2007

An examination of the temporal and spatial stimulus control in emergent symmetry in pigeons

Andrea Jean Frank
University of Iowa

Recommended Citation

Frank, Andrea Jean. "An examination of the temporal and spatial stimulus control in emergent symmetry in pigeons." PhD (Doctor of Philosophy) thesis, University of Iowa, 2007.
http://ir.uiowa.edu/etd/157.

AN EXAMINATION OF THE TEMPORAL AND SPATIAL STIMULUS CONTROL IN EMERGENT SYMMETRY IN PIGEONS

by

Andrea Jean Frank

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Psychology
in the Graduate College of
The University of Iowa

July 2007

Thesis Supervisor: Professor Edward A. Wasserman

ABSTRACT

If an organism is explicitly taught an A→B association, then might it also spontaneously learn the symmetrical B→A association? There is only a small amount of evidence that attests to the detection of emergent symmetry in nonhuman animals (e.g., one chimpanzee and two pigeons). This dissertation examines the necessary and sufficient conditions for finding emergent symmetry in pigeons while attempting to control for the problems of spatial and temporal location found in previous symmetry and stimulus equivalence experiments. Using a successive go/no go matching-to-sample procedure, which showed all of the training and testing stimuli in one location, four experimental manipulations were examined. In Experiment 1 temporal location was controlled without the inclusion of identity matching intermixed with arbitrary matching; Experiment 2 contained identity matching with stimuli different from arbitrary matching; in Experiment 3 identity matching was trained to criterion and then intermixed with arbitrary matching; and in Experiment 4 two sets of arbitrary matching were trained (e.g., AB and CD) but only one of those stimulus sets was trained in identity matching (e.g., AB). No evidence of emergent symmetry was found in Experiments 1 and 2. In Experiment 3, two pigeons showed moderate evidence of emergent symmetry, one pigeon showed suggestive evidence of emergent symmetry, and one pigeon did not show any evidence of emergent symmetry. In Experiment 4, two pigeons showed moderate evidence of emergent symmetry with the AB Stimulus Set (one of those pigeons also showed suggestive evidence of emergent symmetry with the CD Stimulus Set) and one pigeon did not show any evidence of emergent symmetry with either stimulus set. These data suggest that intermixing identity matching with the same stimuli used in arbitrary matching is a necessary, but not sufficient condition to obtaining emergent symmetry in pigeons.

Abstract Approved: ____
Thesis Supervisor

____
Title and Department

____
Date

AN EXAMINATION OF THE TEMPORAL AND SPATIAL STIMULUS CONTROL IN EMERGENT SYMMETRY IN PIGEONS

by

Andrea Jean Frank

A thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Psychology
in the Graduate College of
The University of Iowa

July 2007

Thesis Supervisor: Professor Edward A. Wasserman

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

Andrea Jean Frank

has been approved by the Examining Committee
for the thesis requirement for the Doctor of Philosophy
degree in Psychology at the July 2007 graduation.

Thesis Committee: ___________________________________
Edward A. Wasserman, Thesis Supervisor

____
Mark Blumberg

____
John Freeman

____
Joel Ringdahl

____
Larissa Samuelson

____
John Spencer

To my husband and my beautiful son with all my love.

ACKNOWLEDGMENTS

My sincere thanks to my advisor and partner in arguments, Dr. Ed Wasserman. You have done more for me then you will ever know and I am eternally grateful for all of your help.

Thank you to everyone on my dissertation committee for all of your help and advice: Mark Blumberg, John Freeman, Larissa Samuelson, John Spencer, and Joel Ringdahl.

And last, but not least, thank you to all of the members of Dr. Wasserman's lab who helped run experiments, give advice, and make everyday enjoyable: Olga Lazareva, Michelle Miner, Yasuo Nagasaka, Leyre Castro-Ruiz, Dan Brooks, and Fabian Soto.

ABSTRACT

If an organism is explicitly taught an A→B association, then might it also spontaneously learn the symmetrical B→A association? There is only a small amount of evidence that attests to the detection of emergent symmetry in nonhuman animals (e.g., one chimpanzee and two pigeons). This dissertation examines the necessary and sufficient conditions for finding emergent symmetry in pigeons while attempting to control for the problems of spatial and temporal location found in previous symmetry and stimulus equivalence experiments. Using a successive go/no go matching-to-sample procedure, which showed all of the training and testing stimuli in one location, four experimental manipulations were examined. In Experiment 1 temporal location was controlled without the inclusion of identity matching intermixed with arbitrary matching; Experiment 2 contained identity matching with stimuli different from arbitrary matching; in Experiment 3 identity matching was trained to criterion and then intermixed with arbitrary matching; and in Experiment 4 two sets of arbitrary matching were trained (e.g., AB and CD) but only one of those stimulus sets was trained in identity matching (e.g., AB). No evidence of emergent symmetry was found in Experiments 1 and 2. In Experiment 3, two pigeons showed moderate evidence of emergent symmetry, one pigeon showed suggestive evidence of emergent symmetry, and one pigeon did not show any evidence of emergent symmetry. In Experiment 4, two pigeons showed moderate evidence of emergent symmetry with the AB Stimulus Set (one of those pigeons also showed suggestive evidence of emergent symmetry with the CD Stimulus Set) and one pigeon did not show any evidence of emergent symmetry with either stimulus set. These data suggest that intermixing identity matching with the same stimuli used in arbitrary

matching is a necessary, but not sufficient condition to obtaining emergent symmetry in pigeons.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. LITERATURE REVIEW

When human adults are taught that A = B, they can spontaneously report that B = A (e.g., Sidman, 1971; Sidman, Cressen, & Willson-Morris, 1974; Sidman & Tailby, 1982). In the literature on stimulus equivalence—a type of hierarchical and bidirectional relationship among stimuli which allows one stimulus to substitute for another—this bidirectional association is termed *symmetry* (Sidman & Tailby, 1982). Symmetry has been difficult to observe in non-human animals, even when efforts have been made to enhance symmetrical behavior by using additional training methods or stimuli that may be especially suited to the particular species (e.g., Dugdale & Lowe, 2000; Dymond, Gomez-Martin, & Barnes, 1996; Hogan & Zentall, 1977; Lipkens, Kop, & Werner, 1988; Sidman, Rauzin, Lazar, Cunningham, Tailby, & Carrigan, 1982). In a set of experiments, Frank and Wasserman (2005) found that the methodology typically used in stimulus equivalence and symmetry experiments is not ideal for a non-human animal population, specifically pigeons.

This dissertation will discuss the background of stimulus equivalence research, associative symmetry, bidirectional conditioning, and declarative memory as they pertain to emergent symmetry in non-human animals and detail preliminary research by Frank and Wasserman (2005) that has resulted in emergent symmetry in pigeons. The aim of the dissertation is to introduce and discuss four experiments that served as follow-up experiments to the Frank and Wasserman (2005) paper. The purpose of these four experiments was to elucidate the main factors that are necessary for producing emergent symmetry in non-human animals.

Stimulus equivalence paradigm

Stimulus equivalence was formally defined by Sidman and Tailby (1982) as the spontaneous association between stimuli that occurs after training the relations A = B and B = C; where A, B, and C are arbitrary stimuli. After training the relations A = B and B

= C, the presence of three spontaneous relations can then tested; reflexivity, symmetry, and transitivity. Reflexivity is the relation of a stimulus to itself (e.g., A = A). Symmetry is the bidirectional relationship of any pair of stimuli. For example, if the relation A = B is trained, then the symmetrical relation B = A should emerge during testing. Transitivity is a linear (i.e., logical) relationship among stimuli. For example, if the relations A = B and B = C are trained, then it logically follows that A also equals C (A = C).

Symmetry, within the context of stimulus equivalence, is usually trained (A→B) and tested (B→A) using a simultaneous or 0-s delayed matching to sample (MTS) design. In simultaneous MTS, three to four stimuli are shown on a viewing screen at the same time. The stimulus that is displayed at the top of the screen is the ‘sample’ and the two or three stimuli (depending on the experimenter’s preference) that are displayed across the bottom of the screen are the ‘comparisons.’ In stimulus equivalence training, several “if-then” relationships are trained. For example, if A1 is the sample and B1 and B2 are the comparisons, then the organism would be trained to choose B1, because A1 and B1 have been arbitrarily designated as part of the same class of stimuli. Similarly, if A2 is the sample and B1 and B2 are again the comparisons, then the organism would be trained to choose B2, because A2 and B2 have been arbitrarily designated as part of the same class of stimuli. To test for symmetry, B1 and B2 now become the samples on different testing trials and A1 and A2 become the comparisons on all of the testing trials. If the organism has learned a symmetrical relation based on A → B training, then it should choose the A1 comparison when B1 is the sample and it should choose the A2 comparison when B2 is the sample.

A 0-s delayed MTS task is very similar to the simultaneous MTS task, except that the sample stimulus is shown alone for a set period of time or until a response requirement has been met and then the sample stimulus is removed. Without delay, the comparison stimuli are then shown and the organism is given reinforcement for choosing the “matching” stimulus.

Animals do not show stimulus equivalence

Because animals do not show emergent symmetry, by default they also do not show stimulus equivalence (e.g., Sidman, et. al., 1982). Stimulus equivalence classes have only *reliably* been found in adult humans (e.g., Sidman, 1971; Sidman, et al., 1974; Sidman & Tailby, 1982), typical children (e.g., Sidman, et al., 1982; Smeets & Barnes, 1997), and verbal developmentally delayed children (e.g., Devany, Hayes, & Nelson, 1986).

Of the three properties of an equivalence relation, the properties of reflexivity (e.g., Oden, Thompson, & Premack, 1988; Pack, Herman, & Roitblat, 1991) and transitivity (e.g., D'Amato, Salmon, Loukas, & Tomie, 1985; Kuno, Kitadate, & Iwamoto, 1994) are the only properties to be repeatedly demonstrated successfully with non-human animals. The non-human animals included in these studies were monkeys, chimpanzees, rats, and pigeons.

Associative Symmetry

The basic concept of a symmetrical relation has been debated since the 1920s in different areas of classical conditioning and associative symmetry (i.e., paired associate learning). In these debates, it is often argued that either symmetry results from a spontaneous backward relation (B = A) that emerges due to forward training (A = B) or that symmetry is the result of the direct training of both the forward and backward relations (i.e., the forward and backward relations are independent).

In the area of paired associate learning, humans are trained with a list of word pairs (A = B) followed by a second list of word pairs (C = B); B is identical to B in both lists (e.g., Jenkins, 1963; Jenkins, 1965). In the paired associate literature, there are two different theories that describe symmetrical relations. One theory, the independent association hypothesis, states that the forward relation (A = B) and the backward relation (B = A) are two independent associations. In other words, an association contains information about stimulus direction (Ebbinghaus, 1913). Ebbinghaus (1913) states, however, that if a pair of stimuli (A = B) is learned so well that overlearning has occurred, regardless of training direction (A = B or B = A) then a bidirectional relationship will develop. In other words, presentation of the B stimulus will automatically retrieve a representation of the A stimulus if the relationship B = A is over learned.

The second theory, the associative symmetry hypothesis, states that when a forward association (A = B) is learned, a backward association (B = A) of equal strength is also learned automatically. Asch and Ebenholtz (1962) state that the direction of an association is independent of the association itself. According to this theory, however, if two stimuli are repeatedly presented in such a context that there is an implied order to the stimuli (e.g., respond to A1 first, then B1 second), then there will be a problem retrieving the backward association (B = A) because the A stimulus is not "available" for recall.

Abra (1967) concluded that forward and backward associations are formed independently after he found that there was greater recall of List 2 (C = B) after learning List 1(A = B) in a many-to-one design (e.g., A = B and C = B). Recall for List 2 (A = C), however, was no higher than List 1 (A = B) in a one-to-many design (e.g., A = B and A = C). Because of this discrepancy, Abra concluded that forward and backward associations are formed independently because the backward associations (e.g., B = A and B = C) that were hypothesized to be formed in a many-to-one design should facilitate recall of paired associate lists (i.e., performance on Lists 1 and 2 should be equivalent). However, it is likely that learning List 2 after learning List 1 in the many-to-one design may have caused some retroactive interference or retroactive inhibition (Johnston, 1968). The interference may have only occurred in the many-to-one (A = B and C = B) design because of the common positioning of the B stimuli. Johnston (1968) found that after training both A = B and C = B, both A = B and B = A recall were inhibited compared to when only A = B was trained. This finding is evidence of retroactive interference in both the forward and backward associations when A = B is trained followed by C = B.

In addition, Johnston (1967) found that he could actually facilitate the backward association (B = A) when he tested for both backward (B = A) and forward (A = B) recall after training A = B and C = A stimulus pairs (Group 1) relative to recall of the forward (A = B) and backward (B = A) relations after training A = B and C = D (Group 2). Indeed for Group 1, the recall of the backward association surpassed recall of the forward association. It is possible that subjects were able to form a backward association after seeing the A stimulus in both the first and second locations of the word pairs. Much like Asch and Ebenholtz (1962), Johnston (1967) concluded that presenting A = B and C = A during training may have made the A stimulus more "available" thus enhancing recall of A after being presented with the B stimulus.

Although there is currently no definitive answer to the question of the automaticity of the formation of a backward association when a forward association is learned, Rizzuto and Kahana (2000, 2001), and Kahana (2002) have created several neural network models to compare the independent association hypothesis and the associative symmetry hypothesis. Their simulations have shown support for the associative symmetry hypothesis. By creating a recurrent neural network model based on a set of experimental human data, Rizzuto and Kahana (2001) found that there were "strong correlations between forward and backward recall of paired associates" and they concluded they were "products of a single mechanism" (p. 2088). Rizzuto and Kahana (2001) found that a neural network model based solely on the associative symmetry hypothesis could accurately account for human data in which the forward association (A = B) appeared to be stronger than the backward association (B = A; independent association hypothesis). Therefore, it is possible that one mechanism can allow for the flexible associative performance seen in the human data from the paired associate paradigm. An area of the brain flexible enough to allow associations to occur in the same manner as this neural network model is the hippocampus (Kahana, 2002), which will be discussed later in the dissertation.

Bidirectional Conditioning

While the debate over the formation of a symmetrical relation was clearly unresolved in the paired associate, or associative symmetry literature, this debate also occurred in another experimental area called bidirectional conditioning. Bidirectional conditioning was contained within the classical conditioning literature; it examined the association between a conditioned stimulus and an unconditioned stimulus (e.g., Beritov, 1965) or in some cases an association between two unconditioned stimuli (e.g., Asratyan, 1967). This debate over the formation of a backward relation was very similar in both the associative symmetry literature and the bidirectional conditioning literature.

The idea of bidirectional conditioning was introduced by Beritov (1924) and later incorporated into the classical conditioning literature by Pavlov (1927). Pavlov (1927) stated that a bidirectional relationship occurred within the brain. He claimed that there were bidirectional cortical connections formed during conditioning and that movement activated these connections or they could activate movement. For example, in an experiment by Asratyan (1967), a dog’s paw was lifted and then food was presented. The dog salivated when the food was presented. As is normal with classical conditioning, after several pairings of the paw lifting and food presentation, the dog began to salivate when the paw was lifted. Later, however, the presentation of food alone elicited paw lifting behavior from the dog. This behavior suggests the presence of a backward association.

Beritov (1965) stated that bidirectional relations developed simultaneously, but independently. Therefore, Beritov (1965) suggested that a greater number of trials is needed to get backward conditioning. The necessity of overtraining in order to result in backward associations was also hypothesized by Ebbinhaus (1913).

Asratyan (1967), however, hypothesized that the cortical connections in the brain allow for each of the forward and backward associations to be excitatory at the same time. He also hypothesized that the biological significance of the unconditioned stimulus was the factor that enhanced the significance of a stimulus pairing. Indeed, Gunther, Miller, and Matute (1997) found support for this proposal. Specifically, they found that if stimuli have been equated for biological significance, then they can be shown in either order and still result in conditioned responding.

Asratyan (1967) also states, however, that if stimuli are consistently shown in the same temporal order then the forward association is much stronger than the backward association. If the stimuli are given in an alternating sequence (i.e., A → B alternated with B → A), then the forward and backward associations are equally strong. The problem with this statement is that, rather than being an emergent relation, the backward association is trained. Astratyan (1967), however, hypothesized that it is the formation of bidirectional cortical connections that is spontaneous.

As seen in the Asratyan (1967) experiment, however, backward associations can spontaneously emerge. There are also several other experimental examples of such spontaneous emergence of a bidirectional relation (e.g., Zentall, Sherburne, & Steirn, 1992, Sherburne & Zentall, 1995, and Gerolin & Matute, 1999). One experimental example of spontaneous emergence of a backward association can be seen in Zentall et al. (1992; Experiment 3). They combined classical and operant conditioning in order to examine backward associations. In Phase 1 of the experiment, they trained pigeons to choose a ‘red’ comparison when presented with a ‘dot’ sample and gave split peas as a reinforcer. They also trained pigeons to choose a ‘green’ comparison when presented with a ‘circle’ sample and presented an empty feeder. In order to be sure that there was no differentiation in the peck rate to the two different trial types (food vs. no food), they also included trials in which the sample that is normally followed by an empty feeder (Circle) was followed by peas. During testing, they had two groups of birds; consistent and inconsistent. The consistent group was given grain if they chose the red comparison when presented with split peas as a sample and they were given grain if they chose the green comparison when presented with the empty feeder. The inconsistent group was given grain if they chose the red comparison when presented with the empty feeder as a sample and they were given grain if they chose the green comparison when presented with split peas as a sample. The consistent group performed statistically higher than the inconsistent group (consistent group = 62% correct; inconsistent group = 39.5%); consistent with the presence of a backward association between the reinforcer and the comparison stimulus.

The Zentall et al. (1992; Experiment 3) experiment is one of only a few examples of a backward association by a non-human animal and the question of why non-human animals have not yet shown emergent symmetry in the stimulus equivalence literature, in particular, still remains.

Why should we expect to find emergent symmetry in non-human animals?

It is possible that non-human animals are simply not capable of acquiring a symmetrical relation in the context of a stimulus equivalence experiment? However, the available evidence of spontaneous backward associations in bidirectional conditioning experiments suggests that animals might be capable of showing symmetry (e.g., Asratyan, 1967; Zentall et al., 1992). In addition, non-human animals are capable of many forms of complex categorization (e.g., Astley, Peissig, & Wasserman, 2001; Lazareva, Feidburger, & Wasserman, 2004; Sigala, Gabbiani, & Logothetis, 2002); so it seems as if symmetry should be well within their range of categorization skills. There are several examples of complex categorization with non-human animals that take place in a variety of different laboratory and naturalistic settings: categorization of visual stimuli, same-different categorization, functional equivalence, naturalistic experiments, and ethological observations (e.g., Cheney & Seyfarth, 1999).

Categorization of visual stimuli takes place on several hierarchical levels of association (e.g., subordinate, basic, and superordinate) that include stimulus associations suggestive of the types of complex stimulus associations in non-human animals that might lead to symmetrical responding (e.g., Astley et al., 2001; Astley & Wasserman, 1999; Frank & Wasserman, 2005; Wasserman & DeVolder, 1993 Wasserman, DeVolder, & Coppage, 1992). Basic level categorization, for example, can be the classification of several types of the same animal with one another. For example, cats can be categorized into one basic category (i.e., Persian cats, Siamese cats, tabby cats, etc.). This type of categorization requires the association of features that are common to all cats (e.g., pointy ears, whiskers, meowing noises, etc.). Cats are associated via primary stimulus generalization (Hull, 1939), that is, the association of physically similar features. These stimuli are always presented in concert with one another and can become associated with one another because they have a similar physical appearance. However, there are differences between various different types of cats (i.e., the subordinate level) that must be ignored in order to classify this group of animals as cats. The different features that must be ignored at the basic level are the features that make up the subordinate level of categorization. For example, a subordinate level of cats is Siamese cats. These types of cats all have blue eyes, black tipped ears, and are very lean. This type of categorization is also based on physical similarity (i.e., primary stimulus generalization). Non-human animals are capable of basic level categorization (e.g., Lazareva et al., 2004) and also subordinate level categorization (e.g., Sigala et al., 2002).

