigeons CHC1, CHC3, CHC4, and CHC6, respectively.

The bar graphs shown in the bottom panels of Figures 4 and 5 show the average percentages of symmetry-consistent (“symmetrical”) left versus right side-key responses on the form-hue probe trials for the first and second set of eight test sessions, respectively. For the first eight sessions, these percentages were around 50% correct for the two pigeons (CHC1 and CHC3) whose probe-trial comparison response rates showed evidence of symmetry, whereas they were significantly above chance for the two pigeons (CHC4 and CHC6) whose corresponding response rates did not show evidence of symmetry, $\chi^2(1) = 0.80, 0.12, 5.83$, and 7.26 for pigeons CHC1, CHC3, CHC4, and CHC6, respectively. For the second set of test sessions, however, the percentages of symmetrical side-key responses were significantly above that expected by chance for all pigeons, $\chi^2(1) = 6.37, 3.86, 5.76$, and 8.60 , for pigeons CHC1, CHC3, CHC4, and CHC6, respectively.

Discussion

The results of this experiment are noteworthy for two reasons. First, they replicate Urcuioli’s (2008, Experiment 3) and Frank and Wasserman’s (2005, Experiment 1) findings of associative symmetry in pigeons. Specifically, after concurrently training AB (hue-form), AA (hue-hue) and BB (form-form) successive matching, pigeons responded more frequently to the comparisons on non-reinforced BA (form-hue) probe trials when those trials reversed the order of the positive (reinforced) AB baseline sequences than when they reversed the order of the negative (non-reinforced) AB baseline sequences. This occurred despite the fact that, unlike those previous experiments, reinforcement on the positive AB baseline trials was also contingent upon a correct left versus right side-key response following the comparisons on those trials. This meant that not all positive AB trials ended in food reinforcement, especially early in training. Nevertheless, reinforcement occurred only after certain sample-comparison sequences in the hue-form task. The remaining sequences never ended in reinforcement and these negative sequences occurred as frequently as the positive sequences, a condition Urcuioli (2008) hypothesized may be crucial for pigeons’ stimulus-class formation. The present experiment shows that requiring an additional, simple discrimination between comparisons on the potentially reinforced (positive) AB trials did not preclude the emergence of BA symmetry.

Second, the test results show that associative symmetry was evident in the pigeons’ side-key preferences as well as in the rate at which they pecked the comparisons on the probe test trials.

Specifically, after learning to peck the left key on R1-T2 baseline trials, pigeons then pecked the left key more often than the right key on the symmetrical T1-R2 probe trials. Likewise, after learning to peck the right key on G1-H2 baseline trials, pigeons pecked the right key more often than the left key on the symmetrical H1-G2 probe trials. For two of the four pigeons, this effect did not materialize during the first eight test sessions, but it was clearly apparent in the second set of eight test sessions. It is important to note that this delayed emergence of symmetry-consistent side-key preferences cannot be dismissed as further learning on these test trials because all test-trial responses were non-reinforced.

It is curious that the pigeons that did not show symmetrical side-key preferences in the first set of test sessions nonetheless showed clear evidence of symmetry in their probe-trial comparison-response rates during these sessions. Likewise, the other two pigeons exhibiting significant symmetry-consistent side-key preferences in the first set of test sessions did not show a significant symmetry effect in their comparison-response rates. We have no explanation for this dissociation. In any event, the results from the second set of eight test sessions showed that all pigeons performed in a manner consistent with associative symmetry, both in the rates at which they pecked the comparisons on the positive versus negative BA probe trials and in their left versus right side-key preferences on the positive BA probes.

The choice results from BA testing suggest strongly that the left versus right responses were members of the same class as the samples and comparisons preceding those responses. Nonetheless, we need to consider another possible explanation of the pigeons' side-key preferences on the BA probes. Note that on the baseline AB trials (see Table 1), a left side-key response was reinforced only after a red sample and only after a triangle comparison (viz., only on R1-T2 trials). Likewise, a right side-key response was reinforced only after a green sample and only after a horizontal comparison (viz., only on G1-H2 trials). On the probe trials during testing, pigeons had the opportunity to choose between left and right responses after these same nominal stimuli, albeit in reversed order (e.g., on T1-R2 and H1-G2 probes). Perhaps, then, pigeons preferentially responded left after the triangle sample and the red comparison because the triangle and red stimuli, individually or in combination, had become discriminative for a left-key response during baseline training. Similarly, perhaps pigeons preferentially responded right after the horizontal-lines sample and the green comparison because both horizontal and green, individually or in combination, had become discriminative for a right-key response during training¹.

