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EMERGENT IDENTITY BUT NOT SYMMETRY FOLLOWING SUCCESSIVE OLFACTORY DISCRIMINATION TRAINING IN RATS

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Abstract

The search for symmetry in nonhuman subjects has been successful in recent studies in pigeons (e.g., Urcuioli, 2008). The key to these successes has been the use of successive discrimination procedures and combined training on identity, as well as arbitrary, baseline relations. The present study was an effort to extend the findings and theoretical analysis developed by Urcuioli and his colleagues to rats using olfactory rather than visual stimuli. Experiment 1 was a systematic replication of Urcuioli's (2008) demonstration of symmetry in pigeons. Rats were exposed to unreinforced symmetry probes following training with two arbitrary and four identity conditional discriminations. Response rates on symmetry probe trials were low and provided little evidence for emergent symmetry in any of the seven rats tested. In Experiment 2, a separate group of six rats was trained on four identity relations and was then exposed to probe trials with four novel odor stimuli. Response rates were high on identity probe trials, and low on nonmatching probe trials. The similar patterns of responding on baseline and probe trials that were shown by most rats provided a demonstration of generalized identity matching. These findings suggest that the development of stimulus control topographies in rats with olfactory stimuli may differ from those that emerge in pigeons with visual stimuli. Urcuioli's (2008) theory has been highly successful in predicting conditions necessary for stimulus class formation in pigeons, but may not be sufficient to fully understand determinants of emergent behaviors in other nonhuman species.

Keywords

symmetry; generalized identity; successive conditional discrimination; olfactometer; rats; nose-poke

The search for symmetry in nonhuman animals has been both active and controversial since the seminal paper by Sidman, Rauzin, Lazar, Cunningham, Tailby and Carrigan (1982). Sidman et al. showed emergent symmetry along with the other relations of stimulus equivalence in human children, but not in monkeys or baboons. Interest in the possible significance of this empirical difference between humans and nonhuman animals in the relations that may emerge following arbitrary or symbolic conditional discrimination training has led to numerous follow-up studies with many species and procedural variations

that have yielded mixed results. While emergent identity and transitivity relations have been frequently observed across species, symmetry has been elusive at best (cf., Lionello-DeNolf, 2009; McIlvane, 2013; Zentall, Wasserman & Urcuioli, 2014). Lionello-DeNolf's comprehensive review only found strong evidence for symmetry in two species: in sea lions after extensive training with multiple exemplars and class-specific reinforcers (Kastak & Schusterman, 2002; Schusterman & Kastak, 1993) and in pigeons trained on successive matching-to-sample (Frank & Wasserman, 2005). Frank and Wasserman's use of a successive matching procedure with a single key was implemented to prevent the problem of stimulus control by location of sample versus comparison that is inherent in the more commonly used simultaneous matching procedures with three or more response keys. In the Frank and Wasserman study, concurrent arbitrary (i.e., A-B) and identity training with the same stimulus pairs (i.e., A-A & B-B) were shown to be necessary to produce emergent symmetry (e.g., B-A). Pigeons trained only on the arbitrary A-B conditional discriminations failed to show symmetry.

The use of a successive discrimination procedure coupled with identity training which ensured that each stimulus was presented both as a sample and a comparison were seen as critical features for the successful demonstration of symmetry (Frank & Wasserman, 2005). However, Urcuioli (2008) developed an alternative hypothesis. He posited that, for pigeons, the functional stimuli in successive matching procedures are compounds that include both the visual stimulus projected on the key and the temporal position of the stimulus (i.e., sample vs. comparison). Through this reasoning, concurrent identity and arbitrary training creates a situation in which stimuli in the sample and comparison positions would become class members. For example, in his Experiment 3 (Urcuioli, 2008), the arbitrary conditional discrimination was a red or green sample, followed by a triangle or horizontal bar comparison. Responding to the triangle (but not to the bar) after the red sample produced reinforcement on an FI 5-s schedule, as did responding to the horizontal bar (but not the triangle) following the green sample. This was posited to create two classes: Red (sample or position 1–Red1)–Triangle (comparison or position 2–Triangle2) and Green1–Horizontal2. The identity training is crucial because it is presumed to create additional classes of the form: Red1–Red2, Triangle1–Triangle2, etc. Following this training, the common elements (e.g., Red1 and Green1) would be expected to produce a class merger resulting in one class with Red and Triangle and another class with Green and Horizontal in both the sample and comparison position. Given such a class merger, a Triangle1–Red2 or Horizontal1–Green2 symmetry probe trial would be expected to yield positive results, as was confirmed in Urcuioli's (2008) Experiment 3 replication of Frank and Wasserman (2005).

Urcuioli (2008) provided a more compelling test of the class merger hypothesis in his Experiment 4. Again using a successive matching-to-sample arrangement, pigeons were trained on the same arbitrary (Red1–Triangle2; Green1–Horizontal2) and shape identity (Triangle1–Triangle2; Horizontal1–Horizontal2) discriminations as in Experiment 3. However, color oddity training (Red1–Green2; Green1–Red2) led to different predicted classes. One class was posited to include: Red1, Triangle1, Triangle2, Green2 and the other to include Green1, Horizontal1, Horizontal2, Red2. These classes yield the interesting prediction that rather than showing symmetry (e.g., respond to Red2 given Triangle1 and Green2 given Horizontal1), pigeons should show the opposite pattern (e.g., respond to

Green2 given Triangle1 and Red2 given Horizontal1). Urcuioli (2008) found evidence for such “antisymmetry” in four of five birds tested under these conditions, thus supporting the stimulus class merger hypothesis.

