1-2014

# Associative Concept Learning in Animals

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## Recommended Citation

Zentall, Thomas R.; Wasserman, Edward A.; and Urcuioli, Peter J., "Associative Concept Learning in Animals" (2014). *Department of Psychological Sciences Faculty Publications.* Paper 67.
http://dx.doi.org/http://dx.doi.org/10.1002/jeab.55

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## Abstract

Nonhuman animals show evidence for three types of concept learning: perceptual or similarity-based in which objects/stimuli are categorized based on physical similarity; relational in which one object/stimulus is categorized relative to another (e.g., same/different); and associative in which arbitrary stimuli become interchangeable with one another by virtue of a common association with another stimulus, outcome, or response. In this article, we focus on various methods for establishing associative concepts in nonhuman animals and evaluate data documenting the development of associative classes of stimuli. We also examine the nature of the common within-class representation of samples that have been associated with the same reinforced comparison response (i.e., many-to-one matching) by describing manipulations for distinguishing possible representations. Associative concepts provide one foundation for human language such that spoken and written words and the objects they represent become members of a class of interchangeable stimuli. The mechanisms of associative concept learning and the behavioral flexibility it allows, however, are also evident in the adaptive behaviors of animals lacking language.

Key words: associative concepts, equivalence, within-class representation, many-to-one matching

# Associative Concept Learning in Animals

Evolution has prepared animals to survive and to reproduce in predictable environments by predisposing them to perform particular behaviors in specific contexts. Birds are equipped to build nests and to tend eggs, and cats are prepared to find a mate and to care for their young. Nevertheless, such predisposed behaviors are often insufficient to ensure survival. Learning about the predictive relations between events and about the consequences of behavior each give animals additional, indispensable means to adapt to and survive in complex and ever-changing environments. Primary stimulus generalization (Hull, 1943; see also Honig & Urcuioli, 1981) expands these adaptive processes by allowing animals to respond similarly and appropriately to new events that resemble past events. Yet, even these processes may not be sufficiently broad to permit animals to benefit maximally from past experience. Adaptation and survival can be enhanced still further by categorizing diverse experiences on the basis of “similar meaning” – i.e., on the basis of common associations (e.g., Schusterman, Reichmuth, & Kastak, 2000).

In this paper, we will explore the mechanisms and functions of behavior that arise, not from physical resemblance (as in the case of primary stimulus generalization), but from associations with common experiences (what Hull, 1939, 1943 called secondary stimulus generalization). Our review will underscore the variety of those experiences that can generate associatively equivalent stimuli. It will also adopt a “common representation” perspective for some of the phenomena we describe, in order to illustrate how this perspective has guided systematic research into their controlling variables.

Early on, Miller and Dollard (1941) recognized how categorizing diverse experiences contributes to adaptation:

> It is sometimes desirable … to be able to learn to generalize from one situation to another despite the fact that these situations have no external cues in common. For example, the various enemies surrounding a tribe may not be distinguished by any single physical cue in common; that is, an enemy may be just as similar to members of the tribe as he is to other enemies. Nevertheless, it may be desirable … to learn to generalize a given response, say avoidance, to all enemies.
>
> Such generalization can be mediated by response-produced cues…. The tribesman may learn … to respond to each of a number of people with the same word, “enemy.” … This verbal response produces a cue which is common to all these enemies. Once the response is learned, the cue which it produces may mediate the transfer of other responses. The tribesman may transfer his various responses of retreating, threatening, fighting, etc., learned as reactions to one enemy to any other person whom he also calls an enemy. (pp. 74-75.)

Thus, being able to group objects and events into distinct classes – the essence of concepts (Keller & Schoenfeld, 1950)  allows one to transfer what one has learned about a particular object or event to new objects and events (see also Urcuioli, 2013). In a similar vein, Murphy (2002) proposed that “Concepts are the glue that holds our mental life together … in that they tie our past experiences together to our present interactions with the world, and because the concepts themselves are connected to our larger knowledge structures” (Murphy, 2002, p. 1).

Although human concept learning has been extensively studied (see e.g., Murphy’s 2002 volume *The Big Book of Concepts*), comparative analyses of conceptual behavior in humans and other animals has received considerably less attention, at least in some quarters (e.g., *The Big Book of Concepts* has no references to research on animal conceptual behavior). A major contributing factor to this oversight is the lack of a common terminology among the major research traditions (e.g., see Hampton, 1999) studying the broad topic of concepts, a key notion for which there has been no generally accepted definition in psychology (see, for example, Chater & Heyes, 1994; Delius, 1994; Huber, 1999; Lea, 1984; Medin & Smith, 1984; Schank, Collins, & Hunter, 1986; Thompson, 1995; Wasserman & Bhatt, 1992; Zentall, Galizio, & Critchfield, 2002). But, the absence of a broadly accepted definition has not deterred research aimed at understanding the variety of ways in which objects and events can be grouped together and the benefits that this grouping can convey. Again, Miller and Dollard (1941) used a rather compelling historical example to illustrate one possible origin and its benefits:

> According to the traditional story, Newton was started on his application of the principle of gravity to celestial mechanics by generalizing a response from a falling apple to the moon. An apple and the moon are different in many respects, but are similar in that both are bodies possessing mass. Newton presumably responded on the basis of that similarity. The response generalized was a verbal one "pulled toward the earth." (p. 77).

The most important kinds of concept learning for which there is considerable behavioral evidence in nonhuman animals fall into three categories. The first, *perceptual or similarity-based concept learning,* is perhaps the most familiar form in humans; it involves the sorting of stimuli, like trees or chairs, that share one or more physical properties into classes. Perceptual similarity also guides the responses of nonhuman animals as it does for humans (see e.g., Wasserman & Bhatt, 1992; Wasserman, Kiedinger, & Bhatt, 1988), thus demonstrating that this basic kind of conceptual behavior is not unique to people. In both human and nonhuman animals, the development of perceptual concepts appears to be largely under the control of the behavioral principles of primary stimulus generalization and discrimination (e.g., Mackintosh, 2000; Pearce, 1988; Wasserman et al., 1988).

The second, *relational concept learning*, involves the relationship between (or among) objects. One of the most important and interesting examples is sameness/difference, the ability to report that one object is either the same as or different from another (Wasserman & Castro, 2012, Wright & Katz, 2006). Although we humans have extensive practice with relational concepts and they are an integral part of our language, it is clear that under proper conditions, animals too demonstrate a considerable ability to use relational concepts (Katz, Wright, & Bachevalier, 2002; Wasserman & Young, 2010; Zentall, Edwards, Moore, & Hogan 1981).

The third, *associative concept learning* involves the ability to form categories comprising arbitrary stimuli that are interchangeable with one other in new contexts (e.g., Dougher & Markham, 1994) because of their prior association with each other or with a common event, response, or outcome (in humans, e.g., an object and the word for that object). These concepts are especially interesting because, as Miller and Dollard (1941) noted, they are not based on any particular physical property or inherent relation among the members of the class, but develop through experience. In relational frame theory (e.g., Barnes, 1994; Hayes, Barnes-Holmes, & Roche, 2001), they are examples of “arbitrary applicable relational responding,” the adjective “arbitrary” indicating that physical resemblance is not required.

The general nature and formation of categories is also relevant to another tripartite organizational scheme in the realm of human conceptual behavior comprising: subordinate concepts, basic-level concepts, and superordinate concepts (e.g., Rosch & Mervis, 1975). This familiar scheme proposes that human language concepts can be located at three distinctly different levels, depending on the relative extent of intraclass and interclass stimulus similarity. A basic-level concept, like *chair,* enjoys the advantage of high intraclass similarity and low interclass similarity. A subordinate concept, like *dining chair,* is more difficult to establish because, relative to a basic-level concept, it entails much higher interclass similarity. A superordinate concept, *like furniture,* is even more difficult to establish because, relative to a basic-level concept, it entails much lower intraclass similarity, comprising such strikingly different stimuli as chairs, tables, lamps, rugs, and mirrors (see, for example, Lazareva, Freiburger, & Wasserman, 2004). Superordinate concepts can clearly be seen to arise from what we are terming associative classes or concepts, whereas subordinate and basic-level concepts clearly arise from the more primitive perceptual mechanisms of discrimination and primary stimulus generalization.

Our review focuses on associative concept learning, given its long-recognized importance in the comparative analyses of human and animal behavior (e.g., Lea, 1984) and because the topics of perceptual and relational concept learning have received extensive treatment elsewhere (e.g., Herrnstein, 1984, 1985; Katz, Wright & Bodily, 2007; Mackintosh, 1995; Wasserman & Astley, 1994; Wright & Katz, 2006). Although we adopt a representational viewpoint in parts of our paper, we will not provide a systematic evaluation of the pros and cons of such a perspective vis-á-vis others. Instead, our goal is to illustrate the wide-ranging phenomena encompassed by associative concept learning and to systematically consider their origins.

