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The Search for Symmetry: 25 Years in Review

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Abstract

It has been 25 years since the publication of Sidman and colleagues (1982) report on the search for symmetry in nonhuman animals. They attributed their nonhuman subjects' failure to the absence of some critical experiences (e.g., exemplar training, control of location variables, and generalized identity matching). Since then, species ranging from rats to chimpanzees have been tested on symmetry, and the results have been equivocal. Twenty-four investigations of symmetry in nonhumans are reviewed to determine whether the underlying factors first addressed by Sidman and colleagues have been verified and whether new factors have been identified. The emergent picture shows that the standard procedures as typically implemented on 3-key apparatus are insufficient by themselves to produce emergent symmetry in nonhumans. Recent successful demonstrations of symmetry in sea lions and pigeons have clarified certain important stimulus control variables (e.g., select and reject control) and suggest avenues for future research. Reliable symmetry may be achievable with nonhumans if training and test procedures that encourage compatible stimulus control topographies and relations are designed.

It has been more than 25 years since the publication of Sidman and colleagues' (1982) chronicle of the search for symmetry (the finding that after learning to match samples to comparisons in a conditional discrimination that subjects will match those same stimuli when their respective functional roles are reversed) in nonhuman animals. That paper, and its companion, Sidman and Tailby (1982), have generated considerable interest in the phenomenon of stimulus equivalence and stimulated much follow-up research with college students, young children, and individuals with intellectual disabilities, some of whom exhibited minimal language skills. Further, a range of nonhuman animals, including chimpanzees, monkeys, sea lions, dolphins, rats, and pigeons have been tested for symmetry as well as the other defining properties of stimulus equivalence. There has been substantial variability in the data resulting from these investigations, particularly those concerning nonhuman animals. Despite having reached the quarter-century mark since Sidman and colleagues (1982) published their landmark

paper, no one has reviewed the literature concerning nonhumans, and thus it seems opportune to do so.

In reviewing published studies on symmetry in nonhumans from 1982 through 2007, the current goals are to summarize this research area and assess progress made in this 25-year period. The review begins with a brief summary of the history of the problem before 1982. Next, Sidman and colleagues' (1982) studies with monkeys, baboons, and children are described, followed by an examination of how the issue of symmetry fits within the larger area of stimulus equivalence, as well as a definition of the research problem and certain relevant theoretical considerations. The review concludes with a summary of the extant empirical investigations in order to assess progress, both conceptual and methodological, and to identify questions and issues that require further study.

Backward Associations

Studies with Humans

Interest in symmetrical associations is not limited to the stimulus equivalence literature. Prior to 1982, there was longstanding interest in the problem of so-called "backwards associations." As early as 1885, for example, Ebbinghaus reported savings in humans' backward recall of a list of nonsense syllables 24 hours after learning the list in the forward direction.

In paired associate learning, Asch and Ebenholtz (1962) proposed that once a forward association was established, a backward relation of equal strength was also formed. They conducted several studies showing this to be the case, although their demonstrations did not involve conditional discriminations of the sort used in contemporary equivalence studies. Moreover, they believed that the *asymmetry* sometimes found in paired associates research (e.g., Bartling & Thompson, 1977; Coutu, 1966; Levy & Nevill, 1974; Lockhart, 1969; Wollen, Fox, & Lowry, 1970) was due to differential availability of the items for recall, independent of the strength of forward versus backward associations. Their work showed that backward and forward associations do indeed form in equal strength when item availability is equal. Much additional evidence for backward associations in paired associates also exists (Kahana, 2002; Mandler, Rabinowitz, & Simon, 1981; Murdock, 1962; 1966; Tedford & Hazel, 1973). *Studies with Nonhumans*

In early investigations with nonhumans, researchers trained rats to run various types of mazes and then tested the rats' ability to run the maze in the opposite direction. Accurate running of the maze in the backward direction was taken as evidence of backward associations (e.g.,

Bunch & Lund, 1932; Carr & Freeman, 1919; Dorcas, 1932). Although these studies reported only variable success, interest in backward associations did not wane as the years passed and the phenomenon was studied in different ways.

Within the classical conditioning tradition, interest in backward associations can be traced to Pavlov (1928). In his preparation, an unconditioned stimulus (US) such as food or a shock is presented prior to the presentation of a conditioned stimulus (CS) such as a tone or light. Evidence for backward associations is provided if a conditioned response (CR) develops when the CS is presented. Pavlov's initial findings indicated that CRs develop in backward conditioning when only a few training trials are presented but that the CRs tend to disappear with extended training.

Whether or not backward associations develop as a result of backward conditioning procedures has been controversial. Rather than the development of CRs, some researchers have found evidence for conditioned inhibition after backward conditioning (Delamater, LoLordo, & Sosa, 2003; Moscovitch & LoLordo, 1968; Siegel & Domjan, 1971; Tait & Saladin, 1986). For instance, Moscovitch and LoLordo showed that after repeated backward US-CS pairings, the CS suppressed avoidance behavior when compared to another CS with a history of uncorrelated pairings with the US. Siegel and Domjan showed that backward pairings led to the retardation of conditioned responding when the CS was later used in training with forward CS-US pairings.

Other researchers, however, have provided evidence for an excitatory association after backward US-CS pairings (Arcediano, Escobar, & Miller, 2003; Barnet & Miller, 1996; Hearst, 1989; Keith-Lucas & Guttman, 1975; Wagner & Terry, 1975; see Razran, 1956 and Spetch, Wilkie, & Pinel, 1981 for reviews). For example, Hearst trained pigeons on a task in which a stimulus, CS1, was followed by food on half the trials and a lighted food hopper only (i.e., no food) on the remaining trials. For some pigeons, a second stimulus, CS2, followed all food presentations but for other pigeons, the CS2 followed all no-food presentations. Hearst noted that few pecks occurred to the CS2 during training (i.e., CRs did not develop). However, in a subsequent test in which the CS2 was followed by food on half the trials and no-food on the other half, Hearst found that the former pigeons pecked more to CS2 than the latter pigeons and that the responding of control pigeons (trained without the CS2 or with the CS2 uncorrelated with US presentations) fell between these two.

Researchers in the operant conditioning literature were also interested in the existence of backward associations in animals (e.g., Gray, 1966; Hogan & Zentall, 1977; Holmes, 1979; Rodewald, 1974, see also Kendall, 1983), and their studies directly anticipated Sidman and colleagues' (1982) research interests. The earliest investigations (Gray, 1966; Hogan & Zentall, 1977; Holmes, 1979; Rodewald, 1974) involved pigeon subjects, in which they were trained to match hue or line samples to hue, line or shape comparisons in a standard three response key pigeon chamber. Once the matching tasks were learned to varying levels

of accuracy (75% -90% correct), the roles of the samples and comparisons were reversed. In these studies, the sample stimuli were always presented in a central location, and the comparisons were always presented in side locations. In two studies (Gray, 1966 and Rodewald, 1974), the pigeons were trained to intermediate accuracy levels, and in Gray, testing was done in extinction. In one study, pigeons were given extensive training on identity matching, and then switched to arbitrary matching prior to test (Holmes, 1979). A backward association or symmetry test consisted of presenting former comparisons as samples (now in the central location for the first time) followed by a choice between former samples as comparisons (now in the side locations for the first time). Evidence for symmetry in these studies was poor: accuracy was at chance levels (Gray, 1966; Rodewald, 1974) or at a level comparable to that of initial performance on new relations (Holmes, 1979).

Hogan and Zentall (1977) conducted a study in which baseline relations were trained to high accuracy levels, test-trial performance was reinforced, and a control group to account for possible effects of rapid learning during test sessions was included. Pigeons were divided into consistent and inconsistent test groups. During reinforced symmetry test sessions, choices consistent with symmetry (e.g., pecking vertical after a red sample when pecking red after a vertical sample had been trained) were reinforced for the consistent group, but for the inconsistent group, choices inconsistent with symmetry were reinforced (e.g., pecking horizontal after a red sample given the same training as above). Strong evidence for symmetry is indicated by accuracy well above chance in the consistent group and well below chance in the inconsistent group on the first test session. Weaker evidence is indicated by faster acquisition of the symmetrical relation in the consistent group as compared to the inconsistent group over repeated reinforced test sessions. However, their results showed that first test-session accuracies were at chance for both groups and that the consistent group did not learn the symmetry task any faster than the inconsistent group. This was true after training on both simultaneous and zero-delay matching to sample.

Prior to Sidman and colleagues' report on symmetry, there had been no systematic investigations of backward associations in nonhuman primates (but see Weinstein, 1945). However, there was general interest in the literature to infer linguistic and other higher-order processes from the matching to sample procedure. Further, Savage-Rumbaugh, Rumbaugh, Smith, and Lawson (1980) published an account of a teaching program for two chimpanzees in which they were taught to sort items by category (food or tools) and to label each of the individual items with different lexigrams (i.e., arbitrary forms). Both chimps later

matched the individual lexigrams to the “tool” and “food” category lexigrams, even though this behavior was not explicitly taught. These data suggested the possibility of stimulus equivalence in nonhuman primates.

Stimulus Equivalence and the Search for Symmetry

Sidman and colleagues published their report concurrently with another report that offered a new operational definition of stimulus equivalence derived from mathematical logic (Sidman & Tailby, 1982). These two papers followed more than a decade of research concerning reading comprehension in individuals with intellectual disabilities in which stimulus equivalence had been the central focus. In that work, Sidman and colleagues demonstrated that individuals who lacked basic reading comprehension could be taught a few conditional relations, via auditory-visual (e.g., hear “apple” and choose a picture of an apple from amongst two or more alternatives) and visual-visual (e.g., see the printed word *apple* and choose a picture of an apple) matching to sample procedures. Thereafter, new relations involving dictated words, printed words, and pictures emerged without further training (e.g., Sidman, Cresson, and Willson-Morris, 1974). Similar emergent relations involving a variety of stimulus types have been demonstrated in humans displaying a wide range of intellectual and language abilities (Eikeseth & Smith, 1992; Fields, Adams, Brown, & Verhave., 1993; Sidman, et al., 1982; Spradlin, Cotter, & Baxley, 1973).