The formation of a superordinate category is a bit more complicated. Superordinate categories are made up of items that have a common association. For example, items of furniture all go together because they have common associations -- they are objects that you sit on, lay on, used as eating surfaces, etc. Two distinct items that have common associations become functionally equivalent to one another and are ultimately interchangeable with one another. Functional equivalence is based on secondary stimulus generalization (Hull, 1939), or recognizing an object through a common association. Non-human animals are capable of showing both superordinate categorization (e.g., Astley et al., 2001; Astley & Wasserman, 1999; Wasserman, et. al., 1992) and functional equivalence (e.g., Astley, et al., 1999, 2001; Frank & Wasserman, 2005; Wasserman & DeVolder, 1993). Functional equivalence is thought to be a less complex form of stimulus equivalence; that is, functional equivalence is the association of two distinct stimuli with one another and stimulus equivalence is the association of three distinct stimuli with one another. The properties of stimulus equivalence (i.e., reflexivity, symmetry, and transitivity) are simply the result of what happens when three stimuli are associated with each other.

A different type of categorization that non-human animals are also capable of is same-different categorization (e.g., Wasserman, Fagot, & Young, 2001; Wasserman, Hugart, & Kirkpatrick-Steger, 1995; Young, Wasserman, & Dalrymple, 1997). Same-different categorization is the grouping of stimuli based on their identical appearance or their distinct appearance. For example, pigeons can be trained to respond one way when presented with a display composed of 16 identical stimuli and can be trained to respond another way when presented with a display composed of 16 distinct stimuli. When shown novel stimuli in these same types of displays pigeons show the responses previously trained suggesting that the pigeons have formed a concept of “same” and a concept of “different” (e.g., Young, et al., 1997).

In a naturalistic setting, animals that live in social groups tend to show evidence of categorization and equivalence. Schusterman, Reichmuth, and Kastak (2000) suggested that “animals that live in social groups may benefit by performing complex categorizations that allow them to recognize not only other individuals but also relationships between individuals” (p. 1). Cheney and Seyfarth (1999) describe an experiment with vervet monkeys in which the vocalizations of a juvenile monkey, who was not present, were played on a loudspeaker. Notably, in response to the vocalizations, the adult females who also had offspring (not present in the area) directed their attention toward the juvenile's mother. This finding suggests that there is some association between the juvenile's vocalizations, the juvenile itself, and the juvenile's relation to its mother that could be defined as a stimulus equivalence class (e.g., Sidman, 2000). Remember that symmetry is just one property of a stimulus equivalence class.

Schusterman et al. (2000) has suggested that more social animals may have a need for more complex categorization. For example, Hanggi and Schusterman (1990) found that sea lions are capable of kin recognition, which is seen through a variety of behaviors, including vocalizations. Bond, Kamil, and Balda (2003) have found that Pinyon Jays show better transitive inference performance (e.g., Train A>B, B>C, C>D, D>E; Test B>D) than Scrub Jays, which are the less social of the two species of bird. Ghazanfar and Logothetis (2003) found that rhesus monkeys spend more time looking at a picture of the correct facial expression of another monkey when the corresponding vocalization is played through a loudspeaker. Similarly, Placer and Slobodchikoff (2000) found that prairie dogs make distinct vocalizations that identify their four main predators. In fact, Ackers and Slobodchikoff (1999) found that prairie dogs can even discriminate among alarm calls that describe the size and shape of a certain predator and not just the closeness of the predator as ground squirrels do.

Each of these examples of complex behavior suggests that non-human animals are capable of very complex categorization. Given that non-human animals are capable of this complex level of associative ability and with some past successes with emergent symmetry (e.g., Zentall et al., 1992), it seems reasonable to continue to examine symmetrical relations in stimulus equivalence experiments. The question still remains: Why is it so difficult to find evidence of a symmetrical relation with non-human animals within the context of a stimulus equivalence experiment?

Why do non-human animals fail to reliably show emergent symmetry? Theory 1.

There are several theories that have been proposed to answer this question. One theory states that language is a necessary precursor to emergent stimulus equivalence responding because of the apparent difficulty in finding emergent symmetry in non-human animals and nonverbal developmentally delayed humans (e.g., Hayes, 1991; Horne & Lowe, 1996). For example, when humans are taught to speak, they learn that the spoken word “dog” equals the animal “dog” (A = B) and that the spoken word “dog” also equals a picture of a “dog” (A = C). It is this extensive training history with stimulus relations that might, in fact, be the reason why verbal humans are capable of showing stimulus equivalence classes based on learning only the A = B and B = C relations in experimental settings (Dube, McIlvane, Callahan, & Stoddard, 1993).

Trained symmetry

There are two animal studies that support the hypothesis that an extensive learning history is needed before an animal will show the emergent properties of stimulus equivalence (i.e., symmetry). Both a chimpanzee (Yamamoto & Asano, 1995) and a California sea lion (Schusterman & Kastak, 1993) have shown evidence of an emergent symmetrical relation; however, in both studies, experimenters trained symmetrical relations with several pairs of stimuli before any animals showed an emergent symmetrical relation with novel stimuli.

Yamamoto and Asano (1995) trained one chimpanzee the forward relation (A1 = B1) with colors, lexigrams, and Chinese characters in a simultaneous MTS format. When they tested for the backward relation (B1 = A1), the chimpanzee showed no evidence of a backward relation. They then trained the backward relation to criterion. Yamamoto and Asano (1995) then trained a forward relation (A2 = B2) with a novel pair of stimuli, but the chimpanzee still showed no evidence of symmetry during testing. They trained the backward relation (B2 = A2) of the second pair of stimuli to criterion as well. They then trained the forward relation of a third, novel set of stimuli (A3 = B3) and tested for the backward relation (B3 = A3). They found evidence of a symmetrical relation during the test for the backward relation with the third pair of stimuli.

Similarly, Schusterman and Kastak (1993) also trained and tested multiple pairs of stimuli before they saw any evidence of stimulus equivalence; however, they trained and tested for symmetry and transitivity, rather than symmetry alone. They found emergent evidence of stimulus equivalence class formation, but only after extensive, explicit training of both symmetrical and transitive relations with multiple sets of stimuli.

Why do non-human animals fail to reliably show emergent symmetry? Theory 2.

A more likely theory that might better explain why animals have not yet shown emergent symmetry in a stimulus equivalence test is the persistence in using the simultaneous MTS design to train and test stimulus equivalence. Although some researchers have begun to realize that this may be a problem (e.g., Debert, Matos, & McIlvane, 2007), most researchers still use simultaneous MTS to train and test for stimulus equivalence. Notice that, in order to test for the property of symmetry, stimuli that were previously comparisons during simultaneous MTS training must become samples during testing and vice versa. It is possible that moving the visual stimuli to new spatial locations from training to testing produces a substantial stimulus generalization decrement because the visual and positional attributes of the stimuli may gain joint control over behavior (Sidman, 1992; Lionello & Urcuioli, 1998). Indeed, in a simultaneous MTS task, Lionello-DeNolf and Urcuioli (2000) found that the use of several different sample stimulus locations enhanced pigeons’ discriminative performance. So, the results of symmetry testing could be seriously compromised because “moving [the visual stimuli] to new locations creates functionally different stimuli” (Lionello-DeNolf & Urcuioli, 2000, p. 142).

Additionally, because the stimuli in simultaneous MTS designs have an implied stimulus order (e.g., respond to A1 first, then B1 second), there may also be a temporal order problem. This temporal order problem exists because A1 would be seen in the first temporal location, but never in the second temporal location until testing for emergent symmetry (e.g., respond to B1 first, then A1 second).

Neurological evidence that suggests a spatial and possibly a temporal problem in simultaneous MTS designs

Neurological evidence that supports the hypothesis that there is a spatial and temporal problem in the simultaneous MTS design that prevents non-human animals from showing emergent symmetry can be found in declarative memory research involving the hippocampus. The function of the hippocampal memory system in the formation of declarative memory has been a source of much debate in the neuroscience literature (e.g., O’Keefe & Nadel, 1978; Morris, Garrud, Rawlins, & O’Keefe, 1982). Declarative memory is made up of two subsets of information. One subset is episodic memory. Episodic memory is made up of individual experiences that can be brought to conscious recollection via verbal communication in humans. In animals, episodic memory has been studied by utilizing “what”, “where”, and “when” information because a verbal test is obviously impossible (Eichenbaum & Fortin, 2003). The other subset of declarative memory is semantic memory. Semantic memory is timeless information that makes up a person’s knowledge. It is “accrued from linking multiple experiences that share some of the same information. Ultimately, semantic memory is a complex network of links between some items that have lost unique episodic information and links among maintained episodic memories” (Eichenbaum, 2001, p. 202).

The hippocampal memory system consists of inputs from the cerebral cortex relaying sensory information to the parahippocampus, which is made up of the entorhinal and perirhinal cortices. The parahippocampus then sends information to the hippocampus, which is made up of the dentate gyrus, Ammon's horn, and subiculum. Information is then sent via the subiculum to the fornix and back to the cerebral cortex (Eichenbaum & Cohen, 2001).

There are two different theoretical approaches that have made major statements about the functions of the hippocampal memory system. One theory states that the hippocampus encodes only spatial memory and processes the information about the spatial location of objects in order to create a kind of map in the brain of the location of interest (O'Keefe & Nadel, 1978; Morris et al., 1982; Frank & Greenberg, 1994). This map is made up of the locations of all the objects within the "map area" and their relations to each other.

A second theory states that the hippocampus is used to encode not only spatial information, but also information about most aspects of a learning situation (e.g., Wood, Dudchenko, Robitsek, & Eichenbaum, 2000; Adeyemo, 2002). For example, Wood et al. (2000) trained rats to alternate turning left or right at the end of a T-maze and found that neurons in the CA1 and CA3 areas of the hippocampus were active during almost every point of running the maze (e.g., the starting point, the turning point, the area where food was obtained) and for certain behaviors that the rat was performing (e.g., turning left or turning right). In addition, Wood, Dudchenko, and Eichenbaum (1999) found that rats trained on a non-MTS task (e.g., match red with green instead of red with red) with odor stimuli placed randomly in nine different locations actually showed hippocampal activity in conjunction with both non-spatial events (e.g., approach to cups, odor, match/non-match trial type) and spatial events (e.g., position of odor cups, position and odor, position of cups and match/non-match trial type, and position and odor and match/non-match trial type). Wood et al. (1999) analyzed the activity of 127 neurons in the CA1 and CA3 regions of the hippocampus and found that “the activity of 91 cells was statistically associated with one or more variables tested, and over half of these were associated only with non-spatial variables” (p. 613). “There is a wealth of evidence that many hippocampal neurons respond to highly complex conjunctions of features, such as those that define spatial locations, stimulus configurations, and behavioral actions” (Eichenbaum, 2001, p. 205).

There are several types of configural and inferential tasks that are impaired when the hippocampus, inputs to the hippocampus (e.g., parahippocampus), or outputs from the hippocampus (e.g., fornix) are lesioned. Fortin, Agster and Eichenbaum (2002) found that transitive inference is impaired when the hippocampus (dentate gyrus, Ammon’s horn, and subiculum) is lesioned. They presented odor stimuli in a specific temporal order to rats; each adjacent stimulus pair was always presented sequentially (e.g., A followed by B, B followed by C, etc). They then tested hippocampal lesioned and normal rats with the relations A vs. E and B vs. D: non-adjacent pairs that had never before been seen together. The normal and hippocampal rats were able to choose A over E, a control pair did not require any inferential ability because A had always been chosen first in the past. This control pair (A vs. E) did show, however, that both groups were capable of dealing with a novel pair of stimuli. The hippocampal lesioned rats, however, were not able to choose B over D during testing. This pair of stimuli required the rats to make an inferential decision about the temporal order of the stimuli; B and D had been chosen equally often in the first or second position during training. Other tasks that have been impaired by hippocampal lesions include transverse patterning in rats (A+B-, B+C-, and C+A-; Alvarado & Rudy, 1995; Dusek & Eichenbaum, 1998) and the social acquisition of food preferences in rats in both familiar and novel contexts (Alvarez, Lipton, Melrose, & Eichenbaum, 2001; Alvarez, Wendelken, & Eichenbaum, 2002).

Based on such evidence, Eichenbaum (2001) has hypothesized that the hippocampus is responsible for making inferential decisions about relations between stimuli and using the information in declarative memory in a flexible and novel manner. A difference, however, has been found between the type of processing that is done by the parahippocampus and the hippocampus. Eichenbaum and Bunsey (1995) stated, “The parahippocampal region has the capacity to hold stimulus representations for extended periods, and in doing so, can combine items that occur sequentially or simultaneously” (p. 22). This means that stimuli could be coded in a fused or configural manner when it may appear that they should be coded separately. Alternatively, the hippocampus codes stimuli separately and in elemental form, which allows for the comparison of individual stimuli when necessary. In this way, the parahippocampus and the hippocampus are thought to function in an antagonistic manner.

For example, Bunsey and Eichenbaum (1993a) trained rats odor pairs using a paired associate go/no-go design. In this design, if the two stimuli presented were “paired together”, then the rat would respond by giving a nose poke in a water port, but if two stimuli were presented that were not paired together during training, then the rat would not respond. During testing, they presented two different types of foils: mispairs and non-pairs. The mispairs contained two of the stimuli from the trained paired associates, but the stimuli paired during mispairs were different from those paired together during training. The non-pairs were made up of one of the stimuli from the trained paired associates and one novel stimulus. Rats with parahippocampal (entorhinal and perirhinal cortices) lesions were impaired when choosing the mispairs, but not the non-pairs because the items in the mispairs were both originally part of the trained pairs and the hippocampus would have encoded them separately, thus, making them impossible to distinguish from the trained pairs. “Correct identification of MPs [mispairs] required comparison of odors in the sequence, whereas NR sequences [non-pairs] could be identified by a single item in the stimulus sequence” (Bunsey & Eichenbaum, 1993a, p. 744). Therefore, no comparison of odors could be made for paired associates or mispairs with a parahippocampal lesion because a parahippocampal lesion would prevent a configural representation from being made.

Conversely, Bunsey and Eichenbaum (1993b) used the same experimental design as Bunsey and Eichenbaum (1993a); however, they lesioned the hippocampus rather than the parahippocampus. They found that rats with the hippocampal lesions had no impairment when compared with normal rats in distinguishing the trained pairs from the non-pairs. Instead, they found that the performance of the hippocampal lesioned rats was facilitated compared with normal rats distinguishing paired associates from mispairs. The authors concluded that this facilitation was due to the inability of the rats with hippocampal lesions to compare odors; the lesioned rats were only able to create a configural or fused memory for each stimulus pair. Therefore, the rats were able to identify the mispairs because they were configurally different from the trained pairs.

Otto, Schottler, Staubli, Eichenbaum, and Lynch (1991) stated, “The hippocampus takes precedence over brain regions encoding stimuli individually (nonrelational strategy) or, alternatively competes with those other regions for control over behavioral choice” (p. 118). Because the hippocampus was lesioned in the Bunsey and Eichenbaum (1993b) study, it allowed the parahippocampus to create configural or fused representations for each of the paired associates and mispairs; if the hippocampus and parahippocampus were not in some competition with each other or if the hippocampus did not normally take precedence in the task, then there should have been no facilitation of performance for the rats with hippocampal lesions. Eichenbaum (1997) stated that the hippocampus prevents the fusion that takes place in the parahippocampus and “instead mediates the separate coding of stimulus elements and their association according to the relevant relationships between the items” (p. 562).

Bingman, Strasser, Baker, and Riters (1998), however, found that pigeons had no difficulty in discriminating paired associates from mispairs nor trouble discriminating paired associates from non-pairs using visual stimuli even though the avian hippocampal and parahippocampal regions are thought to be good homologues to the mammalian hippocampus and parahippocampus (perirhinal and entorhinal cortices). A major difference between this experiment and those of Bunsey and Eichenbaum (1993a and 1993b) is that Bingman et al. (1998) lesioned both the homologue of the hippocampus and parahippocampus in the pigeons. The findings of Bingman et al. (1998) therefore indicate that some other area of the brain might also be involved in relational responding.

Of interest here, however, is when information might be coded in a configural or elemental format in a normal learning situation. If, for example, stimuli were presented simultaneously, then would that normally lead to a learning situation where stimuli were coded individually or configurally? Within the stimulus equivalence paradigm, this information would be important because it could support the hypothesis that there are problems with the simultaneous MTS design that could not be easily overcome. It is already apparent that when the stimuli are moved from the comparison to the sample stimulus location (as in tests for symmetry), non-human animals and non-verbal children do not recognize these as the same stimuli. Therefore, it seems likely that the stimuli in a simultaneous MTS design are coded by the hippocampus in an elemental manner where they can be compared with one another rather than in a configural manner by the parahippocampus where there would be no relational comparison.

Given this evidence, it is likely that the hippocampus is responsible for relational responding in stimulus equivalence experiments; however Eichenbaum, Fagan, Mathews, and Cohen (1988) found that the hippocampus codes more than just stimulus relation in simultaneous and successive MTS designs. Eichenbaum et al. (1988) trained normal rats and rats with fornix lesions on three separate tasks. Task 1 was the simultaneous presentation of two odor cues followed by a go-left/go-right choice response. Task 2 was the successive presentation of two odor cues followed by a go-left/go-right choice response. Task 3 was the successive presentation of odor cues with a go/no-go response (not a choice response). They hypothesized that, if the hippocampus were differentially involved in simultaneous and successive MTS, then they would see enhanced responding from normal rats over that of fornix lesioned rats in Task 1. Their reasoning was based on Task 1's simultaneous presentation, which would require a relational comparison of the stimuli, and Task 1's choice response, which would also require a relational comparison between the choices. The authors also believed that there would be enhanced responding from lesioned rats over that of normal rats in Task 3 because Task 3 involved the successive presentation of stimuli which they thought might be mediated by the parahippocampus. In addition, Task 3 did not require a choice response, so there were no relational capabilities required to respond. Task 2 should have yielded intermediate results because there is a successive presentation of stimuli (i.e., not a relational presentation), but a choice response (i.e., relational component that requires comparison of choice items).

Eichenbaum et al. (1988) found that the fornix lesioned rats showed a large impairment in Task 1 compared to normal rats, facilitation for the lesioned rats over the performance of normal rats in Task 3, and only a slight impairment for lesioned rats as compared to normal rats in Task 2. These results show that the hippocampus is important during simultaneous presentations of stimuli (e.g., Task 1) and that the hippocampus is also used during choice responding (e.g., Task 2). Use of the hippocampus during choice responding could either code the spatial location of comparison stimuli in addition to the stimulus that should be chosen or simply compare the presented stimuli to one another. In addition, the facilitation of Task 3 for the fornix lesioned animals shows that the hippocampus is also used for relational responding during successive MTS. Much like in the Bunsey and Eichenbaum (1993b) study, it appears that the hippocampus can be used for a relational strategy and the parahippocampus can be used for simple associations between stimuli; thus allowing for the facilitation of a simple associative response when the relational strategy is no longer available.