Obviously, this simple discrimination explanation ignores the potentially influential ordinal positions of these stimuli in testing vis-à-vis training. Nevertheless, it is a plausible alternative to an account which claims that the reinforced left versus right side-key responses (Left3 and Right 3) are members of the same stimulus classes as the sample and comparison stimuli preceding them in AB baseline training (cf. Figure 2). The purpose of Experiment 2, then, was to conduct a follow-up response membership test whose results would not be amenable to this alternative explanation.

Experiment 2

In Experiment 2, pigeons learned a fourth successive matching task using three small white dots (D) and a homogeneous white (W) field as stimuli. Reinforcement was arranged only on trials in which the comparison physically matched the preceding sample and only if pigeons made a "correct" left or right side-key response on these positive trials (see Table 2). Nonmatching (viz., negative) trials were always non-reinforced. Trials of this CC identity

¹These points are particularly apropos for pigeons CHC4 and CHC6 because they were erroneously run with side-key choice (viz., simple discrimination) contingencies on the matching hue-hue and form-form trials during their first 10 acquisition sessions.

matching task were later intermixed with those of the three previously learned tasks, and training continued until criterion levels of performance were achieved on all four tasks.

Figure 6 shows the stimulus classes hypothesized to arise from all four baseline tasks (cf. Urcuioli, 2008). The stimulus and response notations are the same as before and, once again, elements common to more than one class are bolded and italicized. The two new stimulus classes associated with DW identity matching are shown at the bottom. The two elements in the DW identity classes common to other classes (specifically, to the symbolic classes) are the left and right side-key responses (*Left3* and *Right3*). If these and other common, across-class elements cause their respective classes to merge, the net result will be the two seven-member classes depicted in Figure 7. Given these enlarged classes, new sample-comparison relations involving the D and W samples should emerge in testing. Specifically, pigeons should respond more to the comparisons on novel D1-R2 and W1-G2 trials than to the comparisons on novel D1-G2 and W1-R2 trials because only the former trials consist of elements from the same stimulus class. Likewise, they should respond more to the comparisons on novel D1-T2 and W1-H2 trials than to the comparisons on novel D1-H2 and W1-T2 trials for the same reason. Experiment 2 tested these predictions.

Method

Subjects and Apparatus—The four pigeons that completed Experiment 1 initially participated in this experiment. One pigeon (CHC6) was dropped prior to testing because it failed to maintain its baseline performances.

The apparatus was the same as those used in Experiment 1. However, two new center-key stimuli were introduced: three small white circular dots (D) oriented 45° counter-clockwise from vertical on black background and a white (W) homogeneous field (BRS/LVE Pattern No. 692).

Procedure—This experiment consisted of four phases of baseline training and recovery, which began approximately 2–3 months after the completion of Experiment 1, and two test phases. Each is briefly described below.

Baseline recovery: Each pigeon (CHC1, CHC3, and CHC4) was re-trained on the three baseline successive matching tasks used in Experiment 1 (see Table 1). Baseline re-training for each pigeon continued until its DR was .80 or higher on all three tasks, and it made a minimum of 13 (of 16) correct side-key responses (81.3% correct) on the hue-form task, for five of six consecutive sessions. This was followed by at least 10 overtraining sessions with performances at or above these criteria for five of the last six sessions.

