Superordinate Categorization Via Learned Stimulus Equivalence: Quantity of Reinforcement, Hedonic Value, and the Nature of the Mediator

Suzette L. Astley Cornell College Jessie J. Peissig and Edward A. Wasserman University of Iowa

Three experiments examined superordinate categorization via stimulus equivalence training in pigeons. Experiment 1 established superordinate categories by association with a common number of food pellet reinforcers, plus it established generalization to novel photographic stimuli. Experiment 2 documented generalization of choice responding from stimuli signaling different numbers of food pellets to stimuli signaling different delays to food reinforcement. Experiment 3 indicated that different numbers of food pellets had been paired. The collective results suggest that the effective mediator of superordinate categories that are established via learned stimulus equivalence is not likely to be an accurate representation of the reinforcer, neither is it likely to be a distinctive response that is made to the discriminative stimulus. Motivational or emotional mediation is a more likely account.

How do human beings and nonhuman animals learn to conceptualize the complex environment that they face each day and respond appropriately to it? Psychologists have come to view the categorization of stimuli as an important underpinning of adaptive behavior in a wide variety of domains. The *categorization* or *classification* of stimuli is said to occur when discriminably different stimuli are nonetheless treated similarly. Learned or acquired equivalence may account for the classification together of stimuli with few common attributes or elements. One can know that perceptually distinct stimuli have acquired equivalence when a change in response tendencies to some members of the class generalize spontaneously to other members of the class (Schusterman, Kastak, & Reichmuth, 1997), when members of the class become interchangeable for one another (Sidman, 1994; Zentall, 2000), or both.

Researchers who write about learned equivalence have emphasized its importance for understanding a wide variety of complex behaviors. Schusterman, Reichmuth, and Kastak (2000) described and documented the important role that learned equivalence plays in social behavior toward familiar and unfamiliar conspecifics and kin.

Another domain in which learned equivalence may play a role is in establishing symbolic representation (Zentall, 2000), or what is commonly referred to as *meaning* or *comprehension* of language (e.g., Sidman, 1990, 1994). One important consequence of learned equivalence was noted by Zentall (2000): "Symbolic representation is one of the fundamental building blocks of human language" (p. 122).

Astley and Wasserman (1998a, 1999) have described how learned equivalence might account for the formation of superordinate conceptual categories. Superordinate conceptual categories are aggregations, such as *furniture* or *vehicle*, that encompass diverse sets of exemplars from different basic-level categories that share few common features (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Thus, the existence of superordinate categories can owe little to perceptual resemblance and are more likely to be due to associative learning.

An even more fundamental question related to stimulus equivalence revolves around whether certain types of equivalence may occur in only certain species of organisms. Sidman (1990, 1994) has distinguished functional equivalence classes of the type described at the outset of this article from stimulus equivalence classes. Functional equivalence classes exist, according to Sidman (1990, citing Goldiamond, 1966), when a group of stimuli all control the same behavior. Stimulus equivalence classes are established through the demonstration of reflexivity, symmetry, and transitivity in conditional choice discrimination.

To demonstrate reflexivity an organism must be capable of matching a stimulus to itself; to demonstrate symmetry one must show reversible relations between different stimuli. The key to demonstrating equivalence, however, is the emergence, without direct training, of transitivity. Transitivity is demonstrated when, after training to choose Stimulus B when the sample is Stimulus A, and training to choose Stimulus C when the sample is Stimulus B, the organism chooses Stimulus C when the sample is Stimulus A without explicit training to do so.

Suzette L. Astley, Department of Psychology, Cornell College; Jessie J. Peissig and Edward A. Wasserman, Department of Psychology, University of Iowa.

This research was supported by National Institute of Mental Health Grant MH51562. We thank Lloyd Frei and Keith Miller for their technical assistance, Frank McLaughlin and Michael Prier for their help with data collection, and Masako Jitsumori for helpful comments on an earlier version of this article.

Correspondence concerning this article should be addressed to Suzette L. Astley, Department of Psychology, Cornell College, 600 First Street West, Mount Vernon, Iowa 52314-1098. Electronic mail may be sent to sastley@cornell-iowa.edu.

Functional equivalence classes have been demonstrated in many ways in both humans and many species of nonhuman animals (e.g., Astley & Wasserman, 1996, 1998b, 1999; Delius, Ameling, Lea, & Staddon, 1995; Nakagawa, 1986, 1992; Schusterman et al., 1997; Sidman, Wynne, Maguire, & Barnes, 1989; Urcuioli, Zentall, & DeMarse, 1995; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989; Vaughn, 1988; Wasserman, DeVolder, & Coppage, 1992; Zentall, Steirn, Sherburne, & Urcuioli, 1991). Only a few studies, however, have purportedly demonstrated stimulus equivalence (sometimes called Sidman equivalence) by obtaining reflexivity, symmetry, and transitivity in a single study of nonhuman animals (McIntire, Cleary, & Thompson, 1987; Schusterman & Kastak, 1993); indeed, there has been substantial debate about whether these studies truly demonstrate stimulus equivalence (e.g., Dugdale & Lowe, 1990; Hayes, 1989; Horne & Lowe, 1996; Saunders, 1989; Saunders, Williams, & Spradlin, 1996).

Zentall (1998a, 1998b) has described evidence that pigeons can exhibit reflexivity, symmetry, and transitivity, but he has noted that response mediation may play a role in many of the instances of symmetry and transitivity. Response mediation involves control that is not exerted by the stimuli themselves, but rather by the behaviors engendered by the stimuli. Zentall has noted that all demonstrations of symmetry and transitivity in pigeons have used a biologically significant event, such as food, as one of the elements. Behaviors to previously neutral elements may come to resemble those to the biologically significant events, through processes such as autoshaping; these overt conditioned responses might then mediate the observed symmetry and transitivity. Clearly, we have a great deal yet to learn about species differences in demonstrating the behavioral elements of stimulus equivalence and about the relation between stimulus equivalence and functional equivalence.

So far, we have discussed the broader applications that attest to the centrality of equivalence to many types of adaptive behavior in humans and nonhuman animals. Perhaps of equal importance, however, are questions about the basic foundations of equivalence. How do perceptually distinct stimuli become behaviorally interchangeable for one another? How do perceptually similar stimuli become more distinct as cues for behavior?

These questions, of course, have a long history in research on learning and behavior (e.g., Hull, 1939; Lawrence, 1949, 1950; Reese, 1972; Spiker, 1956). Much of this early work considered mediation as a possible explanation of acquired equivalence and distinctiveness. The mediational model posits that, when associations (e.g., of behavior or outcome) are forged to environmental stimuli, the associations themselves may have stimulus properties that enter into later learning experiences with the environmental stimuli. (See Urcuioli, 1996, for a more thorough discussion of this approach and its usefulness in accounting for many instances of acquired equivalence.)

Thinking about these issues was significantly advanced by early research and theorizing about the differential-outcomes effect (Trapold & Overmier, 1972; see Goeters, Blakely, & Poling, 1992, for a review of research). The differential-outcomes effect occurs when a two-alternative discrimination task is learned faster if different outcomes consistently follow each stimulus-response (S-R) pair than if the outcomes following each S-R pair are randomly presented. Consistent outcomes also promote more accurate performance than do random outcomes when there is a delay interval between the discriminative stimulus and the opportunity to respond. The usual explanation of the differentialoutcomes effect derives from two-factor theory. The outcomes are the same in both the consistent and the random outcomes conditions of differential-outcomes research, so operant conditioning by itself cannot explain the differential-outcomes effect. A Pavlovian conditioning element is the second factor that is added when discriminative stimuli are associated with different outcomes. The Pavlovian element adds a redundant discriminative stimulus—the stimulus-reinforcer expectancy—according to two-factor theory. Such an expectancy arises only in the consistent condition, not in the random condition. Thus, the added Pavlovian element produces faster learning and better retention over a delay in the consistent outcomes group.

Research on the differential-outcomes effect continues (e.g., Urcuioli & DeMarse, 1997; Urcuioli, DeMarse, & Zentall, 1998) that may provide a clearer understanding of its underlying mechanisms. Some research points to bidirectional associations to account for the differential-outcomes effect (Rescorla, 1992, 1994; Rescorla & Colwill, 1989). According to a bidirectional model, response-outcome associations are symmetrical. Once a differential response-outcome expectancy is acquired, according to this model, anything that increases the expectation of the outcome will increase the tendency to make the response. Two-factor theory thus emphasizes differential associations to the sample stimuli, whereas the bidirectional model emphasizes differential associations to the comparisons. Urcuioli and DeMarse (1997) provided evidence for the latter but noted that a more elaborate version of two-factor theory has not yet been ruled out.

Another line of recent research related to the basis of equivalence concerns common coding of stimuli in many-to-one (MTO) matching-to-sample procedures (e.g., Urcuioli et al., 1989; Zentall et al., 1991; also see Wasserman et al., 1992). In tests in a wide variety of situations, samples associated with a common comparison stimulus evoke similar response tendencies. These results are consistent with the notion that samples in MTO matching-tosample come to generate a common representational code that can guide later behavior. The work of Zentall, Urcuioli, and their colleagues is consistent with the notion that MTO training creates a representational code that can cue or direct behavior. In essence, the code established by MTO training can serve a mediating function in later learning experiences (Urcuioli, 1996).