## *Associative Classes*

In contrast to perceptual classes (including subordinate and basic-level concepts), which share common physical characteristics, the basis for the common response to members of an associative class (including superordinate concepts) is altogether arbitrary and must be acquired through training (Hall, 1996; Jitsumori, 2004). The very quality of being arbitrary provides associative classes with a flexibility that can readily be seen in the extent to which they are used in human language (e.g. Hayes et al. 2001). An associative class may consist of an object and its various symbolic representations. For example, the object itself, chair, the spoken word “chair,” and the written word CHAIR are all members of a common associative class.

A critical characteristic of an associative class lies in the fact that one member of the class can *represent* the others – i.e., class members are, within limits, interchangeable with one another. So, what an individual learns about one member of the class can instantly and effectively transfer to other members of the class without any further training. For example, to a young child, the word “dog” may represent an animal having the properties ‘friendly,’ ‘wags its tail,’ and ‘licks one’s face.’ But, if the child later has an unhappy experience with a dog that growls and lunges toward the child in the apparent defense of its territory, then the child may add to its representation of *dog* the attribute ‘may be aggressive.’ If the animal and the word “dog” belong to the same associative class, then without further training, the word “dog” may elicit some of the same anxiety that has been newly associated with the animal itself (e.g., Dymond et al., 2011).

As another example, consider that children routinely learn to call socks, belts, pants, and hats “clothing.” This associative process, which probably proceeds by rote memorization, can be a very protracted affair. Yet, when children later learn that “apparel” is a synonym for “clothing,” they are instantly able to call socks, belts, pants and hats items of "apparel," and do not need to explicitly learn that each article is a member of the new category.

Hull (1939) recognized the importance of such associative classes and proposed secondary stimulus generalization as a means of accounting for how classes of disparate objects/stimuli could develop. He suggested that explicitly learning the same response to a set of disparate stimuli would generate an equivalence among them, so that new behavior trained to a subset of the stimulus class would immediately generalize to the remaining, untrained class members (see, for example, Lowe, Horne, & Hughes, 2005; Molet, Stagner, Miller, Kasinski, & Zentall, 2013; Spradlin, Cotter, & Baxley, 1973; Urcuioli & Lionello-DeNolf, 2001).

Miller and Dollard (1941) called this process the *acquired equivalence of cues* to capture the idea that, via learning, disparate but "equivalent" cues become members of a common class that are now substitutable for one another. The term "emergent relation" broadly refers to the ability of a member of such a stimulus class to "… evoke a reaction … with which it has never been associated" (Hull, 1939, p. 9; see also Shipley, 1935). Indeed, demonstrating emergent or derived relations is the standard way to establish acquired equivalence specifically and associative classes more generally (e.g., Astley & Wasserman, 1998, 1999; Lazareva, Freiburger, & Wasserman, 2004; Roberts & Mazmanian, 1988; Wasserman, DeVolder, & Coppage, 1992; Vonk & McDonald, 2004).

Our review of research into associative concept learning begins with a consideration of the differential outcomes effect – a key phenomenon in which otherwise unrelated stimuli are bound into functional categories because of their pairing with a common outcome.

## *Establishing Associative Classes: The Differential Outcomes Effect*

In a conditional discrimination, such as matching-to-sample, an initial or sample stimulus indicates which of two (or more) comparison stimuli is correct. For example, if the sample is a red light, then the vertical line is correct, whereas if the sample is a green light, then the horizontal line is correct. In matching-to-sample, when a correct response to each of two comparison stimuli is followed by a different outcome (e.g., food following a correct response to one comparison, water following a correct response to the other, a so-called *differential outcomes* procedure), acquisition of the task is often faster than a control condition involving nondifferential outcomes (Trapold, 1970; see also Alling, Nickel, Poling, 1991; Estévez , 2005; Urcuioli, 2005). Furthermore, with differential outcomes, inserting a delay between the offset of the sample stimulus and the onset of the comparison stimuli typically results in higher delayed matching accuracies than for a nondifferential outcomes condition (Brodigan & Peterson, 1976; see also Hochhalter et al., 2000).

In the animal literature, the differential outcomes effect has been interpreted as evidence that outcome expectancies conditioned to the sample stimuli associated with the different outcomes acquire cue properties over and above the samples themselves (Overmier & Linwick, 2001; Peterson, 1984; see also Overmier & Lawry, 1979). More important for the present purposes is that different stimuli signaling the same outcome become functionally equivalent.

For example, Peterson trained pigeons on a conditional discrimination involving differential outcomes of food for a correct response following a sample of one color and a tone for a correct response following a sample of a different color. On other trials, there was single stimulus training in which one shape was followed by food and another shape was followed by the tone. When the pigeons were later tested on trials in which the shapes replaced the colors as samples in the conditional discrimination, positive transfer was found relative to control groups for which differential outcomes were not associated with both pairs of stimuli. Similarly, following training with two identity matching tasks (one involving colors, the other shapes) using differential outcomes of two different kinds of grain (e.g., corn following correct responses to one color and wheat following correct responses to the other; corn following correct responses to one shape and wheat following correct responses to the other), positive transfer was observed when the samples from the two tasks were subsequently interchanged (Edwards, Jagielo, Zentall, & Hogan, 1982). Moreover, these transfer results closely resembled similar findings observed in humans (e.g., Dube et al., 1989; Maki, Overmier, Delos, & Gutman, 1995).

In behavior analysis, results such as these have been viewed in terms of stimulus class formation – viz., stimuli associated with the same reinforcing outcome become members of the same class (e.g., Dube et al., 1989; Urcuioli, 2013). In the animal conditioning and cognition literatures, however, researchers have asked: "What *specific* cues mediate these transfer effects?" One possibility is differential sample responding arising from the sample-outcome associations, given that differential sample responding is known to control comparison choice in other paradigms (Urcuioli & Honig, 1980). In fact, Urcuioli and DeMarse (1994) have reported evidence that cues produced by differential sample responding was sufficient to mediate transfer when samples from a differential-outcomes conditional discrimination are replaced with other stimuli associated (off baseline) with differential sample responding, but with nondifferential outcomes.

In most demonstrations of the differential outcomes effect in nonhuman animals, the different outcomes have differed in quantitative or qualitative value, for example, 1 versus 5 pellets of food (Carlson & Wielkiewicz, 1972), 1.0 versus 0.2 probability of a food outcome for a correct choice (DeLong & Wasserman, 1981; Kruse & Overmier, 1982), food versus water (Honig, Matheson, & Dodd, 1984), or two different kinds of grain (e.g., wheat versus corn; Edwards et al., 1982). Such differences may encourage differential sample behavior.

Yet, even if overtly different sample responding does not develop in a differential outcomes task, the fact that the outcomes are likely to differ in their hedonic value (i.e., one is typically preferred over the other) may lead to differences in the hedonic values of the samples that predict those outcomes. For example, Astley, Peissig, and Wasserman (2001; also see Astley & Wasserman, 1998, 1999) found transfer of training between samples associated with one set of differential outcomes (1 vs. 5 pellets) and other samples associated with another set of differential outcomes (1- vs. 15-s delay of reinforcement). The sole basis for the transfer would appear to have been the differential hedonic value of the outcomes (i.e., 5 pellets and a 1-s delay of reinforcement would have been relatively “good” outcomes, whereas 1 pellet and a 15-s delay of reinforcement would have been relatively “poor” outcomes).

Similar transfer effects were found by Friedrich and Zentall (2010) using differential responding (5 pecks vs. 20 pecks) to one pair of comparison stimuli given one pair of samples and different probabilities of reinforcement (0.2 reinforcement vs. 0.8 reinforcement) following correct responses to a different pair of comparison stimuli given a different pair of samples. Thus, pigeons showed transfer of training when the samples associated with 20 or 5 comparison-stimulus pecks were now paired, respectively, with comparisons associated with 0.2 and 0.8 reinforcement and vice versa. Specifically, the low probability of reinforcement sample was interchangeable with the high fixed-ratio sample and the high probability of reinforcement sample was interchangeable with the low fixed-ratio sample (cf. Azrin, 1961; Flora, 1969).

Astley et al. (2001; also see Astley & Wasserman, 1999) noted that differences in the hedonic value of different outcomes affected how pigeons responded to the sample stimuli themselves, although the authors reported evidence that their pigeons' differential response rates did not accurately predict their comparison choice behavior. More directly, Frank and Wasserman (2005b) found that differential responding (a required low rate of pecking vs. a required high rate of pecking) to stimuli associated with similar outcomes did not transfer to comparison stimuli that were associated with differential outcomes (1 vs. 9 pellets of food) and that supported differential responding to other sample stimuli.

Zentall and Sherburne (1994) attempted to control for differential sample responding in a differential outcomes procedure with pigeons by periodically inserting reinforced presentations of the sample to which fewer responses were made. In spite of the fact that sample response rates were now effectively equated, a strong differential outcomes effect was nevertheless obtained. Thus, it seems more likely that comparison choice was controlled by the anticipation of outcomes with different hedonic values than by overtly different sample responding.