Successive matching acquisition with D and W stimuli: After baseline recovery, each pigeon was trained on successive matching using D and W as center-key (sample and comparison) stimuli. Identity matching contingencies were in effect for all pigeons (see Table 2): Food reinforcement was scheduled on trials in which the sample and comparison were nominally identical (viz., D1-D2 and W1-W2); trials on which they differed (viz., D1-W2 and W1-D2) ended without food. In addition, reinforcement on matching (positive) trials was contingent upon a “correct” left versus right side-key response. In other words, immediately after comparison offset on the D1-D2 and W1-W2 sequences, the left and right side keys were each lit by a white stimulus, and a single peck to either side key within 3 s immediately turned both off and yielded food (if the choice response was designated “correct”) or turned off the house light (if the choice response was designated “incorrect”). If neither side key was pecked within 3 s (a very infrequent event), the side keys and house light went off automatically. For pigeons CHC1 and CHC4, a left response was reinforced after the D1-D2 sample-comparison sequence

and a right response was reinforced after the W1-W2 sequence. For pigeon CHC3, the opposite contingencies were in effect.

Each DW successive matching session consisted of 60 trials divided equally among the four possible trial types. All other procedural details were identical to those described for successive matching acquisition in Experiment 1. Training for each pigeon continued until it achieved a DR (total number of comparison pecks on positive trials ÷ total number of comparison pecks on both positive and negative trials) of at least .80 and made at least 25 out of 30 correct side-key responses (83.3%) for five of six consecutive sessions. At this point, sessions of DW identity matching were alternated across days with training on the three concurrent successive matching tasks from Experiment 1, and this continued until criterion-level performances were met for both session types for five sessions each.

Combined training with all baseline tasks: Prior to testing, pigeons received additional training with trials from all four baseline tasks intermixed. These 96-trial sessions consisted of 24 trials of each baseline task, hue-form symbolic (AB), hue identity (AA), form identity (BB), and dot-white identity (CC), divided equally among the four sample-comparison sequences comprising each task. Combined training continued for each pigeon until its DR was at least .80 for all four tasks and it made at least 10 out of 12 correct side-key responses (83.3%) on both hue-form symbolic and dot-white identity matching for five of six consecutive sessions. At least 10 overtraining sessions then followed. Testing commenced when criterion levels of performances were met for the last five of six overtraining sessions.

Class expansion testing: These 104-trial test sessions consisted of 96 baseline trials, divided equally among the four baseline tasks (cf. Table 2) plus eight non-reinforced probe trials. As in Experiment 1, test sessions were run in blocks of two separated by five baseline sessions at criterion levels of performance. There were two types of test sessions, one in which the non-reinforced probe trials consisted of D or W samples followed by R or G comparisons (viz., D1-R2, D1-G2, W1-R2, and W1-G2) and the other in which the probe trials consisted of D or W samples followed by T or H comparisons (viz., D1-T2, D1-H2, W1-T2, and W1-H2). Each test block was always of one type (CA or CB, respectively), and two blocks of one type were alternated with two blocks of the other type until a total of eight test sessions of each type were completed. For pigeon CHC1, the order of testing was T/H comparisons (CB) – R/G comparisons (CA) – T/H comparisons (CB) – R/G comparisons (CA); for pigeons CHC3 and CHC4, testing occurred in the reverse order. There was no left-right choice component on any test trial in this experiment. Otherwise, all other details were identical to the corresponding test sessions in Experiment 1.

Results

Baseline performances—Pigeons learned the DW identity task quickly, reaching criterion levels of performance within 6–10 sessions, and these accuracies were maintained when this task was later combined with the other three baseline tasks. The average DRs for the five baseline sessions prior to the first R/G comparison test session were .94, .96, .96, and .92 for hue-form symbolic, hue identity, form identity, and DW identity matching, respectively, and the percentages of correct side-key responses for hue-form symbolic and DW identity matching were 99.4% and 99.4%, respectively. The average DRs for the five baseline sessions prior to the first T/H comparison test session were .97, .95, .95, and .94, for hue-form symbolic, hue identity, form identity, and DW identity matching, respectively, and the corresponding percentages of correct side-key responses for hue-form symbolic and DW identity matching were 99.4% and 98.9%, respectively.