Since the Urcuioli (2008) study, Urcuioli and his colleagues have replicated both the symmetry and antisymmetry effects as well as demonstrated several additional emergent effects such as reflexivity and transitivity based on predictions of his hypothesis (Sweeney & Urcuioli, 2010; Swisher & Urcuioli, 2015; Urcuioli, 2011; Urcuioli & Swisher, 2012a; 2012b; Urcuioli & Swisher, 2015). In one recent study, Campos, Urcuioli and Swisher (2014) trained pigeons in a dual oddity task designed to produce class merger of the stimuli involved in arbitrary training in both sample and comparison positions. They found evidence of symmetry in four out of five of these pigeons, demonstrating that identity training is not required to produce the effect. In sum, Urcuioli and colleagues have provided strong support for the hypothesis that past failures to observe symmetry and other equivalence relations in pigeons may be largely due to the fact that the nominal stimulus in the sample position is not functionally identical to that same nominal stimulus in the comparison position without special training (see Urcuioli, 2015 for a review).

The Urcuioli hypothesis provides an explanation for why pigeons have so often failed tests of symmetry and equivalence: Humans presumably have many experiences early in development that result in the abstraction of objects from their ordinal and spatial positions which renders the special training required for class merger in animals unnecessary. While such an account is attractive, it remains premature because, at this point, pigeons are the only species that have been used to test the Urcuioli hypothesis. The purpose of the present study was to extend these analyses to rats with olfactory stimuli. Rats have not frequently been used to study emergent relations, at least in part because performances are generally quite poor when standard visual stimuli are used. For example, Iversen (1993; 1997) trained rats on visual identity matching-to-sample procedures and found that acquisition was slow and further complicated by stimulus location control. In contrast, our laboratory has found fairly rapid acquisition of matching- and nonmatching-to-sample relations when rats were trained to dig in scented sand or respond to scented objects on simultaneous conditional discriminations, and that control by generalized same–different relations emerged following such training (April, Bruce & Galizio, 2011, 2013; Pena, Pitts & Galizio, 2006). Rapid acquisition of matching-to-sample has also been demonstrated with odor stimuli using successive discrimination procedures (go/no-go) in rats (Lu, Slotnick & Silberberg, 1993). In Experiment 1, we adapted the Lu et al. procedures in order to systematically replicate Urcuioli’s (2008) Experiment 3. The goal was to determine whether training a combination of identity and arbitrary conditions designed to create class merger between the nominal odors and their respective positions would result in emergent symmetry. Experiment 2 used the same go/no-go procedures, but only trained identity relations in order to assess whether generalized identity matching-to-sample could be obtained.

Experiment 1

Method

Subjects—The subjects of this experiment were 14 male Sprague-Dawley albino rats approximately 90–150 days old at the beginning of training. Only seven rats reached criterion to be tested on symmetry probes. All rats were individually housed on a reversed 12-hour light–dark cycle. The rats were maintained at 85 percent of their free-feeding weight and received ad libitum access to water in their home cages. All experiments were performed during the dark phase of the cycle between 7:00 a.m. and 6:00 p.m. Rats were fed Lab Diet Rat Chow daily approximately 1 hour following their individual experimental sessions.

Apparatus—Sessions were conducted in Med Associates operant chambers with three response ports located across the front panel. Each port was equipped with a stimulus light, infrared photo beam response detectors, as well as openings for scents to be pumped in and vacuumed. The chamber measured 30.5 cm long by 24 cm wide by 21cm high. Each chamber contained a pellet dispenser located opposite the response ports. Chambers were housed in sound attenuating cubicles with doors sealed to prevent light and sound from entering during testing. Each chamber was interfaced to a computer equipped with MED-PC software. Three 5-channel Med Associates olfactometer systems (ENV-275-5) were added to each chamber. An input pump (Linear AC0102, 2.84 pound per square inch with an airflow of .177 cubic feet per min) delivered air through glass jars containing an odorant solution to solenoids that, when operated, forced scented air through a manifold into the center nose port of the chamber. A vacuum pump (Linear VP0125, –9.84 Hg vacuum and air displacement of .247 cubic feet/min) removed air from a tube located at the bottom of the center port. Thus, the system was capable of delivering 15 separate odors through the center response port (see Fig. 1).

Odorants—Odorants were 12 essential oils purchased from The Great American Spice Co. as well as local stores: banana, strawberry, tangerine, champagne, cinnamon, apricot, bubblegum, root beer, brandy, vanilla butternut, almond and licorice. Olfactometer jars were loaded with a solution of 6.7 ml oil per 100 ml distilled water. Glassware was removed and cleaned at the end of each testing day and solutions were refreshed every morning.

Procedure

Shaping phase—An initial session of magazine training was followed by response training sessions. Session onset was signaled by illumination of the house light and the jewel light inside the center port. Each nose-poke response turned off the house light and center-port light, turned on a light above the food hopper and delivered a sugar pellet. After a 5-s period, the hopper light went out and the house and center-port lights came on and the shaping procedure continued to provide reinforcement on an FR 1 schedule. Once regular responding was established, the reinforcement schedule was changed to FI 2-s, and was progressively moved to FI 5-s over several sessions. In order to acclimate animals to scent delivery through the center port, four odorants were then introduced for each rat (see Table 1). Each trial began with the onset of the house light and center-port light and delivery of

one of the four odorants. Completion of the FI 5-s schedule terminated the lights and odorant delivery, and produced reinforcement and the onset of the hopper light for 5 s. This arrangement continued until rats consistently responded to all four scents throughout the session.

Successive discrimination training trials—All trials consisted of stimulus pairs presented through the center port. Likewise, only responses in the center port were effective throughout the experiment. Trials began with the onset of the house light and center-port light. Following an initial observing nose-poke response, a sample stimulus was presented with the first nose poke after 5 s (FI 5-s schedule) resulting in a 1-s termination of the house and center port lights, and closure of sample-stimulus odor port, followed by the onset of a comparison stimulus and both lights. On positive trials, responding was reinforced on an FI 5-s schedule. The first response after 5 s resulted in termination of the comparison odor, the house light and the center-port light and a 5-s onset of the hopper light, along with delivery of a sugar pellet. On negative trials, the comparison was presented for 5 s and was terminated along with the house and center port lights immediately following that interval. A 30-s intertrial interval began immediately after reinforcement delivery on positive trials and after termination of negative trials. Figure 2 depicts the timeline for trials throughout the experiment.