Equating hedonic value can be accomplished by scheduling different arbitrary cues ending in the same reinforcer. To do so, Miller, Friedrich, Narkavic, and Zentall (2009) trained pigeons on a matching task in which a blue houselight followed correct responses to one comparison stimulus and a tone followed correct responses to the other comparison stimulus prior to food presentations. When pigeons were then tested with delays inserted between the samples and the comparison stimuli, matching accuracy was significantly higher for the differential houselight-outcomes group than for a control group in which the houselights were uncorrelated with the sample stimuli. Thus, samples and correct comparisons paired with arbitrary cues preceding a common food outcome facilitate matching performance, suggesting the possibility of an associative class involving the sample, the correct comparison stimulus, and the arbitrary outcome (see also Fedorchak & Bolles, 1985; Kelly & Grant, 2001).

### *Establishing Associative Classes: Many-To-One Mapping*

*Transfer of training.* Associative classes can be established without differential outcomes simply by mapping two or more sample stimuli onto the same reinforced comparison stimulus in a conditional discrimination, a procedure called many-to-one (MTO) or comparison-as-node matching (Saunders, Saunders, Williams, & Spradlin, 1993; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989; Wasserman et al., 1992). For example, choosing a set of vertical lines by pigeons might be reinforced if the sample is either a red light or a set of vertical lines, whereas choosing a set of horizontal lines might be reinforced if the sample is either a green light or a set of horizontal lines. Although the red and vertical-lines sample are separately paired with the vertical-lines comparison, and similarly for the other two samples paired with the horizontal-lines comparison, their potential membership in a common associative class can be evaluated by an independent test. As in the case of the child learning new characteristics of a dog, and then demonstrating transfer of such new learning to the word “dog,” we can ask if new comparison choices (e.g., choosing between a large circle versus a small dot) acquired by a pigeon for two of the original samples (e.g., red and green) would transfer to the two remaining samples (i.e., vertical and horizontal lines). The design of this experiment is presented in Table 1 (Urcuioli et al., 1989, Experiment 2).

In fact, most pigeons in this experiment showed evidence of transfer (i.e., of emergent relations between the line-orientation samples from original training and the comparisons from interim training, see Figure 1). In other words, most pigeons behaved as though the hue and line samples that occasioned the same reinforced comparison choice in MTO matching belonged to the same associative class by preferentially selecting the “class-consistent” comparisons on the line-sample test trials. The results from experiments with human participants (Delamater & Joseph, 2000; Molet et al., 2012; Wasserman & DeVolder, 1993) and from conceptually similar experiments with rats (Honey & Hall, 1989) have supported similar conclusions.

Again, what specific “cue” (cf. Miller & Dollard, 1941) could be the basis of these emergent stimulus relations? Urcuioli et al. (1989), working within the animal memory literature, suggested that pigeons had commonly represented or “coded” (cf. Lawrence, 1963) samples that were associated with the same comparison stimulus. In general terms, MTO training altered the way in which the organisms implicitly responded to those samples. To test this hypothesis, Zentall, Urcuioli, and their associates conducted a series of experiments to obtain convergent evidence regarding the existence and nature of such common representation(s).

*Delayed matching tests.* Evidence consistent with the development of common representations was obtained by comparing retention functions when a delay was inserted between the sample and comparison stimuli. Typically, hue-sample retention functions for pigeons are generally much shallower than line-sample retention functions (i.e., as the delay increases, matching accuracy is better maintained when the samples are hues) (Farthing, Wagner, Gilmour, & Waxman, 1977; Urcuioli et al., 1989; Wasserman, Bhatt, Chatlosh, & Kiedinger, 1987; Zentall, Urcuioli, Jagielo, Jackson-Smith, 1989). However, the corresponding hue-sample and line-sample retention functions following MTO training are quite similar (i.e., they have comparable slopes) (see Figure 2; Urcuioli et al., 1989, Experiment 1; Zentall et al., 1989), a result consistent with the hypothesis that samples associated with a common comparison stimulus are commonly represented.

*Interference/facilitation effects.* Another source of converging evidence for the establishment of associative classes following MTO matching training was reported by Zentall, Sherburne, and Urcuioli (1993; see also Lippa & Goldstone, 2001). Zentall et al. (1993) initially trained pigeons on MTO matching with hue and line samples after which two of the samples (the hues) from original training were associated with new comparison stimuli (cf. Table 1, Interim Training). Later, delays were inserted between the samples and comparisons on each trial, and training was continued until a high level of accuracy was achieved. On subsequent test trials, one or the other of the *remaining* samples from original training was presented during the retention interval, and accuracy was compared with that on control trials without a retention-interval stimulus (see Table 2).

For pigeons that quickly acquired the more difficult line-sample matching associations during MTO training, test-trial accuracy *increased* when the interpolated stimulus was associatively similar to the sample on that trial (i.e., the interpolated stimulus had been associated with the same comparison as the sample in MTO training). Conversely, accuracy was disrupted when the interpolated stimulus was incompatible with the sample stimulus on that trial (i.e., the interpolated stimulus had been associated with a comparison which was different from the sample in MTO training). Thus, if one inserts into the delay a sample formerly associated with the same comparison stimulus as the current sample, then it facilitates delayed matching accuracy, whereas if one inserts into the delay a sample formerly associated with a different comparison stimulus from the current sample, then it disrupts delayed matching accuracy.

*Sample discriminability tests.* If stimuli which are inherently dissimilar (hues and lines) are commonly represented by being associated with a common comparison stimulus, then requiring an explicit discrimination between them should be relatively difficult (cf. Hall, 1996; Meeter, Shohany, & Myers, 2009). To test this prediction, Kaiser, Sherburne, Steirn, and Zentall (1997) trained pigeons on a simple successive discrimination involving the four samples from MTO matching (see Table 3). When the samples that had been associated with the same comparison were both followed by reinforcement or were both followed by the absence of reinforcement, acquisition of the successive discrimination was more rapid than the condition in which those samples signaled different reinforcement contingencies (viz., one was followed by reinforcement and the other was not; see Figure 3). These results, too, are consistent with the common representation hypothesis.

*Partial- versus total-reversal tests.* Further evidence for an associative relation between samples occasioning the same comparison choice response comes from research involving partial versus total reversals (Zentall, Steirn, Sherburne, & Urcuioli, 1991; cf. Table 4). If such samples are commonly represented, then subsequently reversing the sample-comparison relations for just one pair of samples (e.g., the lines) should yield relatively slow reacquisition. More specifically, such a partial reversal ought to be slower than if all four sample-comparison relations are reversed (a total reversal), even though the latter involves twice as many reversed relations. The rationale for this prediction is that only the total reversal permits the hypothesized common representations between samples associated with the same comparison to remain intact (i.e., red and vertical samples would still be associated with a common response, as would green and horizontal samples).

The results of this experiment indicated that pigeons took longer to relearn the line-sample contingencies of the task when they alone were reversed than when they and the hue-sample contingencies were also reversed (see Figure 4). Interestingly, the same was *not* true for the hue-sample reversal. For this group, there was no retardation of reversal learning produced by reversing only two of the four sample-comparison associations. This behavioral asymmetry has theoretical implications (that will be described later) for the nature of the common sample representation that results from MTO training. For now, it should be noted that this asymmetry rules out a less interesting alternative account: namely, that total reversals are learned faster than partial reversals because the change in contingencies for the total reversal is less discriminable vis-a-vis original training than the change in contingencies for the partial reversal. If discriminating the change in reinforcement contingencies were solely responsible for the partial- versus total-reversal effect, then one would expect comparable retardation for the hue-sample partial reversal group and the line-sample partial reversal group.

The re-learning disadvantage of partial over total reversals can also be shown when training involves simple successive discriminations in which two stimuli (e.g., a red hue and a vertical line) are associated with reinforcement and two other stimuli (e.g., a green hue and a horizontal line) are associated with the absence of reinforcement. When the outcomes associated with only the line samples are reversed, acquisition of the reversal is slower than when the outcomes associated with hue samples are also reversed (Zentall et al., 1991, Exp. 2; see also Nakagawa, 1986).

*Superordinate categorization.* We earlier introduced superordinate categorization as an important form of associative category learning in humans. Research has now confirmed that animals too can categorize stimuli at the superordinate level (e.g., Lazareva et al., 2004; Roberts & Mazmanian, 1988; Wasserman, DeVolder, & Coppage, 1992; Vonk & McDonald, 2004).

In one exemplary experiment, Wasserman et al. (1992) arranged for pigeons to acquire two arbitrary superordinate categories, each comprising two basic-level categories. These researchers found clear evidence that new categories of functionally equivalent stimuli could be learned, thereby supporting the view that much of the richness and complexity of human conceptual behavior can be found in the behavior of nonhuman and nonverbal animals.

Specifically, Wasserman et al. (1992) devised a three-step experiment to determine whether pigeons could be encouraged to amalgamate two basic categories into one broader category that was not defined by any obvious perceptual features. In the first step of the experiment, by reinforcing responding to two different keys, pigeons were trained to sort slides into two arbitrary conjoint categories, such as the conjoint category of cars and people and the conjoint category of chairs and flowers (there were 12 exemplars in each of the four basic-level categories). In the second step of the experiment, the pigeons were trained to make a new response to only one stimulus class in each conjoint category. For example, some birds were trained to peck one new key when a car appeared and to peck another new key when a flower appeared. In the third step involving pecks to the two new keys, the pigeons were tested with slides from all four stimulus classes to see whether the conjoint categories that they had learned in the first step would influence their response to the stimulus classes that had been withheld in the second step (see Bhatt & Wasserman, 1989 for related research into the role of perceptual resemblance in similar reassignment training and testing).

