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Transitive and anti-transitive emergent relations in pigeons: Support for a theory of stimulus-class formation

Peter J. Urcuioli *, Melissa J. Swisher

Purdue University, United States

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ABSTRACT

Stimulus class formation is inferred when conditional discrimination training yields new (emergent) conditional relations between the training stimuli. The present experiments demonstrated two such relations in pigeons after successive matching-to-sample training. Experiment 1 showed that transitivity (AC matching) emerged after training on AB and BC arbitrary matching plus BB identity matching: pigeons responded relatively more to the comparisons on AC test trials in which both the A samples and C comparisons were elements of reinforced arbitrary baseline relations involving the same nominal B stimulus. Experiment 2 showed the opposite effect ("anti-transitivity") after training on the same arbitrary relations but with BB oddity instead: pigeons responded relatively more to the comparisons on AC test trials in which the A sample was an element of a reinforced baseline relation and the C comparison was an element of a non-reinforced baseline relation, or vice versa. Experiment 2 also showed that AB and BC training alone generally does not yield an emergent effect. These findings extend the range of emergent phenomena observed in non-human animals and are consistent with predictions from Urcuioli's (2008) theory of pigeons' stimulus class formation.

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This paper reports two experiments from a continuing line of research with pigeons investigating stimulus-class formation, a topic germane to categorization and concept formation (Lazareva and Wasserman, 2008; Zentall et al., 2014; see also Urcuioli, 2013) and other aspects of cognitive functioning (e.g., Jenkins and Palermo, 1964; Horne and Lowe, 1997; Maydak et al., 1995; Sidman, 1971). The fact that non-human animals can, under certain conditions, also group together disparate stimuli shows that human language is not necessary for categorization (cf. Carr et al., 2000) and that the reinforcement contingencies of training can be sufficient to generate novel forms of stimulus control (Sidman, 2000). For example, stimuli that occasion the same reinforced response, signal the same distinctive reinforcer, or have some other common association are often interchangeable with one another in new contexts (e.g., Edwards et al., 1982; Honey and Hall, 1989; Johnson et al., 2014; Urcuioli et al., 1989; Vaughan, 1988; cf. Goldiamond, 1962) as would be expected if they were members of a stimulus class (Saunders and Green, 1992; Urcuioli, 2013).

An example is the transfer effects shown by pigeons and other animals after training on many-to-one or "comparison-as-node" matching-to-sample (cf. Fields et al., 1984; McDaniel et al., 2001; Spradlin and Saunders, 1986). As the name suggests, this procedure involves reinforcing the same comparison choice response after more than one (separately presented) sample stimulus (Urcuioli et al., 1989; Wasserman et al., 1992; see also Bovet and Vauclair, 1998; Hall et al., 2003; Smeets et al., 1997). Training can be designated as AB and CB matching where the first letter of each pair refers to a set of sample stimuli and the second letter of each pair refers to a set of reinforced comparison stimuli. The notation indicates that subjects learn to match the same B comparisons to two different sets of sample stimuli, A and C. Although such training contingencies might simply result in two independent sets of conditional relations (viz., "match A_n to B_n" and "match C_n to B_n"), another possibility is that A and C samples occasioning the same reinforced B-comparison choice become members of the same stimulus class. To find out, researchers then train subjects to match just the A samples to a new set of comparison stimuli (D), after which they observe whether or not subjects are now able to match the C samples to the D comparisons despite never having been explicitly reinforced to do so. In fact, subjects *are* able to immediately transfer their D comparison choices from the A to the C samples (Spradlin et al., 1973; Urcuioli et al., 1989, Experiment 2; Wasserman et al., 1992). Thus,

* Corresponding author at: Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN 47907, United States.
Tel.: +1 765 494 6881.
E-mail address: urcuioli@purdue.edu (P.J. Urcuioli).

CD relations have emerged from the explicitly trained AB, CB, and AD relations, demonstrating the interchangeability of the A and C samples and indicating that they are members of the same stimulus class.

A second example is seen in the variety of emergent relations observed in humans who have learned other combinations of matching-to-sample tasks (e.g., AB and BC). Following such training, they typically exhibit symmetry in which they now match former comparisons to former samples (viz., BA and CB; the reverse of what was explicitly taught), transitivity in which they now match the A samples to C comparisons (viz., AC matching), and combined symmetry and transitivity (viz., CA matching). Along with an ability to match each stimulus to itself (reflexivity: AA, BB, and CC matching), these findings are evidence for stimulus equivalence/equivalence-class formation (Sidman and Tailby, 1982; Sidman, 1990, 2000).

Until recently and in contrast with humans, non-human animals have only rarely exhibited symmetry. Indeed, the many unsuccessful attempts to demonstrate this emergent relation (e.g., D'Amato et al., 1985; Dugdale and Lowe, 2000; Hogan and Zentall, 1977; Lionello-DeNolf and Urcuioli, 2002; Lipkens et al., 1988; Sidman et al., 1982) led some to argue that language may be a prerequisite for symmetry and for equivalence more generally (see, for example, Devany et al., 1986; Dugdale and Lowe, 1990; Horne and Lowe, 1996). However, the difficulty in finding evidence for symmetry in non-human animals is due more to methodology rather than to capability. Specifically, a symmetry test following arbitrary matching training in the typical n-alternative (choice) paradigm is not a valid one because it does not actually assess what the experimenter believes. The reason is that the functional matching stimuli for many animals include a spatial location component – in other words, each nominal stimulus is actually that-stimulus-at-a-particular-location, e.g., for pigeons, red-on-the-center key, a stimulus that is not the same as red-on-the-left/right-key (Lionello and Urcuioli, 1998; see also Iversen, 1997; Iversen et al., 1986). This is important because in the shift from training to testing, the matching stimuli appear in different locations, thus generating new stimuli for the subject. Because of this, the symmetry test does not assess the truly symmetrical versions of the training relations.