Sidman and Tailby (1982) defined stimulus equivalence in terms of three relational properties: reflexivity, symmetry and transitivity. Reflexivity is shown when an individual matches a stimulus to itself without explicit training on that identity relation. Symmetry entails a bi-directional relationship between two stimuli. For instance, if an individual is taught to match a red sample stimulus to a vertical line comparison stimulus (AB), then symmetry is shown if she or he subsequently matches a vertical line sample to a red comparison (BA) without further training. Finally, transitivity entails a relation among stimuli across two (or more) trained relations. It is demonstrated, for example, if after training to match red to vertical (AB) and vertical to triangle (BC), an individual spontaneously matches red to triangle (AC). A test for the emergence of a CA relation after A-B and B-C training has been termed a “combined” test for all three relational properties of equivalence, because such emergence logically requires those properties (see Sidman, 1994 for detailed consideration of the reasoning behind this assertion).

Another aspect of the Sidman and colleagues (1982) paper was to consider the terminology used to describe the nature of learning in certain conditional discrimination procedures. When “matching to sample” is used to describe the behavior of an individual rather than a type of procedure, they argued, the term “matching” seems to imply that an equivalence relation has been established – the related stimuli “go together.” In this con-

text, the authors argued for a strong distinction between matching to sample as the name of an experimental procedure and matching to sample as a descriptor of behavior. It is easy to see how the distinction could become blurred, particularly when identity relations are trained: when red samples are matched to red comparisons, it may appear that the subject has learned to “match same (or equivalent).” Sidman and colleagues argued, however, such matching need entail neither “sameness” nor equivalence; it may be merely a “rote” (i.e., “if...then”) conditional discrimination. Their arguments were supported subsequently by a number of studies with nonhuman subjects (Iversen, 1997; Iversen, Sidman, & Carrigan, 1986; Lionello & Urcuioli, 1998).

The main purposes of Sidman and colleagues’ (1982) paper were to (1) drive home the distinction between “true” matching (the stimuli bear a relation of sameness) and rote conditional discrimination (stimuli are related by “if...then” rules) in matching to sample procedures and (2) contrast performances of nonhuman primates (monkeys and baboons) with human preschool children on symmetry procedures. A majority of the children exhibited symmetry with very minimal training. The nonhuman primates, by contrast, failed to exhibit symmetry despite a variety of procedure variations that were designed to enhance performance. These variations addressed variables potentially related to symmetry that had not been considered in earlier work with pigeons (e.g., Hogan & Zentall, 1977; Holmes, 1979; Rodewald, 1974). *Methodological Developments*

The Sidman and colleagues (1982) study and its companion by Sidman and Tailby (1982) were noteworthy also because they established *de facto* standard methodology for assessing equivalence relations. This methodology included not only the probe tests for reflexivity, symmetry, and transitivity but also the intermixture of probe trials with baseline trials. The advantage of the intermixture procedure was that baseline relations could be evaluated concurrently with probed relations. If probes did not confirm the presence of a targeted emergent relation (e.g., symmetry), then performance on baseline trials determined if the failure was due to decrement of the prerequisite baseline relations. The symmetry study by Sidman and colleagues also included a procedural variation designed to establish another critical behavioral prerequisite for success – independent assessment of the subjects’ abilities to make successive discriminations among all samples and simultaneous discrimination among all comparisons (cf., Saunders & Spradlin, 1989). The variation was to train directly the identity relations (A-A and B-B) in order to familiarize the animals with all the stimuli in both sample and comparison positions (the issue of stimulus position became an important focus of research and is discussed more fully in the *Studies Failing to Find Evidence* section below). Finally, the probability of reinforcement on baseline trials was lowered so as to render nonreinforcement of probe trials less discriminable.

The consistent failure of Sidman and colleagues' monkey and baboon subjects to exhibit symmetry despite all of these precautions was deemed especially noteworthy, and lead directly to their publication of largely negative results.

Theoretical Considerations

The issue of symmetry in nonhumans becomes especially important when the larger context of stimulus equivalence theory is considered. One of the major points distinguishing the various theoretical accounts is the role of language. Many researchers suggest that the ability to form equivalence classes is related to demonstrable language capabilities (e.g., naming theory, Horne & Lowe, 1996; relational frame theory [RFT], Hayes, Barnes-Holmes, & Roche, 2001; Hayes, Gifford, & Wilson, 1996; Devany, Hayes, & Nelson, 1986), but others disagree (e.g., Carr, Wilkinson, Blackman, & McIlvane, 2000; Sidman, 1990; 1994; 2000).

Although proponents of both naming theory and RFT link equivalence to language ability, they differ in how they posit the two are related. Language ability is a key component of RFT and one interest of RFT is showing that derived stimulus relations such as equivalence and verbal behavior are both the result of relational frames. RFT does not address the abilities of nonhuman animals in general or symmetry in particular. By contrast, naming proponents suggest that naming gives rise to equivalence: stimuli evoke the same name as other stimuli and so the same listener behavior is directed to other members of the same class. If the individual does not overtly or covertly name the sample, matching in accordance with equivalence classes will not occur. Thus, nonhumans and humans lacking language skills will not show symmetry or equivalence.

Finally, Sidman (1990) proposed that stimulus equivalence arises from naturally occurring reinforcement contingencies in the environment that create the prerequisite conditions for the defining behavioral properties of equivalence. Species will have a varying potential to form equivalence relations and additional factors, such as testing conditions, context, and history, will determine whether and how this potential is realized. One good way to settle this debate, of course, is to show conclusively the behavioral relations defining stimulus equivalence in a species with no language ability. There have been positive reports of reflexivity (Barros, Galvão, & McIlvane, 2002; Herman & Gordon, 1974; Herman, Hovancik, Gory, & Bradshaw, 1989; Oden, Thompson, & Premack, 1988) and transitivity (D'Amato, Salmon, Loukas, & Tomie, 1985; Kuno, Kitadate, & Iwamoto, 1994) in nonhumans, but results of studies investigating symmetry have been much more equivocal, as the following review will show.

Symmetry in Nonhumans

This review will focus on empirical studies relating to symmetry in nonhuman animals investigated in matching to sample (i.e., conditional discrimination) contexts. The literature can be divided into three groups, depending on study outcome: those that failed to find evidence of symmetry, those that found mixed evidence, and those that have found strong evidence. Table 1 summarizes the reviewed studies and organizes them by the three aforementioned categories as well as describing some additional characteristics.

Studies Failing to Find Evidence

Of the 24 studies considered, 11, including Sidman and colleagues (1982), failed to find any evidence at all of symmetry. Seven of these used pigeons as subjects, and the remaining used primates such as monkeys, baboons, and chimpanzees. The earliest investigations (Gray, 1966; Hogan & Zentall, 1977; Holmes, 1979; Rodewald, 1974) involved pigeon subjects and were discussed previously.

Table 1

Studies investigating the emergence of symmetry in nonhuman animals

Location Controls?						
Authors	Species	Symm?	Alternative Explanation?	Identity Training?/ Intermixed?	Other Location Controls?	Possible select/reject control trained?
Barros et al. (1996)	Monkey	No (0/1)		No	Yes	No
D'Amato et al. (1985)	Monkey	No (1/6)	Yes	No	No	No
Dugdale & Lowe (2000)	Chimp	No (0/2)		No	No	No
Gray (1966)	Pigeon	No (0/3)		No	No	No
Hogan & Zentall (1977)	Pigeon	No (3/6)		No	No	No
Holmes (1979)	Pigeon	No (0/3)		Yes/No	No	No
Lionello-DeNolf & Urciuoli (2002)	Pigeon	No (0/24)		Yes/No	Yes	No
Lipkens et al. (1986)	Pigeon	No (0/9)		No	Yes	No
Richards (1988)	Pigeon	No (20)		No	Yes	Yes
Rodewald (1974)	Pigeon	No (0/3)		No	No	No
Sidman et al. (1982)	Monkey Baboon	No (0/5)		Yes/No	No	No
Bunsey & Eichenbaum (1996)	Rat	Mixed (10)	Yes	No	No	No
Garcia & Benjumea (2006)	Pigeon	Mixed (22/26)		No	Yes	No
McIntire et al. (1987)	Monkey	Mixed (2/2)	Yes	Yes/Yes	No	No
Nakagawa (2001)	Rat	Mixed (12)	Yes	No	No	No
Santos et al. (2003)	Monkey	Mixed (2*/3)		Yes/No	Yes	Yes
Tomonaga et al. (1991)	Chimp	Mixed (1/3)		Yes/Yes	Yes, smps & cmpts in separate areas	No

Table 1 (*con't*)

Authors	Species	Symm?	Location Controls?			
			Alternative Explanation?	Identity Training?/ Intermixed?	Other Location Controls?	Possible select/reject control trained?
Urcuioli & DeMarse (1997)	Pigeon	Mixed (15/15)		No	Yes	No
Urcuioli et al. (2006)/Urcuioli (in press)	Pigeon	Mixed (4/7)		Yes/Yes	Yes	Yes
Yamamoto & Asano (1995)	Chimp	Mixed (1*/1)		Yes/No	No	No
Zentall et al. (1992)	Pigeon	Mixed (32)	Yes	No	Yes	No
Frank & Wasserman (2005)	Pigeon	Yes (3/4)		Yes/Yes	Yes	Yes
Kastak et al. (2001)	Sea lion	Yes (2/2)		Yes/No	No	Yes
Schusterman & Kastak (1993)	Sea lion	Yes (1/1)		Yes/No	No	Yes

Note: The first number in the “symm?” column indicates the number of subjects showing evidence for symmetry and the second number shows the total number of subjects. For studies reporting group data only, only the total number of subjects is shown. “*” indicates symmetry was demonstrated and then went away. “smps” refers to samples and “cmps” refers to comparisons.

Note. For studies in which only group data were reported, no subjects were assumed to show symmetry if the overall result was negative and all subjects were assumed to show symmetry if the overall result was positive.