Performances on the baseline trials during testing with each set of comparisons were well maintained, with only scattered instances in which a DR fell below .80. The average DRs for hue-form symbolic, hue identity, form identity, and DW identity were .94, .94, .94, and .92, respectively, across the eight test sessions with the R and G comparisons, and .95, .94, .97, and .95, respectively, across the eight test sessions with the T and H comparisons. The corresponding percentages of correct side-key responses on the baseline hue-form and DW identity tasks were 98.6% and 84.8%, respectively, for the former tests, and 99.3% and 84.5%, respectively, for the latter tests. These accuracies never fell below 80% correct on the baseline hue-form symbolic task during either type of test, but did occasionally on the baseline DW identity task (although never below 70% correct). The lower overall accuracy on DW identity than on hue-form symbolic matching is probably attributable to less training on the former than on the latter task (which had been extensively trained in Experiment 1).

Test performances—The top panel of Figure 8 shows the results from each pigeon averaged over the eight test sessions in which probe trials consisted of D and W samples followed by R and G comparisons (viz., CA tests). The bottom panel of the figure shows the corresponding data from the test sessions in which probe trials consisted of D and W samples followed by T and H comparisons (viz., CB tests). “Positive” and “negative” baseline trials in both panels refer to the potentially reinforced versus non-reinforced symbolic training sequences (R1-T2 and G1-H2 versus R1-H2 and G1-T2), respectively. (Each baseline datum point was computed in the same fashion as that described in Experiment 1.) For the probe trials, “positive” and “negative” refer to test-trial sequences in which the sample (D1 or W1) and comparison (R2 or G2, or T2 or H2) were drawn from the same hypothesized stimulus class or different stimulus classes, respectively (see Figure 7). Thus, the D1-R2 and W1-G2 sample-comparison sequences are “positive”, and the D1-G2 and W1-R2 sequences are “negative”, for the R/G comparison tests. Likewise, the D1-T2 and W1-H2 sample-comparison sequences are “positive”, and the D1-H2 and W1-T2 sequences are “negative”, for the T/H comparison tests.

Figure 8 shows that all pigeons maintained their baseline hue-form symbolic performances in both tests as evidenced by much higher comparison response rates on positive than on negative baseline trials. Probe-trial response rates averaged across the eight R/G comparison tests (top panel), on the other hand, were mostly nondifferential: The slightly higher rates on the positive than on the negative probe trials on these tests were not significantly different for pigeons CHC1, CHC3, and CHC4, $F_s(1, 62) = 1.05, 0.48, \text{ and } 0.30$, respectively. Moreover, overall probe-trial response rates were considerably lower than on the baseline trials, and were considerably lower than the overall probe-trial rates with these same (R and G) comparisons on the first eight test sessions in Experiment 1 (see Figure 4). These differences might reflect the cumulative effects of extinction on the probe trials (they were always non-reinforced) which, in turn, could have diminished the chances of obtaining a significant difference between positive and negative probe-trial response rates with these comparisons. Interestingly, CHC3's positive versus negative probe-trial rates over just the first two R-G test sessions (1.38 versus 0.12 pecks/s, respectively) were significantly different, $F(1, 14) = 5.68$.

By contrast, the results from eight test sessions involving the T/H comparisons (bottom panel of Figure 8) showed significantly higher comparison-response rates on positive than on negative probe trials for all three pigeons, $F_s(1, 62) = 166.24, 17.72, \text{ and } 77.86$ for pigeons CHC1, CHC3, and CHC4, respectively. Indeed, these response-rate differentials were comparable to those observed on the hue-form baseline trials.

Discussion

Experiment 2 tested the prediction that new stimulus relations involving D and W samples and R, G, H and T comparisons would emerge if 1) the side-key responses reinforced on the hue-

form (AB) symbolic and dot-white identity (CC) baseline tasks were members of the same hypothetical classes containing the samples and comparisons of those tasks, and 2) classes containing common response elements (see Figure 6) merged in the same manner as classes containing a common sample or comparison element (see Figure 7). Put simply, we assessed whether association with the same response would render two stimuli equivalent.

The probe-trial data from Experiment 2 generally confirmed this prediction. Although the differences between comparison-response rates on positive versus negative trials involving R and G comparisons were not statistically significant when those rates were averaged over all eight tests, one of the three pigeons showed significantly higher rates on the positive probe trials during its initial two R/G test sessions. Moreover, all three pigeons showed significantly higher comparison-response rates on positive than on negative probe trials averaged over all test sessions in which the D and W samples were followed by the T and H comparisons. These results are consistent with the notion that responses can become members of stimulus classes (Sidman, 2000) given that “positive” could only be defined by assuming that common left and right side-key responses merged smaller classes into larger ones that contained the D and W samples and particular hue and form comparisons (see Figure 7).