There were eight different identity trial types (four positive and four negative) and four different arbitrary trial types (two positive and two negative) depicted in the first two sections of Table 2. The odorants used varied from rat to rat, and are identified for each subject by letter in Table 1.

Successive discrimination design—Once successive discrimination training began, rats were exposed to 45 min sessions (48–60 trials) 5 days/week. Ten rats (G10, G19, H4, H9, H13, H18, H19, H20, H21, and H22) began training with concurrent identity and arbitrary discriminations in a mixed baseline that included all 12 training trial types. Trial type order was randomly determined with the constraint that no more than four consecutive positive (reinforced) or negative (nonreinforced) trial types were permitted. Only one rat (G19) showed clear evidence of acquisition within 35–40 sessions, so for all other rats, the design was changed such that training sessions consisted only of the identity or arbitrary trial types with rats randomly assigned to one or the other condition. Training continued on these conditions until a mastery criterion was met such that an average discrimination ratio (DR; responses to S+/responses to S+ and S-) of .80 with a minimum DR of .75 on each trial type was met on two consecutive sessions. Once this criterion was met, rats trained on identity were switched to arbitrary trial types and vice versa. When rats met criterion on both identity and arbitrary conditions, they were generally required to meet criterion once again with the single trial type condition they had first mastered. Then they were returned to mixed identity and arbitrary trial types within the session. When criterion performance was reached on two consecutive mixed sessions, the symmetry probe phase began. Five of the 10 rats (G10, H4, H9, H13, and H20) failed to show criterion level performance after extensive training and were dropped from the study. Four additional rats began their training with identity (H5, H8) or arbitrary (H2, H7) trials only. Two of these animals (H2 and H8) failed

to meet performance criteria and were dropped from the study. When Rat H7 met criterion on arbitrary-only training, he was moved to the symmetry probe phase without receiving identity training. After completing eight probe sessions, H7 then received mixed training followed by another series of symmetry probe sessions. Table 3 shows the sequence and number of sessions across conditions for all animals that completed the study.

Symmetry probe phase—Symmetry probe sessions consisted of 38 trials: 12 positive identity trials, 8 negative identity trials, 6 positive arbitrary trials, 4 negative arbitrary trials and 8 unreinforced symmetry probe trials (the unbalanced ratio of positive to negative baseline trials was designed to keep the overall reinforcement rate closer to that programmed for regular baseline sessions). The probe trials included four positive symmetry probes (two of each trial type: B1A2; D1C2) and four negative probes (two of each trial type: B1C2; D1A2). The session following a probe session was always a mixed baseline session and the next probe session could not be conducted until the animal met criterion (overall DR of .80, with no DR less than .75 on any one trial type) for two consecutive sessions. Additionally, no probe sessions were administered after the weekend or any other break from regular testing. The experiment continued until the rat completed eight probe sessions, with one exception. Rat H7 was tested on eight symmetry probe sessions following training exclusively with arbitrary trial types. Therefore, the symmetry probe sessions were different than described above as they were composed of 30 arbitrary trials with 18 positive (A1B2; C1D2) and 12 negative (A1D2; C1B2) along with the 8 probe trials. After completing 8 symmetry probes, H7 received identity and mixed training to criterion followed by a second set of 8 symmetry probes conducted in the same way as the other animals.

Results and Discussion

Table 3 summarizes number of sessions required across the stages of training for the seven rats that eventually met the training criteria and completed the symmetry probe sequence. G19 acquired discriminative control during the initial exposure to the mixed identity/arbitrary training sequence and eventually met criterion and completed probes without any training interventions in just over 50 sessions (to criterion) and under 90 sessions (to completion of eight probe sessions). The other four rats initially trained with the mixed sequence (H18, H19, H21, H22) failed to show evidence of acquisition and after 38–40 sessions were exposed to training sessions that included only identity trials (H18, H21) or only arbitrary trials (H19, H22). After meeting acquisition criteria, training was changed from identity-only to arbitrary-only or vice-versa. Mastery of these single type discriminations was generally fairly rapid and after a return to the initial single-type discrimination all four rats were returned to the mixed identity and arbitrary training until meeting criterion (see Table 3). Rats H5 and H7 began training with the single-type discriminations and, after meeting criteria, were successful in mastering the mixed training. Finally, it should be noted that of the 14 rats that began training, 7 did not complete the experimental protocol due to failure to show improvement over the course of at least 40 sessions or to failing health.

The outcomes on probe sessions are presented in Figure 3 which shows mean responses per s for baseline and symmetry probe trials for individual rats. Baseline (white circles) response

rates are based on the arbitrary trials (e.g., positive trials A1B2; C1D2) programmed during the eight probe sessions, and all seven rats showed relatively high rates on positive trials and much lower rates on negative trials as expected based on their training histories. Emergent symmetry would be evidenced by performances on probe trials (black circles) that would look similar to baselines with high rates of responding on positive symmetry trials (B1A2; D1C2) and low rates on negative trials (B1C2; D1A2). However, as Figure 3 clearly shows, such an effect was not observed in any of the seven rats. Indeed in all seven cases, response rates were quite low on both positive and negative symmetry trials and there was no evidence of control by symmetry relations. Because probes were conducted in extinction, it seemed possible that combining data across all eight probe sessions might conceal any trends toward symmetry that were manifest very early in testing. In order to evaluate this possibility, Figure 3 also shows response rates from the first probe session for each rat (triangles). However, this analysis yielded the same conclusions. Even during the first probe session, all seven rats showed low levels of responding on symmetry probe trials and although some rats showed slightly higher rates on the first positive probe (H7, H18, H22), others showed less (G19, H21).