D’Amato, Salmon, Loukas, and Tomie (1985) conducted a study using consistent versus inconsistent test manipulations (similar to the test groups used by Hogan & Zentall, 1977); their subjects were six monkeys and each monkey was given both a consistent and an inconsistent test (counterbalanced across subjects). Additionally, the monkeys were trained on four conditional relations and given symmetry tests with all four. In Test 1, symmetry was tested with two of the relations, and half the monkeys were given the consistent test first and the inconsistent test second, with a return to baseline in between. For the other half of the monkeys, the opposite was true. On Test 1, 2 of the 6 monkeys matched at 80% on the consistent test and at 20-30% on the inconsistent test (where chance performance was 50% correct), suggesting symmetry. On Test 2 (with the remaining two relations), however, only one of those same monkeys showed the same pattern (the remaining monkeys matched at chance). Moreover, D’Amato and colleagues suggested this “symmetry” result may have been due to stimulus generalization and not a bidirectional relation between the stimuli because the correct comparison in task 2 was visually similar to the sample in task 1. Thus, when the task 2 comparison became a sample in the symmetry task, control by the sample in task

1 could have generalized to this new sample and resulted in performance that looked like symmetry. Further support for this conclusion was found in the data of a second monkey. This latter monkey received training with task 2 stimulus combinations that should have resulted in below chance accuracy on symmetry trials if stimulus generalization was occurring, which is in fact what the data showed.

Sidman and colleagues' (1982) study was designed to address some of the shortcomings of the pigeon studies. One possible competing source of stimulus control in earlier studies was that switching the roles of the samples and comparisons for the symmetry test caused the stimuli to appear in new locations (i.e., during training, samples were presented only on the center key and comparisons were presented only on the side keys, but during the symmetry test, former samples were presented on side keys as comparisons and former comparisons were presented on the center key as samples). Sidman and colleagues trained their monkey and baboon subjects on identity (A-A, B-B) relations (in separate sessions from A-B training) to provide subjects experience with each stimulus in each role and in each location. In Table 1, the columns under "Location Controls?" indicate whether identity training was used, or whether a method distinct from identity training was used to control for location effects. To control for the possible rapid learning of symmetrical relations due to reinforcement in test, they used a probe trial procedure in which symmetry test trials were unreinforced, and inserted into a baseline session in which the overall density of reinforcement had been reduced. Finally, in one study, they also trained arbitrary relations to ensure the subjects were able to make successive discriminations between sample stimuli. Despite all of these potentially helpful procedural additions, no subject showed symmetry (i.e., they all matched at chance).

Later research with monkey subjects went on to confirm that stimulus location is part of what is learned during matching to sample training. Iversen, Sidman, and Carrigan (1986) showed that when monkeys are trained on identity matching to sample with the samples always presented on the center key and the comparisons on the two side keys, that simply moving the stimuli to new locations (e.g., samples on the left key and comparisons on the remaining two) causes accuracy to fall to chance levels. The reinforcement contingencies remained the same; the only change in the task was the locations in which the stimuli were presented. Later research showed the same is true for rats (Iversen, 1997) and pigeons (Lionello & Urcuioli, 1998). These studies show that animals do not learn to "match A to B." Instead, they learn something much more specific: "match A on the center to B on the side" (i.e., location is a part of stimulus definition). These data seem to suggest it unlikely that animals learn general or conceptual relations between stimuli, and instead learn stimulus-specific relations. Other data, however, suggest that this specificity of learning may be a result of

the particular training procedures used. For example, Lionello-DeNolf and Urcuioli (2000) showed that when pigeons are trained on matching tasks in which the samples and comparisons appear in multiple locations during training, matching performances do transfer to novel locations. This suggests that the training or testing format itself might encourage learning of stimulus-specific relations. In other words, evidence for symmetry or other conceptual relations might be found if a different procedure is used.

Lipkens, Kop, and Matthijs (1988) trained pigeons on matching to sample in a response chamber in which two response keys were located on each of three different walls. When stimuli were presented on either of two side walls, the samples and/or comparisons were colors (when a sample was presented, it appeared with equal probability on the left and right key of a given wall), but when stimuli were presented on the middle wall, the samples and/or comparisons were left and right locations (when a sample was presented, one key was lit orange – left or right; when comparisons were presented, both keys were lit orange). Pigeons were trained to match color samples to location comparisons (i.e., A-B matching where A samples were presented on the left wall and B comparisons were presented on the middle wall), and to match location samples to color comparisons (i.e., B-C matching where B samples were presented on the middle wall and C comparisons were presented on the right wall). For the symmetry test (probe trials inserted into the baseline), samples and comparisons switched roles relative to baseline training, but the *locations* at which they appeared remained the same (i.e., B-A matching where B samples were presented on the middle wall and A comparisons were presented on the left wall; C-B matching where C samples were presented on the right wall and B comparisons were presented on the middle wall). However, pigeons still did not show symmetry and instead matched at chance. Lipkens and colleagues' analysis of error patterns during the probe test suggested that several stimulus control topographies were present. On baseline trials during the test session, location remained a controlling variable. In addition, the pigeons had to traverse different distances when responding to samples and comparisons, depending on where they were presented. For example, when sample A1 was presented on the left key of the left side wall, there was a longer distance to reach the comparisons on the middle wall than when sample A1 was presented on the right key of the left side wall. These distances also may have become part of the functional stimulus.

Lionello-DeNolf and Urcuioli (2002) also conducted a symmetry study in which stimulus location was controlled. Pigeons were trained on matching to sample tasks in which the samples and comparisons were presented in multiple locations during training (cf., Lionello-DeNolf & Urcuioli, 2000). In test, pigeons were tested on the baseline relations presented in a novel location and on symmetry with the samples and comparisons presented in

those same locations. In addition, pigeons were divided into consistent and inconsistent test groups and tested with reinforcement. Both groups matched at chance, however, in testing and learned B-A matching at the same rate. In a follow-up study, the pigeons were further trained on A-A and B-B matching and tested for reflexivity and then symmetry again. The results were again negative. Different pigeons were then trained on three separate arbitrary matching tasks: A-B, C-A and B-D. The logic here was similar to that of training with identity relations: such training gives pigeons experience with the A and B stimuli as both samples and comparisons and in all locations. Each relation was trained in separate sessions, and then the symmetry tests were conducted. If symmetry was not observed in the B-A test, B-A matching was trained to a high accuracy before testing for A-C symmetry. Likewise, if symmetry was not observed, A-C matching was trained to a high accuracy before testing D-B symmetry. This training provided a history of reinforced examples of symmetry, another variable identified as important by Sidman and colleagues. Nonetheless, all pigeons matched at chance and learned the relations at the same rate.

Barros, Galvão, and Fontes (1996) tested one monkey for symmetry on a matching task in which the samples and comparisons were locations. Training was conducted with a nine-key response panel. At the beginning of a trial, a sample, lit white, could appear in one of several locations. After an observing response, three comparisons, also lit white, were presented in random locations. The monkey was trained to match one location to another. For example, when Key 1 was the sample, Key 5 was the correct comparison. The locations of the incorrect comparisons varied across trials. In the symmetry test, Key 5 appeared as the sample, and Key 1 was the correct comparison. In test, the monkey's choices were not based on symmetry. Rather, the monkey tended to respond in the same physical direction as in training. To continue the above example, if choosing comparison Key 5 after sample Key 1 in training meant responding to the left of Key 1, then in test, the monkey responded to the left of Key 5 (rather than to Key 1, which was to the right of Key 5).

Finally, Richards (1988) controlled for stimulus location by training and testing for symmetry using a successive matching procedure: all stimuli were presented in a single location.

For example, red and green sample presentations were followed by a vertical comparison on some trials and a horizontal comparison on others (samples and comparisons were presented for a fixed amount of time). When red was the sample, trials with a vertical comparison ended in reinforcement and trials with a horizontal comparison ended in a black-out period. When green was the sample, trials with a vertical comparison ended in a black-out period and trials with a horizontal comparison ended in reinforcement. The dependent measure was a discrimination ratio: more pecks to vertical than to horizontal after red samples and

more pecks to horizontal than vertical after green samples indicates the pigeons learned the task. In test, vertical and horizontal were presented as samples and red and green were the comparisons. Despite that stimulus location was controlled, the pigeons did not show symmetry (discrimination ratios varied around .5). Subsequent control experiments, which altered the stimulus locations in training and testing, were also unsuccessful in demonstrating symmetry.

The last of the studies that failed to find evidence of symmetry was conducted with two chimpanzees that had extensive training histories to respond via a lexigram-based language system (Dugdale & Lowe, 2000). Dugdale and Lowe reasoned that (1) training multiple examples of symmetry might be required before animals show emergent symmetry with new relations, and (2) using animals with a lengthy history of such experience would provide the best chance of success on a symmetry test. Moreover, these were the same chimps whose prior behavior had suggested formation of equivalence classes, although the formal tests had not been conducted (Savage-Rumbaugh et al., 1980). They had extensive training to match lexigram stimuli to real-world objects and vice versa which seemed to provide a history of multiple exemplar training on symmetrical relations. Dugdale and Lowe then trained the chimps on a matching-to-sample task with hue and form (two-dimensional) stimuli in a standard three-key apparatus. Stimulus location was not controlled. In the initial symmetry test, one chimp was given unreinforced symmetry probe trials inserted into the baseline, and accuracy was at chance. In subsequent test sessions, probes were reinforced, and identity trials were included. Accuracy on symmetry tests was at chance for both chimps, and baseline performances degraded to low levels, suggesting that there was a general loss of stimulus control by the experimenter-defined samples.

Studies Finding Mixed Evidence

These studies can be divided into two categories: (1) those in which symmetry was found, but there may be alternative explanations for the finding, and (2) those in which evidence for symmetry was found in some subjects (but not all), or accuracies on symmetry tests were at intermediate levels (i.e., 70 – 85%).