Because comparison response rates on the probe trials served as the sole dependent variable in Experiment 2, this experiment effectively avoided the interpretation issue that we faced in Experiment 1. Recall that in Experiment 1, pigeons showed symmetry-consistent side-key preferences on BA (form-hue) probe trials that were the reverse of the explicitly trained AB (hue-form) trials. One interpretation of this result is that the left and right responses were also members of stimulus classes involving the A and B elements of the reinforced combinations of the symbolic (AB) and identity (AA and BB) tasks (cf. Figure 2). However, because the nominal stimuli on the BA probe trials were the same as those on the AB baseline trials, it is possible that symmetry-consistent left versus right responding occurred because each side-key response had been explicitly reinforced following a specific A stimulus and a specific B stimulus on the positive AB trials (e.g., left after red and after triangle – cf. Table 1). Consequently, if these nominal stimuli had acquired discriminative control over left versus right responding, our BA probe trials would not have constituted a test for derived (emergent) relations.

In Experiment 2, no such interpretive problem arises because the CA and CB test trials did not include a left- versus right-key choice phase. Instead, response membership was indirectly assessed by asking whether two stimuli associated with the same side-key response generate successive matching behavior consistent with stimulus class formation. Specifically, higher comparison-response rates on positive CA and CB probes than on negative CA and CB probes implies that the left and right responses required during symbolic and DW identity baseline training produced class merger and, with it, enlarged classes whose elements comprised the positive test sequences. The pattern of results we obtained was largely consistent with the pattern predicted by response membership in those classes.

General Discussion

The present study was motivated in part to test Sidman’s (1994, 2000) proposal that the reinforcement contingency itself generates equivalence classes and, more specifically, that under certain baseline conditions, responses will become members of those classes. Shimizu (2006) and Lionello-DeNolf and Braga-Kenyon (in press) studied n-alternative MTS performances in humans and reported data consistent with response membership in stimulus classes. Here, we sought similar evidence in pigeons performing successive matching tasks because they have previously demonstrated emergent stimulus-stimulus relations indicative of class formation in these tasks (e.g., Sweeney & Urcuioli, 2010; Urcuioli, 2008; Urcuioli &

Swisher, 2012). Another motivation for the present study, then, was to assess whether training with successive matching contingencies that include a differential response component would generate classes containing those different responses (cf. Urcuioli, 2008). Thus, our experiments are theoretically important for two reasons. First, they bear directly on Sidman's (1994, 2000) position regarding the origins of equivalence. Indeed, if his prediction of response membership was disconfirmed "...the theory that equivalence arises directly from the reinforcement contingency becomes untenable." (Sidman, 2000, p. 133). Second, they address the processes that Urcuioli (2008) hypothesized are crucial for pigeons' stimulus-class formation.

The two experiments reported here tested predictions regarding response membership by training pigeons in a modified successive matching paradigm (Wasserman, 1976; cf. Konorski, 1959): Rather than simply reinforcing responses to the comparison stimuli on the positive symbolic (AB) baseline sequences, left and right side-key pecks were differentially reinforced following these sequences. Supplementing the conditional discrimination contingencies of successive matching with a simple discrimination involving two side-key responses following the stimuli comprising those contingencies enabled us to obtain independent measures of conditional and simple discrimination accuracies with which to assess emergent relations between the stimuli on positive sequences and the side-key responses they occasioned (cf. Figures 1 and 6). This permitted a straightforward test for emergent symmetrical (BA) relations involving those responses (cf. Figures 2 and 7).