Statistical analyses were conducted using two-tailed matched-pair *t*-tests comparing responses on positive versus negative baseline and probe trials with sessions as the repeated measure. Baseline response rates were significantly higher on positive trials for each rat, but there were no significant differences in responding between positive and negative trials on any of symmetry probes obtained after mixed training (see Table 4). Interestingly, as Table 4 shows, there was a statistically significant outcome on the symmetry tests conducted with Rat H7 prior to his exposure to mixed training (bottom right panel of Fig. 3). However, inspection of the response rate data reveals an outcome essentially similar to those obtained following mixed training. Once again response rates were very low on both positive and negative symmetry trials, but in this case they were consistently so low on negative trials that a statistically significant difference was obtained. Regardless of the statistical effect, there is still little support from Figure 3 of the kind of substitutability that would provide evidence of symmetry relations.

In summary, Experiment 1 showed that rats can acquire a complex set of successive conditional discriminations using olfactory stimuli with schedule parameters based on Urcuioli (2008). However, there was little evidence of symmetry even after training that established the prerequisite relations that have been sufficient to produce symmetry in pigeons (Campos, Urcuioli & Swisher, 2014; Urcuioli, 2008; 2015; Urcuioli & Swisher, 2012a). The procedures were closely patterned after the experimental strategy used by Urcuioli and his colleagues with pigeons, but several changes were necessary to make the transition to rats and olfactory stimuli. Among these were the number of trials per session (generally more in the pigeon studies), the number of probe trials within probe sessions (generally more in the pigeon studies) and the ratio of nonreinforced probe trials to reinforced baseline trials within probe sessions (generally lower in the pigeon studies). The significance of such factors is unknown, but it is certainly possible that they may have worked against a successful demonstration of symmetry in the present study. Parameters which were identical in the present study and Urcuioli's (2008) Experiment 3 may not have

been ideal for the use of olfactory stimuli and rats (e.g., was the FI 5-s schedule suitable for odor delivery?). It is noteworthy that so many of the rats in the present study failed to master the baseline conditional discriminations.

An additional caveat is that six of the seven rats required sequential training with identity- and arbitrary-only trial sessions before mastering the final training in which identity and arbitrary trials were mixed within the sessions. This may have been of significance because Frank and Wasserman (2005-Experiment 3) found less robust evidence for symmetry under similar training conditions with only one of the two pigeons studied showing reliable evidence of symmetry. Of course, Rat G19 in the present study also failed to show evidence of symmetry despite experiencing only the mixed training condition, but the need for sequential training for the other animals may have worked against the emergence of symmetry.

The difficulty of the successive discrimination tasks may also have been a limiting factor. Research from our laboratory has obtained much more rapid and accurate stimulus control using simultaneous discrimination procedures in which odors are presented by allowing rats contact with scented sand or scented plastic objects. Moreover, control by emergent identity and oddity relations has been demonstrated in rats using these procedures (April et al., 2011, 2013; Pena et al., 2006). Thus, a way to help evaluate the role of procedural variations in the failure to find symmetry in Experiment 1 was to use the successive conditional discrimination procedure in the olfactometer to study a different emergent relation that has been observed with odor stimuli in rats: emergent identity (cf. Lu et al., 1993).

Experiment 2

Method

Subjects and Apparatus—The subjects of this experiment were nine male Sprague-Dawley albino rats. Rats were approximately 90 days old at the beginning of training, and housing, feeding arrangements and apparatus were as described for Experiment 1.

Procedure—Basic trial arrangements were the same as described for Experiment 1 (see Fig. 2) with an observing response required to initiate each trial sample stimulus, completion of an FI 5-s schedule required to produce the comparison stimulus, and FI 5-s reinforcement schedule in place for positive trials, with a 5-s response period for negative trials. Only identity training was used in Experiment 2 proper, but Rats K5, K6, K7, K8 and K9 had received 29–30 sessions of arbitrary training as described above with the same stimuli before being assigned to Experiment 2. Two sets of four odorants were selected as training stimuli with three rats trained on each set (see Table 5). Sessions consisted of 48 trials, 24 positive (reinforced) and 24 negative (nonreinforced) with no more than four positive (reinforced) or negative (nonreinforced) trial types in a row. Identity trials always ended in reinforcement (trial types were the following pairs: A1A2+, B1B2+, C1C2+, and D1D2+, see Table 5 for specific odors) and the nonmatching trial types (stimulus pairs: A1C2-, B1D2-, C1A2-, D1B2-) did not. Training continued until an overall DR of .80 was obtained (with no less than a DR of .75 on any one trial type pair) for two consecutive sessions. Six of the nine rats (K7, K8, K9, K34, L23 and L25) met these criteria.

After reaching criterion, rats were tested on identity probe sessions designed to be similar to the symmetry probe sessions of Experiment 1. These sessions consisted of 36 trials with 20 trials using the original training stimuli (16 reinforced identity trials and 12 nonmatching trials) interspersed with 8 probe trials using a novel stimulus set (see Table 5). As in Experiment 1, more positive than negative baseline trials were included to offset the decrease in overall session reinforcement caused by the inclusion of the nonreinforced probe trials. Probe trials never ended in reinforcement and included one presentation of each of the four novel-odor identity trials (AA, BB, CC, DD), and four nonmatching trials (AC, BD, CA, DB). Probe sessions were programmed after sessions in which the training criterion was met for two consecutive days.

Results and Discussion

Table 6 shows the number of sessions required to meet training criterion for the six rats across the course of the experiment. There was considerable variability across rats in the amount of identity training required to meet criterion. The three rats that were initially exposed to the arbitrary matching training condition (K7, K8, K9) were much slower to acquire identity matching than two of the three rats whose initial training was with identity. Given how rapidly Rats L23 and L25 met criterion, it seems possible that the arbitrary training interfered with acquisition of the identity task (two of the three rats that failed to meet training criteria also received initial training with arbitrary matching).