Would the birds peck the new key to which cars had been reassigned when a person appeared? Would they peck the new key to which flowers had been reassigned when a chair appeared?

The average score was 87% correct in the case of stimuli that had been reassigned and 72% in the case of stimuli that had not been reassigned. So, merely by being associated with a common response, perceptually disparate stimuli had amalgamated into a new conjoint category of functionally equivalent stimuli (see also Smeets, Barnes, & Roche, 1997).

### *What is the Nature of the Common Representation?*

Behavior analysts avoid the use of cognitive terminology because they believe that such terminology is superfluous. If terms like common representation are mere *stand ins* to denote stimuli that are members of a stimulus class, then there is indeed no need for nor advantage to the use of such a term. On the other hand, if common representation is used to refer not only to stimuli within an associative class but to their potentially identifiable characteristics (e.g., like those proposed by Miller & Dollard, 1941), then there may be value in its usage. Of course, trying to identify the nature of those representations, especially in a nonverbal organism, is a challenging task.

Nevertheless, one can hypothesize about possible candidates and devise experimental tests based on those hypotheses (Meeter et al., 2009). For example, if two stimuli, A and B, are each associated with a common reinforced comparison stimulus, C, then one possible common representation is a *prospective* representation of Stimulus C. Stated otherwise, seeing either A or B might activate implicit or explicit anticipatory responses of C (e.g., Grant, 1982; Honig & Thompson, 1982; Hull, 1939). It is also possible that presentation of one of the samples, say Stimulus A, activates a representation of the *other* sample, Stimulus B, a transformed *retrospective* representation of the original stimulus.

*The prospective representation hypothesis.* Urcuioli (1996) proposed that a common prospective representation in the form of implicit mediating responses or *response intentions* (see also Honig & Wasserman, 1981) can account for the transfer of training results reported by Urcuioli et al. (1989) According to Urcuioli's model (see Table 5), after the MTO contingencies have been learned, presentation of either the red or vertical-line samples evokes the anticipatory representation of their associated correct comparison stimulus (e.g., circle), and likewise for the presentation of the green and horizontal-lines samples. During interim training, each sample stimulus (e.g., red) and the anticipatory representation of the comparison (e.g., the circle) it continues to evoke (because of continual refresher training on MTO matching) become conditional cues for reinforced responding to a new comparison stimulus (e.g., blue). Finally, on test trials, presentation of the vertical-line sample is able to selectively cue a blue-comparison choice via the link established between the anticipatory (circle) representation and blue during interim training. In other words, the anticipatory representations presumably mediate the generalization of the new comparison responses explicitly learned to the samples in interim training to the remaining, "untrained" samples from MTO matching, resulting in the emergent relations observed in testing (also see Wasserman et al., 1992).

The prospective hypothesis receives support from the finding that the transfer observed after MTO and interim training is *not* observed if pigeons learn the identical sets of conditional relations prior to training (see Table 6), but organized such that initial training involves one-to-many (OTM) or "sample-as-node" matching (Urcuioli, Zentall, & DeMarse, 1995; see also Urcuioli & Zentall, 1993). In OTM matching, each sample occasions two different reinforced comparison responses (albeit on separate trials). As shown in Table 6, prospective comparison representations cannot mediate the association between the samples that were first experienced in Interim Training and the comparison stimuli that were experienced in Original Training, but not in Interim Training. In sum, different comparison stimuli associated with the same sample stimuli are generally not interchangeable with one another (although see the results of Pigeons CG5 and IN1 in Urcuioli et al., 1995 as possible exceptions.)

Interestingly, the absence of interchangeability between “target” stimuli associated with a common antecedent stimulus may be restricted to conditional choice procedures in animals. For example, using rats, Sawa and Nakajima (2002) found that, after OTM training in which a common antecedent flavor preceded (on separate trials) two different target flavors, conditioning a taste aversion to one target transferred to the other target. Similar findings have been reported in CER conditioning with rats by Johns and Williams (1998) as well as Hall, Ray and Bonardi (1993) and in pigeon autoshaping by Bonardi, Rey, Richmond, and Hall (1993). Interestingly, Hall et al. (1993) offered a frustration-based mediational interpretation of their transfer findings.

In any event, Urcuioli and Lionello-DeNolf (2001) obtained results indicating that anticipatory mediated generalization (prospective representation) is <u>not</u> necessary to observe the transfer effects following MTO training. They compared test results from two groups of pigeons. One group was trained in the fashion depicted in Table 5 (viz., MTO training followed by interim, two-sample/two-comparison training). A second group, however, was trained on MTO matching *after* acquiring the two-sample/two-comparison “interim” task. In testing, both groups showed comparable levels of transfer performance when they were required to match the remaining samples from MTO matching to the comparisons appearing in the two-sample/two-comparison task. Apparently, then, from a representational viewpoint, other forms of “common coding” (see below) can yield transfer-of-control effects.

*The retrospective representation hypothesis.* Although Urcuioli’s (1996) model of mediated generalization was based on prospective representations of the comparison stimuli and/or responses, the only representational requirement needed to account for the emergent relations observed after MTO training is that the mediator be common to both samples (cf. Urcuioli & Lionello-DeNolf, 2001, Table 4). An alternative to the prospective representation hypothesis for which there is supportive evidence is the retrospective representation of one of the samples (Zentall, Sherburne, & Urcuioli, 1995; see also Urcuioli & Zentall, 1986).

Such a common retrospective mediator might take the following form (see Table 7): During MTO training, red and vertical samples, for example, would both be represented as ‘red,’ and green and horizontal samples would both be represented as ‘green.’ During subsequent interim training, the red and green samples, coded as ‘red’ and ‘green,’ respectively, would now be associated with new comparisons. Finally, on test trials, the vertical samples coded as ‘red’ and the horizontal sample coded as ‘green’ should (and do) now occasion the same new comparison responses that were explicitly associated with red and green during interim training.

Evidence for the retrospective representation of samples following MTO training comes from two sources. First, as mentioned earlier, evidence for the superiority of total versus partial reversals reported by Zentall et al. (1991) was found for the partial-reversal group in which only the line-orientation-sample associations were reversed, but not for the other partial reversal group in which only the hue-sample associations were reversed. These data are consistent with the hypothesis that the common retrospective mediators are representations of the hues because, for both the partial-reversal hues group and the total reversal group, the associations between the hue mediators and the comparison stimuli would have to be reversed but the original mediators would remain functional. For the partial-reversal line group, however, new mediators would have to be established (the old mediators would still be functional for the maintained hue sample associations).

This account makes an interesting prediction. On the one hand, the *unchanged* hue sample-comparison associations for the partial-reversal lines group should experience very little disruption (as already noted). However, the unchanged line sample-comparison associations for the partial-reversal hues group should experience considerable disruption because, for this group, as the associations between the hue mediators and the comparison stimulus encounter the reversal contingencies, they should no longer be functional for the line samples and new mediators would therefore need to develop.

Which sample dimension serves as the basis for the common representation following MTO training may depend on which samples are more salient (cf. Carter & Eckerman, 1975) or which of the sample-comparison associations are acquired first. For example, if the hue-sample associations are acquired first, then the association of the remaining samples (i.e., line orientations) with those same comparisons may be facilitated if they too are represented as hues. In support of this hypothesis, Zentall et al. (1993) found that overall fast learners acquired the hue-sample associations at about the same rate as overall slow learners, but they acquired the line-orientation-sample associations significantly faster than did the slow learners. If the fast learners represented the line orientations as hues, then this analysis could account for both the absence of faster acquisition of the hue-sample associations and the faster acquisition of line-orientation-sample associations.

More compelling evidence for retrospective representations comes from research involving conditional discriminations with samples of food and the absence of food (viz., “no food”). As noted earlier, food and no-food samples (or, for that matter, any sample dimension defined by the presence vs. absence of an event) typically yield divergent retention functions (Colwill, 1984; Grant, 1991; Sherburne & Zentall, 1993; Wilson & Boakes, 1985). Specifically, the no-food retention function is virtually flat, whereas the food-sample retention function shows the typical decrement in accuracy with increasing delay intervals.

By contrast, retention functions obtained following training with just hue or line-orientation samples are generally parallel for the two samples from each dimension. Thus, if one trains pigeons on MTO matching in which food and no-food samples occasion the same comparison choices as red and green hue samples, respectively, the slopes of the resulting retention functions can be used to infer the nature of the underlying representations. For example, if such training yielded parallel food versus no-food-sample retention functions, then this result would suggest that these samples were represented as red or green hues. Conversely, if the hue-sample retention functions diverge, then this result would suggest that the hues were represented as food or no food.