Studies with Possible Alternative Explanations. There are three such studies. The first was a study with monkeys by McIntire, Clearly, and Thompson (1987). McIntire and colleagues reasoned that if naming facilitated class formation with humans, then teaching monkeys common “names” for stimuli should facilitate class formation for them as well. Monkeys were taught to make a common response (such as holding down a key for 3.5 s continuously) to each member of one training class, and a different response (fixed-ratio [FR] 8) to each member of the other class. For example, on trials in which sample A1 was presented the monkeys were required to respond to it with a “FR” response before the comparisons appeared. Then, when making a comparison choice,

the monkeys were again required to make the “FR” response. In contrast, when sample A2 was presented, a “hold” response was required to produce the comparisons, and again the “hold” response was required when making a choice. Using this procedure, the monkeys were trained on both identity and arbitrary matching to sample. They were then tested for all the defining relationships of equivalence, and passed all the tests. However, Hayes (1989) has argued that this result was not emergence as defined by Sidman & Tailby (1982), but instead was the result of direct training on all the tested relations. For example, on identity trials, the monkey was trained “A1-hold-A1-hold,” “A2-FR-A2-FR,” “B1-hold-B1-hold,” and “B2-FR-B2FR.” The trained relations on arbitrary matching trials were “A1-hold-B1-hold” and “A2-FR-B2FR.” Thus, the animal learned to make a hold response after some stimuli (A1 and B1) and an FR response after others (A2 and B2). The problem is, however, that the common response also could have become a mediating stimulus for comparison choice. In other words, on trials in which a hold response was required, the monkey could have simply learned “after making a “hold” response, chose A1 or B1.” On subsequent symmetry trials, the animal was required to make the following responses: “B1-hold-A1-hold,” and “B2-FR-A2-FR.” Note that prior training directly included these test-trial requirements. Thus, it seems doubtful that these monkeys demonstrated any of the properties of equivalence.

Nakagawa (2001) conducted a study with rats using a T-maze. The rats were trained to run up the base of the “T” to observe a sample stimulus (e.g., A1 or A2). The comparisons (B1 and B2) were presented on the two arms of the “T” with a response bar located in front of each one. The sample remained on while the comparisons were presented. Rats were either trained on A-B matching, overtrained on A-B matching or trained on a pseudo-matching task (not described in the study). The samples and comparison roles were then switched (and choices consistent with symmetry were reinforced). No evidence for symmetry was found on the first B-A training session, but the rats given overtraining on A-B matching learned the B-A task faster than the group trained just to criterion. Both of these groups learned the task faster than the rats given pseudo-training. Despite these between-group differences in the rate of learning the test task, it is unclear that this result indicated symmetry. Typically, when samples and comparisons are reversed for a symmetry test, the B stimuli become samples and the A stimuli become the comparisons (e.g., the sample is B1 and the comparisons are A1 and A2). In this study, however, when a B stimulus (e.g., B1) was a sample, the comparisons were the class-consistent A stimulus and the other B stimulus (e.g., A1 and B2). Rats could have performed this task by means other than on the basis of symmetry. For instance, in training, it is possible that the rats learned the AB relation by rejecting the incorrect comparison rather than selecting the correct comparison (cf., Johnson & Sidman, 1993). To illustrate, with A1 as the sample, reject

B2 (and thus press the only other remaining stimulus, B1) and likewise, with A2 as the sample, reject B1 (and press B2). Now, recall that during symmetry tests the same three stimuli were presented simultaneously (although in a different configuration than in training). In other words, with B1 presented as a sample, B2 and A1 were the comparisons. Assuming continuation of the *reject S*-form of stimulus control, the rats would bar press in front of A1 because responding away from B2 in the presence of B1 and A1 together had been established by training.

Bunsey and Eichenbaum (1996) trained a hippocampus-damaged group of rats and a sham-operated control group on a matching to sample task involving cups of scented sand. Reinforcers for correct matching of scents were buried in the correct comparison cups. The rats were trained on both A-B and B-C matching, and were then tested for transitivity. They were next trained on B-A matching to 78% or better accuracy prior to being tested for C-B symmetry. Rats were allowed to switch back and forth between comparisons until they retrieved the reinforcer and the dependent variable was a preference index based on the amount of time spent digging in the correct (symmetrical) and incorrect comparisons. On the C-B test, there were significant differences between the hippocampal and control groups: the control group spent more time digging in the symmetrical comparison choice than did the hippocampus-damaged group. Whether or not the rats were demonstrating symmetry here is difficult to ascertain, however, because all test trials were reinforced, and no control for possible rapid learning of C-B matching due to reinforcement was included (such as a group reinforced for choices inconsistent with symmetry).

Studies with Less-Than-Perfect Symmetry. The next group of studies considered found varying degrees of evidence for symmetry. Some studies reported group designs in which statistical differences were found between groups, indicating symmetry. Other studies reported choice accuracies that statistically differed from chance but were well below 90%. Also included are studies in which some subjects showed evidence for symmetry while others did not, or a given subject demonstrated symmetry in some instances and not in others.

Tomonaga, Matsuzawa, Fujita, and Yamamoto (1991) tested for symmetry in three chimpanzees. Initial matching to sample training included both arbitrary and identity relations that were trained in intermixed sessions. Samples and comparisons were presented on a computer touch screen. A sample stimulus could appear anywhere on the top half of the screen, and the comparison stimuli could appear anywhere on the bottom half. Probe trials inserted into baseline sessions (consisting of arbitrary and identity matching trials) were used to test for symmetry. No reinforcement was given on the probe trials, and the probability of reinforcement on baseline trials was not reduced. One of the chimps matched at

approximately 75% correct on probe trials (averaged over three sessions for a total of 24 symmetry trials; accuracy on the first eight trials was 100%), but the other two matched at chance. Testing in extinction may have been a factor on test trials. In a follow-up experiment with the one subject demonstrating symmetry, evidence was again obtained after unique stimuli (e.g., flashing screen or stars) were added to the task following both sample and comparison presentation for each defined class (e.g., stars were presented after responses to both A1 and B1 regardless of whether a correct choice was made).

Yamamoto and Asano (1995) tested for symmetry in one chimpanzee trained initially on identity (A-A, B-B) relations and then arbitrary relations (A-B) using multiple stimulus sets. Then, the reinforcement frequency on arbitrary (A-B) baseline trials was reduced and unreinforced symmetry probes were inserted into sessions. The chimp was first given probes with one stimulus set only (e.g., B1-A1). If no evidence for symmetry was found, B1-A1 matching was directly trained with that stimulus set only. Then, B2-A2 symmetry was tested. After training on several B-A relations, the chimp matched at 80% correct on a novel B-A (symmetry) relation (chance was 33% in this study). However, in a subsequent symmetry test with new stimuli, accuracy was once again at chance.

Two studies (Urcuioli and DeMarse, 1997; Zentall, Sherburne, & Steirn, 1992) examined symmetry using matching tasks with class-specific outcomes that followed comparison selections in training. For example, Zentall and colleagues (1992) trained pigeons on identity and arbitrary matching in which correct choices of one comparison were followed by “food” (access to grain in a lit food hopper) and correct choices of the other comparison were followed by “no food” (no access to grain, but the food hopper was lit). No observing response to the samples was required in training; rather, each sample remained on for 6 s and was then followed by display of comparison stimuli, regardless of the bird’s behavior. In test, food and no-food were presented as samples (i.e., a lighted food hopper with or without food was presented) and were followed by choices between the same comparisons as in training, using consistent and inconsistent transfer groups. On the first test session, there was a significant difference between the groups: the consistent group matched above chance and the inconsistent group matched below chance. In other words, the birds more often chose the comparison that had been followed by food in training when food was presented as a sample and they more often chose the comparison that had been followed by no-food in training when no-food was the sample. This result suggests a symmetrical relation between the comparison stimuli and the unique outcomes that followed them.

However, these data can also be explained by another process, mediated generalization, similar to that which could have

been responsible for the findings of McIntire and colleagues (1987). Recall that no responses to the samples were required during training. In fact, however, the pigeons pecked more to one sample (the one related to the comparison whose selection produced food) than to the other (the one related to the comparison whose selection produced no food). It is plausible that in training, comparison choices were mediated by pecking versus not pecking rather than the samples. In other words, the pigeons' behaviors with respect to the samples may have overshadowed the visual samples as controlling stimuli (cf. Urcuioli & Honig, 1980). Further, during testing pigeons pecked at food samples but not at no-food samples. Thus, both in training and test, comparison choices could have been mediated by the presence/absence of pecking rather than symmetrical relations or backward associations between the comparison and outcome stimuli.

However, Urcuioli and DeMarse (1997) conducted a similar manipulation that avoided this problem. Training ensured that pigeons pecked at similar rates to both samples by training a one-to-many (i.e., sample-as-node) matching task. There were two sample stimuli, and each sample could be followed by two different sets of comparisons. For one set, correct choices resulted in the food outcome, and for the other, correct choices resulted in the no-food outcome. For example, on some trials, sample A was followed by comparisons 1 and 2, and correct choices of comparison 1 resulted in food. On other trials, sample A was followed by comparisons 3 and 4, and correct choices of comparison 3 resulted in no-food. Likewise, on some trials sample B was followed by comparisons 1 and 2, and correct choices of comparison 2 were followed by food. On other trials sample B was followed by comparisons 3 and 4 and correct choices of comparison 4 were followed by no food. In testing with previous outcomes as samples, these pigeons matched more accurately than other pigeons that had been trained with common comparison-reinforcer relations, suggesting symmetrical relations between the visual comparison stimuli and the food and no-food outcomes. Because pecking versus not pecking was not differentially associated with comparison choice, this result cannot be explained by mediated generalization.

Garcia and Benjumea (2006) tested for symmetry in pigeons in a task in which the pigeons' own behavior was the sample. In Experiment 1, two response keys were lit white and the pigeons were required to peck either the left or the right key. Comparisons were hues, and reinforcement was given for choosing one hue (e.g., red) after pecking left and the other hue (e.g., green) after pecking right. The symmetry test consisted of probe trials (always unreinforced) in which one of the former comparison stimuli was presented on both keys. To assess symmetry, Garcia and Benjumea recorded where the pigeons initially pecked (the left or right key) and how many pecks were made to each location (a trial ended af-

ter 10 pecks were made, not necessarily on the same key). For instance, on some probes, red was presented on both the left and right key. After 10 total pecks, the trial ended. Symmetry is suggested if a greater proportion of pecks were made to the left key when red was presented and a greater proportion of pecks were made to the right key when green was presented. On probe trials, 9 of 10 pigeons' first responses on each trial were to the location suggesting symmetry (e.g., left when the keys were red and right when the keys were green). Moreover, when all required responses were considered, more than 60% of pecks were made to the locations consistent with symmetry. Similar results were obtained in follow-up experiments with additional pigeons. Although these pigeons responded at levels that were statistically better than chance, the percentage of responses consistent with symmetry was still well below that typical of human subjects in many studies (although humans are not typically given the option of making multiple responses to multiple comparison-stimuli).