The Bunsey and Eichenbaum (1993a, 1993b) and Eichenbaum et al. (1988) experiments strongly imply that, when there is hippocampal damage in rats, it affects simultaneous discrimination of odors, and when there is hippocampal damage, successive discrimination of odors is facilitated. Eichenbaum, Mathews, and Cohen (1989) argue that there is a difference in how simultaneous versus successive presentation affects impairment or facilitation of discrimination because stimuli presented simultaneously encourage explicit comparison whereas stimuli presented successively must be processed independently. They also argue, however, that normal animals must be trying to use a relational strategy or there would not be a change in responding in a successive MTS design with hippocampal lesioning.

Based on the experimental evidence, it appears that when stimuli are presented together in a simultaneous manner, they can be coded by the hippocampus in conjunction with the spatial information. In addition, it appears that when stimuli are presented in a successive manner, the hippocampus is used for a relational strategy. Eichenbaum (1992) has stated that among the different experiments examining the function of the hippocampus, there seems to be two different groups of behavior supported by the hippocampus: the encoding of cues that compose places and scenes and items in context as well as the representation of temporal relations among cues presented sequentially. “Both of these groups are common in that they implicate that the hippocampus processes comparisons among items in memory and the critical relations among items presented either simultaneously or sequentially” (Eichenbaum, 1992, p. 218).

The only experiments that have shown evidence to the contrary have typically been studies that did not test a relational response when the hippocampus was lesioned; they only test simple associative responses which, according to the experiments mentioned previously, would be unaffected and possibly even facilitated by a hippocampal lesion (e.g., Muray, Gaffan, & Mishkin, 1993; Cho & Kesner, 1995; Watanabe, 2002).

In order to again assess the role of the hippocampus in relational responding, Bunsey and Eichenbaum (1996) conducted a stimulus equivalence experiment with rats. Bunsey and Eichenbaum (1996) trained A → B and X→ Y (training Set 1) and B → C and Y → Z (training Set 2) relations to rats using a 0-s delayed MTS design with odor stimuli. They found that normal rats readily showed transitivity during testing (i.e., A → C relation and X → Z relation); however, rats with hippocampal lesions were impaired during transitivity testing. They also found evidence of a symmetrical relation, but much like Schusterman and Kastak (1993) and Yamamoto and Asano (1995), they trained the B → A relation and the Y → X relation using the Set 1 stimuli and then they tested for the C → B relation and the Z → Y relation using the Set 2 stimuli. Bunsey and Eichenbaum (1996) stated, “In constructing this test we took into consideration previous evidence that consistent symmetry is not observed immediately in animals. To address these issues, we first exposed subjects to the symmetry protocol by retraining them on Set 1 with the sample and choice items reversed” (p. 257). The authors did, however, find that unlike normal rats, rats with hippocampal lesions were impaired during symmetry testing with the Set 2 stimuli.

Regardless of how the symmetrical result was obtained for the normal rats, Bunsey and Eichenbaum (1996) effectively illustrated that the hippocampus is involved in the formation of stimulus equivalence classes. In addition, because it is thought that the hippocampus codes for spatial location in addition to relations among items (Eichenbaum et al., 1988), these data also support the hypothesis that the hippocampus codes for the appropriate relation among those items. In this case, the hippocampus coded for location in addition to the stimuli. One can only assume the hippocampus would also code for temporal location in a successive MTS design as was suggested by Eichenbaum and Cohen (2001). If the hippocampus codes for spatial and temporal location in simultaneous MTS and codes for temporal location in successive MTS, then any experiment with non-human animals that controls for temporal and spatial location in a simultaneous MTS design and controls for temporal location in a successive MTS design should find evidence of emergent symmetry.

Experimental control for spatial and temporal location

There are two previous experiments that have controlled for both the spatial and temporal location of stimuli in stimulus equivalence experiments: Tomonaga, Matsuzawa, Fujita, and Yamamoto (1991; Experiment 1) and Lionello-DeNolf and Urcuioli (2002). Tomonaga et al. (1991; Experiment 1) found evidence of emergent (untrained) symmetry in one of three chimpanzees and Lionello-DeNolf and Urcuioli (2002) found no evidence of emergent symmetry in pigeons. There are, however, differences between these experiments that could have allowed for emergent symmetry in Tomonaga et al's (1991) chimpanzee and not in the pigeons in the Lionello-DeNolf and Urcuioli (2002) experiments.

As previously stated, Tomonaga et al. (1991; Experiment 1) observed clear evidence of emergent symmetry without exemplar training in one chimpanzee. Tomonaga et al. trained three chimpanzees on a 0-s delayed MTS task. From the outset of training, identity matching trials (e.g., A→A) were intermixed with arbitrary matching trials (A→B and B→C) consisting of color and shape stimuli; in addition, they arranged for each sample stimulus to appear in more than one possible spatial location and for the comparisons to appear in more than two spatial locations. One of the three chimpanzees showed a symmetrical result during testing that was significantly above chance (75% correct); during the first day of testing, that chimpanzee's performance was at 100% correct. Tomonaga et al. controlled for spatial location by giving stimuli in multiple locations and they controlled for temporal location by giving identity training (A → A). Identity training allowed for all stimuli to be shown in the first and second temporal locations, and therefore, the temporal location of the stimuli during symmetry testing was not novel to the chimpanzees.

To address the problem of spatial location in testing for symmetry with pigeons, Lionello-DeNolf and Urcuioli (2002) gave a 0s delayed MTS task using three response keys: left, center, and right. They randomly showed the sample stimuli on either the left or right key and the comparison stimuli on the remaining two keys. In Experiment 1, they trained pigeons on A1→B1 and A2→B2 relations using lines and hues. During testing, they presented the B samples on the center key and the A comparisons on the left and right keys. They gave half of the pigeons food reinforcement for choosing the A1 comparison when presented with a B1 sample (consistent group), whereas they gave the remaining pigeons reinforcement for choosing the A2 comparison when presented with a B1 sample (inconsistent group). Lionello-DeNolf and Urcuioli (2002) found that the consistent group learned the B→A association at the same rate as the inconsistent group. This result suggests that some factor other than the spatial location of the matching stimuli may need to be controlled in order for symmetry to emerge.

In Experiment 2, Lionello-DeNolf and Urcuioli (2002) trained identity relations (A→A and B→B) plus symbolic relations (A→B) in the same manner as Experiment 1, so that the pigeons could successively discriminate between the B stimuli when they appeared in testing as samples and so that the pigeons could also simultaneously discriminate between the A stimuli when they appeared in testing as comparisons. By including identity training, this design should have effectively controlled for the temporal location of the stimuli. Lionello-DeNolf and Urcuioli tested the pigeons in the same manner as they had in Experiment 1, but they again found no evidence for symmetry: The consistent group did not learn the B→A relations any faster than the inconsistent group.

It is interesting to note that one of the chimpanzees in Tomonaga et al. (1991, Experiment 1) did exhibit symmetrical responding during testing, whereas the pigeons in Lionello-DeNolf and Urcuioli (2002, Experiment 2) did not, even though both experiments used multiple locations for the sample stimuli and they both gave identity training in addition to symbolic training. Why did the pigeons not show emergent symmetry?

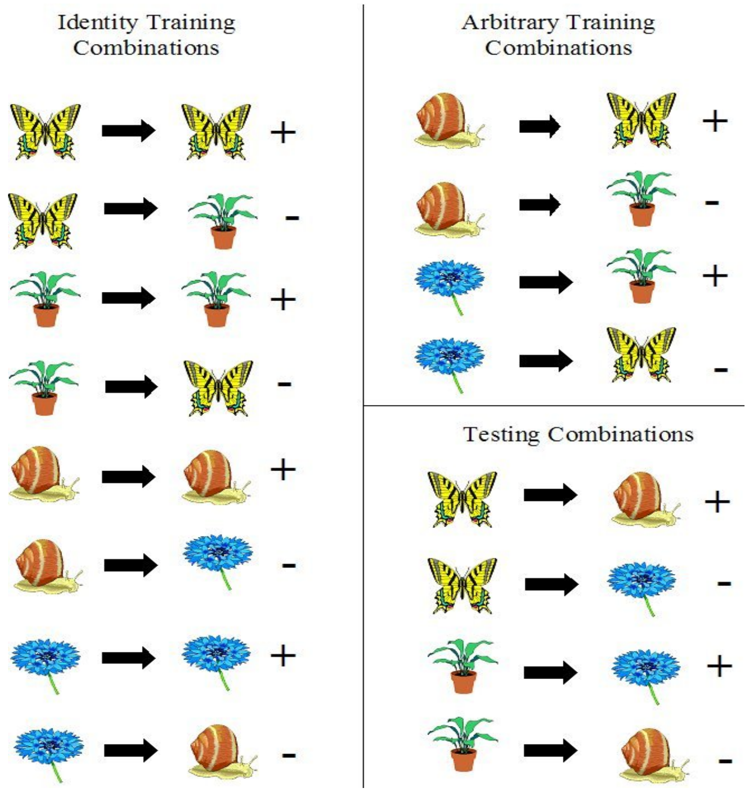


Figure 1. Stimulus combinations from Frank and Wasserman*.

This is a depiction of one of the four counterbalancings from Experiment 1 of Frank and Wasserman (2005). Shown are the identity matching, arbitrary matching, and testing stimulus combinations.

*Source: Frank, A. J., and Wasserman, E. A. (2005). *The Journal of Experimental Analysis of Behavior, 84,* pp. 151.

Even though Lionello-DeNolf and Urcuioli (2002; Experiment 2) gave identity training and arbitrary training, the two types of training trials were never intermixed in the same session; once pigeons learned the identity relations, they were then given a refresher on the arbitrary relations. In addition, during training, Lionello-DeNolf and Urcuioli gave the samples on one of the two side keys (i.e., left or right) and the comparisons on the remaining two keys during both identity and arbitrary training. During testing for symmetry, however, the sample was only given on the center key, whereas during training the sample was given on one of the two side keys. Hence, the B sample had not been seen in the center position until testing. In other words, the spatial and temporal positions of B had not been controlled and this may have led to a null symmetry result.

Preliminary research by Frank and Wasserman (2005)

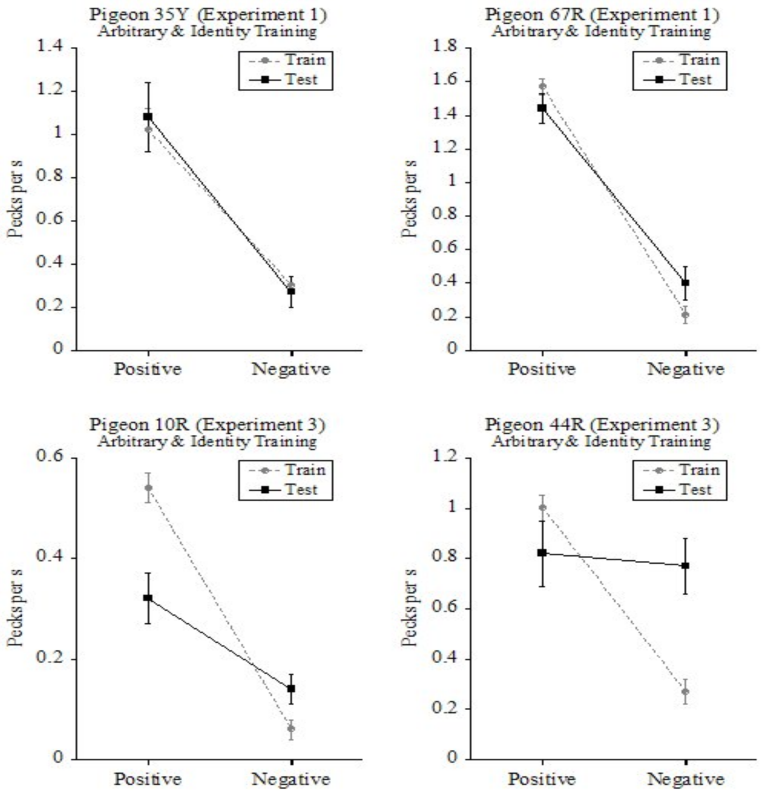
Although Tomonaga et al. (1991, Experiment 1) found emergent symmetry with one chimpanzee, we obviously are still a very long way from having methods for producing robust symmetrical responding in non-human animals without providing exemplar training. Given the small number of prior experiments purporting to find emergent symmetry, it is difficult to come to any firm conclusions about the necessary and sufficient conditions for obtaining this result. It seems that an effective technique must control for the spatial and temporal attributes of visual stimuli that might interfere with acquisition of the appropriate training relations necessary to demonstrate symmetrical responding.

What training procedure might be used to effectively establish such relations? One possibility is successive MTS (e.g., Konorski, 1959; Wasserman, 1976). In this task, the sample (S1) and comparison (S2) stimuli are shown in only *one* location, which completely circumvents any distinctive associations between the matching stimuli and where they appear. In successive MTS, S1 is shown first at a particular location, turned off, after which S2 is shown at that same location. If the two successive stimuli are a "match," then reinforcement is contingent on responding to S2; if the two stimuli are not a "match," then responding to S2 is not reinforced. Typically, pigeons come to respond to S2 when reinforcement is scheduled and refrain from responding when no reinforcement is scheduled (i.e., a go/no go procedure). Although the successive MTS eliminates *spatial* location as a potentially contaminating cue by presenting all of the stimuli in the same location, it does not control for any differential association between those stimuli and their *temporal* location.

In Frank and Wasserman (2005), the successive MTS procedure was used to train and test pigeons for associative symmetry. The use of this procedure allowed us to show each stimulus in only *one* spatial location. Additionally, in Experiment 1, we randomly intermixed both identity matching trials and arbitrary matching trials from the outset of training, so that each stimulus would also be seen in each of *two* temporal locations (Figure 1). Under these conditions, we found robust emergent symmetry during testing (Figure 2).

In Experiment 2, we omitted the intermixed identity matching trials during training: Two pigeons simply learned arbitrary matching (A→B) alone in the successive MTS procedure. When later tested for the symmetrical relation (B→A), neither showed signs of emergent symmetry (Figure 3).

In Experiment 3, we initially trained two pigeons on arbitrary matching alone and then tested for symmetry. As in Experiment 2, the pigeons showed no signs of emergent symmetry (Figure 3). We next trained the same pigeons with identity matching trials intermixed with the already-learned arbitrary matching trials. Once all of the stimulus combinations were mastered, we again tested for symmetry and found evidence for emergent symmetry in only one of the pigeons, but its results were not as strong as those in Experiment 1 (Figure 2).



Pigeon 35Y (Experiment 1) Arbitrary & Identity Training

Pigeon 67R (Experiment 1) Arbitrary & Identity Training

Pigeon 10R (Experiment 3) Arbitrary & Identity Training

Pigeon 44R (Experiment 3) Arbitrary & Identity Training

Figure 2. Data from Frank and Wasserman*.

Each graph shows the mean response rates in pecks per s for the positive and negative training and symmetry combinations for pigeons trained with intermixed identity and arbitrary matching trials.

*Source: Frank, A. J., and Wasserman, E. A. (2005). *The Journal of Experimental Analysis of Behavior, 84*, pp. 155.

There are two possible explanations for the results found in the Frank and Wasserman (2005) experiments: controlling temporal and spatial location allowed for the animals to show emergent symmetry or intermixing identity matching with arbitrary matching allowed for emergent symmetry. The first possible scenario is straightforward. A positive emergent symmetry result in an experiment without identity relations, but with temporal and spatial location controlled would clarify if identity relations or controlling temporal position was responsible for pigeons' ability to show emergent symmetry in Frank and Wasserman (2005).

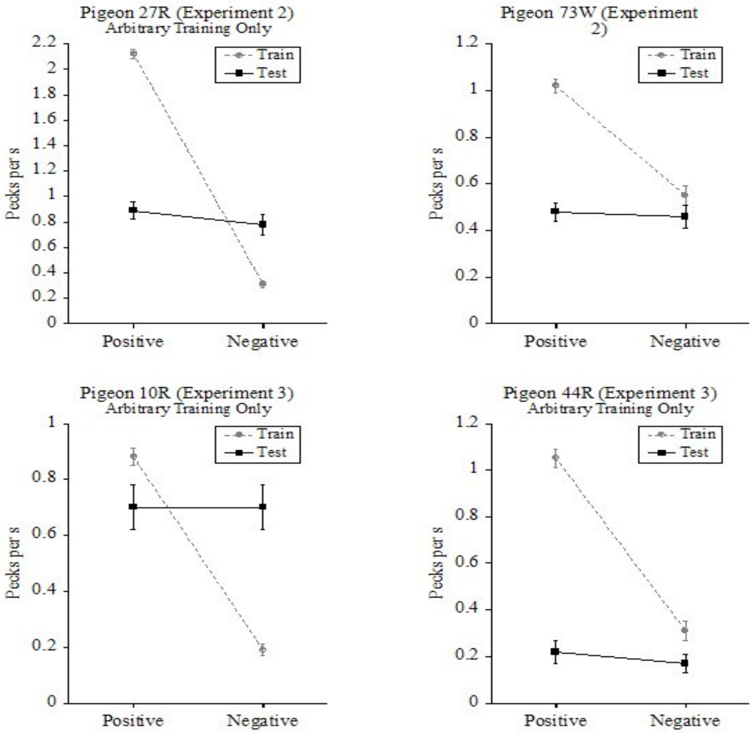


Figure 3. Data from Frank and Wasserman*.

Each graph shows the mean response rates in pecks per s for the positive and negative training and symmetry combinations for pigeons trained with arbitrary matching trials only.

*Source: Frank, A. J., and Wasserman, E. A. (2005). *The Journal of Experimental Analysis of Behavior, 84*, pp. 159.

The second possibility, as stated above, is that intermixing identity relations with arbitrary relations was responsible for the results seen in Frank and Wasserman (2005). The reason for this may rest in the definition of stimulus equivalence proposed by Sidman and Tailby (1982). In the area of symbolic logic, the concept of identity is the same as Sidman and Tailby's (1982) definition of stimulus equivalence. In other words, the concept of identity in symbolic logic is defined as symmetric, transitive, and reflexive (Bergmann, Moor, & Nelson, 1998). It is, therefore, possible that, by receiving training on the identity relation, a non-human animal gains similar learning experience to what human subjects have received long before they participated in the stimulus equivalence experiment.

As suggested by Deacon (1997, Chapter 3), it is also possible that, by training identity matching in addition to arbitrary matching, we taught the pigeons to ignore stimulus order. If we did, indeed, teach the pigeons to ignore stimulus order by intermixing identity with arbitrary matching in Frank and Wasserman (2005, Experiment 1), then this training would explain why the pigeons were capable of showing emergent symmetry during testing. In addition, this training would also explain the results obtained in Experiments 2 and 3. In Experiment 2, the pigeons would not have shown emergent symmetry during testing because they were only trained with arbitrary matching. As stated above, these pigeons may have coded temporal relation in addition to the stimuli themselves. In Experiment 3 (Phase 1), the pigeons showed the same results as in Experiment 2; but what was really interesting was that the pigeons did not show emergent symmetry *after* identity matching was intermixed with arbitrary matching. According to Deacon (1997) the pigeons would have had to *unlearn* that temporal order was important to stimulus presentation and *re-learn* that temporal order was not important. This additional unlearning and re-learning may have led to our failure to find emergent symmetry in Frank and Wasserman (2005, Experiment 3). Given this explanation, animals may require that identity and arbitrary trials be intermixed in order to learn that temporal order does not matter or it may be that controlling temporal order will simply be sufficient to produce emergent symmetry. Showing that giving identity matching trials is sufficient to produce generalized identity matching and hence symmetry was also tested to some extent because generalized identity matching may also be a necessary condition for producing symmetry.