In a recent set of experiments Astley and Wasserman (1999) also examined the role of mediation in acquired equivalence. These experiments studied the binding together of different classes of stimuli by association with a common delay (Experiment 1) or probability (Experiment 2) of food reinforcement. The first phase of these experiments associated stimuli from two classes, C1 and C2, with one outcome (e.g., a short delay of reinforcement) and stimuli from two different classes, C3 and C4, with a different outcome (e.g., a long delay of reinforcement). Photographic stimuli were presented singly on a large center key during this categorization training. Completion of a fixed ratio-20 (FR-20) response requirement then led to the differential outcomes appropriate for each class of stimuli. As in earlier studies, the next choice training phase associated one stimulus class (C1) with one choice response (R1) and another stimulus class (C3) with a different choice response (R2). Testing sessions examined choice behavior to stimuli from C2; stimuli from C4; and novel stimuli

from C1, C2, C3, and C4. Both Experiment 1 (which explored different delays to reinforcement as potential binding events) and Experiment 2 (which explored different probabilities of reinforcement as potential binding events) found strong evidence that choice training with C1 and C3 generalized to the nonchoice-trained C2 and C4 stimuli. Choice of R1 to C2 and choice of R2 to C4 averaged at least 85%.

Of further interest is the finding that discriminative responding can transfer to stimuli associated with different outcomes of similar relative hedonic value. In Experiment 3 of Astley and Wasserman's (1999) study they examined whether choice responding might transfer across delays and probabilities of reinforcement in a three-phase procedure. Specifically, in the first phase of Experiment 3 in Astley and Wasserman's (1998a) study, training was conducted with reinforcement delays of 1 s and 15 s (probability = 1.0) for two classes of stimuli (e.g., C1 and C4, respectively) and with reinforcement probabilities of 0.1 and 0.9 (delay = 0 s) for two other classes of stimuli (e.g., C3 and C2, respectively). Then, choice training associated one response (e.g., R1) with a stimulus class that was previously associated with one of the two better conditions of reinforcement (e.g., C1), and it associated a different response (e.g., R2) with a stimulus class that was previously associated with one of the two worse conditions of reinforcement (e.g., C3). In testing sessions choice responding was examined with all four classes of stimuli. Those tests revealed the transfer of choice responding to stimuli that were associated with outcomes of similar reinforcement value. Specifically, in the counterbalancing conditions that were used in the example above, the pigeons predominantly chose R1 in the presence of the C2 exemplars, and they predominantly chose R2 in the presence of the C4 exemplars. These results suggest that the pigeons' categorization behavior was based on the relative reinforcement or hedonic value of the outcomes that were previously associated with each of the classes of stimuli and not on the parametric details of the various schedules of reinforcement.

In this article we report three experiments that in various ways expand on our earlier research into superordinate categorization by pigeons. In Experiment 1 we asked whether association with a common quantity of reinforcement could create a superordinate category. Specifically, we wanted to know whether associating stimuli from one pair of component classes (C1 and C2) with one food pellet and associating stimuli from a second pair of component classes (C3 and C4) with five food pellets would create two superordinate categories of behaviorally equivalent stimuli (C1–C2 and C3–C4). Would different quantities of a food reinforcer prove to be as effective in creating superordinate categories as had different delays and probabilities in Astley and Wasserman's (1999) study?

In Experiment 2 we asked whether discriminative stimuli for different delays to food reinforcement could substitute on choice trials for discriminative stimuli for different numbers of food pellets. Astley and Wasserman (1999, Experiment 3) found transfer of choice responding across different delays and probabilities of reinforcement when training with the different outcomes was conducted within the same session. In the present Experiment 2 we looked at the potential for transfer across different quantities and delays of reinforcement when training with different delays of reinforcement was begun long after training with different numbers of pellets and when the different types of outcomes never occurred in the same session. Experiment 2 also allowed us to look at superordinate classes made up of more components than ever before. In Experiment 2 each superordinate had the possibility of three component classes: two joined by association with a common number of pellets and a third joined to the first two by a delay of reinforcement that shared a common relative hedonic value.

In Experiment 3 we asked whether different numbers of food pellets could substitute on choice trials for the discriminative photographic stimuli that had been followed by these different quantities of reinforcement. Would a signal for a reinforcer and the reinforcer itself exert similar discriminative control over behavior?

Thus, the present trio of experiments allowed us to examine in more detail several questions concerning the foundations of learned equivalence. Specifically, we were interested in the possibility that some common feature of different types of outcomes—for instance, their hedonic value—might provide a basis for differential choice behavior. The results of Experiment 2 addressed this question, and our discussion of them considers the possibility that response rates might provide the cues that actually guide choice behavior. We were also interested in the possibility that a representation of the outcome itself might provide an effective cue for behavioral mediational basis; this question was addressed in Experiment 3.

Experiment 1

Early work on superordinate categorization with pigeons and young children (e.g., Wasserman & DeVolder, 1993; Wasserman et al., 1992) attempted to bind together photographs of objects from different human conceptual classes by association with a common response. In these experiments a procedure was used that was similar to that of Experiments 1 and 2 of Astley and Wasserman (1999), described above, except that in original training C1 and C2 were associated with one choice response (e.g., R1) and C3 and C4 were associated with another choice response (e.g., R2). In reassignment training, C1 was associated with a new response (R3), and C3 was associated with a different new response (R4). Testing sessions, then, examined generalization of these new responses to C2 and C4, which were withheld during reassignment training. If original training had bound together C1 and C2 stimuli into an aggregation like a human superordinate conceptual category, then individuals should perform R3 in the presence of C2 exemplars and R4 in the presence of C4 exemplars. Indeed, our pigeon and preschool participants performed these responses at above-chance levels; under optimal conditions, they did so nearly 80% of the time.

Astley and Wasserman (1998a) varied several parameters of training that might have improved performance and examined transfer to novel exemplars. We increased the amount of original training to form a stronger bond between classes (Experiment 2), and we increased the number of training exemplars from 12 to 24 to increase the possibility of stimulus generalization between familiar and novel exemplars (Experiment 3). These changes had some effect, but choice responding remained below 65% for both familiar and novel stimuli from the classes that were withheld from choice training (i.e., C2 and C4). The use of digitized images here rather than the 35-mm slides in the earlier work might explain this lower level of performance.

Far more successful were the manipulations performed in Astley and Wasserman's most recent series of experiments (Astley & Wasserman, 1999), described above. These experiments also used the digitized images of Astley and Wasserman (1998a). However, in both Experiment 1 (which examined different delays to reinforcement as potential binding events) and Experiment 2 (which examined different probabilities of reinforcement as potential binding events), the choices indicative of binding by a common outcome averaged at least 85%.

In the present Experiment 1 we varied another quantitative parameter of reinforcement, the number of food pellets, to see if it too would produce the strong binding together of different stimulus classes into a single superordinate category.

Method

Subjects

We studied 8 experimentally naive pigeons that were obtained from the wild. The birds spent several weeks prior to the experiment in the animal colony to acclimate them to human handling and to establish their free-feed weights. The pigeons were kept in individual cages on a 14-hr-10-hr light-dark schedule. During the experiment the pigeons were maintained at 85% of their free-feed weights. The birds were allowed unrestricted access to water and grit in their home cages.

Apparatus

Four custom-built plywood chambers were used in all of the experiments. The interior of each chamber was lined with brushed aluminum. An aluminum frame on one side of the chamber held a clear glass touch screen (Accutouch Model No. 002744-FTM-K1, Elographics, Oak Ridge, TN). A brushed aluminum panel was placed directly in front of the touch screen to allow the pigeons tactual access to defined areas ("buttons") of the touch screen and visual access to a video monitor that was located behind the touch screen. Centered 0.9 cm behind the touch screen was a 38-cm AppleColor High-Resolution RGB monitor. The aluminum panel in front of the touch screen contained five openings. A $7 \text{ cm} \times 7 \text{ cm}$ opening in the center of the panel was used to display photographic stimuli. The panel also contained four circular openings 1.9 cm in diameter, 2.3 cm from each corner of the center opening. The lower left and lower right corner openings were used as report buttons. When operative, each report button was lit with a different color: The lower left report button was green, and the lower right report button was blue. A serial controller board (Model No. 002210-K1, Elographics, Oak Ridge, TN) processed pecks to the touch screen

A Plexiglas food cup was centered on the back wall of the chamber. The food cup was placed level with the wire mesh floor to prevent perching. A pellet dispenser (Model No. ENV-203M, MED Associates, St. Albans, VT) delivered 45-mg Noyes pigeon pellets through a vinyl tube into the food cup. A houselight that was mounted above the food cup lit the chamber during experimental sessions. A digital input-output interface board (Model No. NB-DIO-24, National Instruments, Austin, TX) controlled the houselight and the pellet dispenser. Four Apple Macintosh 7100/66 Power PC computers controlled stimuli in the chambers and recorded responses. A distribution amplifier (Model No. MAC/2 DA2, Extron Electronics, Santa Fe Springs, CA) connected each computer to a monitor in the experimental chamber and to an identical monitor in an adjacent room. The programs were developed in Hypercard (Version 2.3).

Materials

The stimuli comprised 192 photographs of people, flowers, cars, and chairs (48 of each class of stimuli, 24 of which were reserved for testing).

The objects were photographed with a 35-mm SLR Pentax Superprogram camera; these pictures were used as the training and testing stimuli in Experiment 4 of Astley and Wasserman (1998a) and are described in greater detail in that article. The photographs consisted of a small number of the critical stimuli shown in various backgrounds; as much as possible these photographs controlled for object size, position, and brightness. The photographs were digitally transferred to a Kodak PhotoCD to be read by the Hypercard programs. The pictures were displayed as 384×256 PICT file images.

Procedure

A discrete-trial discrimination procedure was used for all phases of the experiment. In addition to the food pellet reinforcers that were given during experimental sessions, the pigeons were given mixed grain in their home cages as needed to maintain their target weights.

During *pretraining*, the pigeons were hand-shaped to peck the center display area and each of the four corner buttons when they were illuminated with solid color stimuli. Once they pecked at the stimuli, the pigeons were trained on increasing ratio schedules of reinforcement, starting at FR-1 and progressing to FR-30. In each block of eight trials, the pigeons were given one trial with each of the corner buttons and four trials with the center opening illuminated. In pretraining, the intertrial interval (ITI) was set randomly to 11, 12, or 13 s; during the ITI, the corner buttons and the center opening were dark, but the houselight remained lit.