The results of the identity probe sessions are shown in Figure 4 which presents response rates in the same format as Figure 3 of Experiment 1. Response rates were high on positive (identity) trials and low on negative (nonmatching) trials for the baseline stimulus set (open circles) as expected given their criterion performances on the previous session. The striking feature of Figure 4 is that most rats also showed similar functions for the novel probe stimuli (closed circles) which were generally apparent on the initial probe session (triangles). Indeed, in four of the six rats (K7, K8, K9 and K34), the slope of the function for baseline and probe stimuli appears to be roughly the same—strong evidence for full generalization of control by identity relations. The effect was evident, but not as strong for Rat L25: His response rates to positive probe trials were clearly higher than on negative probes, but were lower than those obtained on positive baseline trials. Finally, Rat L23 showed little evidence of generalization of identity matching with low response rates on positive and negative probe trials. Table 7 summarizes the statistical analysis comparing response rates and positive versus negative trial types, and it is noteworthy that all twelve tests were statistically significant. Thus, even Rat L23, who showed low rates of probe responding, consistently responded more on identity than on nonmatching probe trials. In summary, Experiment 2 replicated the findings of Lu et al. (1993) in showing that rats can acquire identity matching using a successive discrimination procedure with odor stimuli, and extended their findings to demonstrate generalized identity matching to novel odor stimuli using unreinforced probe conditions.

General Discussion

Experiment 1 was modeled after studies (e.g., Urcuioli, 2008, Experiment 3; Frank & Wasserman, 2005) which found that training on arbitrary and identity conditional discriminations using a successive (go/no-go) procedure resulted in successful demonstrations of emergent symmetry with visual stimuli in pigeons. The present study differed from those by using odor stimuli with rats, but otherwise duplicated most aspects of the pigeon studies. However, the results were strikingly different: None of the seven rats provided evidence for emergent symmetry. The failure to find symmetry in rats under conditions similar to those which have been successful in pigeons is puzzling, so it is worth considering ways in which the procedures of the present study differed. The present study used similar FI 5-s schedules for sample termination and reinforcement delivery during the comparison stimulus, but used a somewhat longer (30 s) intertrial interval. Sessions in the present study contained fewer trials than the pigeon studies, and perhaps of more significance, the ratio of probe to baseline trials was higher in our experiment. Indeed, the concern that the negative probe results may have been due to extinction across the eight probe sessions led to the break out of the initial probe session data in Figure 3, but this analysis also failed to produce substantial evidence for symmetry. The difficulty in mastering the conditional discriminations and the need for successive exposure to identity and arbitrary training before success on mixed conditions in most rats also may have worked against demonstrating symmetry (see Frank & Wasser-man, 2005—Experiment 3). It seems possible that the translation of schedule parameters that have been successful in pigeons may not have produced conditions that are optimal for demonstrating symmetry in rats. For example, it would be interesting to explore a longer FI schedule or perhaps to change the design and provide reinforcement on probe trials. That having been said, it was concern about whether emergent behavior could be seen in rats under the schedule parameters of Experiment 1 that led to the study of identity relations in Experiment 2. Thus, the successful demonstration of emergent identity with relatively high response rates during positive probe trials certainly suggests that failure to obtain symmetry in Experiment 1 is unlikely to have been due to poor translation of schedule or testing parameters.

Indeed, the results of Experiment 2 are noteworthy on their own account. Although previous research from our laboratory has demonstrated generalized matching- and nonmatching-to-sample with olfactory stimuli, these studies used manual training arrangements in which rats responded by digging in scented sand (April et al., 2011; Pena et al., 2006) or responding to scented lids (April et al., 2013). Lu et al. (1993) showed rapid acquisition of identity matching-to-sample using an automated go/no-go arrangement much like the present study. However, in their study, trials with novel odors were not conducted in extinction so it is difficult to determine whether they obtained generalized identity, as their outcomes could have reflected rapid acquisition of individual odor relations. The use of nonreinforced probes in the present study eliminates such a possibility and thus provides strong support for generalized identity matching-to-sample for odors in the rat in the go/no-go arrangement. It is of particular interest that successful generalization occurred after initial training with only four different odors. In most previous studies, training with a more extensive set of exemplars is required in order to produce generalized matching or nonmatching (Bodily,

Katz & Wright, 2008; Daniel, Wright & Katz, 2015; Katz & Wright, 2006) and so emergent identity after four exemplars is surprising and merits additional research attention. Finally, it should be added that the finding of generalized identity occurred here without the sort of training requirements that would be predicted if the temporal position of the odor were part of the functional stimulus (Sweeney & Urcuioli, 2010; Urcuioli, 2011; Urcuioli & Swisher, 2012b). That is, during the generalized identity probes of the present study, rats responded at a high rate to novel odors on matching trials despite the lack of a history of reinforcement with those stimuli in either the sample or comparison position.

Urcuioli's (2008) theory was explicitly designed to address emergent stimulus control in pigeons (cf. Urcuioli, 2015), but it seems possible that it might be more generally applicable to account for failure to show emergent symmetry in other nonhuman species. However, the failure to find symmetry in the present study suggests that for rats, at least with olfactory stimuli, stimulus control topographies develop differently than those observed in pigeons with visual stimuli during go/no-go training. Even if this is so, it remains unclear why rats would show emergent control by identity but not symmetry relations using such similar procedures in the present study. One thing that separates Experiment 1 and 2 is that training with multiple exemplars of identity matching was present in Experiment 2. Perhaps with rats, like sea lions (Schusterman & Kastak, 1993), exposure to multiple exemplars of reinforced symmetry responding would be a more successful way to search for symmetry. Learning more about the specific procedures necessary to obtain symmetry in nonhumans has important implications for theories of stimulus equivalence and other emergent relations in humans as is illustrated by recent controversies regarding the interpretation of associative concept learning (Dymond, 2014; Hughes & Barnes-Holmes, 2014; McIlvane, 2014; Urcuioli, Wasserman & Zentall, 2014; Zentall, Wasserman & Urcuioli, 2014).