Mixed evidence for symmetry in three capuchin monkeys has also recently been reported by Santos, Barros, & Galvão (2003). Training began with simple discrimination and repeated discrimination reversals with two and then three stimuli that could appear in any of nine locations. Next, monkeys were trained on identity relations with those stimuli. Tests for generalized identity matching followed (Barros et al., 2002), and monkeys were not trained on arbitrary matching until they passed these tests. Arbitrary matching performances were trained using a stimulus control shaping technique in order to minimize errors during training (i.e., to avoid the development of unwanted stimulus control topographies; cf. McIlvane, Serna, Dube, & Stromer, 2000).

Prior to a symmetry test, the monkeys were given a series of tests to assess the controlling relations between the samples and comparisons. Specifically, the monkeys were tested to determine if *select* (i.e., select a particular comparison after a given sample) and *reject* (i.e., reject a particular comparison – and press the remaining comparison – after a given sample) controlling relations were present (cf. Johnson & Sidman, 1993). If both select and reject relations were not present, they were directly trained. Santos and colleagues believed it essential that a monkey's choices be based on select control, and the procedure they used to verify this behavior requirement necessitated the inclusion of reject control trials as well. Three monkeys progressed to a symmetry test (a session in which unreinforced symmetry probes were inserted into a baseline session). The results were equivocal. One monkey performed below chance level on initial probes, was re-trained to ensure the presence of both select and reject relations, and then matched at 90% correct on a symmetry re-test. A second monkey performed at chance on two symmetry tests (with baseline retraining and class-specific reinforcement between the two). The third monkey did perfectly on its first symmetry test (B-A matching which followed

A-B training). It was then trained on a new arbitrary relation (B-C), and given three additional symmetry tests with those stimuli, on which it matched at or below chance. Interestingly, no identity training was given with the C stimuli (although this monkey did pass prior tests for generalized identity matching).

Studies Reporting Clear Evidence

There are two reported studies showing evidence for symmetry in two sea lions (Kastak, Schusterman, & Kastak, 2001; Schusterman & Kastak, 1993) and one study showing evidence for symmetry in pigeons (Frank & Wasserman, 2005).

Schusterman and Kastak (1993) were the first to show strong evidence for stimulus equivalence in a nonhuman animal. Their training regimen was designed to give subjects experience with stimuli switching roles (i.e., between sample and comparison) prior to the critical tests. They used what is called the simple-to-complex training protocol by Fields and colleagues (1993). First, training establishes matching to sample relations and tests for symmetry are given. After symmetry is demonstrated, transitivity is tested and confirmed, and finally equivalence (C-A) is tested. The sea lion was trained on matching to sample with 30 stimulus sets (A1-A30, B1-B30, C1-C30) to establish 3-member classes (A1, B1, C1; A2, B2, C2 etc.).

Initial training consisted of A-B matching with all 30 sets to high accuracy. Then, the sea lion was given symmetry tests with stimuli from 12 of the stimulus sets, six sets at a time. If symmetry was not initially demonstrated, the stimulus relations used in the tests were established by direct training to a high accuracy criterion. Then, the second six sets were included in testing. The relations between B and C stimuli were then trained with all 30 sets, and again symmetry was tested with 12 of the stimulus sets, as was transitivity (A-C) and equivalence (C-A).

Symmetry tests consisted of reinforced probe trials inserted into a session consisting of baseline trials. Evidence for symmetry was defined as (1) no more than one error on probe trials and (2) no error on the first probe trial. On a B-A symmetry test with the first six sets, the sea lion passed half of the tests (chance performance). On the B-A test with the second six stimulus sets, the sea lion passed five tests. When C-B symmetry was subsequently tested, the sea lion passed tests with 10 of the 12 stimulus sets (in addition, it passed most tests for transitivity and equivalence). Schusterman and Kastak attributed the sea lion's success to a history of multiple exemplar training (i.e., reinforced history of responding consistent with symmetry with some stimulus sets) and to the use of multiple S-stimuli during training. This ensured that the negative comparison did not become part of the equivalence class (i.e., reject control was not possible).

In a later study (Kastak et al., 2001), the aforementioned sea lion, and an additional sea lion were tested for equivalence in a

different format. The sea lions were first trained on a series of simple simultaneous discriminations and their repeated reversals in order to create two functional classes of stimuli (stimuli classified together because they all share a common function; cf. Vaughan, 1988). After reliable functional classes were established, the sea lions were transferred to conditional (matching to sample) discriminations using those stimuli to see if they would match stimuli belonging to the same functional class. Finally, the sea lions were trained to relate novel stimuli to some of the existing class members and were subsequently tested for equivalence between the novel stimuli and the remaining class members. Both sea lions showed functional class formation, but only when correct responding to the stimuli was reinforced with class-specific outcomes. When nondifferential outcomes were substituted, the classes degraded. In addition, when transferred to a matching to sample task, the sea lions were able to match stimuli belonging to the same functional classes without explicit training to do so. Finally, after being trained to match novel stimuli to a subset of the stimuli from the functional classes, the sea lions were tested for equivalence between the novel stimuli and the remaining functional class members. Both sea lions passed the tests, indicating the existence not only of symmetrical, but also transitive relations as well.

Finally, Frank and Wasserman (2005) have reported the strongest evidence to date for symmetry in pigeons. Pigeons were trained on successive matching-to-sample (e.g., Richards, 1988) in order to control for location variables. Training included A-B as well as A-A and B-B identity relations in an intermixed session in order to control for temporal variables (i.e., a given stimulus can appear at either the beginning of a trial as a sample or in the middle of the trial as a comparison). Stimuli were clip-art pictures presented on a computer screen with a touch sensitive panel in a single location. Samples and comparisons were each presented for 10 s with 3.5 s between sample and comparison presentations. Peck rates during stimulus presentation were recorded. Pigeons remained in training until reaching a discrimination ratio of 0.80. On half of the training trials, a sample was followed by a correct comparison followed by access to grain. On the remaining trials, a sample was followed by an incorrect comparison and no access to grain. Thus, on half of the training trials, no reinforcement was given. Symmetry testing consisted of unreinforced B-A probe trials inserted into a session consisting of baseline (A-B, AA, and B-B) trials. After one test session, the pigeons experienced a return to baseline without probe trials until discrimination ratios were at least 0.80 and then a second test session with probe trials. Two pigeons were tested on this procedure and both pigeons pecked more to comparisons consistent with symmetry than to comparisons inconsistent with symmetry.

In a follow-up experiment, two different pigeons were given similar training, but without the intermixing of identity-

matching trials. Instead, these two pigeons were trained only on arbitrary matching, and were then given symmetry tests. In contrast to the first two pigeons, these pigeons pecked at similar rates to both the comparisons consistent and inconsistent with a symmetrical relation on probe trials. In a final experiment, two additional pigeons were trained on arbitrary relations only prior to a symmetry test. Then, intermixed identity trials were added to the baseline of arbitrary matching trials prior to a second symmetry test. On the symmetry test just after arbitrary-relations-only training, both pigeons pecked at similar rates to the comparisons consistent and inconsistent with a symmetrical relation, replicating the findings of Experiment 2. After subsequent intermixed identity training, one pigeon began to peck more frequently at the comparison consistent with symmetry than the comparison inconsistent with symmetry thus showing the emergence of symmetry only after identity matching was added to the baseline.

The successive matching procedure, however, is not a panacea. In a recent Psychonomic Society presentation (2006), Urcuioli, Michalek, and Lionello-DeNolf reported training pigeons on a procedure like Frank and Wasserman's (see also Urcuioli, *in press*). The main difference between studies was the apparatus: Urcuioli and colleagues used the standard 3-key pigeon chamber with hue and line stimuli. Four of the seven pigeons tested had discrimination ratios of .75 or above over the first two symmetry test sessions, indicating the emergence of symmetry in these pigeons. The reason why the remaining three pigeons did not show symmetry is unclear, but may be related to procedural details that differed between the studies (such as inter-trial interval length or stimuli). This warrants further study.

Summary and Conclusions

Twenty-four studies investigating symmetry in animals were reviewed. In these studies, there were 229 experimental subjects, including pigeons (182), rats (22), primates (23) and sea lions (2; see Table 2). Approximately 80 (41%) of these animals showed some evidence of symmetry. Use of one particular species did not increase the likelihood of demonstrating symmetry: 42% of pigeons, 30% of primates, and 45% of rats did. Note, however, that the number for rats is most likely inflated because the rat studies involved group designs and individual subject data were not reported.

While 11 of the reviewed studies failed to find evidence for symmetry (45%), the remaining 55% found either mixed evidence (10 studies) or strong evidence (3 studies). There were clear procedural differences between these two latter groups of studies and the former that influence the likelihood of finding the effect. Sidman and colleagues (1982) speculated that certain experiences were absent from their subjects' baseline and pre-experimental histories that were critical for the formation of symmetrical relations (which is probably not the case for hu-

mans). Specifically, they suggested a history of multiple exemplar training, stimulus location control procedures, and a history of generalized identity matching. In addition, they believed individual species differences would render other, as yet unidentified, variables important. Sidman and colleagues' analysis proved to be prescient.

Table 2

Species, number of subjects, and number of subjects showing emergent symmetry

Species	Total Number of Subjects	Subjects Showing Symmetry	Percentage Showing Symmetry
Pigeon	182	76	42
Monkey	15	5	33
Baboon	2	0	0
Chimpanzee	6	2	33
Rat	22	10	45
Sea Lion	2	2	100
Total	229	95	41

Note. For studies in which only group data were reported, assumed no subjects showed symmetry if the overall result was negative and assumed all subjects did if the overall result was positive.