Pellet training was designed to create associations between different pairs of stimulus classes and different quantities of food reinforcement. At the start of each trial, a photograph from one of the four stimulus classes was presented in the center display area. For purposes of explanation, the stimulus classes *people*, flowers, cars, and chairs will hereafter be designated as C1, C2, C3, and C4 (see next paragraph for a description of the counterbalancing procedure that we used). After completion of an FR-20 peck requirement to the photograph on the center display area, the pigeon received either one (C1 and C2) or five (C3 and C4) food pellets. An ITI immediately followed. During the ITI, all of the report keys were dark and the houselight remained lit. Half of the pigeons received an ITI set randomly on a trial-by-trial basis to 11, 12, or 13 s; because of a minor programming error, the other half of the pigeons received an ITI that was set randomly to 2, 3, 4, 5, 6, 7, 8, 9, 10, or 11 s. No reliable differences in performance eventuated from this small disparity in the ITIs.

The assignment of the classes of photographic stimuli to C1, C2, C3, and C4 was counterbalanced across pigeons such that for half of the birds the two natural classes of objects (e.g., people and flowers) were paired with the same outcome, and for the other half of the birds a natural class and a human-made class of objects (e.g., people and chairs) were paired with the same outcome. The number of food pellets that followed each of the paired classes was also counterbalanced, so that each pair of classes was followed by one pellet for half of the birds and by five pellets for the other half of the birds. Each daily session consisted of 96 trials, in which the pigeons viewed each of the 24 exemplars in each of the four stimulus classes once.

Choice training began after 24 days of pellet training. The pigeons were trained to peck one or the other of the two report keys in the presence of stimuli from C1 and C3. On completion of the FR-20 peck requirement to a photograph from C1 or C3, the lower right (green) and the lower left (blue) report buttons were illuminated. Responses to the report buttons are referred to as R1 and R2, respectively. For all birds, R1 was the correct response to C1 stimuli, and R2 was the correct response to C3 stimuli. Because of the way in which the classes of objects were assigned to the designations C1, C2, C3, and C4, half the birds were given choice training with "people" and "cars"; birds in this grouping were divided so that equal numbers were trained with R1 as the correct response for "people" and R2 as the correct response for "cars." The remaining birds were given choice training with "flowers" and "chairs";

birds in this grouping were divided so that equal numbers were trained with R1 as the correct response for "flowers" and R2 as the correct response for "chairs" as were trained with R2 as the correct response for "flowers" and R1 as the correct response for "chairs."

Correct choices resulted in one or five food pellets, selected at random for each trial; we used nondifferential quantities of food pellet reinforcement here to prevent the two report keys from becoming associated with different quantities of reinforcement. After each trial, the ITI was randomly set to 11, 12, or 13 s. If the bird chose the incorrect response, then the houselight was darkened for 2 s, and the bird had to complete a correction trial. The pigeon continued with correction trials until it made the correct choice. Correction trials were identical to choice trials, but they were not scored.

Choice training sessions consisted of two types of trials: pellet training trials and choice training trials. We included both types of trials in these sessions to ensure that all of the appropriate associations would remain active just prior to the testing stage. Pellet training trials were identical to those in the pellet training phase, and they were given in blocks of 12; blocks included 3 exemplars from each of the four classes (C1, C2, C3, and C4). Blocks of pellet training trials were followed by choice training trials, also given in blocks of 12; blocks included 6 exemplars from C1 and 6 exemplars from C3. Blocks of pellet training and choice training trials alternated four times, for a total of 96 trials in a session. Within each daily session, pellet training trials included only 12 of the 24 familiar exemplars from each category of stimuli; the same restricted set of exemplars was used on choice training trials with C1 and C3. Two different sets of 12 exemplars from each category alternated daily, so that the birds saw all 96 stimuli within a 2-day period. Each subject remained in choice training until it met the criterion of 90% correct or higher on the choice training trials in four consecutive sessions.

Testing began on the first session following attainment of the criterion for choice training. Testing sessions consisted of two types of trials: pellet training trials and choice trials. Choice trials in testing were identical to those in choice training, except that pigeons were presented with the familiar photographs and with 24 novel photographs from each of the four categories of stimuli. On the trials with familiar stimuli from C1 and C3, the birds were reinforced only for correct choices, and they were required to perform correction trials until the correct response was made. On trials with familiar stimuli from C2 and C4 and with novel stimuli from all four classes, the birds' choice responses were nondifferentially reinforced (i.e., choices of either R1 or R2 were reinforced), and no correction trials were given. For purposes of analysis, responses to familiar and novel exemplars from C2 were considered "correct" if the pigeon made the same response as that assigned to C1. Responses to familiar and novel exemplars from C4 were considered "correct" if the pigeon made the same response as that assigned to C3. Responses to the novel stimuli from C1 and C3 were considered "correct" if the pigeon made the response corresponding to the correct choice for the familiar stimuli from the same class. After each trial, the ITI was randomly set to 11, 12, or 13 s.

Pellet training trials were given in blocks of 12, with blocks structured as in the choice training phase. The choice trials were given in blocks of 22; blocks included 8 trials each of exemplars from C1 and C3 ($8 \times 2 = 16$), 1 trial each of exemplars from C2 and C4 ($1 \times 2 = 2$), and 1 trial each of novel exemplars from all four classes of stimuli ($1 \times 4 = 4$). Blocks of pellet training alternated with blocks of choice training three times, for a total of 102 trials in a session. During the 8 days of testing, the birds were tested once with each of the 24 familiar stimuli from C2 and C4, once with each of the 24 novel stimuli from the four classes of stimuli, and eight times with each of the 24 familiar stimuli from C1 and C3. Sessions of testing were alternated with sessions of pellet training to maintain the pigeons' discriminative performance.

All of the results were analyzed for statistical significance at p < .05. All follow-up analyses were planned comparisons.

Results

Peck Rate Data

The pigeons exhibited faster peck rates to the two classes of stimuli (C3 and C4) that were associated with five pellets of food reinforcement than to the two classes of stimuli (C1 and C2) that were associated with one pellet of food reinforcement, thus showing that they learned these stimulus-reinforcer associations. In Figure 1 are graphed the mean response rates for the two photographic classes that were associated with one pellet of food and the two photographic classes that were associated with five pellets of food over the twelve 2-day blocks of pellet training.

We analyzed these data using a 2 (one pellet vs. five pellets) \times 12 (blocks of training) repeated measures analysis of variance (ANOVA). We found a significant main effect of number of food pellets, F(1, 7) = 46.70; for stimuli associated with five pellets the mean response rate was 1.97 pecks per second, and for stimuli associated with one pellet the mean response rate was 1.57 pecks per second. There was also a significant main effect of blocks of training, F(11, 77) = 5.84, indicating that response rates changed over the twelve 2-day blocks of pellet training. The Number of Pellets × Blocks of Training interaction was also significant, F(11, 77) = 20.67. Additional analyses indicated that this interaction was due to a greater increase in peck rates over the 12 blocks of training for the stimuli associated with five pellets, $F(11, 77) = 13.60, \omega^2 = .58$, than for the stimuli associated with one pellet, F(11, 77) = 3.14, $\omega^2 = .19$. (Treatment magnitudes were estimated using the procedures recommended by Keppel, 1991, for within-subject designs.)

During choice training the birds continued to exhibit higher rates of responding to the stimuli that were associated with five pellets of food than to the stimuli that were associated with one pellet of food (see Figure 2). We analyzed the choice training data using a 2 (choice-trained vs. untrained categories) \times 2 (one pellet vs. five pellets) repeated measures ANOVA of the response rates on pellet trials from the last 4 days of choice training. We found a significant main effect of the number of pellets, F(1, 7) = 35.17;

Figure 1. Mean peck rates to stimuli associated with one pellet or with five pellets of reinforcement during 2-day blocks of pellet training in Experiment 1.





Figure 2. Peck rates to discriminative stimuli during choice training in Experiment 1.

for stimuli associated with five pellets the mean response rate was 1.81 pecks per second, and for stimuli associated with one pellet the mean response rate was 1.39 pecks per second. There was no significant main effect of choice training, F(1, 7) = 3.36. Although there appeared to be a greater response rate difference for the untrained stimuli (C2 and C4) than for the choice-trained stimuli (C1 and C3), the interaction between choice training and the number of pellets (one pellet vs. five pellets) was not significant, F(1, 7) = 5.14. This tendency for slightly reduced discrimination of the choice-trained stimuli was presumably produced by the equalization of reinforcement quantities to all of these stimuli (half of the time one pellet was delivered, and the other half of the time five pellets were delivered) on choice training trials; this effect was also observed in earlier work (Astley & Wasserman, 1999).

Choice Data

Figure 3 shows the mean accuracy of choices during the testing phase for the two classes that were given in choice training (C1 and C3) and for the two classes that were not given in choice training (C2 and C4). The novel stimuli (those that were first viewed in the testing phase) are shown separately from the familiar stimuli (those that were seen from the pellets training phase through the completion of the experiment); accuracy scores were averaged for the stimuli that were associated with the small and large quantity of reinforcement. The percentages presented in Figure 3 were all significantly above chance (50%) on the binomial test. For the classes of stimuli that were choice trained (C1 and C3), mean accuracy for familiar stimuli was 90.79% (z = 27.71, N = 3,072), and for novel stimuli it was 77.86% (z = 10.92, N = 384). For the classes of stimuli that did not receive choice training (C2 and C4), mean accuracy for familiar stimuli was 75.26% (z = 9.90, N = 384), and for novel stimuli it was 62.24% (z = 4.80, N = 384).