Zentall et al. (1995) found that following MTO training with red/green and food/no-food samples, the retention functions diverged not only for the food/no-food samples, but for the red/green samples as well. Importantly, a flat function was observed for the hue sample that occasioned the same comparison choice as the no-food sample, whereas a decremental function was observed for the hue sample that occasioned the same comparison choice as the food sample (see Figure 5); this outcome is consistent with the hypothesis that samples associated with the same comparison are commonly represented.

Similar results were reported by Urcuioli, DeMarse, and Zentall (1994) after training pigeons on MTO matching with three pairs of samples (food vs. no-food, 20 pecks vs. 1 peck, and red vs. green) mapped onto one pair of comparison stimuli (blue and white). Typically, when delays are introduced between the samples and the comparison stimuli, differential sample pecking, as well as food versus no-food samples, result in divergent retention functions following one-to-one matching training (cf. Fetterman & MacEwen, 1989), but not following red versus green samples. However, following MTO training with the three sets of samples, the retention functions for red versus green sample trials resembled those on the food versus no-food and 20-peck versus 1-peck sample trials. Specifically, the function for the green sample, that occasioned the same comparison choice as the no-food sample and the 1-peck sample, was relatively flat, whereas the function for the red sample, that occasioned the same comparison choice as the food sample and the 20-pecks sample, was relatively steep. This pattern of results suggests that red and green had been represented in a fashion similar to those of the other pairs of samples – viz., in terms of presence versus absence. This retrospective representation account certainly fits the observed pattern of findings much better that an unembellished prospective account, which predicts parallel retention functions for the two samples within each sample dimension. These data underscore the benefits of adopting a representational viewpoint, without which these data would be difficult to explain.

### *Other Procedures for Creating Associative Classes*

*Common reinforcement history.* An especially interesting case of the common representation of arbitrary stimuli was first reported by Vaughan (1988). In his research, the defining characteristic of each of two stimulus classes was whether responding to the members of each class (viz., stimuli which were randomly placed into each of two sets) was reinforced or nonreinforced; this characteristic was repeatedly reversed across blocks of sessions as soon as pigeons met a predetermined discrimination criterion. Because the overall reinforcement value of each set was the essentially the same over sessions (i.e., the stimuli in each set served equally often as “positive” or S+ stimuli and as “negative” or S− stimuli), the only feature that could be used to distinguish between the sets was the reinforcement conditions that were constant *within* a training session.

Vaughan first randomly assigned photographs of trees to two arbitrary sets: A and B. After pigeons had learned that responses to stimuli in Set A were reinforced and that responses to stimuli in Set B were not, the valence associated with each set was reversed until reacquisition reached high levels of discriminative performance, and then reversed again, etc. After a large number of such reversals, Vaughan found that early in a session (i.e., after a small number of stimuli from each set had been presented), pigeons would respond appropriately to the remaining members of each set. These data imply the formation of contingency-based associative classes, given that once the current status of a member or members of a set was determined in a session, animals then responded appropriately to the remaining members of the set, despite not yet having experienced the reversed contingencies for those members in that session and despite the fact that they shared no more in common (in terms of physical similarity and overall reinforcement histories) than they did with members of the other class (although see Hayes, 1989, for an alternative account).

Jitsumori and her colleagues later deployed Vaughan's reversal design in an innovative series of experiments with pigeons further investigating a variety of issues in associative class formation, including the role of perceptual resemblance (Delius, Jitsumori, & Siemann, 2000; Jitsumori, Shimada, & Inoue, 2006; Jitsumori, Siemann, Lehr, & Delius, 2002). Further follow-up findings have been reported for dolphins by von Fersen and Delius (2000) and for a chimpanzee by Tomonaga (1999).

*Symmetry training*. Having two stimuli associated with the same comparison or outcome may not be the only procedure that can produce acquired equivalence. Zentall, Clement, and Weaver (2003) asked if bidirectional training (A→B and B→A) will make those stimuli functionally equivalent. The rationale for this procedure was that if directionality plays an important part in the nature of an association (e.g., A always followed by B, or A was always first and B was always second), then perhaps training the association in both directions might eliminate its directionality component and yield an associative class which contains the two nominal stimuli (see also Schusterman & Kastak, 1993).

In symmetry training, subjects learn that when Stimulus A appears first, it is always followed by Stimulus B and when Stimulus B appears first, it is always followed by Stimulus A. If this procedure effectively establishes an acquired equivalence between A and B, then one should be able to train a new association between one of those stimuli (e.g., A) with new Stimulus C and then show that an emergent relation has developed between the remaining stimulus (i.e., B) and new Stimulus C. The design of this experiment appears in Table 8. Zentall et al. (2003) found that such training produced significant transfer to a new association (61.2%) when one of those symmetry-trained stimuli was associated with a new stimulus in a matching-to-sample task and the remaining symmetry-trained stimulus then replaced the first (see also, Yamamoto & Asano, 1995).

*Associative symmetry*[1] *and stimulus equivalence*. Associative concept learning also aptly describes the findings of an extensive program of research on stimulus equivalence that began with a now classic experiment by Sidman (1971). He trained a severely disabled child with limited verbal ability to select the appropriate picture (B) of an object upon hearing the spoken word (A) for that object (A→B) and to select the appropriate written word (C) for an object upon hearing the spoken word for the object (A→C). Sidman then found that these two explicitly trained relations yielded a new (untrained) relation C→B: The child was now able select the picture of an object when presented with the written word for that object. In other words, training resulted in [A, B, C] classes consisting of objects, the spoken words for those objects, and the written word for the objects.

Sidman and Tailby (1982) formalized the notion of stimulus equivalence in behavior based upon the mathematical (set theory) definition of an equivalence relation. Specifically, an equivalence relation among Stimuli A, B, and C is established by demonstrating three emergent behavioral effects following training: (1) Reflexivity = matching each stimulus to itself (typically inferred from a participant's ability to exhibit generalized identity matching), (2) Symmetry = following training to select Comparison B after being presented with Sample A, participants will now select Comparison A after being presented with Sample B, and (3) Transitivity = following training to select Comparison B after being presented with Sample A and to select Comparison C after being presented with Sample B, subjects will now select Comparison C after being presented with Sample A.

For the present purposes, we wish to emphasize three points. First, “The study of equivalence relations…leads directly into matters of classification, representation, and reference (Sidman, 2008, p. 323).” Second, the transfer (emergent) performances that are observed in equivalence relations tests also demonstrate the power of common associations (e.g., in A→B and B→C training or in A→B and A→C training) in yielding associative concepts, despite lingering questions about the necessity or value of representational or mediational accounts of such transfer (e.g., Sidman, 1994, pp. 110-117; Sidman, Cresson, & Willson-Morris, 1974). Third, and perhaps most importantly: “Symmetry precepts are always involved with categorization, with classification (Wade, 2006, p. 1).”

Not surprisingly, then, the “search for symmetry” in nonhuman animals (Lionello-DeNolf, 2009; Lionello-DeNolf & Urcuioli, 2002; Sidman et al., 1982) has long occupied the attention of researchers interested in animal conceptual behavior and, until recently, has been an especially elusive phenomenon (although see Schusterman & Kastak, 2003; Yamamoto & Asano, 1995).

A large part of the reason for this elusiveness has been the misidentification of the effective or functional stimulus for the animal, something which does not necessarily correspond to the experimenter’s definition (McIlvane et al., 2000). For instance, for pigeons and monkeys, *where* a stimulus appears (viz., its spatial location) is an important component of the functional stimulus (Iversen et al. 1986, Lionello & Urcuioli, 1998). Consequently, when the samples and comparisons of an arbitrary (A→B) matching task switch locations during a symmetry test (B→A), the animal essentially encounters novel stimuli: In other words, B on the center key (as a sample) is not the same stimulus, despite appearances to us, as B on the side key (as a comparison). Similarly, *when* a stimulus appears within a trial is also important (cf. Zentall, 1996), as indicated by other findings in both the Pavlovian and operant conditioning literatures (e.g., Balsam & Gallistel, 2008; D'Amato & Colombo, 1988; Honig, 1981; Miller & Barnet, 1993; Terrace, 1986).

These considerations are germane to recent successful demonstrations of symmetry in pigeons (Frank & Wasserman, 2005a; Urcuioli, 2008a, Experiment 3) using successive or go/no-go matching to sample (Wasserman, 1976; see also Konorski, 1957). In successive matching, only one comparison is presented after the sample on each trial and that comparison appears at the same location as the preceding sample. This procedure avoids any changes in stimulus location when shifting from training to testing and it also ensures the same requisite (viz., successive) discriminations between samples and between comparisons (cf. Saunders & Green, 1999). The task involves reinforcing responding to one comparison after one sample but not after the other, and vice versa for responding to the alternative comparison. Each comparison is presented for an extended period of time (e.g., 5 or 10 sec) so that the rate of responding to it can be assessed, and one main measure of discriminative performance is the difference in the rate of responding to the comparisons on reinforced trials versus nonreinforced trials.