CHAPTER 2. CURRENT AIMS

Pigeons’ excellent visual system makes them the ideal animal, besides primates, to study stimulus equivalence, and more specifically, emergent symmetry. This fact is especially true given the preliminary results found in Frank and Wasserman (2005). The aim of the four experiments discussed here was to elucidate the necessary and sufficient conditions for emergent symmetry in non-human animals; specifically, to determine if controlling temporal position of visual stimuli or if intermixing identity relations with arbitrary relations is necessary for emergent symmetry. The implications of Deacon’s (1997) assertions about learning and unlearning will also be discussed in terms of their relation to the learning that could be taking place for the pigeons during the experiments.

In Experiment 1 of this dissertation, the temporal position of the visual stimuli was controlled, but no identity training was given. This experiment, and all of the experiments in this dissertation, utilized the successive MTS design used in Frank and Wasserman (2005). In Experiment 2 of this dissertation, identity relations were intermixed with arbitrary relations; however, the identity relations shown were composed of stimuli different from those used in the arbitrary relations; this design was used to determine if a generalized identity relation would be sufficient for emergent symmetrical responding. In Experiment 3 of this dissertation, identity relations were trained first; once the identity relations were learned, arbitrary relations were then trained. As seen in Frank and Wasserman (2005; Experiment 3), the order of training arbitrary and identity relations appears to be important to the expression of emergent symmetry. Perhaps by having trained identity relations first, using the same stimuli as the arbitrary relations, emergent symmetrical responding might have been enhanced. In Experiment 4 of this dissertation, arbitrary matching was trained with two sets of stimuli (e.g., AB and CD), but identity matching was trained only with one set of those stimuli (e.g., AB). Both sets of stimuli were tested for symmetrical relations. What follows is a detailed explanation, the hypotheses and aims, and the results of each experiment.

Experiment 1

Controlling temporal location without training identity relations.

Given the results of Frank and Wasserman (2005), it can be hypothesized that either temporal location or intermixing identity relations with arbitrary relations was responsible for the pigeons' ability to show emergent symmetry when no other non-human species has consistently been able to do so. *The aim of this experiment was to determine if pigeons can show emergent symmetry when spatial and temporal locations are controlled without the addition of identity relations.*

Method

Participants

Participants were four feral pigeons (*Columba livia*). The pigeons were kept at 85% of their free-feeding weights on a 14-h light/10-h dark schedule with free access to water and grit.

Apparatus

Two custom-built operant chambers were used for training and testing (Gibson, Wasserman, Frei, & Miller, 2004). Each operant chamber measures 36 (h) x 36 (l) x 41 (w) cm in size and was constructed with ¼ inch black opaque Plexiglas. Centered on the front wall of each chamber was a 28.5 cm x 18.5 cm square opening on which a 7 cm x 7 cm area was illuminated for each trial in the center of the chamber opening. Behind the opening was a 15-inch glass touchscreen (Model 452981-000, Elo TouchSystems, Fremont, CA). Behind each touchscreen, stimuli were displayed on a 15-inch LCD flat screen monitor (NEC, Melville, NY, Model 1550V). Reinforcers were 45-mg pellets (Pigeon Pellets M Pigeon Diet, Test Diets (Land O Lakes), Richmond, IN) and were delivered by a 45-mg pellet feeder (Model ENV-203IR, Med Associates Inc., Georgia, VT), which were positioned behind the back wall of the chamber. Each chamber was controlled by an Apple eMac (Model Z083, Apple, Cupertino, CA) and computer programs were created with HyperCard (Version 2.4). Stimuli were eight photo realistic clip art images (The Big Box of Art, Hemera, Quebec).

Procedure

Pretraining. Four experimentally naïve pigeons were initially pretrained to peck the center 7 cm x 7 cm illuminated area of the computer screen. Pretraining consisted of 150 trials during which one of four colors (green, yellow, red, or blue) were pseudo-randomly displayed on the computer screen. Initially, one peck at the color resulted in pellet reinforcement and the screen went black. The number of pecks necessary to complete each trial was increased daily until each pigeon completed a fixed ratio (FR) of 20 pecks on each trial.

Training. Each training trial began with an orienting stimulus—a white screen with a central black plus sign. After a single peck to the orienting stimulus, each pigeon was shown the first stimulus (S1) in a training combination. S1 was shown against a square white background for a fixed interval of 10 s. When the pigeon made its first peck after 10 s, S1 was removed from the screen, the white square background remained for 0.5 s, and then the second stimulus (S2) was shown against the square white background. If the training combination was a “match,” then a single peck to S2 after 10 s resulted in a food reinforcer (positive training combination); if the training combination was not a “match,” then at the end of 10 s, the screen turned black (negative training combination). Because a food reinforcer only followed the positive training combinations, it was expected that the pigeons would peck faster to S2 of the positive training combinations than to S2 of the negative training combinations. There were 12 arbitrary matching combinations. The birds were trained with six positive arbitrary matching trials (A1 → C1, B1 → A1, D1 → B1, A2 → C2, B2 → A2, and D2 → B2) and with six negative arbitrary matching trials (A1 → C2, A2 → C1, B1 → A2, B2 → A1, D1 → B2, D2 → B1). See Figure 4 for pictorial representations of these sequences.

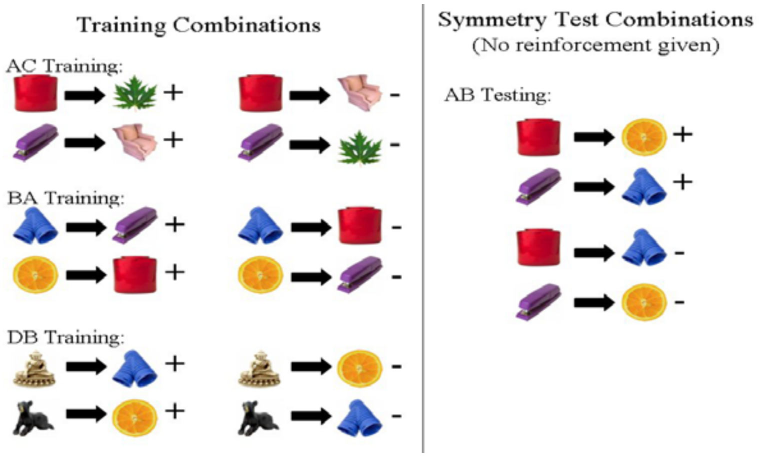


Figure 4. Stimulus combinations for Experiment 1.

This is a depiction of the training and testing stimulus combinations from one of the four counterbalancings from Experiment 1. "+" indicates a positive stimulus combination and "-" indicates a negative stimulus combination.

Initially, all trials were followed by an intertrial interval (ITI) of a random 5 to 10 s; however, if a pigeon was not learning (i.e., there was no differentiation between the peck rates for negative training and positive training combinations), then the ITI was increased following negative training combinations in order to make the negative training combinations more aversive and deter pecking.

Peck rate was recorded only during S2 (the comparison stimulus), from which six discrimination ratios were calculated following each session. Each discrimination ratio was calculated by dividing the number of responses to the positive training combination by the sum of the positive training combination and the negative training combination.

If a pigeon pecked equally often to the positive and negative training combinations, then the discrimination ratio would be 0.50. If a pigeon pecked faster to the positive training combination than to the negative training combination, then the discrimination ratio was greater than 0.50; a discrimination ratio of 1.00 meant that the pigeon pecked only at the comparisons appearing in the positive training combination. If a pigeon attained the 0.80 performance criterion, then that pigeon was given symmetry testing on the following day.

Each training session consisted of seven blocks of trials. Each block contained 2 of each of the 12 training combinations (i.e., 24 trials in each block) for a total of 168 trials per daily training session.

Symmetry Testing. Symmetry testing sessions contained the 12 arbitrary stimulus training combinations used in training plus four new testing stimulus combinations: two new positive symmetry testing combinations (A1 → B1 and A2 → B2) and two new negative symmetry testing combinations (A1 → B2 and A2 → B1). See Figure 4 for pictorial representations of these sequences. No food reinforcement was given following the symmetry testing trials. Additional testing sessions were conducted following at least one training session during which the pigeon was again required to attain the 0.80 training performance criterion during a complete training session in order to return to testing.

Each symmetry testing session consisted of a warm-up block involving one of each of the training stimulus combinations (i.e., 12 trials) followed by six blocks of trials that contained two of each training stimulus combination and one of each symmetry testing combination (i.e., 28 trials per block). The final block of each testing session contained one of each training stimulus combination and one of each symmetry testing combination (i.e., 16 trials). There were 196 trials in each symmetry testing session. Training and testing trials were given in this manner so that: (1) a testing trial would not be seen first in any symmetry test session and (2) testing trials were infrequently given as they never ended in reinforcement. Eight discrimination ratios were calculated: the same six training arbitrary matching ratios described previously plus two symmetry test ratios. A total of six testing sessions were conducted for each bird.

Results and Discussion

Throughout the results sections for all of the experiments, “positive training combinations” will refer to those arbitrary matching combinations of stimuli that were associated with food and “negative training combinations” will refer to those arbitrary matching combinations of stimuli that were not associated with food. “Positive identity combinations” will refer to those identity matching combinations that were associated with food and “negative identity combinations” will refer to those identity matching combinations that were not associated with food. “Positive testing combinations” are temporal inversions of the positive training (arbitrary) combinations and “negative testing combinations” are temporal inversions of the negative training (arbitrary) combinations. Neither the positive nor the negative testing combinations were associated with food (i.e., the symmetry test trials were run in extinction).

An analysis of variance (ANOVA) of Trial Type (training or testing) x Positive/Negative (positive or negative stimulus combination) was conducted for each individual bird in all of the experiments. Identity relations were not included in the statistical analyses for any bird in any of the experiments. Data reported in all experiments is for Test Days 1-6[1].

Pigeon 17B

Symmetry Test 1 for Pigeon 17B occurred after 66 days of training (0 incomplete and 66 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations training (Table A1).

The mean response rates of Pigeon 17B to the positive and negative training and testing combinations are depicted in Figure A1 (Top Left). The peck rate difference between the positive and negative testing combinations (0.086 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (0.97 pecks per s). The overall difference between positive and negative combinations (both training and testing) was highly reliable (Table A2). In addition, there was also a reliable difference between the trial types (training and testing). The interaction between trial type and positive and negative combinations was also highly reliable.

Follow-up tests show that all differences were significant except the difference between positive testing and negative testing (Table A3). This indicates that the pigeon did not respond to the testing combinations as it did the training combinations, which should have occurred if the pigeon had shown emergent symmetry.

If this pigeon had shown emergent symmetry, then there might also have been no difference between the positive training and the positive testing and no difference between the negative training and the negative testing combinations. In addition, there should have been a reliable difference between the positive testing and negative testing combinations.

---

[1] A summary for the data from all pigeons for Test Day 1 is reported in Appendix B.

Pigeon 3B

Symmetry Test 1 for Pigeon 3B occurred after 153 days of training (8 incomplete and 145 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A1).

The mean response rates of Pigeon 3B to the positive and negative training and testing combinations are depicted in Figure A1 (Top Right). The peck rate difference between the positive and negative testing combinations (-0.03 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (0.23 pecks per s). In fact, this pigeon pecked faster to the negative testing combinations than to the positive testing combinations. The overall difference between positive and negative combinations (both training and testing) was highly reliable (Table A2). In addition, there was also a reliable difference between the trial types (training and testing). The interaction between trial type and positive and negative combinations was also highly reliable.

Follow-up tests show that all differences were significant except the different between positive testing and negative testing (Table A3). This indicates that the pigeon did not respond to the testing stimulus combinations as it did the training combinations, which should have occurred if the pigeon had shown emergent symmetry. Again if emergent symmetry was shown, then there might also have been no difference between the positive training and the positive testing and no difference between the negative training and the negative testing combinations, and there should have been a reliable difference between the positive testing and negative testing stimulus combinations.

Pigeon 68Y

Symmetry Test 1 for Pigeon 68Y occurred after 61 days of training (2 incomplete and 59 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A1).

The mean response rates of Pigeon 68Y to the positive and negative training and testing combinations are depicted in Figure A1 (Bottom Left). The peck rate difference between the positive and negative testing combinations (-0.13 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (0.71 pecks per s). This pigeon pecked faster to the negative testing combinations than to the positive testing combinations, which is the opposite of what should have been seen if the pigeon had shown evidence of emergent symmetry. The overall difference between positive and negative combinations (both training and testing) was highly reliable (Table A2). In addition, the interaction between the trial type and the positive and negative combinations was also highly significant. However, for this pigeon the reliable difference between the trial types (training and testing) did not meet a $p<0.05$ level, but it did meet a $p<0.10$ level. This suggests that the training and testing combinations were not strongly different from one another, but this result was in the wrong direction (i.e., peck rates to the negative testing combinations were higher than peck rates to the positive testing combinations).

Follow-up tests show that all differences were significant (Table A3), however, the reliable difference between the positive and negative testing combinations was in the wrong direction.

Pigeon 89B

Symmetry Test 1 for Pigeon 89B occurred after 77 days of training (1 incomplete and 76 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A1).

The mean response rates of Pigeon 89B to the positive and negative training and testing combinations are depicted in Figure A1 (Bottom Right). The peck rate difference between the positive and negative testing combinations (-0.37 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations

(1.33 pecks per s). This pigeon also pecked faster to the negative testing combinations than to the positive testing combinations. The overall difference between positive and negative combinations (both training and testing) was highly reliable (Table A2). There was also a reliable difference between the trial types (training and testing), and a reliable interaction between the trial types and positive and negative stimulus combinations.

Follow-up tests show that all differences were significant (Table A3); however, the reliable difference between the positive and negative testing combinations was in the wrong direction for this pigeon as well.

General Discussion

The goal of this experiment was to test if just controlling for the temporal location problem would result in emergent symmetry in pigeons. It was expected that the pigeons would show emergent symmetry in this experiment because both the temporal and spatial location problems inherent in previous emergent symmetry experiments were corrected for here despite the fact that identity relations were not given. However, none of the pigeons in this experiment showed evidence of emergent symmetry.

It is possible that Frank and Wasserman (2005; Experiment 1) taught the pigeons to ignore temporal order due to the training of identity relations (Deacon, 1997). In other words, the pigeons in this experiment have not been *explicitly* trained to ignore the temporal order of the stimuli and therefore do not show symmetrical responding. Perhaps controlling for the temporal location was not explicit enough for the pigeons to learn that stimuli were the same even though they were in different temporal locations. In other words, if the results found in Frank and Wasserman (2005, Experiment 1) were obtained because the pigeons were taught to ignore temporal order via training identity matching (Deacon, 1997), then it may be the case that pigeons need identity relations to be intermixed with arbitrary relations in order to show emergent symmetry. Therefore, identity might be a necessary relation that must be learned in order to obtain emergent symmetry.

Experiment 2

Training identity relations with stimuli different from those used in training arbitrary relations.

As stated earlier, it can be hypothesized that either temporal location or intermixing identity relations with arbitrary relations was responsible for the pigeons' ability to show emergent symmetry when no other non-human species has consistently been able to do so (Frank & Wasserman, 2005). Given that the results for Experiment 1 suggested that controlling for temporal location alone does not result in emergent symmetry for the pigeons, it seemed even more important to focus on conditions that involved identity training. *The aim of this experiment was to determine if pigeons can show emergent symmetry when identity training is given using stimuli different from arbitrary training; this design allows for identity training to be given without controlling for the temporal locations of the stimuli used in arbitrary training.*

Method

Participants

Participants were four feral pigeons (*Columba livia*). The pigeons were kept at 85% of their free-feeding weights on a 14-h light/10-h dark schedule with free access to water and grit.

Apparatus

The same apparatus used in Experiment 1 was also used in this experiment. Stimuli were eight photo realistic clip art images (The Big Box of Art, Hemera, Quebec).

Procedure

Pretraining. Pretraining was conducted in the same manner as in Experiment 1.

Training. Training was conducted in the same manner as in Experiment 1, except that there were four arbitrary matching combinations. The birds were trained with two positive arbitrary matching trials (A1 → B1, A2 → B2) and with two negative arbitrary matching trials (A1 → B2, A2 → B1). In addition, there were eight identity matching combinations. The birds were trained with four positive identity matching trials (C1 → C1, C2 → C2, D1 → D1, D2 → D2) and there were four negative identity matching trials (C1 → C2, C2 → C1, D1 → D2, D2 → D1). See Figure 5 for pictorial representations of these sequences.

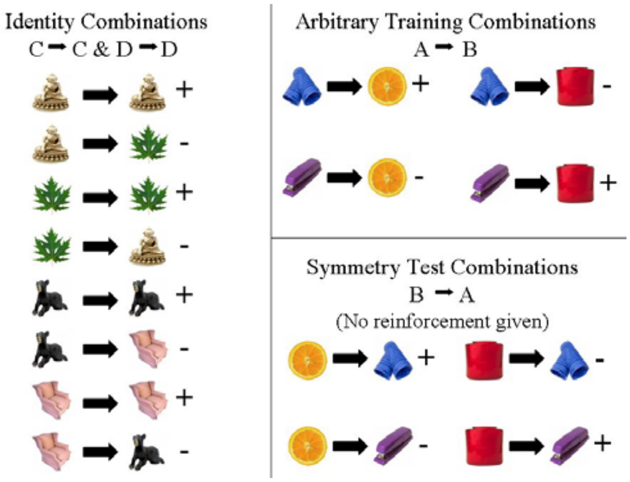


Figure 5. Pictures and stimulus combinations
used in Experiment 2.

In addition, there were six discrimination ratios calculated for each training session: two discrimination ratios for arbitrary training and four discrimination ratios for identity training. Discrimination ratios were calculated in the same manner as in

Experiment 1. If a pigeon attained the performance criterion of 0.80 for each of the discrimination ratios, then that pigeon was given testing on the following day.

Each training session consisted of eight blocks of trials. Each block contained two of each of the 12 training combinations (i.e., 24 trials in each block) for a total of 192 trials per daily training session.

Symmetry Testing. Testing was also conducted in the same manner as in Experiment 1, except symmetry testing sessions contained four arbitrary stimulus combinations and eight identity stimulus combinations used in training plus four new testing stimulus combinations: two new positive symmetry testing combinations (B1 → A1 and B2 → A2) and two new negative symmetry testing combinations (B1 → A2 and B2 → A1). See Figure 5. In addition, there were eight discrimination ratios calculated at the end of each testing session: two discrimination ratios for arbitrary training, four discrimination ratios for identity training, and two discrimination ratios for testing combinations.

Each symmetry testing session consisted of a warm-up block involving one of each of the training stimulus combinations (i.e., 12 trials) followed by seven blocks of trials that contained two of each training stimulus combination and one of each symmetry testing combination (i.e., 28 trials per block). The final block of each testing session contained one of each training stimulus combination and one of each symmetry testing combination (i.e., 16 trials). There were 224 trials in each symmetry testing session. A total of six symmetry testing sessions were conducted for each bird.

Results and Discussion

Pigeon 33B

Symmetry Test 1 for Pigeon 33B occurred after 86 days of training (3 incomplete and 83 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A4).