For the ANOVA, we transformed the percentage correct scores using the following logit function: (.5 $\ln p/100 - p$).

This transformation is suggested for use with percentage data to assure that the variances are equivalent across conditions (Cohen & Cohen, 1983). We analyzed the data with a 2 (choice trained vs. untrained) \times 2 (familiar vs. novel) repeated measures ANOVA. We found a significant main effect of choice training condition, F(1, 7) = 15.04, and novelty, F(1, 7) = 33.52. As Figure 3 shows, these effects are due to higher accuracy for choice-trained stimuli than for untrained stimuli and higher accuracy for familiar stimuli than for novel stimuli.

Furthermore, the interaction between type of training and novelty was significant, F(1, 7) = 6.05. Follow-up analyses suggested a somewhat stronger effect of choice training condition between the familiar stimuli, F(1, 7) = 21.77, $\omega^2 = .89$, than between the novel stimuli, F(1, 7) = 7.41, $\omega^2 = .78$.

Discussion

One of our goals in conducting this initial experiment was to see how strongly different classes of stimuli might be bound together by their association with the same number of food pellets. Some previous experiments bound different classes of stimuli together by association with a common response (e.g., Astley & Wasserman, 1998a) and obtained statistically significant but numerically weak evidence for the creation of superordinate categories by learned equivalence. In a more recent set of experiments, Astley and Wasserman (1999, Experiments 1 and 2) found very strong effects with two parameters of reinforcement: delay and probability. Thus, we wondered whether another parameter of reinforcement—quantity—might also produce strong binding effects.



Figure 3. Percentage correct choice on testing trials of Experiment 1.

Indeed, the binding effects that we observed here were numerically larger than in earlier experiments that used different responses as binding events (Astley & Wasserman, 1998a). As we described earlier, when different classes of stimuli were associated with a common response, choice responding generalized across conjoined classes at levels below 65%. In the present experiment, when classes of stimuli were associated with either one or five pellets, choice responding generalized at a level of 75% for familiar stimuli. This level is a bit lower, however, than the more than 85% that has been observed when different delays or probabilities of reinforcement were used as binding events (Astley & Wasserman, 1999, Experiments 1 and 2).

It is very likely that the slightly lower level of generalization that was seen here than in the studies with probability and delay of reinforcement are due to the particular numbers of pellets that we used. Astley and Wasserman (1999, Experiments 1 and 2) were able to choose two reinforcement values that they knew would be quite different from one another. The only constraint in those studies was that the less desirable outcome should not be so undesirable that the pigeons would fail to work for it. In the present experiment, however, we could not present fewer than one pellet, neither could we choose a maximum pellet value that was greater than 5. With five pellets as the larger reinforcement value we had to reduce the number of training trials per day to half the value of our earlier studies to prevent the birds from exceeding their target weights. So, we were forced to choose values-1 pellet versus five pellets-that we suspected might not be as different from one another as the 1- versus 15-s delays or the .1- versus .9-probability values used in earlier studies. Indeed, the results of the present experiment indicate that the 1- and 5-pellet values are not as distinctively different from one another as are the probability and delay values that we chose in our earlier experiments.

Nevertheless, this experiment very clearly showed that association with a common number of food pellets was sufficient to produce strong learned equivalence between different classes of photographic stimuli.

Experiment 2

Prior research in our laboratory has shown the transfer of discriminative responding across stimuli that were associated with different outcomes of similar hedonic value (Astley & Wasserman, 1999). In Experiment 2 we further examined the transfer of discriminative responding between different classes of stimuli that were associated with similar hedonic events by varying the timing of training with the different types of events. Experiment 3 of Astley and Wasserman's (1999) study associated each of the four classes of stimuli with a different outcome during each training session. In the present experiment, however, two stimulus classes were associated with different delays to reinforcement long after four other stimulus classes were associated with different quantities of reinforcement. We wanted to see whether the association of new classes of stimuli with outcomes of a similar hedonic value to those that had been used earlier would place those new classes of stimuli into already-established superordinate categories.

In Experiment 2 we used the same pigeons from Experiment 1 that had already shown stimulus equivalence via association with the same quantities of food reinforcement. These pigeons had also been tested in Experiment 3 (described next) to examine the

control of choice responding by different numbers of pellets. The results of Experiment 2 are described here, out of chronological order, to better focus on critical issues that are related to one another.

Experiment 2 began with training that paired two completely new classes of photographic stimuli (e.g., guns and minerals) with either a short (C5 = 1 s) or a long (C6 = 15 s) delay to food reinforcement. Testing sessions examined the transfer of choice responding from the C1 and C3 stimuli that were associated with different numbers of pellets in Experiment 1 to the new classes of stimuli (C5 and C6) that were associated with different delays to reinforcement. So, in addition to examining the transfer of control across stimulus classes when association with different outcomes takes place in different training sessions, the present experiment examined the potential for superordinate equivalence classes that are larger than those that had been established in earlier research (Astley & Wasserman, 1992; Astley & Wasserman, 1998a, 1998b; Wasserman & Astley, 1994; Wasserman & DeVolder, 1993; Wasserman et al., 1992). This earlier research has examined superordinate equivalence categories that each comprised two component classes; if differential choice responding generalizes within the relative hedonic values of the outcomes in the present experiment, then we will have documented superordinate equivalence categories that comprise three component classes.

Method

Subjects

The same 8 pigeons from Experiment 1 continued to serve in this experiment. The birds were housed and maintained as described in Experiment 1.

Materials

This experiment used only the set of 96 photographic representations of people, flowers, cars, and chairs from the pellets training phase of Experiment 1. In addition, we created 36 brand-new stimuli each from the classes of "guns" and "minerals." The stimuli in the "guns" class were images of rifles and handguns that were selected from advertisements in gun magazines; the stimuli in the "minerals" class were images of minerals that were selected from guides to the identification of rocks and minerals. The images were in color and were chosen to represent a wide range of different types of guns and minerals.

Special effort was made to ensure that the backgrounds of the gun and mineral images were like those of the people, flowers, cars, and chairs images in Experiment 1. For this purpose, the focal object was removed from 18 photographs each of people, flowers, cars, and chairs that were previously used in Astley and Wasserman's (1998a) study but were not used in this study. We used Adobe Photoshop 4.0 (1989) to remove the focal object from these photographs and to restore the empty area to resemble the surrounding portions of the photograph. Then we used Photoshop to superimpose the gun and the mineral images over equal numbers of backgrounds that had previously depicted people, flowers, cars, and chairs. The balancing of background type across the classes of guns and minerals was intended to maximize the similarity of backgrounds across these two classes. Furthermore, we wanted to minimize the possibility that pigeons would find either of the two new classes to be similar to any one of the original classes of people, flowers, cars, and chairs based on the type of background by equalizing background type across the new classes. Thus, although the backgrounds of the new classes are similar to those of the "old" classes, the pigeons should not have been differentially cued to make a particular choice response based on background cues alone.

Apparatus and Procedure

The apparatus was the same as that used in Experiment 1. Following the completion of Test 1 of Experiment 3 (described in the Experiment 3 section), each pigeon was returned to the pellet training procedure of Experiment 1 and remained on it until all of the pigeons in a 4-bird squad were responding at a high level of discriminative performance. The numbers of days that individual birds remained on the pellet training procedure ranged from 10 to 24.

The aim of new stimulus training was to associate 24 pictures from each of the categories "guns" and "minerals" with different delays to food reinforcement. At the start of each trial, a photograph of a gun or a mineral was presented in the center display area. After completion of an FR-20 peck requirement to the photograph on the center display area, the pigeon received either one or five pellets, randomly, after a delay of either 1 s (C5) or 15 s (C6). An ITI immediately followed. During the ITI, the report keys were dark, and the houselight remained lit. The ITI was randomly set to 11, 12, or 13 s. For half of the birds, pictures of guns were followed by reinforcement with a 1-s delay, and pictures of minerals were followed by reinforcement with a 15-s delay. For the other half of the birds, pictures of guns were followed by reinforcement with a 15-s delay, and pictures of minerals were followed by reinforcement with a 1-s delay. There were 196 trials in each new stimulus training session, so that each of the 24 exemplars of guns and minerals were presented 4 times daily. New stimulus training continued for 24 days.

Pigeons were then returned to the choice training procedure of Experiment 1 for 2 days before moving on to testing. Testing sessions consisted of two types of trials: new stimulus training trials and choice trials. The choice trials in testing were identical to those in choice training, except that the pigeons were also tested with photographs of guns and minerals. On the trials with stimuli from C1 and C3 the birds were reinforced only for correct choices, and they were required to complete correction trials until the correct response was made. On trials with stimuli from C2, C4, guns, and minerals, the birds were nondifferentially reinforced (i.e., reinforced for choices of either R1 or R2), and no correction trials were given. For purposes of analysis, choice responses to gun and mineral exemplars were labeled as "correct" as determined by the delay condition of the stimuli. On the basis of earlier research, we expected that the pigeons would make the same choice response to the stimulus class (guns or minerals) that was associated with the short delay as to the stimulus class that was associated with five pellets; thus, these responses were labeled as "correct" for purposes of analysis. By the same logic, we expected that the pigeons would make the same choice response to the stimulus class that was associated with the long delay to reinforcement as to the stimulus class that was associated with one pellet; thus, these responses were labeled "correct." After each trial, the ITI was randomly set to 11, 12, or 13 s.

Each session of testing began with a block of 12 new stimulus training trials. The testing trials were given in blocks of 12; blocks included 4 trials each of exemplars from C1 and C3 ($4 \times 2 = 8$), 1 trial each of exemplars from C2 and C4 ($1 \times 2 = 2$), and 1 trial each of exemplars of guns and minerals ($1 \times 2 = 2$). Blocks of new stimulus training trials alternated with blocks of test trials six times, for a total of 144 trials in a session. During the 4 days of testing, the birds were tested once with each of the stimuli from C2 and C4, once with each of 24 stimuli from the classes gun and mineral, and four times with each of the familiar stimuli from C1 and C3. Sessions of testing were alternated with sessions of pellet training to maintain discriminative performance.