In our estimation, the data we report here provide good evidence that pigeons' stimulus classes can include their differential responses. This evidence took two forms. First, Experiment 1 showed that symmetrical BAR relations emerged from ABR baseline training (viz., symbolic – AB – matching with an added choice-response – R – component) combined with AA and BB identity training. In other words, after learning which hue-form (AB) sample-comparison sequences were potentially reinforced and which side-key response (R) to make after each positive AB combination, pigeons made that same left or right response more often than the alternative response on test trials that reversed the positive baseline sequences. Thus, if one component of ABR training involved positive trials consisting of a red sample, a triangle comparison, and a left response, then in testing, pigeons pecked left more often than right on trials beginning with a triangle sample and a red comparison. This associative symmetry effect was complemented by the additional finding that pigeons pecked more to the comparison stimuli themselves on positive test trials (viz., the reverse of the reinforced AB baseline trials) than on negative test trials (viz., the reverse of the non-reinforced AB baseline trials). In short, conditional discrimination performance on the BA probe trials coincided with simple discrimination (left key peck vs. right key peck) performance on those same trials.

Second, Experiment 2 showed that after CCR training (viz., dot-white identity matching with a side-key response requirement) was added to the ABR, AA, and BB baseline tasks, pigeons responded in a class-consistent fashion on CB and, to a lesser extent, on CA test trials. It is important to note that the samples and comparisons of the CCR task did not overlap with the samples and comparisons of the ABR, AA, and BB tasks; only the left and right responses in the CCR and ABR matching tasks did. Without reference to those common responses, it would not be possible to classify the dot and white stimuli in the CCR task as belonging to, or not belonging to, the same stimulus class as the red, green, triangle and horizontal stimuli appearing on the other baseline tasks. In other words, "class consistent" has no meaning on the CA and CB probe trials unless an expanded class can be derived via overlapping elements in the individual stimulus classes proposed to arise from the four baseline tasks. As Figure 6 shows, two of the required overlapping elements were the left and right responses (Left3 and Right3) that were components of the positive symbolic (AB) and positive dot-white identity (CC) training trials.

Emergent relations involving left and right side-key responses have also been reported in pigeons by García and Benjumea (2006, Experiment 1). They devised a novel conditional discrimination training procedure in which five consecutive pecks to either the left or right key (the “sample”) of a white two-key display replaced that display with red and green comparison stimuli randomized across locations. Pecking the red comparison was reinforced after one side-key-response sample and pecking the green comparison was reinforced after the other side-key-response sample. After these [side-key-response – color comparison] baseline relations were learned to high levels of accuracy, the possibility that those relations were symmetrical was tested by occasionally presenting non-reinforced probe trials where both keys were lit either red or green. García and Benjumea found that pigeons preferentially pecked the left or right key on the red-red and green-green test trials in accordance with which side-key response was associated with each color comparison in training (see also Vasconcelos & Urcuioli, 2011). For example, if a red comparison choice had been reinforced following a left-response sample in training, then pigeons pecked the left key more often than the right key on test trials where red appeared on both keys.

This symmetry effect suggests that baseline training had produced two classes, each of which contained a response member – namely, [left response, red] and [right response, green]. García and Benjumea (2006, Experiment 3) also showed that pigeons did not exhibit side-key-response preferences in testing if they did not peck the left- and right-key samples during baseline training. In other words, simply presenting (without the requirement to peck) a lit left key or a lit right key prior to the color comparisons during training was not sufficient to produce a preference for pecking left versus pecking right on subsequent red-red and green-green test trials. These findings suggest that the differential proprioceptive stimulation generated by emitting left- versus right-key responses, rather than the differential exteroceptive stimulation provided by different lit-key locations, was responsible for the reported symmetrical relations.

Although our results support Sidman’s (2000) response membership proposal, they suggest an alternative to his definition of responses in conditional discriminations. Sidman (1986, 1994, 2000) assumed that the subject’s responses in these procedures were the actions required to operate whichever manipulandum displayed a specific stimulus. Thus, he assumed that conventional, *n*-alternative MTS tasks involve a single response such as a button press (see Table 3 in Sidman, 1986, and Figure 2 in Sidman, 2000). In contrast, we defined responses in terms of which specific manipulandum was operated (e.g., left-key pecks and right-key pecks). Although the two side-key responses featured in only simple discriminations (i.e., two three-term contingencies) in our experiments, evidence for these responses becoming members of stimulus classes suggests that the responses in conventional MTS might also be usefully defined in terms of their spatial location (see Jones, 2003). MTS can still be conceptualized as four-term contingencies providing that the various comparison-stimulus arrays are viewed as the discriminative stimuli (see Figure 9 in Jones, 2003). Future research should explore the implications of this approach to response definition for research into equivalence relations.