The mean response rates of Pigeon 33B to the positive and negative training and testing combinations are depicted in Figure A2 (upper left). The peck rate difference between the positive and negative testing combinations (-0.51 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (0.72 pecks per s). This pigeon pecked faster to the negative testing combinations than to the positive testing combinations. There was a good peck rate difference between the positive and negative identity combinations (0.75 pecks per s).

The overall difference between positive and negative combinations (both training and symmetry), the difference between trial types (training and testing), and the interaction between trial type and positive and negative combinations were all reliable (Table A5).

Follow-up tests show that all differences were significant except the difference between positive testing and negative testing (Table A6). This indicates that the pigeon did not respond to the testing combinations as it did the training combinations, which should have occurred if the pigeon had shown emergent symmetry. If emergent symmetry was shown, then there might also have been no difference between the positive training and the positive testing and no difference between the negative training and the negative testing combinations.

Pigeon 66W

Symmetry Test 1 for Pigeon 66W occurred after 121 days of training (11 incomplete and 110 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A4).

The mean response rates of Pigeon 66W to the positive and negative training and testing combinations are depicted in Figure A2 (upper right). The peck rate difference between the positive and negative testing combinations (-0.12 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (0.87 pecks per s). This pigeon pecked faster to the negative testing combinations than to the positive testing combinations. There was a good peck rate difference between the positive and negative identity combinations (1.00 pecks per s).

The overall difference between positive and negative combinations (both training and testing), the difference between trial types (training and testing), and the interaction between trial type and positive and negative combinations were all reliable (Table A5).

Follow-up tests show that all differences were significant except the difference between positive testing and negative testing (Table A6). This indicates that the pigeon did not respond to the testing combinations as it did the training combinations, which should have occurred if the pigeon had shown emergent symmetry. Again, if emergent symmetry was shown, then there might also have been no difference between the positive training and the positive testing and no difference between the negative training and the negative testing combinations.

Pigeon 12W

Symmetry Test 1 for Pigeon 12W occurred after 32 days of training (1 incomplete and 31 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A4).

The mean response rates of Pigeon 12W to the positive and negative training and testing combinations are depicted in Figure A2 (lower left). The peck rate difference between the positive and negative testing combinations (0.06 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (1.03 pecks per s). There was a good peck rate difference between the positive and negative identity combinations (1.43 pecks per s).

The overall difference between positive and negative combinations (both training and testing), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A5).

Follow-up tests show that all differences were significant except the difference between positive testing and negative testing (Table A6), indicating that the pigeon did not respond to the testing combinations as it did the training combinations, which should have occurred if the pigeon had shown emergent symmetry.

Pigeon 93W

Symmetry Test 1 for Pigeon 93W occurred after 88 days of training (15 incomplete and 73 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A4).

The mean response rates of Pigeon 93W to the positive and negative training and testing combinations are depicted in Figure A2 (lower right). The peck rate difference between the positive and negative testing combinations (0.02 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (0.52 pecks per s). There was a good peck rate difference between the positive and negative identity combinations (0.48 pecks per s).

The overall difference between positive and negative combinations (both training and testing), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A5).

Follow-up tests show that all differences were significant except the difference between positive testing and negative testing (Table A6), indicating that the pigeon did not respond to the testing combinations as it did the training combinations, which should have occurred if the pigeon had shown emergent symmetry.

General Discussion

The goal of this experiment was to test if intermixing identity matching combinations that comprised stimuli different from those used in arbitrary matching combinations would result in emergent symmetry in pigeons. There were two possible outcomes for this experiment depending on what the pigeons learned in the experiment. (1) The pigeons could have shown emergent symmetry based on learning a generalized identity matching via identity training and this generalized identity could have led to the generality of identity with all of the stimuli trained in arbitrary matching (i.e., the stimuli not involved in identity matching). (2) Alternatively, the pigeons might not have shown emergent symmetry because they did not learn a generalized identity matching. If they did not learn a generalized identity concept they would not show emergent symmetry because the stimuli shown in arbitrary matching were not shown in all temporal locations.

In this experiment, it was the case that none of the pigeons showed emergent symmetry. It can be assumed that the pigeons either did not learn a generalized identity from identity training or that there was a failure to generalize an identity rule to the stimuli used in arbitrary matching. In all likelihood, it is probably difficult to learn a generalized identity matching with only two exemplars. Future experiments can elucidate whether more exemplars would result in a generalized identity matching and, hence, emergent symmetry.

It is noteworthy that Deacon’s (1997) theory that learning to ignore the temporal location based on identity training did not hold in this experiment. One might expect that since identity training was given, albeit not with the same stimuli that were given in arbitrary matching, that the pigeons may have learned that temporal location was not important. It seems, however, that identity training with the same stimuli given in arbitrary matching is a very important feature of emergent symmetry in pigeons.

Experiment 3

Train identity relations first and arbitrary relations after identity relations have been learned.

Frank and Wasserman (2005, Experiment 3) found that, when pigeons learn arbitrary relations before intermixing arbitrary relations with identity relations, birds show only weak evidence of symmetry. This evidence of symmetry is not nearly as strong as the emergent symmetrical results found when identity and arbitrary relations are intermixed from the outset of training. Given that identity training might explicitly teach the pigeons that the temporal order of the stimuli does not matter (Deacon, 1997), then it should be easier for the pigeons to show emergent symmetry if they are explicitly trained that stimulus order does not matter in advance of arbitrary matching. *The aim of this experiment was to determine if training identity relations before training arbitrary relations would also affect the pigeons' ability to show emergent symmetry.*

Method

Participants

Participants were four feral pigeons (*Columba livia*). The pigeons were kept at 85% of their free-feeding weights on a 14-h light/10-h dark schedule with free access to water and grit.

Apparatus

The same apparatus used in Experiment 1 was also used in this experiment. Stimuli were four photo realistic clip art images (The Big Box of Art, Hemera, Quebec).

Procedure

Pretraining. Pretraining was conducted in the same manner as in Experiment 1.

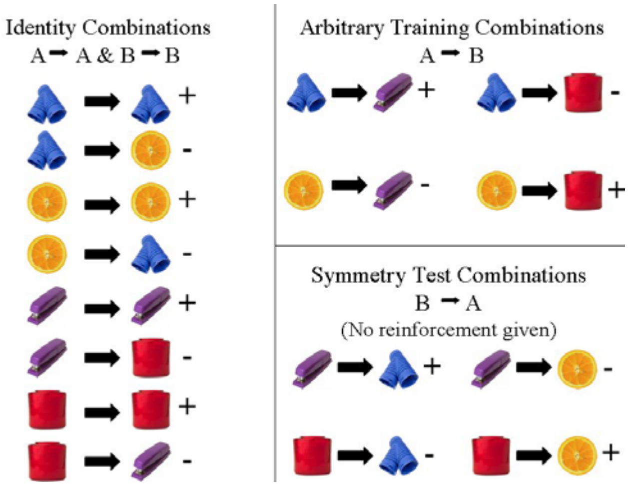


Figure 6. Pictures and stimulus combinations used in Experiment 3.

Identity Training. Identity training was conducted in the same manner as training in Experiment 1, except that the pigeons were trained with eight identity matching combinations: four positive identity combinations (A1 → A1, A2 → A2, B1 → B1, B2 → B2) and four negative identity combinations (A1 → A2, A2 → A1, B1 → B2, B2 → B1). See Figure 6 for a pictorial representation of the stimulus combinations. Four discrimination ratios were calculated at the end of each identity training session. Discrimination ratios were calculated in the same manner as in Experiment 1. If a pigeon attained the performance criterion of at least 0.80 for each of the discrimination ratios, then that pigeon was given identity matching combinations intermixed with arbitrary combinations beginning on the following day.

Each identity training session consisted of seven blocks of trials. Each block contained three of each of the eight identity combinations (i.e., 24 trials in each block) for a total of 168 trials per daily identity training session.

Identity and arbitrary training. Identity and arbitrary training intermixed was conducted in the same manner as training in Experiment 1, except that the pigeons were trained with eight identity matching combinations: four positive identity combinations (A1 → A1, A2 → A2, B1 → B1, B2 → B2) and four negative identity combinations (A1 → A2, A2 → A1, B1 → B2, B2 → B1). See Figure 6 for a pictorial representation of the stimulus combinations. In addition, the identity combinations were intermixed with four arbitrary stimulus combinations: two positive arbitrary combinations (A1 → B1, A2 → B2) and two negative arbitrary combinations (A1 → B2, A2 → B1). Six discrimination ratios were calculated at the end of each identity and arbitrary training session. Discrimination ratios were calculated in the same manner as in Experiment 1. If a pigeon attained the performance criterion of at least 0.80 for each of the discrimination ratios, then that pigeon was given symmetry testing the following day. There was at least one day of identity and arbitrary training in between each testing session and the pigeon had to meet the 0.80 criterion in order to be given a subsequent symmetry testing session.

Each identity and arbitrary training session consisted of seven blocks of trials. Each block contained two of each of the eight identity combinations and four arbitrary combinations (i.e., 24 trials in each block) for a total of 168 trials per daily training session.

Symmetry Testing. Testing was also conducted in the same manner as in Experiment 1, except symmetry testing sessions contained four arbitrary stimulus combinations and eight identity stimulus combinations used in training plus four new testing stimulus combinations: two new positive symmetry testing combinations (B1 → A1 and B2 → A2) and two new negative symmetry testing combinations (B1 → A2 and B2 → A1). See Figure 6. In addition, there were eight discrimination ratios calculated at the end of each testing session: two discrimination ratios for arbitrary training, four discrimination ratios for identity training, and two discrimination ratios for testing combinations.

Each symmetry testing session consisted of a warm-up block involving one of each of the training stimulus combinations (i.e., 12 trials) followed by six blocks of trials that contained two of each training stimulus combination and one of each symmetry testing combination (i.e., 28 trials per block). The final block of each testing session contained one of each training stimulus combination and one of each symmetry testing combination (i.e., 16 trials). There were 196 trials in each symmetry testing session. A total of six symmetry testing sessions were conducted for each bird.

Results and Discussion

Pigeon 83Y

Symmetry Test 1 for Pigeon 83Y occurred after 71 days of training (1 incomplete and 70 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A7).

The mean response rates of Pigeon 83Y to the positive and negative training and testing combinations are depicted in Figure A3 (upper left). The peck rate difference between the positive and negative testing combinations (0.04 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (1.60 pecks per s). There was a good peck rate difference between the positive and negative identity combinations (1.75 pecks per s).

The overall difference between positive and negative combinations (both training and symmetry), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A8).

Follow-up tests show that all differences were significant except the difference between positive testing and negative testing (Table A9), indicating that the pigeon did not respond to the testing combinations as it did the training combinations, which should have occurred if the pigeon had shown emergent symmetry. If emergent symmetry was shown, then there might also have been no difference between the positive training and the positive testing and no difference between the negative training and the negative testing combinations.

<u>Pigeon 34R</u>

Symmetry Test 1 for Pigeon 34R occurred after 68 days of training (1 incomplete and 67 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A7).

The mean response rates of Pigeon 34R to the positive and negative training and testing combinations are depicted in Figure A3 (upper right). The peck rate difference between the positive and negative testing combinations (0.19 pecks per s) was nowhere near the peck rate difference between the positive and negative training combinations (1.54 pecks per s). There was a good peck rate difference between the positive and negative identity combinations (1.83 pecks per s).

The overall difference between positive and negative combinations (both training and testing), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A8).

Follow-up tests show that all differences were significant except the difference between positive testing and negative testing (Table A9). The difference between positive testing and negative testing was not significant at the $p<0.05$ level, but there was a significant difference at the $p<0.10$ level (score was $p<0.08$). This indicates that the pigeon did not respond to the testing combinations as it did the training combinations, but there was some indication that this pigeon did learned some association that resulted in a differentiation between the positive and negative testing combinations. While this is not solid evidence of emergent symmetry it is suggestive of a symmetrical relation.

Pigeon 12W

Symmetry Test 1 for Pigeon 12W (not the same pigeon as 12W in Experiment 2) occurred after 13 days of training (0 incomplete and 13 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A7).

The mean response rates of Pigeon 12W to the positive and negative training and testing combinations are depicted in Figure A3 (lower left). The peck rate difference between the positive and negative testing combinations (0.16 pecks per s) was not the same as the peck rate difference between the positive and negative training combinations (0.94 pecks per s). In addition, there was a good peck rate difference between the positive and negative identity combinations (1.18 pecks per s).

The overall difference between positive and negative combinations (both training and testing), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A8).

Follow-up tests show that all differences were significant except the difference between negative training and negative testing (Table A9). To clarify, there was a significant difference between the positive testing and negative testing indicating that the pigeon did respond to the testing combinations as it did the training combinations. Even though this pigeon did show evidence of emergent symmetry, there was a discrimination decrement. This can be seen by the significant difference between the positive training and positive testing, but there was no significant difference between negative training and negative testing. The pecks per s for the negative training and testing combinations was the same, but the pecks per s for the positive training and testing combinations were not the same.

Pigeon 57B

Symmetry Test 1 for Pigeon 57B occurred after 149 days of training (22 incomplete and 127 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations (Table A7).

The mean response rates of Pigeon 57B to the positive and negative training and testing combinations are depicted in Figure A3 (lower right). The peck rate difference between the positive and negative testing combinations (0.59 pecks per s) was not the same as the peck rate difference between the positive and negative training combinations (1.26 pecks per s). There was a good peck rate difference between the positive and negative identity combinations (1.05 pecks per s).

The overall difference between positive and negative combinations (both training and testing), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A8).

Follow-up tests show that all differences were significant except the difference between positive training and positive testing (Table A9). To clarify, there was a significant difference between the positive testing and negative testing indicating that the pigeons responded to the testing combinations as it did the training combinations. Even though this pigeons showed1` evidence of emergent symmetry, there was a slight discrimination decrement. This can be seen by the significant difference between the negative training and negative testing, but there was no significant difference between positive training and positive testing. The pecks per s for the negative training and testing combinations was not the same, but the pecks per s for the positive training and testing combinations were the same.

General Discussion

The goal of this experiment was to test if giving identity matching combinations first and then intermixing arbitrary and identity matching combinations would result in emergent symmetry in pigeons. It was hypothesized that by training identity matching combinations to criterion first might facilitate formation of emergent symmetry because the pigeons would be learning that temporal order did not matter before they learned the arbitrary stimulus combinations (Deacon, 1997). Alternatively, the pigeon's performance could have been facilitated by giving identity matching combinations first because the principles of identity in symbolic logic suggest that identity relations are by definition symmetrical relations as well (Bergmann, et al., 1998).

In this experiment, two pigeons showed moderate evidence of emergent symmetry, one pigeon showed suggestive evidence of emergent symmetry, and one pigeon did not show emergent symmetry. However, it can be noted that the moderate evidence of emergent symmetry by the two pigeons in this experiment were not as strong as the pigeons in Frank and Wasserman (2005, Experiment 1).

It can be assumed that the pigeon's performance was not facilitated by giving identity stimulus combinations before intermixing them with arbitrary matching. While it appears that giving identity training with the same stimuli given in arbitrary matching is a very important feature of emergent symmetry in pigeons, it also appears that the best emergent symmetry result is produced by intermixing arbitrary and identity matching combinations from the outset of training (Frank and Wasserman, 2005 Experiment 1).

Experiment 4

Train arbitrary matching with two sets of stimuli and identity matching with only one of those sets of stimuli. Test both sets of stimuli for symmetry.

In Frank and Wasserman (2005; Experiment 1), it was found that pigeons could show emergent symmetry when they were trained with identity and arbitrary matching from the outset of training. As previously mentioned, it can be hypothesized that such training methods could have taught the pigeons to ignore the temporal order of the stimuli (Deacon, 1997). *The aim of this experiment was to determine if training arbitrary relations with two sets of stimuli and identity relations with only one of those sets of stimuli will result in emergent symmetry with both sets of stimuli given in arbitrary training.*

Method

Participants

Participants were three homing pigeons and one feral pigeon (*Columba livia*). The change in bird species was necessary due to supplier changes. The pigeons were kept at 85% of their free-feeding weights on a 14-h light/10-h dark schedule with free access to water and grit.

Apparatus

The same apparatus used in Experiment 1 was also used in this experiment. Stimuli were eight photo realistic clip art images (The Big Box of Art, Hemera, Quebec).

Procedure

Pretraining. Pretraining was conducted in the same manner as in Experiment 1.

Training. Training was conducted in the same manner as in Experiment 1, except that there were eight arbitrary matching combinations. The birds were trained with four positive arbitrary matching trials (A1 → B1, A2 → B2, C1 → D1, C2 → D2) and with four negative arbitrary matching trials (A1 → B2, A2 → B1, C1 → D2, C2 → D1). In addition, there were eight identity matching combinations. The birds were trained with four positive identity matching trials (A1 → A1, A2 → A2, B1 → B1, B2 → B2) and there were four negative identity matching trials (A1 → A2, A2 → A1, B1 → B2, B2 → B1). See Figure 7 for pictorial representations of these sequences.

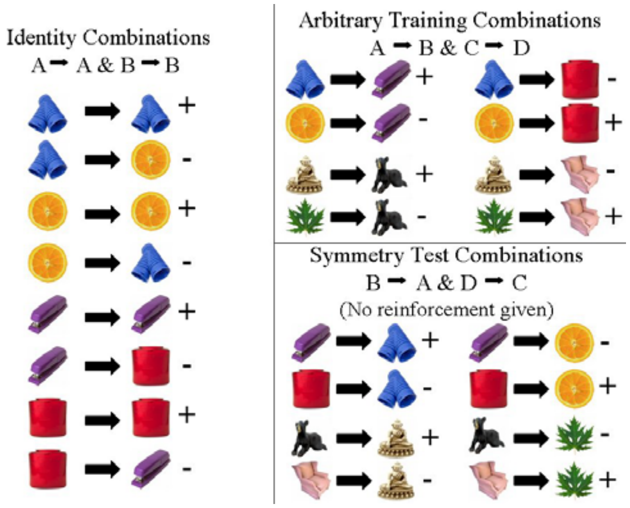


Figure 7. Pictures and stimulus combinations
used in Experiment 4.

In addition, there were eight discrimination ratios calculated for each training session: four discrimination ratios for arbitrary training and four discrimination ratios for identity training. Discrimination ratios were calculated in the same manner as in

Experiment 1. If a pigeon attained the performance criterion of 0.80 for each of the discrimination ratios, then that pigeon was given testing on the following day.

Each training session consisted of five blocks of trials. Each block contained two of each of the 16 training combinations (i.e., 32 trials in each block) for a total of 160 trials per daily training session.

Symmetry Testing. Testing was also conducted in the same manner as in Experiment 1, except symmetry testing sessions contained eight arbitrary stimulus combinations and eight identity stimulus combinations used in training plus eight new testing stimulus combinations: four new positive symmetry testing combinations (B1 → A1, B2 → A2, D1 → C1, D2 → C2) and four new negative symmetry testing combinations (B1 → A2, B2 → A1, D1 → C2, D2 → C1). See Figure 7. In addition, there were twelve discrimination ratios calculated at the end of each testing session: four discrimination ratios for arbitrary training, four discrimination ratios for identity training, and four discrimination ratios for testing combinations.

Each symmetry testing session consisted of a warm-up block involving one of each of the training stimulus combinations (i.e., 16 trials) followed by four blocks of trials that contained two of each training stimulus combination and one of each symmetry testing combination (i.e., 40 trials per block). There were 176 trials in each symmetry testing session. A total of six symmetry testing sessions were conducted for each bird.