Results

Peck Rate Data

The pigeons should have come to exhibit faster peck rates to the new stimulus class (C5) that was associated with a 1-s delay to food reinforcement than to the new stimulus class (C6) that was associated with a 15-s delay to food reinforcement if they learned these new stimulus-reinforcer associations. Figure 4 depicts mean response rates for the stimulus class that was associated with a 1-s delay to reinforcement and for the stimulus class that was associated with a 15-s delay of reinforcement over 2-day blocks of new stimulus training; it shows that clear discrimination learning did indeed take place. We analyzed these data using a 2 (1-s delay vs. 15-s delay) \times 12 (blocks of training) repeated measures ANOVA. We found no significant main effect of delay, F(1, 7) = 3.83, neither was there a significant main effect of blocks of training, F(11, 77) = 1.12. The Delay \times Block of Training interaction was, however, significant, F(11, 77) = 23.47. Additional analyses indicated that this interaction was due to a significant increase in peck rates over the 12 blocks of training for the stimuli that were associated with a 1-s delay to reinforcement, F(11, 77) = 3.77, and to a significant decrease in peck rates over the 12 blocks for the stimuli that were associated with a 15-s delay to reinforcement, F(11, 77) = 13.30.

The pigeons maintained their differential peck rates to the new stimuli during the testing sessions, and they maintained their differential peck rates to the choice-trained and the untrained classes from Experiment 1. Figure 5 shows the differential peck rates to the choice trained, untrained, and new classes of stimuli during test sessions. A 3 (stimulus class: choice trained vs. untrained vs. new) \times 2 (hedonic value: high vs. low) ANOVA conducted on the test peck rate data revealed a significant effect of stimulus class, F(2, 14) = 38.40; a significant effect of hedonic value, F(1, 7) = 126.01; and a significant Stimulus Class \times Hedonic Value interaction, F(2, 14) = 24.05. Pairwise analyses revealed that the interaction was primarily produced by greater discrimination based on hedonic value in the new stimulus classes



Figure 4. Mean peck rates to stimuli associated with a 1-s or a 15-s delay to reinforcement during 2-day blocks of new stimulus training in Experiment 2.



Figure 5. Peck rates to discriminative stimuli during testing in Experiment 2.

than in the choice-trained or the untrained classes. Consistent with our earlier speculations, 1-s and 15-s delays to reinforcement appear to be more hedonically different than are one and five pellets of food. As well, the discrimination was greater for the untrained than for the choice-trained stimulus classes that were associated with different numbers of food pellets. Specifically, the pairwise ANOVAs revealed an effect of hedonic value in the choice-trained classes, F(1, 7) = 18.35, $\omega^2 = .19$; in the untrained classes, F(1, 7) = 34.80, $\omega^2 = .35$; and in the new classes, F(1, 7) = 34.80, $\omega^2 = .35$; and in the new classes, F(1, 7) = 34.80, $\omega^2 = .35$; and in the new classes, F(1, 7) = 34.80, $\omega^2 = .35$; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and in the new classes, F(1, 7) = .35; and F(1, 7) = .35; 7) = 143.17, ω^2 = .72. The ω^2 scores in the preceding analysis suggest that association with different delays accounts for a greater proportion of the variance in peck rates than does association with different numbers of pellets, in both the choice-trained and the untrained classes. Furthermore, a greater proportion of the variance in the peck rate scores was associated with the untrained classes than with the choice-trained classes.

Choice Data

Figure 6 shows mean choice accuracy in the 4 days of testing for the choice-trained, untrained, and new stimulus classes; as before, accuracy scores were averaged for the stimuli that were associated with the large and small quantities of reinforcement for the choicetrained and untrained classes and for the short and long delays to reinforcement for the new classes. The percentages that are illustrated in Figure 6 were ordered choice trained > untrained > new; all of these percentages were significantly above chance by the binomial test. For the classes that were choice trained, mean accuracy was 90.36% (z = 31.64, N = 1,536); for the classes that did not receive choice training, mean accuracy was 79.17% (z = 11.41, N = 384); and for the new classes, mean accuracy was 72.92% (z = 8.98, N = 384).

We analyzed the logit-transformed choice percentage data in testing with a 3 (stimulus class: choice trained, untrained, or new) \times 4 (day of testing) repeated measures ANOVA. We found

a significant main effect of stimulus class, F(2, 14) = 4.84; but no effect of days of testing, F(3, 21) < 1; and no interaction between stimulus class and day of testing, F(6, 42) = 1.52. Pairwise comparisons revealed a significant effect of stimulus class in the logit-transformed choice percentages to the choice-trained stimuli and the untrained stimuli, F(1, 7) = 21.92. There was no significant effect of stimulus class in the pairwise comparisons between the choice-trained stimuli and the new stimuli, F(1, 7) = 4.07, p > .05, or between the untrained and the new stimuli, F(1, 7) < 1. These seemingly inconsistent results, which show larger effects in comparisons with smaller mean differences, are presumably due to the lower levels of error variance in responding to the trained and untrained stimuli than in responding to the new stimuli. There was no significant effect of day of testing or any significant interaction in these follow-up analyses.

Discussion

Earlier work (Astley & Wasserman, 1999, Experiment 3) demonstrated that association with different outcomes could bind together two disparate classes of stimuli into a single superordinate category, provided that the outcomes shared a common hedonic value. Experiment 2 added three new elements to our understanding of this effect.

First, we found that categories that were associated with different delays to food reinforcement could be mapped onto categories that were associated with different quantities of food reinforcement. Astley and Wasserman's (1999) Experiment 3 used outcomes that differed in delay and probability of food reinforcement.

Second, Experiment 2 found that association with different outcomes of a common hedonic value need not occur within the same training session. In fact, binding by outcomes of a common hedonic value can occur even when training with the different types of outcomes is done sequentially in separate phases of



Figure 6. Percentage correct choice on testing trials of Experiment 2.

discrimination training. In Experiment 2, classes of stimuli were first associated with different quantities of food reinforcement. Then, after additional training and testing (which are described in Experiment 3), training was conducted in which two additional classes of stimuli were associated with different delays to food reinforcement. The two new classes that were associated with different delays to reinforcement engendered choice responding that was similar in pattern to that engendered by the classes of stimuli that were associated with different quantities of reinforcement.

Third, Experiment 2 found larger superordinate categories than had been found in any of our previous work. Astley and Wasserman's (1999) Experiment 3, for example, found learned equivalence for two classes of stimuli: one that was associated with a particular delay to reinforcement and another that was associated with a particular probability of reinforcement. Experiment 2 documented learned equivalence among three classes of stimuli: two that were associated with a particular quantity of reinforcement and one that was associated with a particular delay to reinforcement.

The use of different numbers of pellets as binding events for C1, C2, C3, and C4 allowed us to further examine one mechanism (mediation by a representation of a common outcome) that might have producing learned equivalence in Experiment 1. If a representation of different numbers of pellets is the mediator that binds together different classes of stimuli, then we should be able to substitute the actual presentation of one or five food pellets on choice trials for the arbitrary stimuli with which these outcomes are associated. Specifically, this model leads us to predict that if C1 and C2 were both followed by one pellet of food, and if the choice response of R1 were reinforced after the presentations of C1 stimuli, then pigeons should produce R1 when given one pellet of food as a discriminative stimulus on choice testing trials. We explored this possibility in Experiment 3.

Experiment 3

How might one account for the learned stimulus equivalence that is produced via association with a common response, a common delay, a common probability, or a common quantity of reinforcement? In several articles, Astley and Wasserman (1998a, 1999; Wasserman & Astley, 1994) have offered an explanation of superordinate categorization that is based on secondary or mediated generalization; Urcuioli and his colleagues (Urcuioli, 1996; Urcuioli et al., 1995) have applied this account to related results that have been obtained in matching-to-sample procedures. This mediational account follows directly from Hull's (1943) behavior theory and from Trapold and Overmier's (1972) elaboration of the role of stimulus associations in learning. (Other discussions of this approach have been published over the years by Osgood, 1953; Underwood, 1966; and Kendler & Kendler, 1975.)

Figure 7 depicts the mediational associative processes that might explain differential choice responding to the C2 and C4 stimuli in Astley and Wasserman's (1999) experiments and in Experiments 1 and 2 of the present article. For ease of explanation, we discuss here only the C1 and C2 contingencies; Figure 7 depicts the contingencies for four classes of stimuli.

The model depicted in Figure 7 hypothesizes that the first phase of training forges an association of the C1 and C2 stimuli with a



Figure 7. A model of the mediational processes that might account for superordinate categorization by functional equivalence training with different outcomes. C = class; O = outcome; R = response; Reinf. = reinforcement; S = stimulus.

particular outcome, symbolized as O1 in Figure 7. The stimulusoutcome associations presumably bestow the photographic stimuli that are drawn from C1 and C2 with the ability to elicit outcome representations (so1) that are related to the reinforcement conditions that prevail during the first phase of training. When R1 is conditioned to the C1 stimuli, then R1 is also conditioned to the s₀₁ cues that are elicited by the C1 stimuli. Testing trials with the C1 stimuli are exactly like those in choice training; both the C1 stimuli and the sol cues are available to guide the choice of R1. Testing trials with the C2 stimuli are critical, because the C2 stimuli have never before been presented while the choice responses were available; without invoking additional associative mechanisms, these stimuli should produce no differential tendency to make either R1 or R2. According to this mediational analysis, however, the C2 stimuli will evoke the so1 cues, and these cues (but not C2) should guide the pigeons' choice of R1. This account of differential choice responding to the C2 stimuli predicts that responding to the C2 stimuli should be less discriminative than to the C1 stimuli; responding to the C1 stimuli is guided by the same cues as in choice training $(C1 + s_{O1})$, whereas responding to the C2 stimuli is guided by somewhat different cues from those in training (C2 [instead of C1] + s_{O1}). A drop in choice accuracy between the choice-trained C1 and C3 stimuli and the untrained C2 and C4 stimuli has in fact been observed in most of our experiments on learned stimulus equivalence (Astley & Wasserman, 1998a, 1998b, 1999; Wasserman & Astley, 1994; Wasserman &

DeVolder, 1993; Wasserman et al., 1992), and it again occurred in Experiments 1 and 2 of the present project (see Figure 3 and Figure 6).