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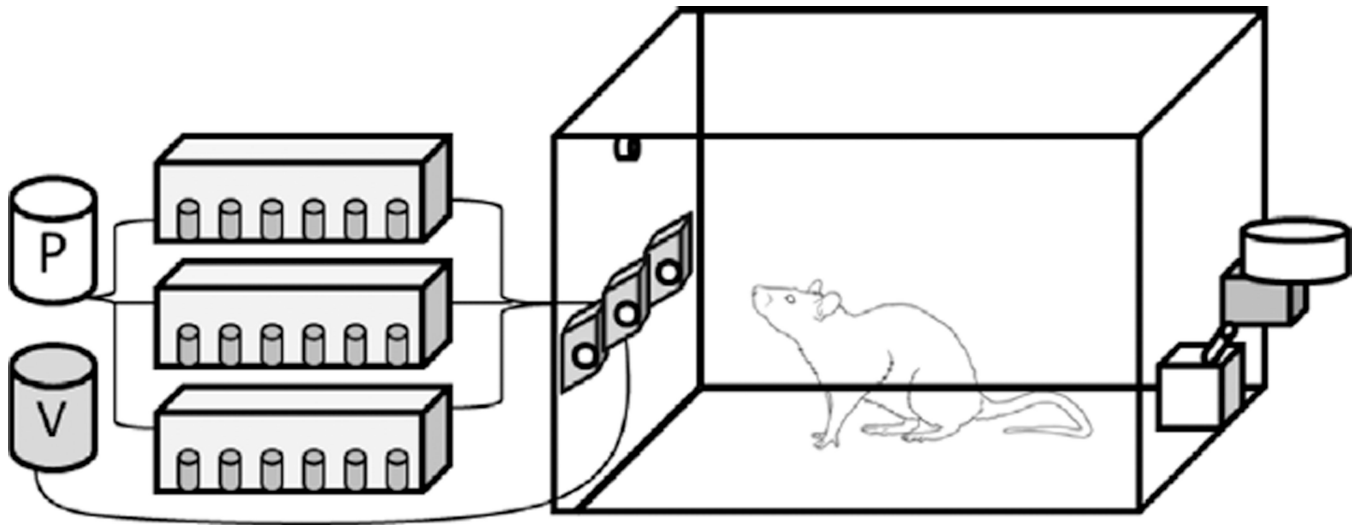


Fig. 1. Schematic diagram of olfactometer and chamber system. The input pump (P) sends air through jars containing diluted odorants. Scented air is delivered to the center port only when the gating solenoid is open. A vacuum pump (V) removes scented air from the center port area.

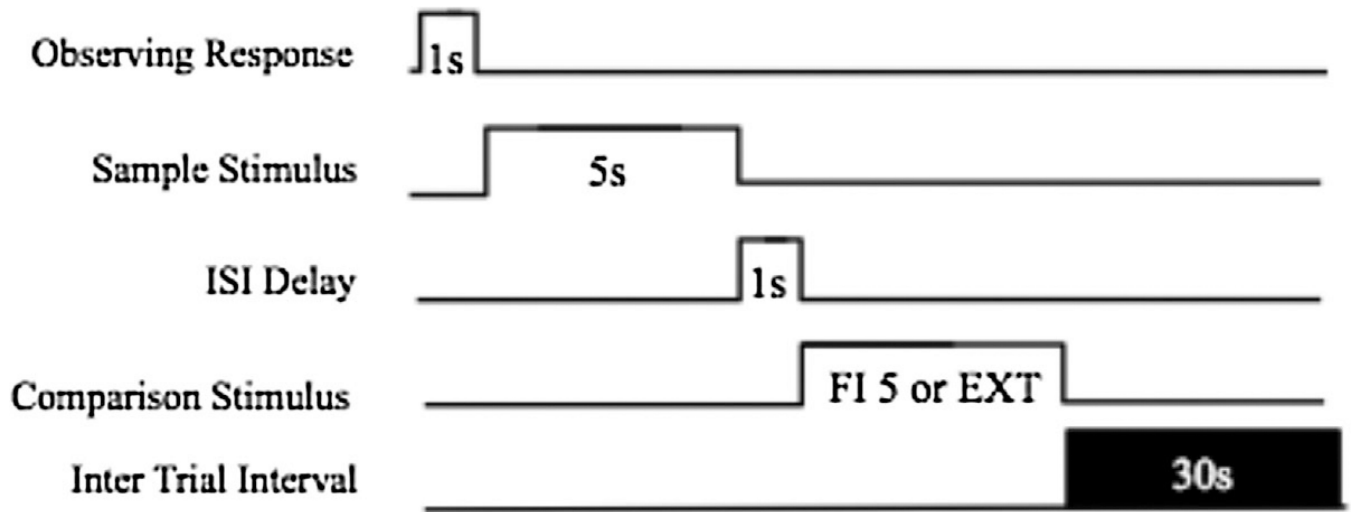


Fig. 2.
Timeline for successive discrimination trials in Experiments 1 and 2.