Results and Discussion

One of the pigeons had to be removed from the experiment because it could not learn the training combinations even with extensive training and remediation. Reported here are the results of the remaining three pigeons.

Pigeon 28B

Symmetry Test 1 for Pigeon 28B occurred after 69 days of training (2 incomplete and 67 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations for Stimulus Set AB and Stimulus Set CD (Table A10).

The mean response rates of Pigeon 28B to the positive and negative training and testing combinations are depicted in Figure A4 (upper middle). The peck rate difference between the positive and negative testing combinations for Set AB (0.39 pecks per s) was not the same as the peck rate difference between the positive and negative training combinations for Set AB (1.30 pecks per s). The peck rate difference between the positive and negative testing combinations for Set CD (0.13 pecks per s) was also not the same as the peck rate difference between the positive and negative training combinations for Set CD (1.60 pecks per s). There was a good peck rate difference between the positive and negative identity combinations (1.41 pecks per s).

The overall difference between positive and negative combinations (both training and testing), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A11).

Follow-up tests show that all differences were significant except the difference between CD positive testing and CD negative testing and between AB negative testing and CD negative testing (Table A12). To clarify, there was a significant difference between the AB positive testing and AB negative testing indicating that the pigeon did respond to the AB testing combinations similar to its responding to the AB training combinations. The CD positive testing was not significantly different from the CD negative testing. This means that this pigeon showed suggestive evidence of emergent symmetry for the AB set (i.e., the stimulus set also trained with identity matching) and no evidence of emergent symmetry for the CD set (i.e., the set not trained with identity matching).

This pigeon’s performance was only suggestive of emergent symmetry because the AB positive training was significantly different from the AB positive testing and likewise for AB negative training and AB negative testing. It can be expected that the results for these two follow-up tests might not have been significantly different if this pigeon had shown very clear emergent symmetry.

Pigeon 97W

Symmetry Test 1 for Pigeon 97W occurred after 92 days of training (3 incomplete and 89 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations for Stimulus Set AB and Stimulus Set CD (Table A10).

The mean response rates of Pigeon 97W to the positive and negative training and testing combinations are depicted in Figure A4 (bottom left). The peck rate difference between the positive and negative testing combinations for Set AB (0.30 pecks per s) was not the same as the peck rate difference between the positive and negative training combinations for Set AB (0.75 pecks per s). The peck rate difference between the positive and negative testing combinations for Set CD (0.15 pecks per s) was also not the same as the peck rate difference between the positive and negative training combinations for Set CD (0.67 pecks per s). There was a good peck rate difference between the positive and negative identity combinations (0.70 pecks per s).

The overall difference between positive and negative combinations (both training and testing), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A11).

Follow-up tests show that all differences were significant except the difference between AB negative training and AB negative testing, AB positive testing and CD positive testing, and AB negative testing and CD negative testing (Table A12). To clarify, there was a significant difference between the AB positive testing and AB negative testing indicating that the pigeon did respond to the AB testing combinations similarly as it did to the AB training combinations. The CD positive testing was also significantly different from the CD negative testing indicating that the pigeon also responded to the CD testing combinations similarly as it did to the CD training combinations. This means that this pigeon showed suggestive evidence of emergent symmetry for the AB set (i.e., the stimulus set also trained with identity matching) and suggestive evidence of emergent symmetry for the CD set (i.e., the stimulus set not used in identity training).

This pigeon seemed to show stronger evidence of emergent symmetry for the AB set than the CD set because the AB negative training was not significantly different from the AB negative testing, meaning that the bird pecked similarly to these stimulus combinations. Results for this bird were only suggestive of emergent symmetry for the AB set because the AB positive training was significantly different from the AB positive testing. In addition, results for this bird were only suggestive of emergent symmetry for the CD set because the CD positive training was significantly different from the CD positive testing and the CD negative training was significantly different from the CD negative testing. It can be expected that the results for these follow-up tests might not have been significantly different if this pigeon had shown very clear emergent symmetry.

Pigeon 85R

Symmetry Test 1 for Pigeon 85R occurred after 194 days of training (22 incomplete and 172 complete sessions). Following training with arbitrary matching there was good discrimination between the positive and negative training combinations for Stimulus Set AB and Stimulus Set CD (Table A10).

The mean response rates of Pigeon 85R to the positive and negative training and testing combinations are depicted in Figure A4 (bottom right). The peck rate difference between the positive and negative testing combinations for Set AB (-0.16 pecks per s) was not the same as the peck rate difference between the positive and negative training combinations for Set AB (0.49 pecks per s). This bird actually pecked faster to the AB negative testing combinations than to the AB positive testing combinations. The peck rate difference between the positive and negative testing combinations for Set CD (-0.05 pecks per s) was also not the same as the peck rate difference between the positive and negative training combinations for Set CD (0.50 pecks per s). This bird also pecked faster to the CD negative testing combinations than it did to the CD positive testing combinations. There was a good peck rate difference between the positive and negative identity combinations (0.53 pecks per s).

The overall difference between positive and negative combinations (both training and symmetry), the difference between trial types (training and testing), and the interaction between trial type and positive and negative stimulus combinations were all highly reliable (Table A11).

Follow-up tests show that all differences were significant except the difference between CD positive testing and CD negative testing and the difference between CD positive training and CD positive testing (Table A12). To clarify, there was no significant difference between the CD positive testing and CD negative testing indicating that the pigeon did not respond to the CD testing combinations as it did to the CD training combinations. AB positive testing was significantly different from the AB negative testing; however, this pigeon's pecks per s were in the wrong direction (i.e., the bird pecked faster to the negative testing combinations than to the positive testing combinations). This indicates that the pigeon did not respond to the AB testing combinations as it did to the AB training combinations. This means that this pigeon did not show any evidence of emergent symmetry for the AB or CD sets.

General Discussion

The goal of this experiment was to test if giving arbitrary matching with two different sets of stimuli (AB and CD) and training identity matching combinations with only one of those sets of stimuli (AB) would result in emergent symmetry for the AB set and if it would also result in emergent symmetry for the other set (CD) as well. It was hypothesized that by training identity matching combinations with only one set of stimuli (AB) that the pigeons would show emergent symmetry for the AB set of stimuli, but not for the CD set of stimuli. This was because in previous experiments, pigeons that had not been given identity matching with the same stimuli as arbitrary matching had not shown emergent symmetry.

In this experiment, two pigeons showed moderate evidence of emergent symmetry with the AB set; one of those pigeons also showed suggestive evidence of emergent symmetry with the CD set as well. Alternatively, one pigeon did not show emergent symmetry with either set of stimuli.

It can be concluded that intermixing identity matching with arbitrary matching does not always result in emergent symmetry for all pigeons. In addition, it seems possible that by learning identity intermixed with arbitrary matching with one set of stimuli (i.e., AB Set) that some pigeons will show emergent symmetry with stimuli that were only seen in arbitrary matching (i.e., CD Set).

There are two possible reasons for a pigeon showing suggestive evidence of emergent symmetry with both sets of stimuli. The first possibility is that 97W learned a generalized identity from being trained with identity matching combinations with A and B stimuli, however, a test for generalized identity was not done in this experiment. The other possibility is that this pigeon did not start showing evidence of symmetry with the CD Set immediately (i.e., during the first test session). Each pigeon is given six symmetry testing sessions and it is possible that this pigeon generalized its symmetry performance after receiving the symmetry test with the AB Set. In fact, this is the more likely of the two possibilities (Figure A5). This pigeon did not start showing any evidence of emergent symmetry with the CD Set until the second day of testing indicating that this pigeon may have generalized its symmetry performance to the CD Set after showing evidence of emergent symmetry with the AB Set. Similar analysis of the data for Pigeon 28B showed no evidence of emergent symmetry with the CD Set on any of the test days.

Conclusions

The aim of the four experiments reported in this dissertation was to elucidate the necessary and sufficient conditions for emergent symmetry in non-human animals: specifically, to determine if the temporal position of the visual stimuli or if intermixing identity relations with arbitrary relations is critical for emergent symmetry.

In Experiment 1 of this dissertation, the temporal position of visual stimuli was controlled, but no identity training was given. None of the pigeons in this experiment showed any evidence of emergent symmetry. The failure to produce emergent symmetry in this experiment is quite important because it shows that controlling for temporal location alone is not sufficient to produce emergent symmetry. The two variables in Frank and Wasserman (2005; Experiment 1) that could have been responsible for those pigeons showing emergent symmetry was either controlling temporal location or giving identity training. Thus, the data from the current experiment provide good evidence that identity training is a necessary condition for emergent symmetry.

In Experiment 2 of this dissertation, identity relations were intermixed with arbitrary relations; however, the identity relations that were shown were composed of stimuli different from those used in the arbitrary relations. None of the pigeons in this experiment showed any evidence of emergent symmetry. Identity training with the same stimuli as in arbitrary matching must be shown in order to produce emergent symmetry in pigeons. Producing emergent symmetry in pigeons might be possible if the pigeons are trained with enough identity relations that a generalized identity concept is formed; however, it would be unlikely that the pigeons in this experiment would have formed a generalized identity concept based on only two sets of identity relations.

In Experiment 3 of this dissertation, identity relations were trained first and then arbitrary relations were intermixed. As seen in Frank and Wasserman (2005; Experiment 3), the order of training arbitrary and identity relations appears to be important to the expression of emergent symmetry. In that experiment, arbitrary relations were trained first and then intermixed with identity matching. Those pigeons showed weak evidence of emergent symmetry. In Experiment 3 of this dissertation, however, it was thought that by training identity matching first with the same stimuli as in arbitrary matching and then intermixing identity relations with arbitrary relations, emergent symmetrical responding might be facilitated. In other words, if the pigeons were shown that each stimulus was the same at Time 1 and at Time 2, then emergent symmetry might be more readily produced in this experiment than it was in Frank and Wasserman (2005; Experiment 3).

Two of the pigeons in Experiment 3 of this dissertation showed moderate evidence of emergent symmetry, one pigeon showed suggestive evidence of emergent symmetry, and one pigeon showed no evidence of emergent symmetry. So, this experimental manipulation can result in emergent symmetry for some pigeons; however, training identity relations first does not appear to facilitate symmetrical responding. This pattern of results suggests that there might be some interference produced by training identity relations first followed by arbitrary matching. When identity relations are trained first, the pigeons are being taught that the temporal order of the stimuli does not matter. When the pigeons are subsequently trained with arbitrary relations, however, they might then learn that the temporal order of the stimuli does matter. These opposing concepts might cause interference which lowers the ability of the pigeons to show emergent symmetry in this experiment.

In Experiment 4 of this dissertation, arbitrary matching was trained with two sets of stimuli (e.g., AB and CD), but identity matching was trained with only one of those sets of stimuli (e.g., AB). Two pigeons showed moderate evidence of emergent symmetry with the AB Set and one of those pigeons showed suggestive evidence of emergent symmetry with the CD Set. The final pigeon in this experiment did not show any evidence of emergent symmetry with either set of stimuli. Interestingly, the pigeon that showed emergent symmetry with Stimulus Set CD did not show evidence of emergent symmetry until Test Day 2. It is possible that this pigeon may have generalized the concept of symmetry to the CD Set after having seen the AB test trials during Test Day 1, but the pigeon's initial performance on the CD Set showed no evidence of emergent symmetry. These results emphasize what was established in Experiments 1-3 of this dissertation: that identity training with the same stimuli that are shown in arbitrary training is necessary for producing emergent symmetry in pigeons. Identity training is not, however, a sufficient condition for producing emergent symmetry; all of the pigeons given identity matching with the same stimuli used in arbitrary matching did not show evidence of emergent symmetry.

Interestingly, the pigeons in Experiment 4 of this dissertation did not show responding to the testing combinations that was as strong as their responding to the training combinations. This experiment does not differ greatly from Frank and Wasserman (2005; Experiment 1) and the pigeons in that experiment exhibited peck rates during testing that were virtually the same as the peck rates during training. In other words, they showed almost perfect emergent symmetry. In examining these two experiments, it is worth noting that there are a few differences between them that could be of some importance: addition of stimulus sets CD, different visual stimuli, and the delay between S1 and S2. The addition of stimulus sets CD introduced four stimulus combinations that were not in Frank and Wasserman (2005; Experiment 1). Perhaps 20 stimulus combinations were too much for the pigeons to fully learn. The change in stimuli from the 2D cartoon pictures used in Frank and Wasserman (2005; Experiment 1) to the 3D realistic photos used in Experiment 4 of this dissertation should not have made a great difference in behavior, but that is an empirical question. The one difference between the two experiments that may have made the most difference was the delay between S1 and S2. In Frank and Wasserman (2005; Experiment 1) there was a 3.5 s delay between S1 and S2. In Experiment 4 of this dissertation there was a 0.5 s delay between S1 and S2. Perhaps the additional 3.0 s between S1 and S2 in Frank and Wasserman (2005; Experiment 1) gave the pigeons time to rehearse the first stimulus, thereby resulting in stronger emergent symmetry. These factors that could have made the difference between emergent symmetrical results as reported in Frank and Wasserman (2005; Experiment 1) and Experiment 4 of this dissertation invites the question, what other conditions might produce emergent symmetry in non-human animals?

The goal of the experiments in this dissertation was to elucidate the necessary and sufficient conditions for producing emergent symmetry, but all of the necessary and sufficient conditions for emergent symmetry might not be found in this series of experiments alone. In addition to the time between S1 and S2, there are a few other variables that can be utilized to examine methods that might produce emergent symmetry in non-human animals. Notably, as suggested in Frank and Wasserman (2005; Experiment 1) and correspondingly similar in Experiments 3 and 4 of this dissertation, the reason for emergent symmetry could be due to having trained many-to-one relations. This training is not overt, but rather a side effect of the experimental design in which pigeons are trained identity relations with the same stimuli as those used in arbitrary matching. To explain, if the pigeons consider a stimulus at Time 1 to be different from a visually identical stimulus at Time 2, then it is very possible that the pigeons have learned many-to-one relations in these experiments (Table 1). A pigeon might view an identity trial as A1-a1 instead of A1-A1.

The training depicted in Table 1 would produce interchangeable stimuli. For example, A1 is paired with b1 and B1 is paired with b1. This type of training has been shown to produce stimuli that are interchangeable with one another -- in this case A1 and B1 (e.g., Urcuioli, 1996). If A1 and B1 are interchangeable with one another, then pigeons respond similarly to B1-a1 (a testing trial) as they would to A1-a1. However, if all of the trial types are taken into account (i.e., both positive trials and negative trials), then many-to-one matching might be an invalid explanation for the emergent symmetry seen in Experiments 3 and 4 (Table 2).

Table 1. Many-to-one matching relations from Frank and Wasserman*.

Arbitrary Relations	A1-b1	A2-b2
Identity Relations	B1-b1	B2-b2
Identity Relations	A1-a1	A2-a2
Testing Relations	B1-a1	B2-a2

The stimuli used at time one are shown in capital letters and the stimuli used at time two are shown in lower case letters.

*Source: Frank, A. J. and Wasserman, E. A.(2005). *The Journal of the Experimental Analysis of Behavior, 84*, pp. 163.

All stimulus combinations considered (i.e., positive and negative), A1 and B1 are seen equally often in a pairing that results in reinforcement and a pairing that results in no reinforcement. The same is true for A2 and B2. This information renders the question of whether many-to-one matching can be considered a necessary or sufficient condition an empirical one. Such a finding would not negate the evidence of emergent symmetry found in Experiments 3 and 4 of this dissertation or the results found in Frank and Wasserman (2005; Experiment 1). Instead, it would provide an additional method to obtain emergent symmetry.

Another experimental manipulation that could produce strong emergent symmetry in pigeons is training several identity matching relations until the pigeons form a generalized identity matching concept. This technique might negate the necessity of training a pigeon identity matching with the same stimuli used in arbitrary matching.

Table 2. Many-to-one matching relations with all stimuli considered.

Arbitrary Relations	A1-b1+	A2-b2+
Identity Relations	B1-b1+	B2-b2+
Arbitrary Relations	A1-b2-	A2-b1-
Identity Relations	B1-b2-	B2-b1-

Stimuli at time one are shown in capital letters and stimuli used at time two are shown in lower case letters. “+” indicates that stimulus pair was followed by food reinforcement. “-“ indicates that stimulus pair was not followed by food reinforcement.

Currently, the question of whether non-human animals are capable of showing emergent symmetry has been answered (e.g., Frank and Wasserman, 2005; Tomonaga et. al, 1991; and this dissertation), but emergent symmetry still seems to be an obscure finding. Why is finding emergent symmetry with non-human animals so difficult?

There are three factors that may affect why non-human animals have so much trouble showing emergent symmetry: species differences, training differences, and language differences. There are some very obvious species differences in complex associative learning and particular species might be more inclined to show emergent symmetry than others. As discussed earlier, for example, species that live in social hierarchies might be more inclined to show emergent symmetry due to advantages in identifying group members and rank. In addition, there are species differences in complex associative learning that exemplify the fact that certain species more readily show certain complex associative behaviors. For example, Capuchin and Rhesus monkeys learn a same-different concept much faster than pigeons (Wright and Katz, 2006); however, neither baboons nor pigeons are readily capable of showing same-different conceptualization with only two items (Wasserman, Frank, and Young, 2002; Wasserman, Young, and Fagot, 2001).

There is considerable experimental evidence which suggests that non-human animals should be capable of making very complex associations, but perhaps a bidirectional or symmetrical relationship is not a readily extrapolated association. As discussed earlier in this dissertation, the properties of stimulus equivalence (i.e., reflexivity, symmetry, and transitivity) have reliably been found with adult humans and verbal human children; but, when humans are taught to speak, they learn that the spoken word “dog” equals the animal “dog” (A = B) and that the spoken word “dog” also equals a picture of a “dog” (A = C). This extensive training history with stimulus relations might be the reason why verbal humans are capable of showing stimulus equivalence classes based on learning only the A = B and B = C relations in experimental settings (e.g., Dube et al., 1993). Verbal humans have a training history that is so expansive that the complex associations learned throughout language development might give them the training history that makes a symmetrical relationship a readily extrapolated association.

If symmetrical associations are not readily shown without a great deal of training, then why would symmetrical responding be beneficial in everyday life? As mentioned previously, for non-human animals symmetrical responding might be beneficial in recognizing kin relationships. For humans a practical everyday use for symmetrical responding can be seen when students learn a second language. Typically, when an English speaking person is learning a second language (e.g., Spanish) in school that person uses flashcards. On one side of the card the person will write the English word and on the other side of the card he/she will write Spanish equivalent. When studying for an exam the student will look at the English side of the flashcards and test him/herself to produce the Spanish equivalent. But, when studying in this way, only rarely does a person test themselves from English to Spanish. During some part of studying, the person will also study the cards from Spanish to English. It is important to look at the cards in this way to learn the words in a symmetrical manner, because when using the new language, the student must be able to produce the new language and be able to comprehend it as well. He/she must translate what they want to say from English to Spanish and when the instructor speaks to the student in Spanish, the student must then translate from Spanish to English in order to understand what the instructor has said. Presumably, this method of translation might be used when an infant is beginning to learn its first language. There might be some nonverbal to verbal translation and vice versa.