If the assumptions of Urcuioli’s (2008) theory that prompted the present experiments are sound, they make other predictions that can and should be tested in future research. First, the ostensible class-expansion effect reported in Experiment 2 should occur only if baseline DW identity training requires differential side-key responding on the two positive sample-comparison sequences. In other words, pigeons trained in the same manner as those in Experiment 2 but without the left-right choice phase in the DW identity task should respond non-differentially on subsequent CA and CB probe trials. Nevertheless, such training (viz. concurrent ABR, AA, BB, and CC successive matching) would still be expected to yield symmetrical BA comparison-response effects and symmetrical BAR spatial-response effects, like those observed in Experiment 1.

Second, Urcuioli's (2008) theoretical assumptions predict that concurrent training on AB, AA, and BBR successive matching will also yield the same two five-member classes shown in Figure 2. Consequently, if later given a left versus right choice following the positive AA trials, pigeons trained in this fashion should respond differentially to the side keys. Specifically, they should preferentially peck the left key after a R1-R2 probe trial and preferentially peck the right key after a G1-G2 probe trial. If obtained, this result could not be explained in terms of explicit training to peck left versus peck right after the red versus green (A) nominal stimuli, respectively, because no such training is provided in any of the AB, AA, and BBR baseline tasks.

Third, new successive matching relations should emerge following just hue-form symbolic and DW identity training so long as both baseline tasks include a left versus right side-key response requirement (i.e., ABR and CCR, respectively). Thus, if a red sample – triangle comparison – left response (R1-T2-Left3) sequence is reinforced as part of hue-form symbolic matching, and a dot sample – dot comparison – left response (D1-D2-Left3) sequence is reinforced as part of DW identity matching, Urcuioli's (2008) theory predicts the emergence of red sample – dot comparison (R1-D2) and dot sample – triangle comparison (D1-T2) symbolic relations. In other words, these novel sequences should yield relatively high comparison response rates in testing.

Ideally, evidence for response membership in stimulus classes obtained from tests like those just described would be complemented by results from tests of the sort reported by Shimizu (2006) in which the differential responses themselves serve as probe-trial samples and are found to control class-consistent comparison responding. For instance, after training pigeons on tasks similar to those used in Experiment 1 (viz., ABR, AA, and BB), perhaps they would respond more often to certain comparisons than to others on test trials that begin with either a left- or a right-key response (the "sample") to produce the center-key comparison (i.e., on RA and RB successive matching probes). Such an outcome would provide especially compelling support for the view that stimulus-class formation in pigeons can, as in humans, incorporate their different responses.

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Figure 1.

The six stimulus classes hypothesized to result from hue-form symbolic, hue identity, and form identity successive matching training in Experiment 1. Bolded italics denote elements that appear in more than one stimulus class.

Figure 2.
The two five-member stimulus classes hypothesized to result from the merging of individual classes containing common elements (cf. Figure 1) in Experiment 1.

Figure 3.

Acquisition of the three concurrently trained successive matching tasks over the first 20 two-session blocks of training for each pigeon in Experiment 1. Discrimination ratios (filled symbols) are the proportions of all comparison responses occurring on the positive sample-comparison trials of each task. The percentage of correct symbolic choices (open triangles) is the percentage of correct side-key responses on positive hue-form matching trials.

First 8 Test Sessions

Figure 4.

Top panels: Comparison-response rates in pecks/s (± 1 SEM) on the symbolic matching baseline trials (open circles) and the non-reinforced symmetry probe trials (filled circles) averaged over the first eight test sessions for each pigeon in Experiment 1. Positive = potentially reinforced symbolic baseline trials and test trials in which the samples and comparisons of the potentially reinforced baseline trials were presented in reverse order. Negative = non-reinforced symbolic baseline trials and test trials on which the samples and comparisons of the non-reinforced baseline trials were presented in reverse order. Bottom panel: The percentage of symmetry-consistent side-key responses for each pigeon on the positive symmetry probe

trials averaged over its first eight test sessions in Experiment 1. Error bars = one SEM; stars denote significant deviation from chance (50%).