Successive or go/no-go matching (Wasserman, 1976) avoids this spatial location problem by arranging that the individually presented sample and comparison stimulus on each matching trial appear in the same location. Responding to a particular comparison is reinforced after a particular sample stimulus ("go" trials) but not after the alternative sample stimulus ("no-go" trials). Each comparison (like each sample) is presented for some extended period of time (e.g., 5 or 10 s), so rate of comparison responding (rather than percentage correct) is the dependent variable. Learning and accurate conditional discrimination performances are indexed by higher rates on reinforced than on non-reinforced trials. Importantly, Frank and Wasserman (2005) and Urcuioli (2008, Experiment 3) showed that pigeons concurrently trained to accurate levels of performance on AB, AA, and BB successive matching subsequently showed BA symmetry in testing. Specifically, they responded more to the comparisons on BA test trials that were the reverse of the reinforced AB training trials than on BA test trials that were the reverse of the non-reinforced AB training trials (see also Campos et al., 2014).

Initially, the rationale for concurrently training AA and BB identity matching with AB arbitrary matching was to minimize generalization decrement from AB training to BA testing by insuring that pigeons saw each nominal stimulus both as a sample and as a comparison prior to testing. However, Urcuioli (2008, Experiment 4) and Urcuioli and Swisher (2012b) showed that if one of the concurrently trained tasks was oddity rather than identity, the opposite effect – termed "antisymmetry" – emerged in testing. In

other words, pigeons responded relatively more to the comparisons on BA test trials that were the reverse of the *non*-reinforced (rather than reinforced) AB training trials. To take a specific example, if a red sample – triangle comparison combination was reinforced in training, but a red sample – horizontal-lines comparison combination was not, in testing pigeons responded relatively more to the red comparison after the *horizontal* sample, not after a triangle sample. Clearly, the tasks trained concurrently with AB successive matching did something more than to minimize generalization decrement.

The antisymmetry effect prompted Urcuioli (2008) to propose a theory of pigeons' stimulus class formation based in large part on the assumption that each *functional* matching stimulus consists of its nominal properties plus its ordinal position within a trial (first or second – i.e., as a sample or as a comparison, respectively). Thus, a red sample is functionally red-in-the-first-ordinal-position (R1) whereas a red comparison is functionally red-in-the-second-ordinal-position (R2). (Note that the theory also recognizes a spatial location component, but that component can be safely ignored when all stimuli appear in the same location – cf. Swisher and Urcuioli, 2013). The theory assumes that successive matching contingencies are conducive to stimulus class formation because *non*-reinforced sample-comparison combinations occur equally as often as reinforced combinations throughout training (i.e., independent of the level of discriminative performance). This should promote segregation of the functional stimuli into different classes each of which is assumed to consist of the elements of a reinforced combination (cf. Sidman, 2000). For example, if a red sample – triangle comparison and a green sample – horizontal combination are reinforced, but a red sample – horizontal comparison and a green sample – triangle combination are not, this should yield a [R1, T2] class and a [G1, H2] class.[1] Urcuioli's theory also assumes that elements common to more than one class will cause their respective classes to merge (cf. Johnson et al., 2014; Sidman et al., 1985). For instance, a [R1, T2] class and a [T1, T2] class should merge via the common T2 element into a larger [R1, T1, T2] class. Finally, theory assumes that responding will occur more frequently to a comparison in the same class as its preceding sample. Both symmetry and antisymmetry can be derived from these theoretical assumptions (see Urcuioli, 2008), as can other emergent relations (e.g., Sweeney and Urcuioli, 2010).

Here, we test and confirm theoretically derived predictions for two other emergent relations, transitivity and its opposite – which we call "anti-transitivity" – in separate experiments. Each derivation along with its corresponding training relations is described more fully in the introduction to each experiment.

1. Experiment 1

In Experiment 1, pigeons were trained on two arbitrary successive matching tasks (AB and BC) in which the nominal comparisons for one task were the nominal samples for the other, along with identity matching with those common stimuli (BB). Concurrent AB, BC, and BB training should, according to Urcuioli (2008), yield emergent AC matching (transitivity) in testing. For this experiment, the A

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[1] The notation used in reference to Urcuioli's (2008) theory of stimulus class formation differs from that typically used in the stimulus equivalence literature. Here, the numerals 1 and 2 designate a stimulus' ordinal position within a matching trial, *not* the hypothesized class to which it belongs. Likewise, the letter before each numeral (e.g., R, G, T, etc.) designates a specific matching stimulus (like red, green, triangle, etc.) rather than a set of stimuli. In the stimulus equivalence literature, the letters "A", "B", and "C" are used to denote sets of stimuli which we do here as well but only when describing baseline or test relations and never in combination with a numeral. The notation differences may pose a challenge for some readers, but we think it's important to maintain our notation to be consistent with Urcuioli's (2008) theory and with the experiments that followed it.