It is obvious that there is still much to learn about the role symmetrical responding plays in the associative processes in many areas. The fact remains that methods that result in *reliable* emergent symmetry in non-human animals still need to be found in order to determine the role of symmetrical responding in various areas of association. Establishing these methods in non-human animals is important because non-human animals are inherently nonverbal organisms. The most important applied use for finding reliable methods of producing emergent symmetry is to facilitate language and communication skills in nonverbal developmentally delayed humans. As discussed earlier in this dissertation, symmetry is just one of three properties of stimulus equivalence. Stimulus equivalence has been used as a method to train developmentally delayed and autistic children and adults language and communication skills (e.g., Rosales & Rehfeldt, 2007; Vause, Martin, Yu, Marion, & Sakko, 2005). Because symmetry has not been produced with nonverbal humans, the methods reported in this dissertation could provide clues for training nonverbal humans the skills they need to have a more social life.

Additionally, methods resulting in emergent symmetry can also be used to study memory in the hippocampus (Bunsey & Eichenbaum, 1996). The role of the hippocampus in complex concept formation, such as stimulus equivalence, would be very important tool to learning how the brain processes and stores complex concepts and how new associations are formed. Animals with hippocampal lesions might show emergent symmetry without training identity matching because such animals lose the ability to put stimuli in order when the hippocampus is damaged (Fortin, et. al., 2002). This could mean that a non-human animal might not consider a visually identical stimuli at Time 1 and Time 2 to be different stimuli.

Reliable methods for producing emergent symmetry in non-human animals has a wide variety of potential uses in both experimental research with non-human animals and uses in applied therapies with humans. Based on the data reported here, we know that identity matching intermixed with arbitrary matching using the same set of stimuli can produce emergent symmetry and it seems that methods for reliably producing emergent symmetry are finally within reach. However, more research is needed to determine if other methodologies such as many-to-one matching and generalized identity are additional methods for producing reliable emergent symmetry.

REFERENCES

Abra, J. C. (1967). Time changes in the strength of forward and backward associations. *Journal of Verbal Learning and Verbal Behavior, 6*, 640-645.

Ackers, S. H., & Slobodchikoff, C. N. (1999). Communication of stimulus size and shape in alarm calls of Gunnison's prairie dogs, Cynomys Gunnisoni. *Ethology, 105*, 149-162.

Adeyemo, S. A. (2002). A review of the role of the hippocampus in memory. *Psychology and Education – An Interdisciplinary Journal, 39*, 46-63.

Alvarado, M. C., & Rudy, J. W. (1995). Rats with damage to the hippocampal formation are impaired on the transverse-patterning problem but not on elemental discriminations. *Behavioral Neuroscience, 109*, 204-211.

Alvarez, P., Lipton, P. A., Melrose, R., & Eichenbaum, H. (2001). Differential effects of damage within the hippocampal region on memory for a natural, nonspatial odor-odor association. *Learning & Memory, 8*, 79-86.

Alvarez, P., Wendelken, L., & Eichenbaum, H. (2002). Hippocampal formation lesions impair performance in an odor-odor association task independently of spatial context. *Neurobiology of Learning and Memory, 78*, 470-476.

Asch, S. E., & Ebenholtz, S. M. (1962). The principle of associative symmetry. *Proceedings of the American Philosophical Society, 106*, 135-163.

Asratyan, A. E. (1967). Some peculiarities of formation, functioning and inhibition of conditioned reflexes with two-way connections. In Fessard, A. and Jasper, H. H. (Eds). *Brain Reflexes* (pp. 8-20). Amsterdam: Elsevier.

Astley, S. L., Peissig, J. J., & Wasserman, E. A. (2001). Superordinate categorization via learned stimulus equivalence: Quantity of reinforcement, hedonic value, and the nature of the mediator. *Journal of Experimental Psychology: Animal Behavior Processes*, *27*, 252-268.

Astley, S. L. & Wasserman, E. A. (1999). Superordinate category formation in pigeons: Association with a common delay or probability of food reinforcement makes perceptually dissimilar stimuli functionally equivalent. *Journal of Experimental Psychology: Animal Behavior Processes, 25*, 415-432.

Bergmann, M., Moor, J., & Nelson, J. (1998). *The Logic Book*. New York, NY: The McGraw-Hill companies, Inc.

Beritov, I. S. (1965). *Neural Mechanisms of Higher Vertebrate Behavior*. Boston, MA: Little.

Bingman, V. P., Strasser, R., Baker, C., & Riters, L. V. (1998). Paired-associate learning is unaffected by combined hippocampal and parahippocampal lesions in homing pigeons. *Behavioral Neuroscience, 112*, 533-540.

Bond, A. B., Kamil, A. C., & Balda, R. P. (2003). Social complexity and transitive inference in corvids. *Animal Behaviour, 65*, 479-487.

Bunsey, M., & Eichenbaum, H. (1993a). Critical role of the parahippocampal region for paired-associate learning in rats. *Behavioral Neuroscience, 107,* 740-747.

Bunsey, S. M., & Eichenbaum, H. (1993b). Selective hippocampal lesions facilitate performance in a paired associate task in rats. *Abstracts of the Society for Neuroscience, 19,* 358.

Bunsey, S. M., & Eichenbaum, H. (1996). Conservation of hippocampal memory function in rats and humans. *Nature, 379,* 255-257.

Cheney, D. L. & Seyfarth, R. M. (1999). Recognition of other individuals' social relationships by female baboons. *Animal Behavior, 58,* 67-75.

Cho, Y. H., & Kesner, R. P. (1995). Relational object association learning in rats with hippocampal lesions. *Behavioural Brain Research, 67,* 91-98.

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.

Deacon, T. W. (1997). *The Symbolic Species.* New York, NY: W. W. Norton & Company.

Debert, P., Matos, M., & McIlvane, W. (2007). Conditional relations with compound abstract stimuli using a go/no-go procedure. *Journal of the Experimental Analysis of Behavior,* 87, 89-96.

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.

Dube, W. V., McIlvane, W. J., Callahan, T. D., & Stoddard, L. T. (1993). The search for stimulus equivalence in nonverbal organisms. *The Psychological Record, 43,* 761-778.

Dugdale, N. A., & 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.

Dusek, J. A., & Eichenbaum, H. (1998). The hippocampus and transverse patterning guided by olfactory cues. *Behavioral Neuroscience, 112,* 762-771.

Dymond, S., Gomez-Martin, S., & Barnes, D. (1996). Multi-modal conditional discrimination in rats: Some preliminary findings. *The Irish Journal of Psychology, 17,* 269-281.

Ebbinghaus, H. (1913). *Memory: A contribution to experimental psychology.* New York, NY: Teachers College, Columbia University.

Eichenbaum, H. (1992). The hippocampal system and declarative memory in animals. *Journal of Cognitive Neuroscience, 4,* 217-231.

Eichenbaum, H. (1997). Declarative memory: Insights from cognitive neurobiology. *Annual Review of Psychology, 48,* 547-572.

Eichenbaum, H. (2001). The hippocampus and declarative memory: Cognitive mechanisms and neural codes. *Behavioural Brain Research, 127*, 199-207.

Eichenbaum, H. & Bunsey, M. (1995). On the binding of associations in memory: Clues from studies on the role of the hippocampal region in paired-associate learning. *Current Directions in Psychological Science, 4*, 19-23.

Eichenbaum, H. & Cohen, N. J. (2001). *From conditioning to Conscious Recollection.* New York, NY: Oxford University Press.

Eichenbaum, H., Fagan, A., Mathews, P., & Cohen, N. J. (1988). Hippocampal system dysfunction and odor discrimination learning in rats: Impairment or facilitation depending on representational demands. *Behavioral Neuroscience, 102*, 331-339.

Eichenbaum, H., & Fortin, N. (2003). Episodic memory and the hippocampus: It's about time. *Current Directions in Psychological Science, 12*, 53-57.

Eichenbaum, H., Mathews, P., & Cohen, N. J. (1989). Further studies of hippocampal representation during odor discrimination learning. *Behavioral Neuroscience, 103*, 1207-1216.

Fortin, N. J., Agster, K. L., & Eichenbaum, H. (2002). Critical role of the hippocampus in memory for sequences of events. *Nature Neuroscience, 5*, 458-462.

Frank, A. J. & Wasserman, E. A. (2005a). Response rate is not an effective mediator of learned stimulus equivalence in pigeons. *Learning & Behavior, 33*, 287-295.

Frank, A. J. & Wasserman, E. A. (2005b). Associative symmetry in the pigeon after successive matching-to-sample training. *Journal of the Experimental Analysis of Behavior, 84*, 147-165.

Frank, D. A. & Greenberg, M. E. (1994). CREB: A mediator of long-term memory from mollusks to mammals. *Cell, 79*, 5-8.

Gerolin, M. & Matute, H. (1999). Bidirectional associations. *Animal Learning & Behavior, 27*, 42-49.

Ghazanfar, A. A., & Logothetis, N. K. (2003). Facial expressions linked to monkey calls. *Nature, 423*, 937-938.

Gibson, B. M., Wasserman, E. A., Frei, L., & Miller, K. (2004). Recent advances in operant conditioning technology: A versatile and affordable computerized touchscreen system. *Behavior Research Methods, Instruments & Computers, 36*, 355-362.

Gomez, S., Lopez, F., Martin, C. B., Barnes-Holmes, Y., & Barnes-Holmes, D. (2007). Exemplar training and a derived transformation of functions in accordance with symmetry and equivalence. *Psychological Record*, 57, 273-294.

Gunther, L. M., Miller, R. R., & Matute, H. (1997). CSs and USs: What's the difference? *Journal of Experimental Psychology: Animal Behavior Processes, 23*, 15-30.

Hanggi, E. B., & Schusterman, R. J. (1990). Kin recognition in captive California sea lions. *Journal of Comparative Psychology, 104*, 368-372.

Hayes, S. C. (1991). A relational control theory of stimulus equivalence. In L. J. Hayes & P. N. Chase (Eds.), *Dialogues on verbal behavior* (pp. 19-40). Reno, NV: Context Press.

Hogan, D. E., & Zentall, T. R. (1977). Backward associations in the pigeon. *American Journal of Psychology, 90*, 3-15.

Horne, P. J., & Lowe, C. F. (1996). On the origins of naming and other symbolic behavior. *Journal of the Experimental Analysis of Behavior, 65*, 185-241.

Hull, C. L. (1939). The problem of stimulus equivalence in behavior theory. *Psychological Review*, *46*, 9-30.

Jenkins, J. J. (1963). Mediated associations: Paradigms and situations. In C. N. Cofer & B. S. Musgrave (Eds.), *Verbal behavior and learning: Problems and processes*. New York: McGraw-Hill.

Jenkins, J. J. (1965). Mediation theory and grammatical behavior. In S. Rosenberg (Ed.), *Directions in psycholinguistics.* New York: Macmillan.

Johnston, W. A. (1967). S-R, R-S independence and the interference potency of latent R-S associations. Journal of Experimental Psychology, 74, 511-516.

Johnston, W. A. (1968). Bidirectional interference in an A-B, C-B paradigm. *Journal of Verbal Learning and Verbal Behavior, 7*, 3005-311.

Kahana, M. J. (2002). Associative symmetry and memory theory. *Memory & Cognition, 30*, 823-840.

Konorski, J. (1959). A new method of physiological investigation of recent memory in animals. *Bulletin De L'Academie Polonaise Des Sciences, 7*, 115-117.

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.

Lazareva, O. F., Freiburger, K. L., & Wasserman, E. A. (2004). Pigeons concurrently categorize photographs at both basic and superordinate levels. *Psychonomic Bulletin & Review, 11*, 1111-1117.

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., & Werner, M. (1988). A test of symmetry and transitivity in the conditional discrimination performances of pigeons. *Journal of the Experimental Analysis of Behavior, 49*, 395-409.

Morris, R. G. M., Garrud, P., Rawlins, J. N. P, & O'Keefe, J. (1982). Place navigation impaired in rats with hippocampal lesions. *Nature, 297*, 681-683.

Murray, E. A., Gaffan, D., & Mishkin, M. (1993). Neural substrates of visual stimulus – stimulus association in Rhesus Monkeys. *The Journal of Neuroscience, 13*, 4549-4561.

O'Keefe, J., & Nadel, L. (1978). *The Hippocampus as a Cognitive Map*. New York, NY: Oxford University Press.

Oden, D. L., Thompson, R. K. R., & Premack, D. (1988). Spontaneous transfer of matching by infant chimpanzees. *Journal of Experiment Psychology: Animal Behavior Processes, 14*, 140-145.

Otto, T., Schottler, F., Staubli, U., Eichenbaum, H., & Lynch, G. (1991). Hippocampus and olfactory discrimination learning: Effects of entorhinal cortex lesions on olfactory learning and memory in a successive-cue, go-no-go task. *Behavioral Neuroscience, 105*, 111-119.

Pack, A. A., Herman, L. M., & Roitblat, H. L. (1991). Generalization of visual matching and delayed matching by a California sea lion (Zalophus californianus). *Animal Learning & Behavior, 19*, 37-48.

Pavlov, I. P. (1927). *Conditioned Reflexes*. London: Oxford University Press. Placer, J., & Slobodchikoff, C. N. (2000). A fuzzy-neural system for identification of species-specific alarm calls of Gunnison's prairie dogs. *Behavioural Processes, 52*, 1-9.

Rizzuto, D. S., & Kahana, M. J. (2000). Associative symmetry vs. independent associations. *Neurocomputing, 32-33*, 973-978.

Rizzuto, D. S., & Kahana, M. J. (2001). An autoassociative neural network model of paired-associate learning. *Neural Computation, 13*, 2075-2092.

Schusterman, R. J., Reichmuth, C. J., & Kastak, D. (2000). *Current Directions in Psychological Science, 9*, 1-6.

Schusterman, R. J. & Kastak, D. (1993). A California sea lion (Zalophus Californianus) is capable of forming equivalence relations. *The Psychological Record, 43*, 823-839.

Sherburne, L. M. & Zentall, T. R. (1995). Delayed matching in pigeons with food and no-food samples: Further examination of backward associations. *Animal Learning & Behavior, 23*, 177-181.

Sidman, M. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research, 14*, 5-13.

Sidman, M. (1992). Equivalence relations: Some basic considerations. In S. C. Hayes & L. J. Hayes (Eds.), *Understanding verbal relations* (pp. 15-27). Reno, NV: Context Press.

Sidman, M. (2000). Equivalence relations and the reinforcement contingency. *Journal of the Experimental Analysis of Behavior, 74*, 127-146.

Sidman, M., Cressen, O., & 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 discrimination of rhesus monkeys, baboons, and children. *Journal of the Experimental Analysis of Behavior, 37*, 23-44.

Sidman, M., & Tailby, W. (1982). Conditional discriminations vs. matching-to-sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior, 37*, 5-22.

Sigala, N., Gabbiani, F., & Logothetis, N. K. (2002). Visual categorization and object representation in monkeys and humans. *Journal of Cognitive Neuroscience, 14*, 187-198.

Smeets, P. M., & Barnes, D. (1997). Emergent conditional discriminations in children and adults: Stimulus equivalence derived from simple discriminations. *Journal of Experimental Child Psychology, 66*, 64-84.

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. (1996). Acquired equivalences and mediated generalization. In T. R. Zentall & P. M. Smeets (Eds.), *Stimulus class formation in humans and animals* (pp. 55-70). Amsteram: Elsevier.

Wasserman, E. A. (1976). Successive matching-to-sample in the pigeon: Variations on a theme by Konorski. *Behavior Research Methods & Instrumentation, 8*, 278-282.

Wasserman, E. A. & DeVolder, C. L. (1993). Similarity- and nonsimilarity-based conceptualization in children and pigeons. *Psychological Record, 43*, 779-793.

Wasserman, E. A., Fagot, J., & Young, M. E. (2001). Same-different conceptualization by baboons (Papio papio): The role of entropy. *Journal of Comparative Psychology, 115*, 42-52.

Wasserman, E. A., DeVolder, C. L., & Coppage, D. J. (1992). Non-similarity-based conceptualization in pigeons via secondary or mediated generalization. *Psychological Science, 3*, 374-378.

Wasserman, E. A., Frank, A., J., & Young, M. E. (2002). Stimulus control by same-versus-different relations among multiple visual stimuli. *Journal of Experimental Psychology: Animal Behavior Processes, 28*, 347-357.

Wasserman, E. A., Hugart, J. A., & Kirkpatrick-Steger, K. (1995). Pigeons show same-different conceptualization after training with complex visual stimuli. *Journal of Experimental Psychology: Animal Behavior Processes, 21*, 248-252.

Wasserman, E. A., Young, M. E., & Fagot, J. (2001). Effects of number of items on the baboon's discrimination of same from different visual displays. *Animal Cognition, 4*, 163-170.

Wood, E. R., Dudchenko, P. A., & Eichenbaum, H. (1999). The global record of memory in hippocampal neuronal activity. *Nature, 397*, 613-616.

Wood, E. R., Dudchenko, P. A., Robitsek, J. R., & Eichenbaum, H. (2000). Hippocampal neurons encode information about different types of memory episodes occurring in the same location. *Neuron, 27*, 623-633.

Wright, A. A., Katz, J. S. (2006). Mechanisms of same/different concept learning in primates and avians. *Behavioural Processes, 72*, 234-254.

Yamamoto, J., & Asano, T. (1995). Stimulus equivalence in a chimpanzee (Pan troglodytes). *The Psychological Record, 45*, 3-21.

Young, M. E., Wasserman, E. A., & Dalrymple, R. M. (1997). Memory-based same-different conceptualization by pigeons. *Psychonomic Bulletin & Review, 4*, 552-558.

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.

APPENDIX A

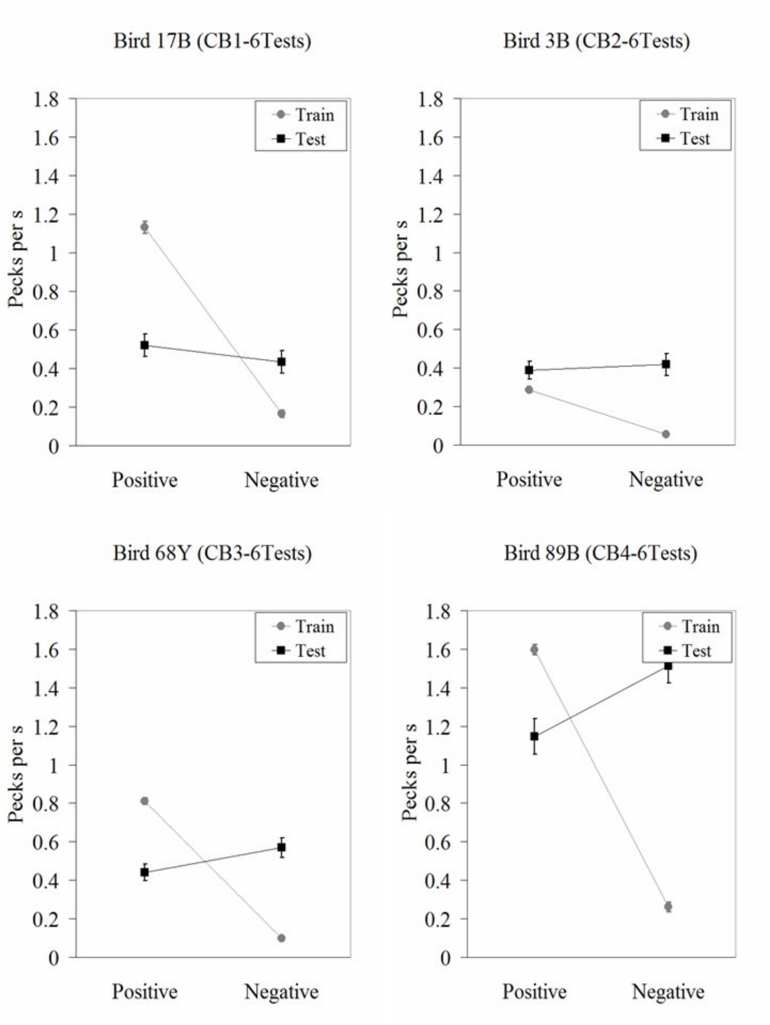


Figure A1. Pecks per s for all pigeons in Experiment 1.