One variable identified by Sidman and colleagues (1982) that has been shown to be important is multiple exemplar training. Recall that Schusterman and Kastak (1993) tested a sea lion on symmetry with only a subset of the original training stimuli. Then, symmetry was directly trained with that subset, prior to additional tests for emergent symmetry with the remaining stimuli. Symmetry was evident after the sea lion had been trained on several symmetrical associations. There is another example of success after multiple exemplar training in the literature, although the concept involved was not symmetry. Katz and Wright (2006) used a similar procedure to test for emergent same/different performance in pigeons and found evidence of such emergence after a large number of training examples. Why the multiple exemplar training procedure was effective for symmetry is not definitive. One reason may be that training the multiple examples of symmetry meant that the samples and comparisons were now appearing in new locations and thus, control by stimulus location may have been reduced. In other words, maybe learning that some samples and comparisons can appear in multiple locations was sufficient for the generalization that all stimuli can appear in all the locations.

Perhaps too exemplar training was effective because not only does it reduce control by *where* a stimulus appears, but also *when* it appears. In other words, the fact that samples always appear first in a trial and comparisons second may become a salient stimulus characteristic that gains control over behavior. One reason this may be is the unidirectional nature of a trial. Responding to

sample stimuli is never reinforced, but is always followed by a choice between comparisons, and correct choices are followed by reinforcement. Of course, this is true for human subjects as well, but for animals the reinforcer has biological significance (e.g., food) whereas for humans, it does not (e.g., points, money, course credit). Moreover, humans have extensive pre-experimental experience of bi-directional relationships between objects or events that animals lack. Multiple exemplar or symmetry training thus may emphasize that certain stimuli “go together” and reduce the saliency of directionality. Why then, was such training not successful in facilitating emergent symmetry in the two other studies reviewed here that used it? One reason may be that while the chimpanzees tested by Dugdale and Lowe (2000) had a history of bi-directional responding to object and lexigram stimuli, it was remote from the experimental situation and involved vastly different stimuli than those used in the critical symmetry test. Moreover, other procedural factors, such as lack of reinforcement on test trials, may have contributed. The remaining study, Lionello-DeNolf & Urcuioli (2002), only provided a history of symmetry with two stimulus sets, which was most likely an insufficient number. The sea lion did not show symmetry until after training on at least six stimulus sets. Moreover, the pigeons tested by Katz and Wright (2006) for same/different concept learning did not show emergence until after training with approximately 256 stimulus sets.

Prior to Sidman and colleagues (1982) the traditional assessment method had been to train arbitrary A-B matching, and then simply to test for B-A matching. In addition, it became typical to present the sample stimulus in an invariant central location and the comparison stimuli (usually two but sometimes three) on side locations or in a row beneath the sample. Unfortunately, this procedure, while routinely successful with humans, seems to be the least likely one to yield symmetry in animals. Seven of the reviewed studies used this training procedure, and only two (29%) showed at least mixed evidence for symmetry. Moreover, those two (Bunsey & Eichenbaum, 1996; Nakagawa, 2001) both have alternative explanations of the data.

Table 1 indicates that when researchers deviated from the typical training procedure, animals were more likely to show symmetry. One deviation was to train identity matching relations, often as a procedure to reduce control by stimulus location. Six studies used identity matching as the sole method of location control, and four (66%) found at least mixed evidence for symmetry. Another deviation was to use a test procedure that explicitly controlled location (e.g., training with multiple locations, using only one location, etc.). Six studies did so, and did *not* also include additional identity training. Of those, three (50%) showed at least mixed evidence for symmetry. Interestingly, five studies included both identity training and additional location procedures, and four of them (80%) showed some evi-

dence for symmetry. Thus, as Sidman and colleagues predicted, controlling for the effects of stimulus location seems to aide the emergence of symmetry, particularly if it is combined with additional identity training.

Evidence of symmetry was also more likely when alternatives to 3-key matching to sample procedures were used. While only a few of the studies failing to find evidence of symmetry used alternative procedures (e.g., Barros et al., 1996; Lipkens et al., 1986; Richards, 1988), a majority of the mixed-evidence studies did. Often, these studies took advantage of some of the species-specific variables referred to by Sidman and colleagues (1982). For example, Bunsey and Eichenbaum (1996) presented odor cues to rats and Zentall and colleagues (1992) and Urcuioli and DeMarse (1997) used biologically important stimuli (i.e., the presence and absence of food) as discriminative stimuli.

Why is Symmetry More Likely With Alternative Procedures?

It seems evident that symmetry performances can be encouraged (or discouraged) by the type of training procedure used. The most effective alternative procedure is one that provides training on identity relations and also explicitly controls for stimulus location effects. Two reasons that identity training may be needed in addition to explicit location controls is that identity training ensures the animals can make successive and simultaneous discriminations between the stimuli (prerequisites for symmetry) and may control temporal variables (i.e., animals learn that a given stimulus can either appear first as a sample or second as a comparison). This review suggests that the importance of identity training may go beyond these variables. When studies employing identity training are considered, some evidence for symmetry has been found whenever trials involving identity matching were *intermixed* with arbitrary matching training: in four studies, three found mixed evidence and one found strong evidence (but see Urcuioli, in press). However, when identity training took place separately from arbitrary matching training (i.e., before or after A-B relations were learned), evidence for symmetry has been less compelling: in seven studies, three found no evidence, two found mixed evidence, and two found strong evidence. Possibly, studies that included intermixed identity training with arbitrary training were successful because they increased the likelihood for *consistent select* controlling relations between the sample stimulus and the reinforced comparison. Interestingly, among the seven studies that included identity relations trained separately from arbitrary ones, three included training that may have encouraged consistent *select* (or *reject*) controlling relations (the right-most column of Table 1 indicates in which studies training procedures may have encouraged *select/reject* control). What follows will consider this and related possibilities in more detail.

Select and Reject Control. When performing a conditional

discrimination, it is possible logically to make a comparison choice by *selecting* a particular comparison after a given sample on all trials, by *rejecting* a particular comparison (and responding to the opposite comparison) on all trials (Carrigan & Sidman, 1992), by doing both, or by doing a combination of these across trials in a session. If one assumes *select* control at the end of A-B arbitrary matching training, emergent symmetrical relations could logically result: the animal learns that A and B stimuli “go together” such that in test, it chooses A1 after B1 and A2 after B2. Consider the possibility, however, that in baseline training, the animal performs the task by rejecting B2 after A1 (touching B1) and rejecting B1 after A2 (touching B2). Johnson and Sidman (1993) argued that even if A-B matching is under such *reject* control, symmetry is still predicted because the reject relation between the A and B stimuli still holds (e.g., if “see A1, reject B2” is learned then in test the subject should “see B2, reject A1” and touch A2). Evidence from their human participants further confirmed symmetry when arbitrary matching explicitly establishes *reject* control.

In the absence of special training procedures to bias the subject toward a particular controlling relation, will exclusive *select* or exclusive *reject* control develop? Logically, the animal could display *reject* control on some baseline trials and *select* control on others. Early in training when accuracy on the matching problems is at chance, the animals’ choices could be governed by a mixture of stimulus properties, termed stimulus control topographies by Dube and McIlvane (1996). As training continues, however, differential reinforcement would tend to favor development of control by stimulus aspects consistent with the experimenter-defined relations. In the case of 2-choice matching to sample, both *select* and *reject* control could be reinforced throughout training because both are compatible with the training contingencies. Thus, by the end of training, choice on some trials could be due to select relations and choice on other trials to reject relations. Notably, the baseline accuracy score would not reveal these controlling relations. Moreover, in the human literature, there is strong evidence that conditional discrimination performance may be governed concurrently by *select* and *reject* control (Dixon & Dixon, 1978; Stromer & Osborne, 1982). In addition, recent data from the simultaneous discriminations of *Cebus apella* suggest both *select* and *reject* control is possible in the same baseline (Goulart, Mendonca, Barros, Galvão, & McIlvane, 2005).

To the extent that animal’s performances represent an uneven mixture of *select* and *reject* control within and across trials just prior to test, symmetry outcomes become uncertain. For example, suppose that the nature of an animal’s baseline performance could be described as: “if A1 then select B1; if *anything else* then reject B1.” In test, it is difficult to specify a predicted basis for the animal’s performance. If matching A1 to B1 is symmetrical, performance on trials with B1 as a sample would be based on “if B1 then

select A1,” resulting in high accuracy on those trials. But what about on trials that displayed B2 as the sample? Because the baseline selections of B2 were made by rejecting B1 in relation to all non-A1 samples, discrimination of the defining features of B2 was never established (i.e., “if B2 then select [what]?”). It does not follow to expect the emergence of “if the sample is anything other than B1, then select anything other than A1 (or reject A1).” Of course, this is just one example of any number of select/reject control patterns that could develop during training (e.g., see the example involving specific stimulus configurations below). Potentially, such test situations may set up an impossible discrimination of the sort that may abolish discrimination baselines (Stoddard & Sidman, 1971).

Potentially compounding this problem, nonhuman baseline performances are only rarely at or near perfection (which can be contrasted to that of typical humans in many studies). If baseline accuracy is only 85%-90%, for example, then the proportion of irrelevant, typically unidentified controlling relations involving position and/or local trial effects can be estimated at 20%-30% in a two-comparison task (Dube & McIlvane, 1996). These controlling relations also may be incompatible with symmetry (cf. McIlvane et al., 2000), perhaps interacting with *select/reject* controlling relations in unpredictable ways. For instance, consider a situation where on trials with one sample, the animal’s choice is under *select* control (e.g., “if red, choose vertical”), but on trials with the other sample, the animal’s choice is a combination of configural and *select/reject* control (e.g., “if green followed by vertical on the left and horizontal on the right, reject vertical” and “if green followed by vertical on the right and horizontal on the left, select horizontal”). Such behavioral variability could lead to unpredictable results at test.

Carrigan and Sidman (1992) suggested that identity-matching trials may be more likely than other trial types to occasion *select* control. We do not know empirically, however, whether identity trials do in fact render *select* control more likely. Some data suggest that when pigeons are trained on matching to sample in which an identity relation is involved, that the development of *select* versus *reject* controlling relations depends on reinforcement contingencies (Zentall, Edwards, Moore and Hogan, 1981). Zentall and his colleagues trained pigeons on either matching to sample or oddity from sample and subsequently replaced either the correct or incorrect comparisons with another (familiar) stimulus. Pigeons trained on the matching task were more accurate on trials in which the incorrect comparison was replaced than those in which correct comparison was replaced, suggesting *select* control. Pigeons trained on the oddity task, however, were more accurate on trials in which the correct comparison was replaced than those in which the incorrect comparison was replaced, suggesting *reject* control. The overall pattern of results suggested a conceptual relation between

the samples and comparisons based on identity and, importantly, is consistent with Carrigan and Sidman's assertion that identity training tends to engender *select* control in matching to sample.