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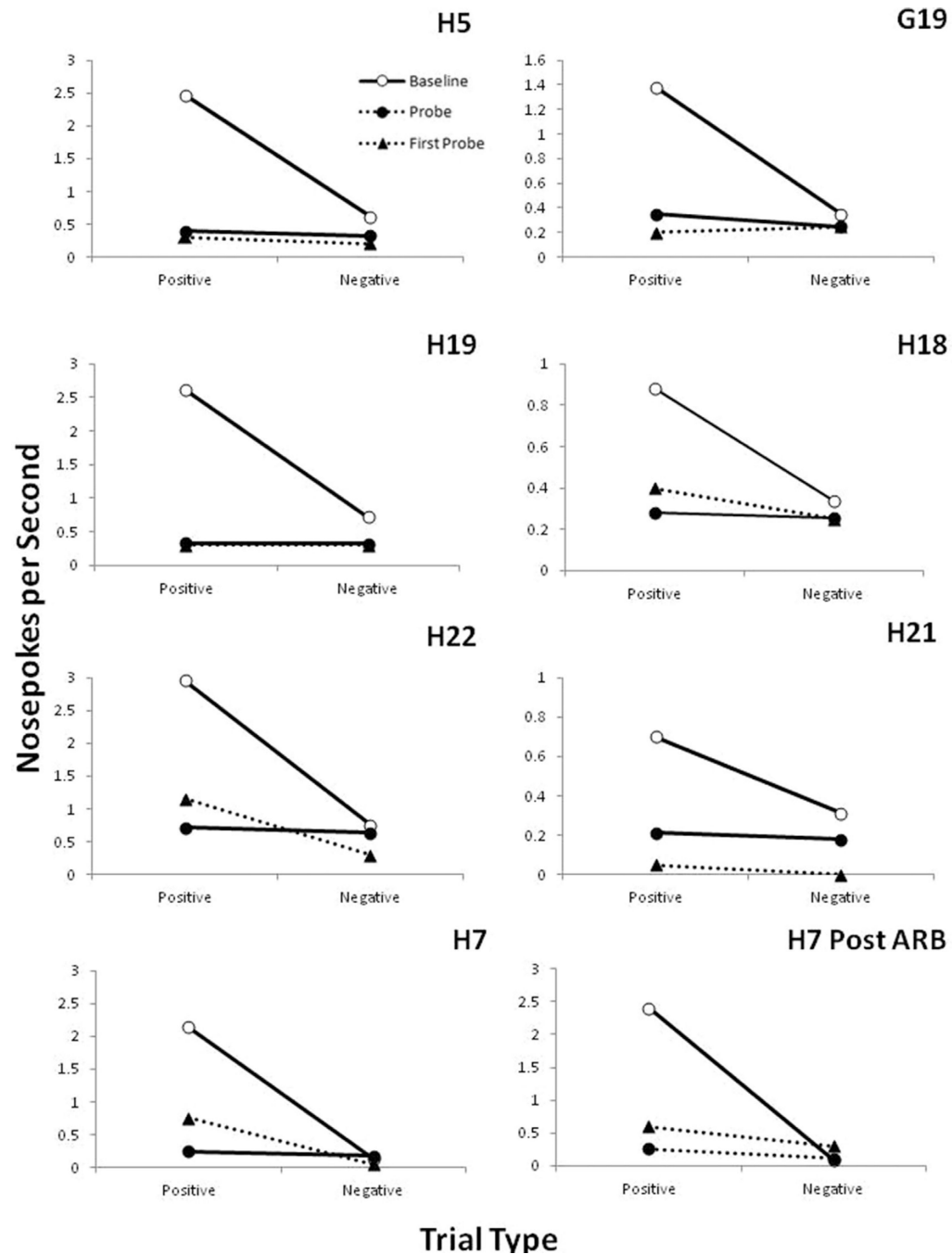


Fig. 3. Mean response rates from the symmetry probe sessions for each rat in Experiment 1. Response rates on arbitrary baseline trials are represented by open circles. Response rates to probe trials are represented by closed circles. Response rates on the first symmetry probe session are represented by triangles. The bottom panels show the two sets of probe sessions administered to Rat H7 with the left panel showing probe sessions following mixed identity-arbitrary training and the right panel showing the first set of probe sessions obtained following training only with the arbitrary conditional discrimination.