Frank and Wasserman (2005a) and Urcuioli (2008a, Experiment 3) concurrently trained pigeons on arbitrary (A→B) successive matching and on two identity successive matching tasks involving the stimuli appearing in the arbitrary task (viz., A→A and B→B matching). Thus, not only did this training ensure that each nominal stimulus was seen both as a sample and as a comparison prior to symmetry (B→A) testing, but it arranged for common associations among the various matching stimuli (cf. Frank, 2007). Specifically, the A and B comparisons were both associated with the A samples (viz., via A→B and A→A training) and the A and B samples were both associated with the B comparisons (viz., via A→B and B→B training). The net result (see Figure 6) was that on subsequent, nonreinforced symmetry probe trials (B→A), pigeons responded more frequently to the comparisons on probes that were the reverse of the reinforced baseline (A→B) relations than to the comparisons on probes that were the reverse of the nonreinforced baseline (A→B) relations. In other words, new relations had emerged from the explicitly trained (baseline) relations. Interestingly, these demonstrations of associative symmetry in pigeons appear to directly contradict Relational Frame Theory, given its assertion that a *history* of such arbitrary applicable relational responding (in this case, of "mutual entailment") is necessary to observe emergent symmetrical responding (e.g., Barnes, 1994). Mutual entailment means that "A related to B" necessitates ("entails") that "B is related to A", symmetry being one (albeit not the only) example of it. According to Relational Frame Theory, prior reinforced experience with different examples of symmetrical relations is required in order to observe emergent symmetry. Clearly, in our demonstrations, there was no such history.

Urcuioli (2008a) has proposed a theory of pigeons' stimulus-class formation to explain these results and to successfully predict other emergent stimulus control effects (e.g., Urcuioli, 2008a, Experiment 4; Sweeney & Urcuioli, 2010). Although non-mediational in nature, the theory nonetheless derives its predictive power from the idea that common sample and comparison associations generate classes that contain the elements necessary for the emergence of symmetry and other derived stimulus relations. In other words, those common associations yield associative concepts or classes whose elements are stimuli that are hypothesized to consist of the nominal stimulus itself (e.g., red), *when* it appears in a matching trial (viz., first as a sample or second as a comparison), and *where* it appears (e.g., on the center key – cf. Swisher & Urcuioli, 2013).

## *Conclusions*

The experiments described in this review suggest that MTO matching and related procedures result in the development of emergent relations between samples associated with a common comparison that can be described as acquired equivalence or associative concepts. Perhaps the most convincing evidence of these associative concepts comes from the results of transfer of training procedures in which, following many-to-one matching and the reassignment of some of the original samples to new comparisons, emergent relations can be shown to have developed between the remaining samples and the new comparison stimuli. These emergent relations direct the organism to correct comparison alternatives that have *never* before been given in the presence of the remaining sample stimuli. Further research has indicated that the nature of the associative concept is likely to be a common representation of the different sample stimuli that were associated with the same comparison stimulus. Learned stimulus equivalences of this sort would appear to be foundational to what cognitive psychologists have termed superordinate concepts.

There is also evidence that acquired equivalence is not unique to the MTO matching procedure. It has also been found following symmetry training and following Vaughan's (1988) multiple-reversal procedure. Thus, the development of associative classes is a robust and general phenomenon in the nonhuman animal literature.

Formal equivalence – a special case of emergent stimulus relations involving reflexivity, symmetry, and transitivity – appears to have been difficult to demonstrate in pigeons; however, this failure may result from the fact that a stimulus that appears as a sample need not be the same as a stimulus that appears as a comparison, either in its spatial or in its temporal location. Once that fact is taken into account, good evidence for symmetry can readily be demonstrated.

The defining feature of an associative class is that members of such a class are related arbitrarily (e.g., an object and its various symbolic representations) and membership must be acquired through training. This feature provides associative classes with a flexibility that makes them suitable for use with human language. The great advantage that associative classes provide is that once an associative class has been formed, if a new response is learned to one member of the class, then that new response should generalize to the other members of that class. The research with animals suggests that the ability to form associative classes is not unique to humans. Thus, these building blocks of language, arguably one of the abilities that distinguishes humans from other animals (at least quantitatively), is well developed in other animals too.

## *Coda*

We began our consideration of different kinds of concepts by discussing perceptual concepts. Such concepts are not arbitrary or contrived for convenience, but real. To use Plato's famous words, they "cut nature at its joints." Critically, Quine (1969) believed similarity to be the bedrock of perceptual concepts. According to Quine, both humans and animals possess an innate standard of similarity; he further asserted that standard to be absolutely *animal* in its lack of intellectual status. This analysis suggests that, although both humans and animals might form and use perceptual concepts, perhaps only humans might form and use associative concepts, where something more intellectually advanced that mere similarity must come into play.

The research that we have reviewed here argues against that human-animal distinction: animals can indeed acquire and adaptively deploy associative concepts. If we theorize that humans contrive such concepts for functional convenience, then there is no reason to believe that the associative mechanisms that permit such adaptive conceptualization are not shared by animals as well. Fully understanding and appreciating the role of associative concepts in behavior will require a comparative understanding of their participation in the adaptive actions of both humans and animals.

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Table 1

*Many-to-One Transfer Design (after Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989).*

| Original Training | Interim Training | Test |
|---|---|---|
| R → V | R → C | |
| G → H | G → D | |
| V → V | | V → C |
| H → H | | H → D |

*Note*. R = red, G = green, V = three vertical white lines, H = three horizontal white lines, C = a white line-drawn circle, D = a white dot. All lines and shapes were projected on a black background. For each trial type, the first letter represents the sample and the second the correct comparison. In Test, samples from Original Training that were *not* presented in Interim training were presented with the comparisons from Interim Training.

Table 2

*Many-to-one Transfer Design; Interference/Facilitation (after Zentall, Sherburne, & Urcuioli 1993).*

| Original Training | Interim Training | Delay Training | Test | | |
|---|---|---|---|---|---|
| R → V | R → C | R——C | R--------C | R—V—C | R—H—C |
| G → H | G → D | G——D | G--------D | G—H—D | G—V—D |
| V → V | | | | | |
| H → H | | | | | |

*Note*. R = red, G = green, V = three vertical white lines, H = three horizontal white lines, C = a white line-drawn circle, D = a white dot. All lines and shapes were projected on a black background. For each trial type, the first letter represents the sample and the second the correct comparison. In test, samples from Phase 1 that were *not* presented in Phase 2 were presented with the comparisons from Phase 2 and reinforced responding was either consistent with or inconsistent with the presumed common representations.

Table 3

*Sample Discriminability Design Following Many-to-One Matching (after Kaiser, Sherburne, Steirn, & Zentall. 1997).*

| Train | Transfer | |
|---|---|---|
| | Consistent | Inconsistent |
| R → C | R+ | R+ |
| G → D | G- | G- |
| V → C | V+ | V- |
| H → D | H- | H+ |

*Note*. R = red, G = green, V = three vertical black lines, H = three horizontal black lines, C = a line-drawn circle, D = a 2mm dot. All lines and shapes were projected on a black background. For each trial type the first letter represents the sample and the second the correct comparison. The transfer test for Group Consistent consisted of simple successive discrimination in which the samples presumed to represent one stimulus class were discriminated from the samples presumed to represent the other stimulus class. The transfer test for Group Inconsistent consisted of a similar simple successive discrimination but one sample from each presumed stimulus class had to be discriminated from the other sample in its presumed class.

Table 4

*Many-to-One Partial Versus Total Reversal (after Zentall, Sherburne, Steirn, Randall, Roper, & Urcuioli, 1992).*

| Original Training | Reversal | | |
|---|---|---|---|
| | Partial Reversal | | Total Reversal |
| All Groups | Group Hue | Group Line | Group Hue-Line |
| R → C | R → D | R → C | R → D |
| G → D | G → C | G → D | G → C |
| V → C | V → C | V → D | V → D |
| H → D | H → D | H → C | H → C |

*Note*. The first letter of each pair represents the sample (R = red, G = green, V = vertical, H = horizontal) and the second letter represents the correct comparison (C = circle, D = dot).

Table 5

*A Prospective Mediated Generalization Account of Common Representation Effects in Many-to-One Matching.*

| Training | | Testing |
|---|---|---|
| Original Training | Interim Training | |
| R -“c” → C + | R -“c”=> B+ | |
| G -“d” → D + | G -“d”=> W+ | |
| V -“c” → C+ | | V -“c”=> B+ |
| H -“d” → D+ | | H -“d”=> W+ |

*Note*. R = red, G = green, V = vertical lines, H = horizontal lines, C = circle, D = dot. “c” and “d” represent circle and dot mediating responses, respectively, to the samples (R, G, V & H). → represents associations formed during Original Training. => represents associations formed during Interim Training. Thus, in Testing, V and H will elicit mediating responses “c” and “d” and transfer of training should result.

Table 6

*A Prospective Mediated Generalization Account of the Failure to Find Transfer of Training with One-to-Many Matching.*

| Training | | Testing |
|---|---|---|
| Original Training | Interim Training | |
| R -“c” → C + | V -“c” => C+ | |
| G -“d” → D + | H -“d” => D+ | |
| R -“b” → B+ | | V -“c”=> (B+) |
| G -“w” → W+ | | H –“d”=> (W+) |

.