Regarding symmetry, important variables may well prove to be the nature and consistency of controlling relations across trials (i.e., all select relations, all reject relations, or select and reject relations involving all of the sample-comparison relations). Data cited above from both pigeons (Zentall et al., 1981) and monkeys (Goulart et al., 2005) indicate animals' choices on matching tasks can be based on either *select* or *reject* controlling relations. If the identity-matching procedure does in fact foster development of consistent *select* control, for example, then intermixing identity-and arbitrary-matching training trials within a session may make it more likely that consistent *select* control develops overall (i.e., not only on the A-A and B-B trials, but also on the A-B matching trials). In such a situation, stimulus equivalence relations, including symmetry, may be more likely to be observed.

The training approach used by Schusterman and Kastak (1993) may have encouraged consistent *select* control. They used a two-choice matching procedure in which a different incorrect comparison was presented on every baseline trial. Thus, the number of possible *reject* relations greatly exceeded the number of possible *select* relations, and the procedure thus would be expected to render the latter more probable (cf. Cumming & Berryman, 1965). In addition, the sea lion's history of generalized identity matching may have encouraged *select* control. Interestingly, the successive matching procedure, used in the successful demonstration of symmetry in pigeons (Frank & Wasserman, 2005), may have engendered *select* control as well as *reject* control, as follows: On every trial, only one comparison was presented after each sample. On half the trials, therefore, a sample was followed by an incorrect comparison and the pigeons had to refrain from responding. In other words, by the end of training, the pigeons were forced to learn to respond to each matching sample-comparison pair (*select* control) and to refrain from responding to each nonmatching sample-comparison pair (*reject* control).

Notably, some studies showing mixed evidence employed neither intermixed identity training nor training that explicitly encouraged *select* control. They did, however, employ other alternative procedures that may have capitalized on unique characteristics for the population studied. We do not know whether such procedures led to partial success because they encouraged consistent *select* or *reject* controlling relations, because they encouraged stimulus control topography coherence, or for some other reason (see, for example, Urcuioli, in press). They do, however, underscore the point that standard procedures as typically implemented on 3key apparatus are insufficient by themselves to produce emergent symmetry in nonhumans.

Future Directions

This review has suggested that replicable, reliable symmetry may be achievable with nonhumans if training and test procedures that encourage compatible stimulus control topographies and relations are designed. Such a procedure needs to demonstrate that the animal can make both successive and simultaneous discriminations between all of the stimuli involved and control for stimulus location variables. Moreover, baseline training procedures should ensure consistent *select* and/or *reject* controlling relations. One possibility is to intermix identity matching trials with arbitrary ones from the onset of baseline training. To minimize or eliminate control by location, one could use a successive matching procedure or a procedure in which samples and comparisons are presented in many locations throughout training. Animals trained in this manner may be more likely to show symmetry than those trained similarly, but without identity training or without intermixed identity training. Additional procedures can also be employed to determine both the presence and absence of *select* and *reject* controlling relations between the stimuli, and even to bias the subject toward *select* or *reject* control. These ideas are testable and will bring us a step closer to understanding the nature and possibility of symmetrical relations in nonhumans.

References

- Arcediano, F., Escobar, M., & Miller, R.R. (2003). Temporal integration and temporal backward associations in human and nonhuman subjects. *Learning & Behavior*, 31, 242-256.
- Asch, S.E., & Ebenholtz, S.M. (1962). The principle of associative symmetry. *Proceedings of the American Philosophical Society*, 106, 135-163.
- Barnet, R.C. & Miller, R.R. (1996). Second-order excitation mediated by a backward conditioned inhibitor. *Journal of Experimental Psychology: Animal Behavior Processes*, 22, 279-296.
- Barros, R.S., Galvão, O.F., & McIlvane, W.J. (2002). Generalized identity matching-to-sample in Cebus apella. *The Psychological Record*, 52, 441-460.
- Barros, R. S., Galvão, O. F., & Fontes, J. C. S. (1996). Un teste de simetria treino de discriminacoes condicionais de posicao com macaco "Ateles paniscus paniscus. *Acta Comportamentalia*, 4, 181-204.
- Bartling, C.A., & Thompson, P. (1977). Encoding specificity: Retrieval asymmetry in the recognition failure paradigm. *Journal of Experimental Psychology: Human Learning & Memory*, 3, 690-700.
- Bunch, M.E., & Lund, W.R. (1932). An experiment on backward associations in animal learning. *Journal of Comparative Psychology*, 13, 143-156.
- Bunsey, M. & Eichenbaum, H. (1996). Conservation of hippocampal memory function in rats and humans. *Nature*, 379,

255-257.

- Carr, H.A., & Freeman, A.S. (1919). Time relationships in the formation of associations. *Psychological Review*, 26, 465-473.
- Carr, D., Wilkinson, K. M., Blackman, D., & McIlvane, W. J. (2000). Equivalence classes in individuals with minimal verbal repertoires. *Journal of the Experimental Analysis of Behavior*, 74, 101-114.
- Carrigan, P. F. & Sidman, M. (1992). Conditional discrimination and equivalence relations: A theoretical analysis of control by negative stimuli. *Journal of the Experimental Analysis of Behavior*, 58, 183-204.
- Coutu, E.W. (1966). Associative asymmetry in paired associates. *Psychonomic Science*, 5, 389-390.
- D'Amato, M.R., Salmon, D.P., Loukas, E., & Tomie, A. (1985). Symmetry and transitivity of conditional relations in monkeys (*cebus apella*) and pigeons (*columba livia*). *Journal of the Experimental Analysis of Behavior*, 44, 35-47.
- Delamater, A.R., LoLordo, V.M., & Sosa, W. (2003). Outcome-specific conditioned inhibition in Pavlovian backward conditioning. *Learning & Behavior*, 31, 393-402.
- Devany, J. M., Hayes, S. C., & Nelson, R. O. (1986). Equivalence class formation in language-able and language-disabled children. *Journal of the Experimental Analysis of Behavior*, 46, 243-257.
- Dixon, M. H., & Dixon, L.S. (1978). The nature of standard control in children's matching-to-sample. *Journal of the Experimental Analysis of Behavior*, 30, 205-212.
- Dorcas, M.D. (1932). The establishing of backward associations in forward learning of the maze by albino rats. *Journal of Comparative Psychology*, 13, 11-18.
- Dube, W. V. & McIlvane, W. J. (1996). Some implications of a stimulus control topography analysis for emergent stimulus classes. In T. R. Zentall & P. M. Smeets (Eds.), *Stimulus class formation in humans and animals* (pp. 197-218). Amsterdam, NL: Elsevier.
- Dugdale, N., & Lowe, C.F. (2000). Testing for symmetry in the conditional discriminations of language-trained chimpanzees. *Journal of the Experimental Analysis of Behavior*, 73, 5
22. Ebbinghaus, H. (1885). *Memory* (Translated H.A. Ruger and C.E. Bussenius), New York, Teachers College, 1913.
- Eikeseth, S. & Smith, T. (1992). The development of functional and equivalence classes in high-functioning autistic children: The role of naming. *Journal of the Experimental Analysis of Behavior*, 58, 123-133.
- Fields, L., Adams, B.J., Brown, J.L., & Verhave, T. (1993). The generalization of emergent relations in equivalence classes: Stimulus substitutability. *The Psychological Record*, 43, 235-254.
- Frank, A. J., & Wasserman, E. A. (2005). Associate symmetry in the pigeon after successive matching-to-sample training. *Journal of the Experimental Analysis of Behavior*, 84, 147-165.
- Garcia, A., & Benjumea, S. (2006). The emergence of symmetry in a conditional discrimination task using different responses as proprioceptive samples in pigeons. *Journal of the Experimental*

- Analysis of Behavior*, 86, 65-80.
- Gray, L. (1966). Backward association in pigeons. *Psychonomic Society*, 4, 333-334.
- Goulart, P. R. K., Mendonca, M. B., Barros, R. S., Galvao, O. F., & McIlvane, W. J. (2005). A note on select-and reject-controlling relations in the simple discrimination of capuchin monkeys (*Cebus apella*). *Behavioural Processes*, 69, 295-302.
- Hayes, S. C. (1989). Nonhumans have not yet shown stimulus equivalence. *Journal of the Experimental Analysis of Behavior*, 51, 385-392.
- Hayes, S. C., Barnes-Homes, D., & Roche, B. (2001). Relational frame theory: A précis. In S. C. Hayes, D. Barnes-Homes, & B. Roche (Eds). *Relational Frame Theory: A Post-Skinnerian Account of Human Language and Cognition* (pp. 141-154). New York: Kluwer Academic/Plenum.
- Hayes, S. C., Gifford, E. V., & Wilson, K. G. (1996). Stimulus classes and stimulus relations: arbitrary applicable relational responding as an operant. In T. R. Zentall & P. M. Smeets (Eds.) *Stimulus Class Formation in Humans and Animals* (pp. 279-299).
- Hearst, E. (1989). Backward associations: Differential learning about stimuli that follow the presence versus the absence of food in pigeons. *Animal Learning & Behavior*, 17, 280-290.
- Herman, L.M., & Gordon, J.A. (1974). Auditory delayed matching in the bottlenose dolphin. *Journal of the Experimental Analysis of Behavior*, 21, 19-26.
- Herman, L.M., Hovancik, J.R., Gory, J.D., & Bradshaw, G.L. (1989). Generalization of visual matching by a bottlenose dolphin (*Tursiops truncatus*): Evidence for invariance of cognitive performance with visual and auditory materials. *Journal of Experimental Psychology: Animal Behavior Processes*, 15, 124-136.
- Hogan, D.E. & Zentall, T.R. (1977). Backward associations in the pigeon. *American Journal of Psychology*, 90, 3-15. Holmes, P. W. (1979). Transfer of matching performance in pigeons. *Journal of the Experimental Analysis of Behavior*, 31, 103-114. Horne, P.J. & Lowe, C.F. (1996). On the origins of naming and other symbolic behavior. *Journal of the Experimental Analysis of Behavior*, 65, 185-242.
- Iversen, I. (1997). Matching-to-sample performance in rats: A case of mistaken identity? *Journal of the Experimental Analysis of Behavior*, 68, 27-47.
- Iversen, I., Sidman, M., & Carrigan, P. (1986). Stimulus definition in conditional discriminations. *Journal of the Experimental Analysis of Behavior*, 45, 297-304.
- Johnson, C., & Sidman, M. (1993). Conditional discrimination and equivalence relations: control by negative stimuli. *Journal of the Experimental Analysis Behavior*, 59, 333-347.
- Kahana, M.J. (2002). Associative symmetry and memory theory. *Memory & Cognition*, 30, 823-840.
- Kastak, C.R., Schusterman, R.J., & Kastak, D. (2001). Equivalence classification by California sea lions using class-specific reinforcers. *Journal of the Experimental Analysis of Behavior*, 76, 131-158.
- Katz, J. S., & Wright, A. A. (2006). Same/different abstract-concept