This model posits that a distinctive set of mediating cues (s_{O1}) produces discriminative choice responding to the C2 stimuli. The representations that provide these mediating cues might be similar to the differential outcomes themselves (see Hall, 1996, for elaboration of this argument). If so, then the outcomes themselves might successfully substitute as discriminative stimuli for the photographic stimuli on choice trials. Specifically, if the C1 stimuli are associated with one pellet of food, and if R1 is reinforced in the presence of the C1 stimuli, then one pellet of food given as a discriminative stimulus on choice trials might produce R1. This was the logic that inspired Experiment 3.

We conducted a first test of control by the pellets immediately after Experiment 1. We conducted second test of control by the pellets stimuli after Experiment 2 to see whether additional experience with the pellets as discriminative stimuli might change the results.

Method

Participants

The same 8 pigeons from Experiments 1 and 2 served in this experiment. The birds were housed and maintained as in Experiments 1 and 2.

Apparatus and Procedure

The apparatus was the same as that used in Experiments 1 and 2. In this experiment we used only the set of 96 photographs of people, flowers, cars, and chairs from the pellets training phase of Experiment 1; the "novel" stimuli from those categories were not used.

After the last day of testing in Experiment 1, each pigeon was returned to the pellet training procedure from Experiment 1 for 5 days, and it was then returned to the choice training procedure from Experiment 1 for 2 days. Each pigeon then completed 1 day of red screen training (described below), 2 more days of choice training, and 4 days of Test 1 (also described below).

After the last day of testing in Experiment 2, pigeons were again returned to the pellet training procedure of Experiment 1 for five sessions and to the choice training procedure of Experiment 1 for two sessions. Test 2 sessions were identical to those of Test 1. A total of four Test 2 sessions were administered.

Red screen training. This phase of training was devised to give the pigeons a discriminative cue that signaled the availability of food pellets and that could be used later on choice trials involving different numbers of pellets as the discriminative stimuli. The single session of red screen training consisted of 24 trials with the ITI set randomly to 11, 12, or 13 s. On each trial, the screen on the front panel of the chamber was illuminated with a red light until an FR-5 requirement to the screen was completed. On the last peck of the FR requirement, the screen darkened, and one pellet was presented on half of the trials, and five pellets were presented on the other half of the trials. Trials were arranged in blocks of 6; each block included 3 trials with one pellet of reinforcement and 3 trials with five pellets of reinforcement, randomly determined.

Tests 1 and 2. As described earlier, Test 1 followed the second exposure to choice training after Experiment 1, and Test 2 followed exposure to choice training after Experiment 2. Test sessions consisted of two types of trials: pellet training trials and choice trials. Choice trials in test sessions were identical to those in Experiment 1, except that there were also interspersed trials in which the center display screen was red and either one or five food pellets served as the discriminative stimulus. Choice trials with

different numbers of pellets as the discriminative stimuli began with the display screen illuminated with a red light. After five pecks to the red screen, either one or five pellets was delivered as a discriminative stimulus and, 0.5 s later, the lower left and lower right response keys were made available.¹ On the trials with C1 and C3 as the discriminative stimuli, the birds were reinforced only for correct choices; correction trials were given until the birds made correct choices. On trials with C2 or C4 as the discriminative stimuli or with one pellet or five pellets as the discriminative stimuli, the birds' choice responses were nondifferentially reinforced (i.e., they were reinforced for choices of either R1 or R2), and no correction trials were given. Although these choice responses were nondifferentially reinforced, R1 was labeled as "correct" for the 1-pellet stimulus, and R2 was labeled as "correct" for the 5-pellet stimulus; the responses that were labeled as correct for the pellet stimuli were those that were expected from the notion that outcome representations formed the effective mediator in Experiment 1. After each trial, the ITI was randomly set to 11, 12, or 13 s.

Test sessions consisted of alternating blocks of pellet training and choice trials. Each block of 8 randomly ordered pellet training trials contained 2 trials with stimuli randomly selected from each of C1, C2, C3, and C4. The choice trials were given in blocks of 24; blocks included 8 trials each with photographs from C1 and C3 ($8 \times 2 = 16$), 2 trials each with photographs from C2 and C4 ($2 \times 2 = 4$), and 2 trials each with one or five food pellets ($2 \times 2 = 4$). Blocks of pellet training alternated with blocks of choice training three times, for a total of 104 trials in a session. During the 4 days of each test the birds were tested 8 times with each of the stimuli from C1 and C3, 2 times with each of the stimuli from C2 and C4, 24 times with one pellet, and 24 times with five pellets. Sessions of test were alternated with sessions of pellet training to maintain discriminative performance.

The experimenters observed at least two Test 1 trials and found that each pigeon reliably ate the pellets that preceded the choice opportunity.

Results

Peck Rate Data Prior to Test 1

We first wanted to see whether the birds had maintained differential peck rates to the photographic stimuli that were associated with one or five pellets of food. Analysis of peck rates during the 5 days of retraining on the pellet training procedure showed that the birds did, indeed, maintain higher peck rates to the photographic stimuli that were associated with five pellets than to the photographic stimuli that were associated with one pellet. The mean peck rate on pellet training trials to the choice-trained classes was 1.41 pecks per second to the 1-pellet stimuli and 1.86 pecks per second to the 5-pellet stimuli; the mean peck rates to the untrained classes were 1.10 and 1.86 pecks per second, respectively, to the 1- and 5-pellet stimuli. We analyzed the response rates using a 2 (1 pellet vs. 5 pellets) \times 2 (choice trained vs. untrained classes) repeated measures ANOVA. We found a significant main effect of number of pellets, F(1, 7) = 21.44; a significant main effect of choice training, F(1, 7) = 43.93; and a significant interaction between the number of pellets and the choice training condition, F(1, 7) = 38.82. There was a somewhat smaller effect of the number of pellets between the classes that were given choice training (C1 and C3), F(1, 7) = 12.18, $\omega^2 = .4$, than between the classes that were not given choice training (C2

 $^{^{1}}$ The 0.5-s interval between the last peck to the red screen and the lighting of the keys was intended to partially accommodate for the time that was taken for the birds to turn back toward the feeder to eat the pellets and then turn again toward the front panel and be able to peck the choice keys.

and C4), F(1, 7) = 30.98, $\omega^2 = .65$; nevertheless, each of these reinforcement quantity discriminations was statistically significant.

The pigeons continued to exhibit different rates of responding to the stimuli that were associated with one pellet and five pellets of food during the subsequent phase of choice training. For the choice-trained classes the mean peck rate was 1.38 pecks per second to the 1-pellet stimuli and 1.83 pecks per second to the 5-pellet stimuli; for the untrained stimuli these rates were 1.18 and 1.89 pecks per second, respectively, for the 1- and 5-pellet stimuli. We analyzed choice training using a 2 (1 pellet vs. 5 pellets) \times 2 (choice-trained vs. untrained classes) repeated measures ANOVA on the response rates on pellet trials. We found a significant main effect of the number of pellets, F(1, 7) = 18.91; a significant main effect of choice training, F(1, 7) = 17.76; and a significant interaction between choice training and the number of pellets, F(1, 7) = 9.53. Once again there was a somewhat smaller effect of the number of pellets between the classes that were given choice training (C1 and C3), F(1, 7) = 14.91, $\omega^2 = .46$, than between the classes that were not given choice training, (C2 and C4), F(1, 7) = 19.82, $\omega^2 = .54$; nevertheless, each of these reinforcement quantity discriminations was statistically significant. The mean peck rates during choice training prior to Test 1 in Experiment 3 are shown in Figure 8.

Test 1 Choice Data

The leftmost panel of Figure 9 shows the mean accuracy of the pigeons' choices that were made during the testing phase for the two photographic classes that were given choice training (C1 and C3), the two photographic classes that were not given choice training (C2 and C4), and the pellets-only testing trials; as before, the accuracy scores were averaged for the stimuli that were asso-



Figure 8. Peck rates to discriminative stimuli during choice training prior to Test 1 in Experiment 3.



Figure 9. Percentage correct choice on Test 1 and Test 2 of Experiment 3.

ciated with the small and large quantities of reinforcement. Figure 9 shows that the choice percentages were high to both the choice-trained and the untrained photographic stimuli, but they were near chance to the pellets stimuli. The choice percentages for the choice-trained and untrained stimuli were significantly above chance (z = 32.91, N = 1,536; and z = 12.54, N = 384, respectively), but the choice percentage to the pellets stimuli was not (z = 1.18, N = 384).