*Note*. R = red, G = green, V = vertical lines, H = horizontal lines, C = circle, D = dot. “r”, “g”, “v”, and “h” represent red, green, vertical, and horizontal mediating responses, respectively, to the samples (C and D). Dashes (-) represent associations formed during Phase 1. Double dashes (=) represent associations formed during Phase 2. Dashes (-) represent associations formed during Phase 1. Double dashes (=) represent associations formed during Phase 2. Stimuli in parentheses represent the actual comparison stimuli in Phase 3. Thus, in Testing, B and W will elicit mediating responses “r” and “g” rather than “v” and “h” and transfer of training should not result.

Table 7

*A Retrospective Mediated Generalization Account of Common Representation Effects in Many-to-One Matching.*

| Training | | Testing |
|---|---|---|
| Original Training | Interim Training | |
| R -“r” → C + | R -“r”=> B+ | |
| G -“g” → D + | G -“g”=> W+ | |
| V -“r” → C+ | | V -“r”=> B+ |
| H -“g” → D+ | | H -“g”=> W+ |

*Note*. R = red, G = green, V = vertical lines, H = horizontal lines, C = circle, D = dot. “r”, “g”, represent red and green mediating responses, respectively, to the samples (R and G, and V and H). “→” represents associations formed during original training. => represents associations formed during interim training. Thus, in testing, V and H will elicit mediating responses “r” and “g” and transfer of training should result.

Table 8

*Design of Symmetry Training Experiment (after Zentall, Clement, & Weaver, 2003)*

| Training | | | Testing |
|---|---|---|---|
| Successive Presentations | | Matching-to-Sample | Matching-to-Sample |
| Red – Circle | Circle – Red | Circle → Yellow (Blue) | Red → Yellow (Blue) |
| Green – Plus | Plus – Green | Plus → Blue (Yellow) | Green → Blue (Yellow) |

Note - All successive presentations were followed by food. For matching-to-sample the first stimulus represents the sample, the second stimulus the correct comparison. The incorrect comparison is presented in parentheses. All stimuli were counterbalanced.

# Author Note

Preparation of this manuscript and the authors' research were supported by Grants MH59194 and HD060996 to TRZ, Grants MH51562, MH47313, and EY019781 to EAW, and Grant HD061322 to PJU.

# Footnote

[1] The meaning of the term “associative symmetry” and the term “symmetry” in the stimulus equivalence literature is the same, and we use them interchangeable. In one important respect, the term “associative symmetry” is preferable because it refers to an emergent relation derived from associative learning processes (cf. Asch & Ebenholtz, 1962). The term “symmetry,” on the other hand, can also refer to perceptual effects (e.g., mirror-image or bilateral symmetry).

## Figure Captions

*Figure 1.* Transfer of training for individual pigeons demonstrating the class consistent responding developed during many-to-one training (adapted from Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989).

*Figure 2.* Retention functions following matching training in which hue samples and line-orientation samples were associated with different comparisons (one-to-one matching) or common comparisons (many-to-one matching ) (adapted from Zentall, Urcuioli, Jagielo, & Jackson-Smith, 1989).

*Figure 3.* Following many-to-one matching training pigeons were transferred to a successive discrimination in which responding to samples associated with the same comparison stimulus during training were either both reinforced or not reinforced (consistent) or responding to one sample was reinforced but not the other (inconsistent) (adapted from Kaiser, Sherburne, Steirn, & Zentall. 1997).

*Figure 4.* Following many-to-one matching training, sample-comparison associations were reversed for only the hue samples, only the line samples, or for all of the samples (adapted from Zentall, Sherburne, Steirn, Randall, Roper, & Urcuioli, 1992).

*Figure 5.* Retention functions following many-to-one matching training in which red and food samples were associated with choice of a vertical-line comparison and green and no-food samples were associated with choice of a horizontal-line comparison (adapted from Zentall, Sherburne, & Urcuioli, 1995).

*Figure 6.* Comparison-response rates (in pecks/sec) on arbitrary matching baseline (Training) trials and on non-reinforced symmetry (Probe) trials during the first two test sessions following successive matching training involving hue samples and form comparisons (arbitrary matching)

and hue and form identity training. Data are from two pigeons (EXT2 and EXT7) run in Urcuioli (2008a) and one pigeon (PRF4) run in Urcuioli (2008b).