Second 8 Test Sessions

Figure 5.

Top panels: Comparison-response rates in pecks/s (± 1 SEM) on the symbolic matching baseline trials (open circles) and the non-reinforced symmetry probe trials (filled circles) averaged over the second eight test sessions for each pigeon in Experiment 1. Positive = potentially reinforced symbolic baseline trials and test trials in which the samples and comparisons of the potentially reinforced baseline trials were presented in reverse order. Negative = non-reinforced symbolic baseline trials and test trials on which the samples and comparisons of the non-reinforced baseline trials were presented in reverse order. Bottom panel: The percentage of symmetry-consistent side-key responses for each pigeon on the

positive symmetry probe trials averaged over its second eight test sessions in Experiment 1. Error bars = one SEM; stars denote significant deviation from chance (50%).

Figure 6.

The eight stimulus classes hypothesized to result from hue-form symbolic, hue identity, form identity, and dot-white (DW) identity successive matching training in Experiment 2. Bolded italics denote elements that appear in more than one stimulus class.

Figure 7.

The two seven-member stimulus classes hypothesized to result from the merging of individual classes containing common elements (cf. Figure 6) in Experiment 2.

R-G Comparisons Test *T-H Comparisons Test* **Figure 8.**

Top panels: Comparison-response rates in pecks/s (± 1 SEM) on the symbolic matching MTS baseline trials (open circles) and the class expansion probe trials (filled circles) using red and green comparisons averaged over eight test sessions for each pigeon in Experiment 2. Bottom panels: Comparison-response rates in pecks/s (± 1 SEM) on the symbolic matching MTS baseline trials (open circles) and the class expansion probe trials (filled circles) using triangle and horizontal-lines comparisons averaged over eight test sessions for each pigeon in Experiment 2.

Table 1**Baseline Successive Matching Contingencies in Experiment 1**

<u>Hue-Form Symbolic</u>	<u>Hue-Hue Identity</u>	<u>Form-Form Identity</u>
R → T - FI 5 s – Left+	R → R - FI 5 s+	T → T - FI 5 s+
R → H - EXT	R → G - EXT	T → H - EXT
G → T - EXT	G → R - EXT	H → T - EXT
G → H - FI 5 s – Right+	G → G - FI 5 s+	H → H - FI 5 s+

Note. R = red, G = green, T = triangle, H = horizontal, FI = fixed interval schedule, EXT = non-reinforced, + = reinforced. The first and second center-key stimuli in a trial sequence (sample and comparison, respectively) are shown to the left and to the right of the arrows, respectively. Positive (i.e., potentially reinforced) hue-form matching trials ended with food only if pigeons made the designated (left or right) side-key choice response after the comparison stimulus; otherwise, the trial ended without food. Counterbalancing of the hue-form contingencies has been omitted.

Table 2**Expanded Baseline Successive Matching and Choice Contingencies in Experiment 2**

<u>Hue-Form Symbolic</u>	<u>Hue-Hue Identity</u>	<u>Form-Form Identity</u>
R → T - FI 5 s – Left+	R → R - FI 5 s+	T → T - FI 5 s+
R → H - EXT	R → G - EXT	T → H - EXT
G → T - EXT	G → R - EXT	H → T - EXT
G → H - FI 5 s – Right+	G → G - FI 5 s+	H → H - FI 5s+
<u>Dot-White Identity</u>		
D → D - FI 5 s – Left+		
D → W - EXT		
W → D - EXT		
W → W - FI 5 s – Right+		

Note. R = red, G = green, T = triangle, H = horizontal, D = dots, W = white, FI = fixed interval schedule, EXT = non-reinforced, + = reinforced. The first and second left-key stimuli in a trial sequence (sample and comparison, respectively) are shown to the left and to the right of the arrows, respectively. Positive (i.e., potentially reinforced) hue-form and dots/-white matching trials ended with food only if pigeons made the designated (left or right) side-key choice response after the comparison stimulus; otherwise, the trial ended without food. Counterbalancing of the hue-form contingencies and of the dots-white identity choice contingencies have been omitted.