- learning by pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 32, 80-86.
- Keith-Lucas, T., & Guttman, N. (1975). Robust single-trial delayed backward conditioning. *Journal of Comparative and Physiological Psychology*, 88, 468-476.
- Kendall, S. B. (1983). Tests for mediated transfer in pigeons. *The Psychological Record*, 33, 245-256.
- Kuno, H., Kitadate, T., & Iwamoto, T. (1994). Formation of transitivity in conditional matching to sample by pigeons. *Journal of the Experimental Analysis of Behavior*, 62, 399-408.
- Levy, C.M., & Nevill, D.D. (1974). BA learning as a function of degrees of AB learning. *Journal of Experimental Psychology*, 102, 327-329.
- Lionello, K.M. & Urcuioli, P.J. (1998). Control by sample location in pigeons' matching to sample. *Journal of the Experimental Analysis of Behavior*, 70, 235-251.
- Lionello-DeNolf, K.M. & Urcuioli, P.J. (2000). Transfer of pigeons' matching to sample to novel sample locations. *Journal of the Experimental Analysis of Behavior*, 73, 141-161.
- Lionello-DeNolf, K.M., & Urcuioli, P.J., (2002). Stimulus control topographies and test of symmetry in pigeons. *Journal of the Experimental Analysis of Behavior*, 78, 467-495.
- Lipkens, R., Kop, P.F.M., & Matthijs, W. (1988). A test of symmetry and transitivity in the conditional discrimination performances of pigeons. *Journal of the Experimental Analysis of Behavior*, 49, 395-409.
- Lockhart, R.S. (1969). Retrieval asymmetry in the recall of adjectives and nouns. *Journal of Experimental Psychology*, 79, 12-17.
- Mandler, G., Rabinowitz, J.C., Simon, R.A. (1981). Coordinate organization: The holistic representation of word pairs. *American Journal of Psychology*, 92, 209-222.
- McIlvane, W.J., Serna, R.W., Dube, W.V., & Stromer, R. (2000). Stimulus control topography coherence and stimulus equivalence: Reconciling test outcomes with theory. In J. Leslie & D.E. Blackman (Eds.). *Experimental and applied analysis of human behavior*. (pp. 851-110). Reno, NV: Context Press.
- McIntire, K.D., Cleary, J., & Thompson, T. (1987). Conditional relations by monkeys: Reflexivity, symmetry, and transitivity. *Journal of the Experimental Analysis of Behavior*, 47, 279-285.
- Moscovitch, A., & LoLordo, V. M. (1968). Role of safety in the Pavlovian backward fear conditioning procedure. *Journal of Comparative and Physiological Psychology*, 68, 673-678.
- Murdock, B.B. (1962). The serial position effect of free recall. *Journal of Experimental Psychology*, 64, 482-488.
- Murdock, B.B. (1966). Forward and backward associations in paired associates. *Journal of Experimental Psychology*, 71, 732-737.
- Nakagawa, E. (2001). Acquired equivalence of cues in learning a matching-to-sample task by rats. *The Psychological Record*, 51, 453-467.
- Oden, D.L., Thompson, R.K., & Premack, D. (1988). Spontaneous transfer of matching by infant chimpanzees. *Journal of Experi-*

- mental Psychology: Animal Behavior Processes*, 14, 140-145.
- Pavlov, I. P. (1928). *Lectures on Conditioned Reflexes*. New York: International Publishers.
- Razran, G. (1956). Backward conditioning. *Psychological Bulletin*, 53, 55-69.
- Richards, R.W. (1988). The question of bidirectional associations in pigeons' learning of conditional discrimination tasks. *Bulletin of the Psychonomic Society*, 26, 577-579.
- Rodewald, H.K. (1974). Symbolic matching-to-sample by pigeons. *Psychological Reports*, 34, 987-990.
- Santos, J.R., Barros, R.S., & Galvão, O. (2003). Symmetry in cebus apella. Paper presented at the 29th Annual meeting of the Association for Behavior Analysis, San Francisco, CA.
- Saunders, K. J., & Spradlin, J. E. (1989). Conditional discrimination in mentally retarded adults: The effects of training the component simple discriminations. *Journal of the Experimental Analysis of Behavior*, 52, 1-12.
- Savage-Rumbaugh, E. S., Rumbaugh, D. M., Smith, S. T., & Lawson, J. (1980). Reference: the linguistic essential. *Science*, 210, 922-925.
- Schusterman, R.J. & Kastak, D. (1993). A California sea lion (*zalophus californianus*) is capable of forming equivalence relations. *The Psychological Record*, 43, 823-839.
- Sidman, M. (1990). Equivalence relations: Where do they come from? In D.E. Blackman & H. Lejeune (Eds.) *Behavior analysis in theory and practice: Contributions and controversies*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Sidman, M. (1994). *Equivalence relations and behavior: A research story*. Boston, MA: Authors Cooperative, Inc.
- Sidman, M. (2000). Equivalence relations and the reinforcement contingency. *Journal of the Experimental Analysis of Behavior*, 74, 127-146.
- Sidman, M., Cresson, O. Jr., & Willson-Morris, M. (1974). Acquisition of matching to sample via mediated transfer. *Journal of the Experimental Analysis of Behavior*, 22, 261-273.
- Sidman, M., Rauzin, R., Lazar, R., Cunningham, S., Tailby, W., & Carrigan, P. (1982). A search for symmetry in the conditional discriminations of rhesus monkeys, baboons, and children. *Journal of the Experimental Analysis of Behavior*, 37, 23-44.
- Sidman, M. & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior*, 37, 5-22.
- Siegel, S., & Domjan, M. (1971). Backward conditioning as an inhibitory procedure. *Learning and Motivation*, 2, 1-11.
- Spetch, M.L., Wilkie, D.M., & Pinel, J.P.J. (1981). Backward conditioning: A reevaluation of the empirical evidence. *Psychological Bulletin*, 89, 163-175.
- Spradlin, J.E., Cotter, V.W., & Baxley, N. (1973). Establishing a conditional discrimination without direct training: A study of transfer with retarded adolescents. *American Journal of Mental Deficiency*, 77, 566-566.
- Stoddard, L. T., & Sidman, M. (1971). The removal and restoration of stimulus control. *Journal of the Experimental Analysis of Behavior*, 16, 143-154.
- Stromer, R., & Osborne, J. G. (1982). Control of adolescents' arbitrary matching-to-sample relations. *Journal of the Ex-*

- perimental Analysis of Behavior*, 37, 329-348.
- Tait, R.W. & Saladin, M.E. (1986). Concurrent development of excitatory and inhibitory associations during backward conditioning. *Animal Learning & Behavior*, 14, 133-137.
- Tedford, W.H. & Hazel, J.S. (1973). Stimulus location as a factor in associative symmetry. *Journal of Experimental Psychology*, 101, 189-190.
- Tomonaga, M., Matsuzawa, T., Fujita, K., & Yamamoto, J. (1991). Emergence of symmetry in a visual conditional discrimination by chimpanzees (pan troglodytes). *Psychological Reports*, 68, 51-60.
- Urcuioli, P. J. (in press). Associative symmetry, "anti-symmetry", and a theory of pigeons' equivalence-class formation. *Journal of the Experimental Analysis of Behavior*.
- Urcuioli, P. J., & DeMarse, T. B. (1997). Further tests of response-outcome associations in differential-outcome matching-to-sample. *Journal of Experimental Psychology: Animal Behavior Processes*, 23, 171-182.
- Urcuioli, J. P., & Honig, W. K. (1980). Control of choice in conditional discriminations by sample-specific behaviors. *Journal of Experimental Psychology: Animal Behavior Processes*, 6, 251-277.
- Urcuioli, P. J., Michalek, S., & Lionello-DeNolf, K. M. (2006). The continuing search for symmetry in pigeons. Presented at the 47Annual Meeting of the Psychonomic Society, Houston, TX.
- Vaughan, W. (1988). Formation of equivalence sets in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 14, 36-42.
- Wagner, A.R., & Terry, W.S. (1975). Backward conditioning to a CS following an expected vs. a surprising UCS. *Animal Learning & Behavior*, 3, 370-374.
- Weinstein, B. The evolution of intelligent behavior in rhesus monkeys. *Genetic Psychology Monographs*, 31, 3-48.
- Wollen, K. A., Fox, R. A., & Lowry, D.H. (1970). Variations in asymmetry as a function of degree of forward learning. *Journal of Verbal Learning and Verbal Behavior*, 86, 416-419.
- Yamamoto, J. & Asano, T. (1995). Stimulus equivalence in a chimpanzee (pan troglodytes). *The Psychological Record*, 45, 3-21.
- Zentall, T. R., Edwards, C. A., Moore, B. S., & Hogan, D. E. (1981). Identity: the basis for both matching and oddity learning in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 7, 70-86.
- Zentall, T. R., Sherburne, L. M., & Steirn, J. N. (1992). Development of excitatory backward associations during the establishment of forward associations in a delayed conditional discrimination by pigeons. *Animal Learning & Behavior*, 20, 199-206.

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