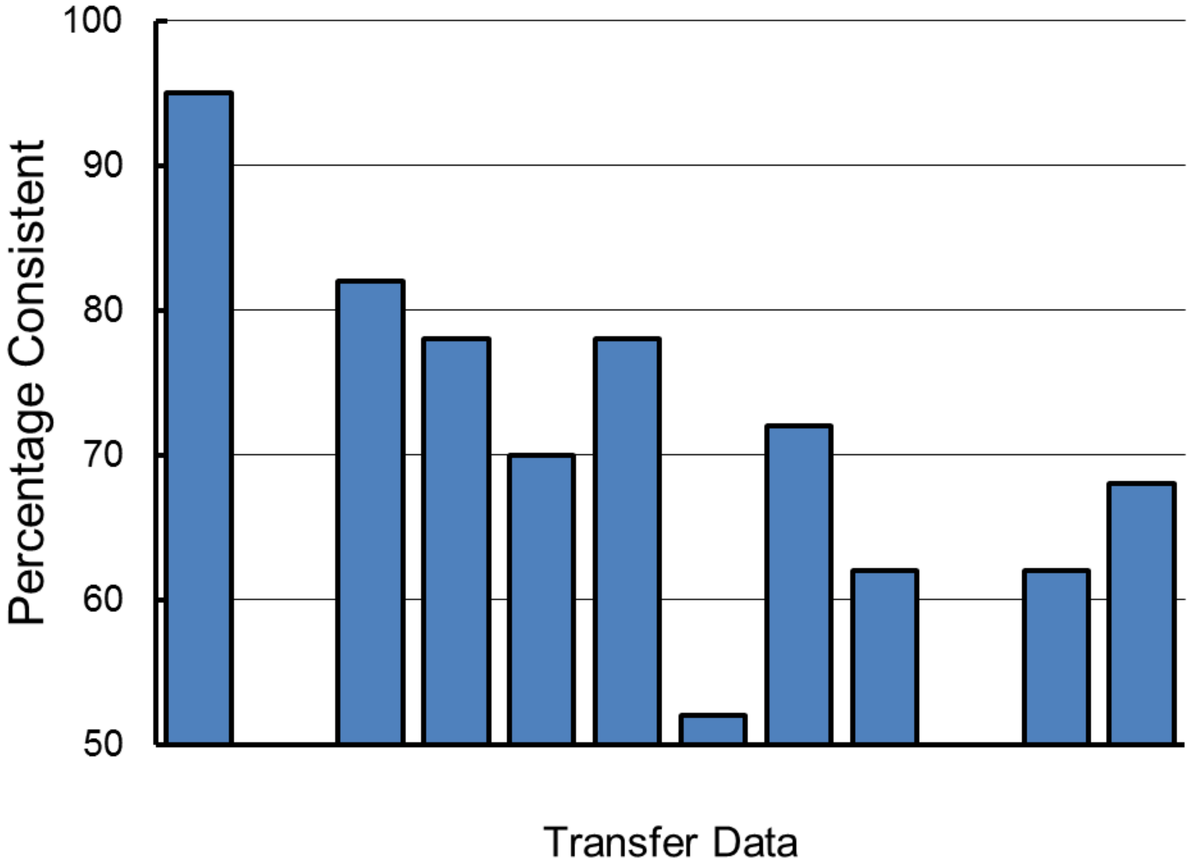

Figure 1

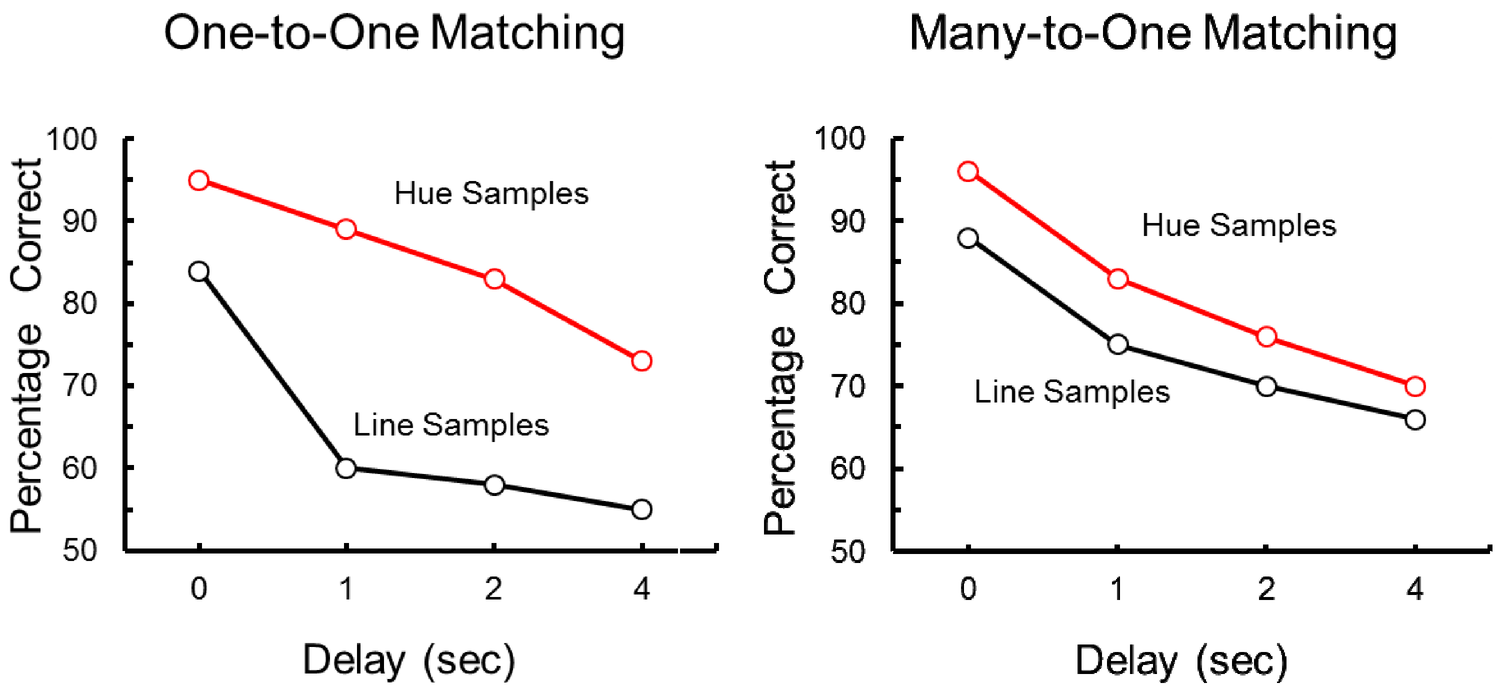
One-to-One Matching
Many-to-One Matching
Percentage Correct
100
90
80
70
60
50
Hue Samples
Line Samples
0
1
2
4
Delay (sec)

Figure 2

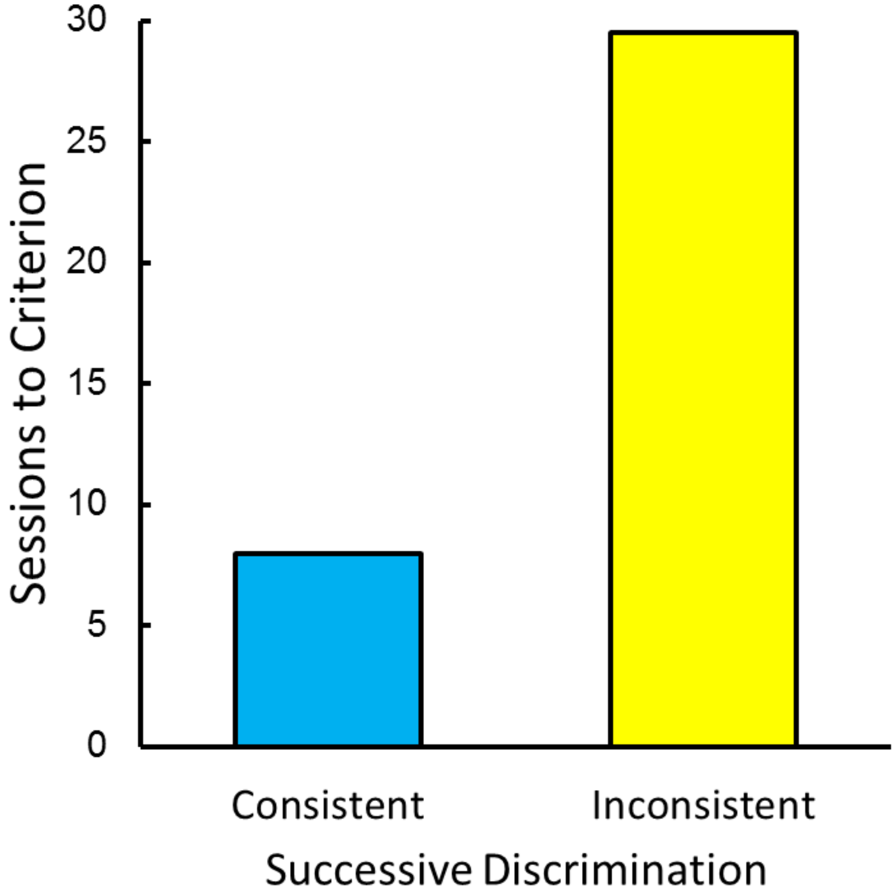
30
25
20
15
10
5
0
Sessions to Criterion
Consistent
Inconsistent
Successive Discrimination

Figure 3

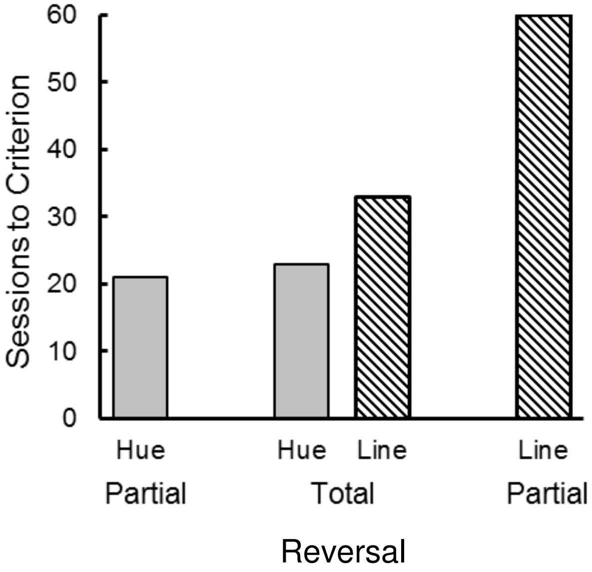
Sessions to Criterion
0
10
20
30
40
50
60
Hue
Hue
Line
Line
Partial
Total
Partial
Reversal

Figure 4

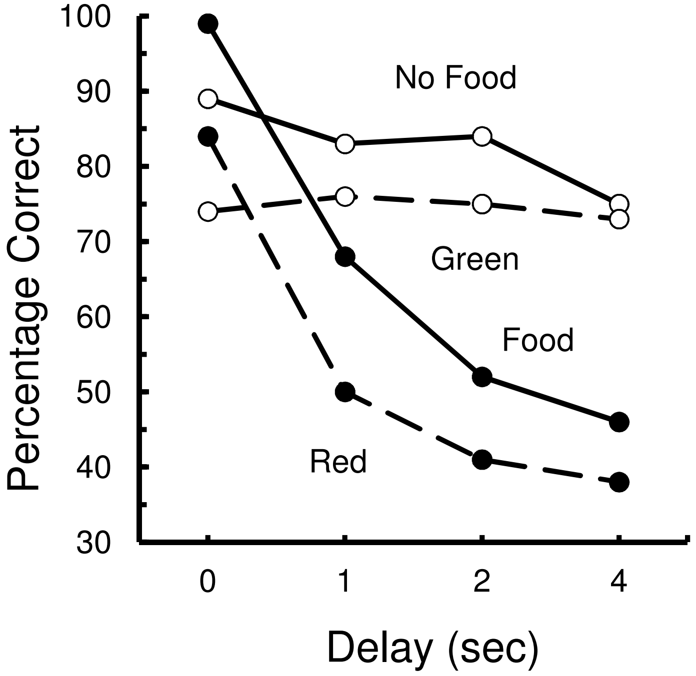
100
90
80
70
60
50
40
30
Percentage Correct
No Food
Green
Food
Red
0
1
2
4
Delay (sec)

Figure 5

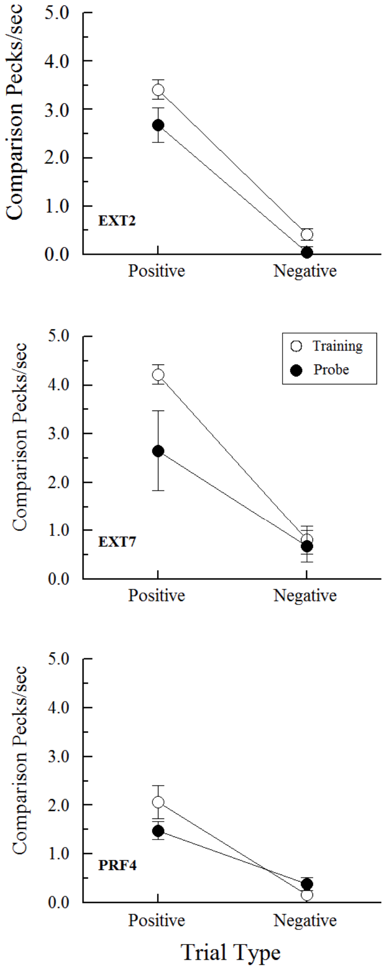
Comparison Pecks/sec
5.0
4.0
3.0
2.0
1.0
0.0
EXT2
Positive
Negative
Training
Probe
EXT7
PRF4
Trial Type

Figure 6