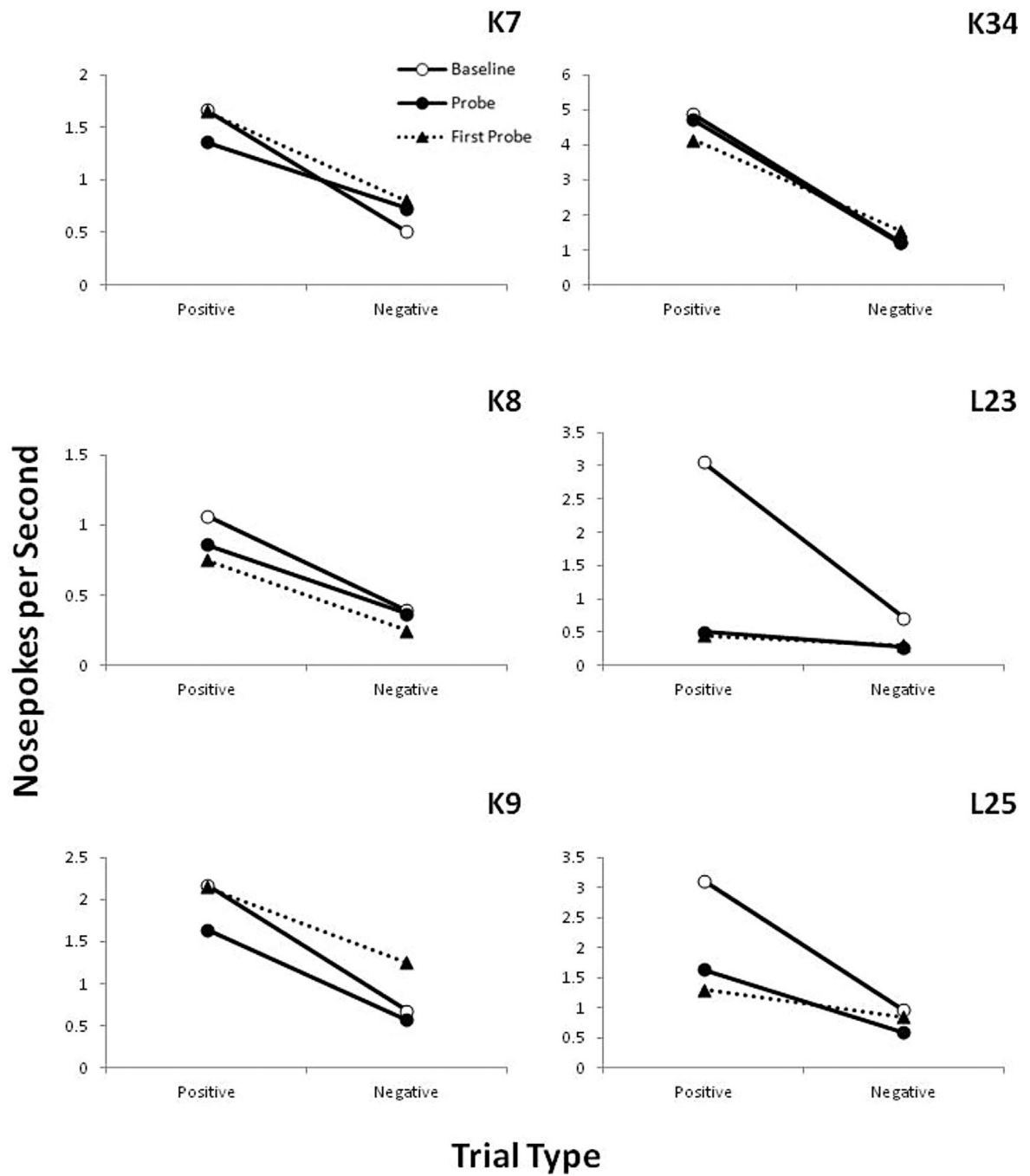


Fig. 4. Mean response rates from the identity probe sessions for each rat of Experiment 2. Response rates on baseline trials are represented by open circles and rates on probe trials closed circles. Response rates on the first identity probe session are represented by triangles.

Table 1

Olfactory Stimuli for Subjects in Experiment 1

Subject	A	B	C	D
G19	Brandy	Vanilla Butternut	Almond	Licorice
H18	Brandy	Vanilla Butternut	Almond	Licorice
H19	Brandy	Vanilla Butternut	Almond	Licorice
H22	Brandy	Vanilla Butternut	Almond	Licorice
H5	Cinnamon	Apricot	Bubblegum	Root Beer
H7	Cinnamon	Apricot	Bubblegum	Root Beer
H21 ^a	Banana	Strawberry	Tangerine	Champagne
	Cinnamon	Apricot	Bubblegum	Root Beer

^aH21 was initially trained with banana, strawberry, tangerine and champagne, but after showing little evidence of acquisition, scents were changed to the cinnamon, apricot, bubblegum, root beer stimulus set on which he met the discrimination criteria.

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Table 2

Trial Types in Experiment 1

Arbitrary	Identity	Symmetry
A1→B2	A1→A2	B1→A2
	FI-5s Pellet	EXT
A1→D2	A1→C2	D1→C2
	EXT	EXT
C1→D2	B1→B2	B1→C2
	FI-5s Pellet	EXT
C1→B2	B1→D2	D1→A2
	EXT	EXT
	C1→C2	FI-5s Pellet
	B1→A2	EXT
	D1→D2	FI-5s Pellet
	D1→B2	EXT

Note. Sample stimuli are indicated by the numeral 1, comparison stimuli by numeral 2.

Table 3
 Number and Sequence of Sessions across Each Training and Testing Condition for the Rats in Experiment 1

	H18	H19	H21	H22	H5	H7	G19
Shaping	6	6	6	7	8	8	9
Initial Mixed	40	40	38	38	-	-	145
Identity	28	-	35	-	17	-	-
Arbitrary	8	25	8	63	21	46 ^a	-
Identity	8	8	10	27	11	4	-
Arbitrary	-	2	-	11	-	1	-
2 nd Mixed	117	124	31	13	48	32	-

^aRat H7 was given a series of probes immediately following arbitrary training and then another set following mixed training.

Note. - indicates that the rat was not tested in that condition at that time.

Table 4

Statistical Analysis Summary for Experiment 1

Rat	Positive Symmetry vs. Negative Symmetry	Positive Baseline vs. Negative Baseline
G19	$t = 0.92, NS$	$t = 7.36, p < 0.001$
H18	$t = 0.28, NS$	$t = 6.16, p < 0.001$
H19	$t = 0.22, NS$	$t = 7.30, p < 0.001$
H21	$t = 0.64, NS$	$t = 4.94, p < 0.001$
H22	$t = 0.54, NS$	$t = 13.09, p < 0.001$
H5	$t = 0.83, NS$	$t = 14.42, p < 0.001$
H7	$t = 0.30, NS$	$t = 24.77, p < 0.001$
H7 ^a	$t = 2.81, p = 0.026$	$t = 24.28, p < 0.001$

^aResults from first symmetry probes that were conducted after initial arbitrary-only training.

Note. All $dfs = 7$.

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Table 5

Odor Stimuli used in Experiment 2

Subjects	Training Stimulus Set	Probe Stimulus Set
K7, L23, L25	A: Cinnamon	A: Clove
	B: Apricot	B: Honey
	C: Bubble Gum	C: Blueberry
	D: Root Beer	D: Geraniol
K8, K9, K34	A: Brandy	A: Cinnamon
	B: Vanilla Butternut	B: Apricot
	C: Almond	C: Bubble Gum
	D: Licorice	D: Root Beer

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Table 6

Number of Sessions for Each Subject in the Conditions of Experiment 2

	Subjects					
	K7	K8	K9	K34	L23	L25
Shaping	8	8	8	11	7	9
ARB Training ^a	29	31	30	-	-	-
ID Training	284	216	181	181	48	72

^aK7, K8, and K9 received training on arbitrary relations before beginning Experiment 2.

Table 7

Statistical Analysis Summary for Experiment 2

Subject	Positive Identity vs. Negative Identity	Positive Baseline vs. Negative Baseline
K7	$t = 7.76, p < 0.001$	$t = 26.13, p < 0.001$
K8	$t = 4.02, p < 0.01$	$t = 13.49, p < 0.001$
K9	$t = 12.34, p < 0.001$	$t = 55.10, p < 0.001$
K34	$t = 9.20, p < 0.001$	$t = 27.38, p < 0.001$
L23	$t = 3.57, p < 0.01$	$t = 13.65, p < 0.001$
L25	$t = 4.48, p < 0.01$	$t = 17.76, p < 0.001$

Note. All $dfs = 7$.

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