An ANOVA on the choice percentages provides further evidence that the pellets stimuli did not exert discriminative control over choice responding. We analyzed the logit-transformed choice percentage data with a 3 (stimulus type: choice-trained pictures vs. untrained pictures vs. pellets only) \times 4 (days of testing) repeated measures ANOVA. We found a significant main effect of stimulus type, F(2, 14) = 23.73; but no main effect of days of testing, F(3, 14) = 23.73; but no main effect of days of testing, F(3, 14) = 10021) = 2.85; and no interaction between discriminative stimulus and day of testing, F(6, 42) < 1. There was a significant effect of stimulus type in the pairwise comparisons between the choicetrained stimuli and the pellets stimuli, F(1, 7) = 37.58; and between the untrained stimuli and the pellets stimuli, F(1,7) = 42.84; but there was no significant effect of stimulus type in the pairwise comparison between the choice-trained and the untrained stimuli, F(1, 7) = 3.41. There was no significant effect of day of testing or any significant interactions in any of these follow-up analyses.

Peck Rate Data Prior to Test 2

The birds continued to maintain higher peck rates to the photographic stimuli that were associated with five pellets than to the photographic stimuli that were associated with one pellet in the pellet training before Test 2. The mean peck rate on pellet training trials to the choice-trained classes was 1.58 pecks per second to the 1-pellet stimuli and 2.16 pecks per second to the 5-pellet stimuli; the mean peck rates to the untrained classes were 1.30 and 2.09 pecks per second, respectively, to the 1- and 5-pellet stimuli. We analyzed the response rates using a 2 (one pellet vs. five pellets) \times 2 (choice trained vs. untrained classes) repeated measures ANOVA. We found a significant main effect of number of pellets, F(1, 7) = 66.95; a significant main effect of choice training, F(1, 7) = 9.54; and a significant interaction between the number of pellets and the choice training condition, F(1, 7) = 9.53. There was a somewhat smaller effect of the number of pellets between the classes that were given choice training (C1 and C3), F(1, 7) = 43.84, $\omega^2 = .72$, than between the classes that were not given choice training (C2 and C4), F(1, 7) = 70.86, $\omega^2 = .82$; nevertheless, each of these reinforcement quantity discriminations was statistically significant.

The pigeons continued to exhibit different rates of responding to the stimuli that were associated with one pellet and five pellets of food during the subsequent phase of choice training. For the choice-trained classes the mean peck rate was 1.66 pecks per second to the 1-pellet stimuli and 2.08 pecks per second to the 5-pellet stimuli; for the untrained stimuli these rates were 1.35 and 2.13 pecks per second, respectively, for the 1- and 5-pellet stimuli. We analyzed choice training using a 2 (one pellet vs. five pellets) \times 2 (choice-trained vs. untrained classes) repeated measures ANOVA on the response rates on pellet trials. We found a significant main effect of the number of pellets, F(1, 7) = 181.83; a significant main effect of choice training, F(1, 7) = 23.28; and a significant interaction between choice training and the number of pellets, F(1, 7) = 15.47. There was a smaller effect of the number of pellets between the classes that were given choice training (C1 and C3), F(1, 7) = 32.58, $\omega^2 = .60$, than between the classes that were not given choice training (C2 and C4), F(1, 7) = 252.17, ω^2 = .77; nevertheless, each of these reinforcement quantity discriminations was statistically significant.

Test 2 Choice Data

Again, the choice percentages were high to both the choicetrained and the untrained photographic stimuli, but they were near chance to the pellets stimuli. The rightmost panel of Figure 9 shows the choice percentages on Test 2. The choice percentages for the choice-trained and untrained stimuli were significantly above chance (z = 35.0, N = 1,536; and z = 14.08, N = 384, respectively), but the choice percentage to the pellets stimuli was not (z = 1.02, N = 384).

An ANOVA on the choice percentages provides further evidence that the pellets stimuli did not exert discriminative control over choice responding in Test 2. We analyzed the logittransformed choice percentage data with a 2 (stimulus type: choice-trained pictures vs. untrained pictures vs. pellets only) $\times 4$ (day of testing) repeated measures ANOVA. We found a significant main effect of stimulus type, F(2, 14) = 17.76; but no main effect of day of testing, F(3, 21) < 1; and no interaction between discriminative stimulus and day of testing, F(6, 42) < 1. There was a significant effect of stimulus type in the pairwise comparisons between the choice-trained stimuli and the pellets stimuli, F(1,7) = 97.07; and between the untrained stimuli and the pellets stimuli, F(1, 7) = 8.95; but there was no significant effect of stimulus type in the pairwise comparison between the choicetrained and the untrained stimuli, F(1, 7) = 4.29. There was no significant effect of day of testing or any significant interactions in any of these follow-up analyses.

Choice accuracy to the choice-trained (M = 94.67) and to the untrained (M = 85.98) photographs remained high in Test 2, whereas choice accuracy to the pellet stimuli (M = 47.40) was again very near chance.

Discussion

The pigeons in Experiment 3 showed no tendency to generalize their discriminative choice responding from the photographic stimuli that were associated with different numbers of pellets to those numbers of pellets themselves. This finding contrasts with the results of reports by Steirn, Jackson-Smith, and Zentall (1991); Urcuioli and DeMarse (1997, Experiment 2); Zentall, Sherburne, and Steirn (1992); and Zentall, Sherburne, and Urcuioli (1995, Experiment 2). The Steirn et al. (1991), Zentall et al. (1992), and Zentall et al. (1995) studies all found a significant degree of interchangeability between food-no-food events and other stimuli that served as signals for those events as samples in MTO discriminations. The effects, however, were numerically small. In the case of Zentall et al. (1995), evidence of interchangeability emerged only when the speed of learning the original MTO discrimination was taken into consideration. Zentall et al. (1995) interpreted these data as evidence that the fast learners were more likely to code hue stimuli as food or no food; for these pigeons, the hues substituted for the food or no-food outcomes.²

Less equivocal were the matching-to-sample tests in Experiment 2 of Urcuioli and DeMarse (1997), who obtained clear evidence that food-no-food events could substitute as samples for the stimuli that signaled them. These researchers tested a bidirectional account of response transfer across stimuli that share similar outcomes. In earlier training for some of the pigeons, food and no-food outcomes were differentially associated with four different comparison stimuli (but the outcomes were not differentially associated with the two samples). For other pigeons, the comparison stimuli had no differential association with the outcomes. Food and no-food events were then substituted for the samples in test sessions. Urcuioli and DeMarse (1997) found no differential choice tendencies on the first test session. A second test limited the number of correction trials to minimize inadvertent reinforcement of incorrect choices by repetition of pellet sample trials. For pigeons given initial training with differential outcomes, Urcuioli and DeMarse (1997) found that food could effectively substitute as the sample for food-associated comparisons and that no food could effectively substitute as the sample for no-food-associated comparisons.

² To examine whether the speed of learning might have affected the results of Experiment 3, we divided the 8 pigeons into two groups on the basis of the speed of their acquisition of discriminative responding during the pellet training phase of Experiment 1. We calculated a ratio of the response rate to the stimuli that were associated with five pellets divided by the response rate to the 5-pellet stimuli plus the response rate to the 1-pellet stimuli. We counted the number of days of training until the pigeons exceeded a .55 ratio for two sessions and then classified as "fast learners" the 4 birds that took the fewest days to reach the criterion and as "slow learners" the 4 birds that took the most days to reach the criterion. We then conducted a *t* test comparing choice accuracy to the pellet stimuli in the slow and fast learners. This analysis found no difference in choice accuracy to the pellet stimuli for the slow (M = .46) and the fast learners (M = .48), t(6) = 0.43.

Why did we not observe any tendency in either of our tests for different quantities of food to substitute for the photographic stimuli? One possibility is that performance may have suffered because of the novelty of the appearance of food for the first time as a discriminative stimulus on choice trials. In all of the prior successful experiments, the substituted events had previously served as samples for other comparison stimuli; in our Experiment 3, the different numbers of pellets had never before served as a discriminative stimulus on choice trials.

One way to determine whether novelty affected choice responding is to compare choice latencies to the pellet discriminative stimuli and to the photographic discriminative stimuli. If differential choice response tendencies were low because of novelty when pellets first appeared as discriminative stimuli on choice trials, then response latencies should have been relatively long on these trials. Choice latencies were calculated as the time elapsing between the illumination of the choice keys and the choice response. (Recall that on pellets-only test trials the choice keys were illuminated 0.5 s after the FR requirement was met to the red screen stimulus. This was intended to compensate for the time necessary to collect and consume the pellets.) The mean latencies to choice were shortest after the choice-trained photographic stimuli (M = 1.75 s), slightly longer after the untrained photographic stimuli (M = 2.12 s), and longest after the pellets stimuli (M = 2.63 s). We analyzed choice latencies in a 3 (stimulus type: choice trained vs. untrained vs. pellets) \times 4 (day of testing) ANOVA that revealed a significant effect of stimulus type, F(2,14) = 12.50; but no significant effect of day of testing, F(1, 7) <1; and no Stimulus Type \times Day of Testing interaction, F(2,14) = 1.44. There was no significant effect of stimulus type in pairwise comparisons between the latencies to the choice-trained and the untrained photographic stimuli, F(1, 7) = 1.03. There was, however, a significant effect of stimulus type in the pairwise comparison between the choice-trained and the pellets stimuli, F(1, 7) = 26.55, and in the pairwise comparison between the untrained and the pellets stimuli, F(1, 7) = 12.49. There was no significant effect of day of testing or any interaction in these pairwise comparisons.

The 0.5-s delay before choice keys were available on pelletsonly test trials was designed to accommodate the additional time necessary for the pigeons to collect the pellets. Recall that the pellet dispenser was on the back wall of the experimental chamber. However, our informal observations of the birds indicate that, on most trials, it took substantially longer than 0.5 s for the birds to turn away from the front panel of the chamber after meeting the FR-20 requirement to collect the pellets, consume them, and turn back toward the choice keys. So, the time taken to collect and consume the pellets may still have contributed to the longer latencies to choice on the pellets-only test trials.

To more thoroughly examine the temporal patterns of responding we calculated the percentage of choice latencies in 1-s intervals to the pellet stimuli in Experiment 3 and to the untrained photographic stimuli in Experiments 1 and 3 (see Table 1). We included the latencies from Experiment 1 to see if prior use as discriminative stimuli might have shortened latencies to the untrained photographic stimuli in Experiment 3. There was a similar distribution of choice latencies to the untrained photographic stimuli in Experiments 1 and 3; in fact, the mean choice latency was actually slightly shorter in Experiment 1 (M = 2.02). Although there was

Table 1

Percentages of Choice Latencies in 1-s Intervals to the Pelle
Stimuli in Experiment 3 and to the Untrained Stimuli in
Experiments 1 and 3

Interval in seconds	Pellet stimuli, Experiment 3	Untrained stimuli, Experiment 3	Untrained stimuli, Experiment 1
Latency ≤ 1	3	13	13
$1 > Latency \le 2$	50	62	60
$2 > Latency \le 3$	23	11	14
$3 > Latency \le 4$	9	3	4
$4 > Latency \le 5$	7	3	3
Latency > 5	8	8	6

a large difference between the distributions of latencies to the untrained photographs and to the pellet stimuli, the most striking differences fell within the first three intervals; there was no difference in the last interval (>5 s). So, the average latency difference between the pellets and the untrained photographic stimuli is not due to a substantial proportion of long latencies to the former. The major difference between the pellet and untrained photographic stimuli is largely in latency intervals that differ by 1 or 2 seconds from one another.

We see little evidence that the novelty of pellets as sample stimuli led to increased latencies of choice responding. Test 2 provides further evidence that the lack of differential choice responding is not due to the novelty of the pellet stimuli as samples. Pellets had already been used as discriminative stimuli in Test 1 prior to Test 2. Nevertheless, the pellet stimuli were still not effective in promoting differential choice behavior in Test 2.

Clearly, our results were different from those of Urcuioli and DeMarse (1997, Experiment 2). Why? It may be that prior exposure to pellets as discriminative stimuli that are effective in producing differential choice behavior (with comparison stimuli different than those that were used in this test) is necessary to bring about the desired result. However, prior service as effective discriminative stimuli was not necessary for our untrained photographic stimuli. The untrained photographic stimuli had, like the pellets, never before served as effective discriminative stimuli on choice trials. Nevertheless, the untrained photographs occasioned very high levels of differential choice behavior throughout Experiments 1-3, despite the nondifferential schedule of reinforcement that was in place for all choice trials with these stimuli. Of course, other photographic stimuli (i.e., those in the choice-trained classes) had effectively served as discriminative stimuli that guided the pigeons' choice behavior, but no stimuli remotely like the pellets had ever served as discriminative stimuli. Thus, the pellets might have been so unusual as discriminative stimuli that no choice response tendencies were dominant following them; however, the overall choice latencies in Test 1 were not sufficiently long to corroborate this suggestion.

One might argue that Experiment 3 was not a strong test of control by pellets themselves for other reasons. In choice training, our pigeons learned to make choice responses based on what they saw on the center display screen. In Tests 1 and 2 of Experiment 3, however, the center display was red on both 1-pellet and 5-pellet sample trials. It is possible that attention to the stimulus on the center display screen might have masked control by the number of pellets. It is also possible that the delay between receiving the pellet sample at the rear of the chamber and making the choice response on the front of the chamber might have weakened control by the number of pellets. These possibilities cannot be ruled out. The complete absence of control by the number of pellets, however, indicates that, if these factors were present, then they must have been sufficiently strong to overcome all control by pellets that would otherwise have been observed.

We should finally mention that the results of Experiment 3 might also be considered a failure to demonstrate symmetry and transitivity. In pellets training, the C1 and C2 stimuli were followed by a particular outcome (e.g., one pellet). In choice training a particular response (e.g., R1) was reinforced in the presence of the C1 stimuli. If presenting one pellet as a sample on choice trials had differentially evoked the R1 response, then our pigeons should have demonstrated both symmetry and transitivity; after learning C1 \rightarrow 1 pellet and C1 \rightarrow R1, our birds should have demonstrated a 1 pellet \rightarrow C1 \rightarrow R1 connection. That our birds did not do so is a failure of symmetry and transitivity.

General Discussion

Functional Equivalence Via a Common Hedonic Value

The trio of experiments that we have reported in this article add further evidence that learned stimulus equivalence can be a very robust means of creating superordinate categories from different basic-level classes of stimuli. We learned in Experiment 1 that quantity is yet another parameter of reinforcement that produces strong binding of component classes. Here, the binding effects were slightly smaller than those that were produced by reinforcement delay or probability (Astley & Wasserman, 1999). If we had used a greater disparity between the numbers of pellets (e.g., 1 vs. 10), then we would probably have increased the absolute size of the binding effect that we obtained. However, because of motivational effects, increasing the number of pellets to the more preferred schedule would have meant further reducing the number of training trials per day; that reduction might produce other, undesirable side effects.

We also learned more about how the association with different reinforcement outcomes can nevertheless forge stimuli from different component classes into a single superordinate category—so long as the different outcomes share a common hedonic or reinforcement value. Experiment 2 showed that: (a) stimuli that are associated with different delays to reinforcement can bind with stimuli that are associated with different quantities of reinforcement; (b) the association of discriminative stimuli with different outcomes need not occur in the same session, but can be done sequentially in different training phases; and (c) this sequential grouping process can produce superordinate categories that contain as many as three component classes.

Mediation by Differential Peck Rates

In earlier work (Astley & Wasserman, 1999), we bound together different classes of stimuli by association with a common delay (Experiment 1) or probability (Experiment 2) of reinforcement or by a combination of probability and delay of reinforcement with a common hedonic value (Experiment 3). Those manipulations produced differential peck rates to the different classes of stimuli, as did association with different quantities of reinforcement in the work reported here. This fact raises the possibility that differential peck rates to the classes of stimuli might, in fact, be the effective mediator that produces functional equivalence between C1 and C2 and between C3 and C4.

There is clear evidence that differential peck rates can guide choice responding (e.g., Urcuioli & Honig, 1980). For instance, Urcuioli and DeMarse (1994) demonstrated transfer of symbolic matching-to-sample behavior based on whether pigeons frequently or infrequently pecked the sample stimuli in a differential outcome paradigm. Zentall and Sherburne (1994), however, independently varied both sample responding and outcome differentiation in a delayed matching-to-sample task. They found that differential sample responding enhanced accuracy of responding when outcomes were nondifferential, but it had no effect on choice behaviors when outcomes were differentially related to the correct comparison stimuli.

Did differential peck rates guide choice responding to C2 and C4 in the research of Astley and Wasserman (1999) and in the research that we have reported here? Astley and Wasserman (1999) cited two pieces of evidence that argued against differential pecking as the primary guide to choice responding to C2 and C4 stimuli. First, the pigeons that showed larger differences in peck rates reached criterion in choice training no more quickly than did the pigeons that showed smaller differences in peck rates. Second, there was no difference in the accuracy of choice responding on testing trials by pigeons that demonstrated above-average and below-average peck rate differences.

The present set of experiments provides further evidence against the notion that our pigeons based their choice responses to the untrained stimuli (C2 and C4) and to the new classes of photographic stimuli (C5 and C6, which were introduced in Experiment 3) on the differential peck rates to the stimuli. If differential peck rates were the prime determiner of choice responding, then the conditions that produced more divergent peck rates should have produced higher accuracies on choice trials.

Figure 5 shows the peck rates to all of the classes of stimuli that were included in Experiment 2. Note that the peck rate difference between the better and the worse condition of reinforcement was ordered: new > untrained > choice trained. Figure 6 shows, however, that choice responding was ordered in exactly the opposite way: choice trained > untrained > new. Thus, choice responding to each pair of stimuli was opposite what one might expect if differential peck rates contribute to choice accuracy. The difference in peck rates was largest to the C5 and C6 stimuli, but choice responding indicative of superordinate categorization was strongest to the C2 and C4 stimuli.³ This result argues against peck rate as the effective mediator guiding the pigeon's choice responding.

It is still possible that differential peck rates played some role in the acquired equivalence observed in Experiment 2, even if peck

³ In Experiment 2 the choice-trained and untrained categories had been tested previously, and the new categories had not. Thus, a comparison among these three categories is confounded by number of tests. Our comments apply equally well, however, to comparisons of the choice percentages to the new classes in Experiment 2 and the choice-trained and untrained classes in Experiment 1.

rates did not directly and precisely mediate choice. It may be that a generally high versus low peck rate to the center key prior to choice guided behavior, rather than choices being guided by a specific rate of responding. Relative peck rates are confounded with the hedonic value of the outcomes in these experiments, so we cannot rule out this possible explanation for our results.

Although we cannot now definitively specify the nature of the mediator that is producing learned stimulus equivalence in the studies reported here and in earlier publications, we do believe that it is very unlikely to be either a representation of the differential outcomes themselves or the pigeon's own differential rates of pecking. Relative hedonic or reinforcement value remains one of several viable options that we plan to explore in future experimentation.

Concluding Comments

Work on superordinate categorization has used the linking devices of association with a common response (Astley & Wasserman, 1998a, 1998b; Wasserman & DeVolder, 1993; Wasserman et al., 1992) and association with a common parameter of reinforcement (Astley & Wasserman, 1999). Of course, there are many other possible common experiences that might create learned stimulus equivalence, such as association with a common location in space or a common location in a serial order, that are yet to be experimentally investigated (see Chen, Swartz, & Terrace, 1997, and Orlov, Yakovlev, Hochstein, & Zohary, 2000, for suggestive evidence of common coding in a serial order).

A number of questions about the nature of learned stimulus equivalence remain to be answered—indeed, this is very fertile ground for future investigative endeavors.

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Received July 10, 2000

Revision received February 5, 2001

Accepted February 5, 2001