Depicted are pecks per s for all four pigeons in Experiment 1. The light grey line represents the pecks per s for the positive and negative arbitrary training combinations and the black line represents the positive and negative testing combinations. Counterbalance (CB) is listed for each bird.

Table A1. Mean response rates and standard error for all pigeons in Experiment 1.

Pigeon	Stimulus Combinations	Mean Response Rate	Standard Error
17B	Positive Training	1.132	0.030
	Negative Training	0.165	0.019
	Positive Testing	0.519	0.058
	Negative Testing	0.433	0.058
3B	Positive Training	0.286	0.012
	Negative Training	0.055	0.006
	Positive Testing	0.388	0.046
	Negative Testing	0.418	0.058
68Y	Positive Training	0.812	0.016
	Negative Training	0.098	0.011
	Positive Testing	0.440	0.044
	Negative Testing	0.569	0.050
89B	Positive Training	1.598	0.027
	Negative Training	0.263	0.025
	Positive Testing	1.146	0.091
	Negative Testing	1.513	0.088

Table A2. Inferential statistics results for all pigeons in Experiment 1.

Pigeon	Source	*df*	F	*p*
17B	Trial Type (TT)	1	13.84	0.0002
	Pos/Neg (PN)	1	128.69	<0.0001
	TT x PN	1	90.19	<0.0001
	Error	1172	0.31	
3B	Trial Type (TT)	1	109.31	<0.0001
	Pos/Neg (PN)	1	20.35	<0.0001
	TT x PN	1	34.20	<0.0001
	Error	1172	0.07	
68Y	Trial Type (TT)	1	3.40	NS
	Pos/Neg (PN)	1	117.66	<0.0001
	TT x PN	1	243.80	<0.0001
	Error	1172	0.10	
89B	Trial Type (TT)	1	60.49	<0.0001
	Pos/Neg (PN)	1	88.84	<0.0001
	TT x PN	1	274.49	<0.0001
	Error	1172	0.38	

Error reported for all pigeons is Mean Square Error.

Table A3. Follow-up test results for all pigeons in Experiment 1.

Pigeon	Source	*Df*	*t*	*p*
17B	P Training vs. N Training	2	27.57	<0.0001
	P Testing vs. N Testing	2	0.99	NS
	P Training vs. P Testing	2	9.35	<0.0001
	N Training vs. N Testing	2	-4.09	<0.0001
	Error	1172		
3B	P Training vs. N Training	2	13.70	<0.0001
	P Testing vs. N Testing	2	-0.72	NS
	P Training vs. P Testing	2	-3.26	0.0012
	N Training vs. N Testing	2	-11.53	<0.0001
	Error	1172		
68Y	P Training vs. N Training	2	35.00	<0.0001
	P Testing vs. N Testing	2	-2.58	0.0102
	P Training vs. P Testing	2	9.74	<0.0001
	N Training vs. N Testing	2	-12.34	<0.0001
	Error	1172		
89B	P Training vs. N Training	2	34.39	<0.0001
	P Testing vs. N Testing	2	-3.86	<0.0001
	P Training vs. P Testing	2	6.22	<0.0001
	N Training vs. N Testing	2	-17.21	<0.0001
	Error	1172		

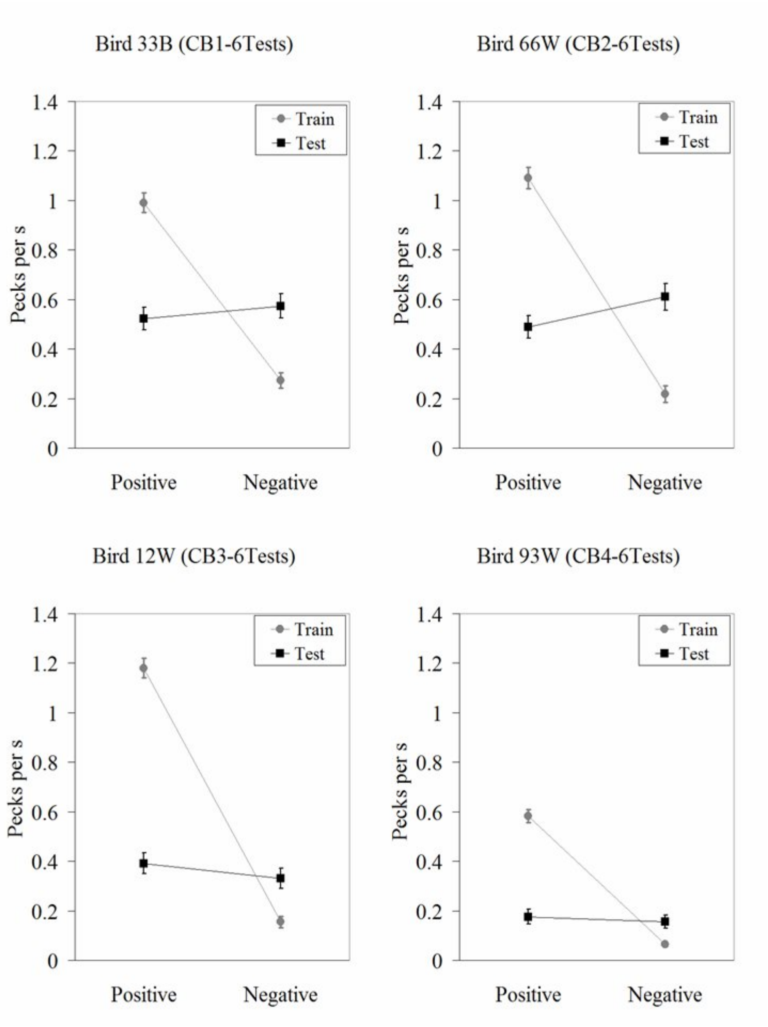


Figure A2. Pecks per s for all pigeons in Experiment 2.

Depicted are pecks per s for all four pigeons in Experiment 2. The light grey line represents the pecks per s for the positive and negative arbitrary training combinations and the black line represents the positive and negative testing combinations. Counterbalance (CB) is listed for each bird.

Table A4. Mean response rates and standard error for all pigeons in Experiment 2.

Pigeon	Stimulus Combinations	Mean Response Rate	Standard Error
33B	Positive Identity	0.972	0.024
	Negative Identity	0.227	0.018
	Positive Training	0.990	0.039
	Negative Training	0.273	0.031
	Positive Testing	0.523	0.045
	Negative Testing	0.574	0.048
66W	Positive Identity	1.304	0.030
	Negative Identity	0.303	0.027
	Positive Training	1.090	0.044
	Negative Training	0.217	0.034
	Positive Testing	0.489	0.046
	Negative Testing	0.610	0.055
12W	Positive Identity	1.459	0.025
	Negative Identity	0.031	0.003
	Positive Training	1.180	0.040
	Negative Training	0.155	0.023
	Positive Testing	0.392	0.042
	Negative Testing	0.331	0.041
93W	Positive Identity	0.600	0.017
	Negative Identity	0.124	0.010
	Positive Training	0.582	0.026
	Negative Training	0.065	0.010
	Positive Testing	0.176	0.029
	Negative Testing	0.156	0.026

Table A5. Inferential statistics for all pigeons in Experiment 2.

Pigeon	Source	*df*	F	*p*
33B	Trial Type (TT)	1	3.87	0.0497
	Pos/Neg (PN)	1	62.02	<0.0001
	TT x PN	1	82.48	<0.0001
	Error	572	0.22	
66W	Trial Type (TT)	1	5.02	0.0255
	Pos/Neg (PN)	1	65.08	<0.0001
	TT x PN	1	114.16	<0.0001
	Error	572	0.28	
12W	Trial Type (TT)	1	63.07	<0.0001
	Pos/Neg (PN)	1	198.68	<0.0001
	TT x PN	1	156.91	<0.0001
	Error	572	0.19	
93W	Trial Type (TT)	1	42.36	<0.0001
	Pos/Neg (PN)	1	123.81	<0.0001
	TT x PN	1	106.23	<0.0001
	Error	572	0.07	

Error reported for all pigeons is Mean Square Error.

Table A6. Follow-up results for all pigeons in Experiment 2.

Pigeon	Source	*df*	*t*	*p*
33B	P Training vs. N Training	2	14.69	<0.0001
	P Testing vs. N Testing	2	-0.74	NS
	P Training vs. P Testing	2	7.81	<0.0001
	N Training vs. N Testing	2	-5.03	<0.0001
	Error	572		
66W	P Training vs. N Training	2	16.24	<0.0001
	P Testing vs. N Testing	2	-1.60	NS
	P Training vs. P Testing	2	9.14	<0.0001
	N Training vs. N Testing	2	-5.97	<0.0001
	Error	572		
12W	P Training vs. N Training	2	23.06	<0.0001
	P Testing vs. N Testing	2	0.96	NS
	P Training vs. P Testing	2	14.47	<0.0001
	N Training vs. N Testing	2	-3.24	0.0013
	Error	572		
93W	P Training vs. N Training	2	18.56	<0.0001
	P Testing vs. N Testing	2	0.50	NS
	P Training vs. P Testing	2	11.89	<0.0001
	N Training vs. N Testing	2	-2.69	0.0074
	Error	572		

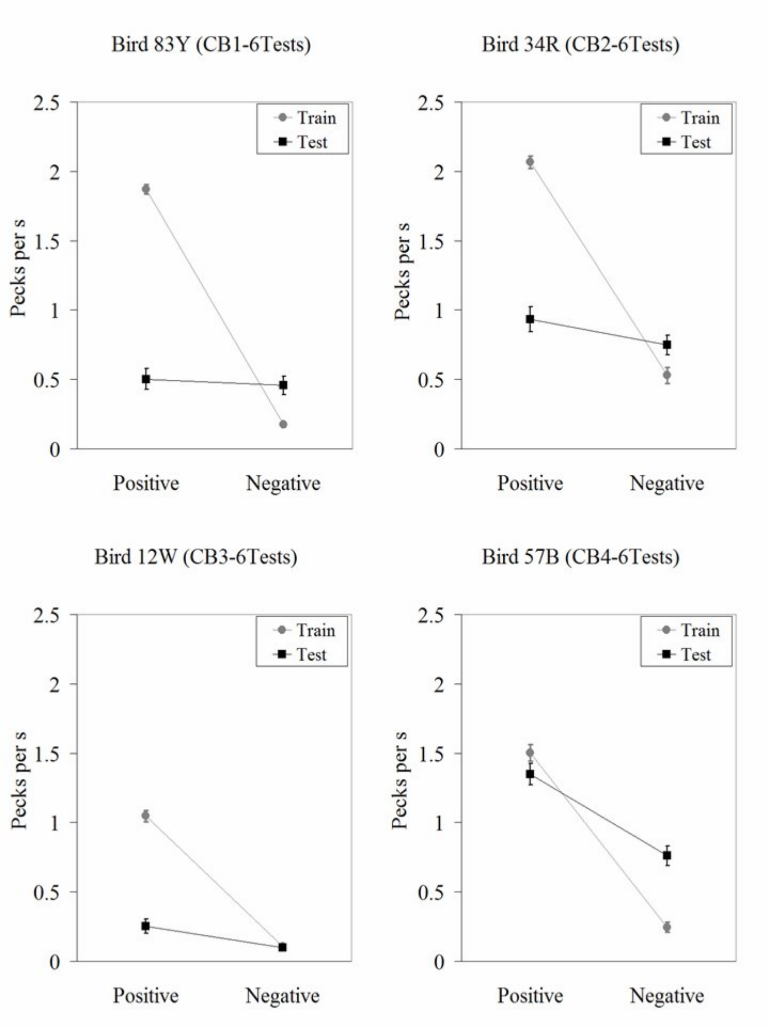


Figure A3. Pecks per s for all pigeons in Experiment 3.

Depicted are pecks per s for all four pigeons in Experiment 3. The light grey line represents the pecks per s for the positive and negative arbitrary training combinations and the black line represents the positive and negative testing combinations. Counterbalance (CB) is listed for each bird.

Table A7. Mean response rates and standard error for all pigeons in Experiment 3.

Pigeon	Stimulus Combinations	Mean Response Rate	Standard Error
83Y	Positive Identity	1.881	0.039
	Negative Identity	0.136	0.016
	Positive Training	1.849	0.060
	Negative Training	0.249	0.035
	Positive Testing	0.501	0.075
	Negative Testing	0.457	0.067
34R	Positive Identity	2.157	0.032
	Negative Identity	0.332	0.028
	Positive Training	2.066	0.046
	Negative Training	0.529	0.056
	Positive Testing	0.932	0.090
	Negative Testing	0.748	0.070
12W	Positive Identity	1.273	0.026
	Negative Identity	0.095	0.010
	Positive Training	1.048	0.041
	Negative Training	0.106	0.017
	Positive Testing	0.252	0.053
	Negative Testing	0.096	0.019
57B	Positive Identity	1.361	0.038
	Negative Identity	0.315	0.027
	Positive Training	1.503	0.059
	Negative Training	0.246	0.037
	Positive Testing	1.350	0.076
	Negative Testing	0.761	0.070

Table A8. Inferential statistics for all pigeons in Experiment 3.

Pigeon	Source	*df*	F	*p*
83Y	Trial Type (TT)	1	88.41	<0.0001
	Pos/Neg (PN)	1	184.12	<0.0001
	TT x PN	1	164.92	<0.0001
	Error	500	0.41	
34R	Trial Type (TT)	1	49.17	<0.0001
	Pos/Neg (PN)	1	173.81	<0.0001
	TT x PN	1	107.28	<0.0001
	Error	500	0.48	
12W	Trial Type (TT)	1	117.57	<0.0001
	Pos/Neg (PN)	1	218.61	<0.0001
	TT x PN	1	112.08	<0.0001
	Error	500	0.15	
57B	Trial Type (TT)	1	8.69	0.0033
	Pos/Neg (PN)	1	225.89	<0.0001
	TT x PN	1	29.54	<0.0001
	Error	500	0.42	

Error reported for all pigeons is Mean Square Error.

Table A9. Follow-up results for all pigeons in Experiment 3.

Pigeon	Source	*df*	*t*	*p*
83Y	P Training vs. N Training	2	22.87	<0.0001
	P Testing vs. N Testing	2	0.45	NS
	P Training vs. P Testing	2	15.73	<0.0001
	N Training vs. N Testing	2	-2.43	0.0154
	Error	500		
34R	P Training vs. N Training	2	20.39	<0.0001
	P Testing vs. N Testing	2	1.73	NS
	P Training vs. P Testing	2	12.28	<0.0001
	N Training vs. N Testing	2	-2.37	0.0184
	Error	500		
12W	P Training vs. N Training	2	23.28	<0.0001
	P Testing vs. N Testing	2	2.72	0.0007
	P Training vs. P Testing	2	16.05	<0.0001
	N Training vs. N Testing	2	0.19	NS
	Error	500		
57B	P Training vs. N Training	2	17.71	<0.0001
	P Testing vs. N Testing	2	5.88	<0.0001
	P Training vs. P Testing	2	1.76	NS
	N Training vs. N Testing	2	-5.93	<0.0001
	Error	500		

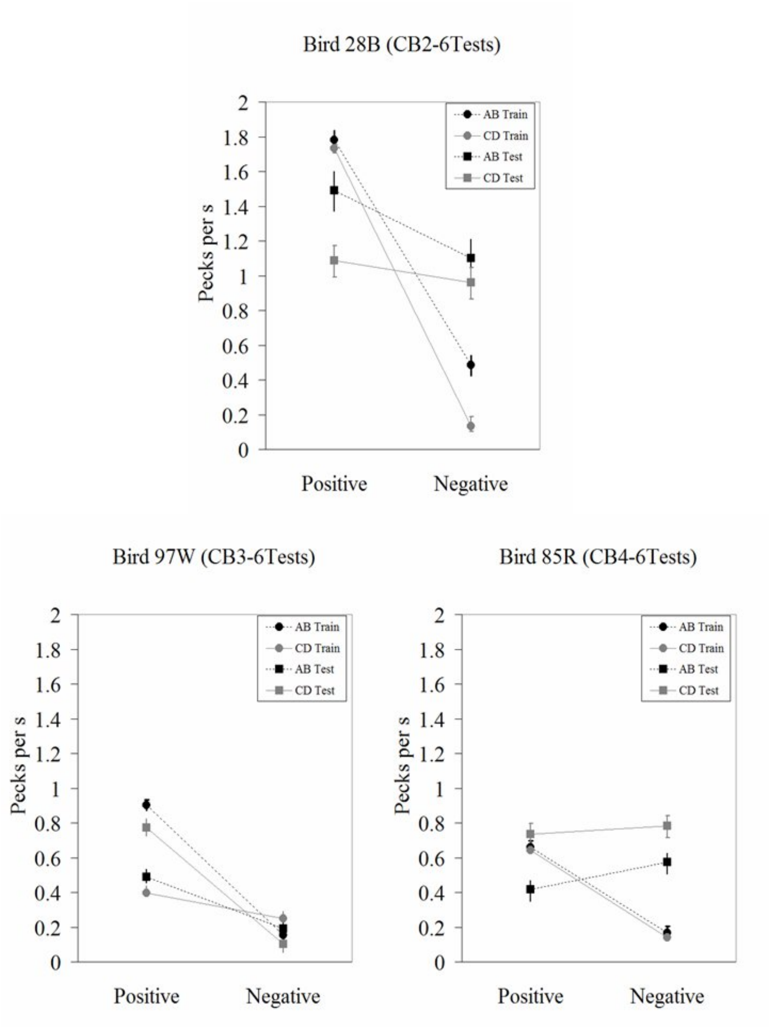


Figure A4. Pecks per s for all pigeons in Experiment 4.

Depicted are pecks per s for all the pigeons in Experiment 4. The black lines represent the pecks per s for the AB Set of stimuli for the positive and negative training and testing trials and the light grey lines represent the pecks per s for the CD Set of stimuli for the positive and negative training and testing trials. Counterbalance (CB) is listed for each bird.

Table A10. Mean response rates and standard error for all pigeons in Experiment 4.

Pigeon	Stimulus Combinations	Mean Response Rate	Standard Error
28B	Positive Identity	1.816	0.038
	Negative Identity	0.403	0.035
	Positive Training AB	1.781	0.054
	Negative Training AB	0.485	0.062
	Positive Training CD	1.735	0.057
	Negative Training CD	0.132	0.028
	Positive Testing AB	1.492	0.107
	Negative Testing AB	1.102	0.121
	Positive Testing CD	1.088	0.085
	Negative Testing CD	0.960	0.095
97W	Positive Identity	0.817	0.019
	Negative Identity	0.122	0.017
	Positive Training AB	0.902	0.030
	Negative Training AB	0.153	0.028
	Positive Training CD	0.775	0.042
	Negative Training CD	0.102	0.019
	Positive Testing AB	0.490	0.045
	Negative Testing AB	0.192	0.037
	Positive Testing CD	0.396	0.050
	Negative Testing CD	0.250	0.047
85R	Positive Identity	0.719	0.025
	Negative Identity	0.190	0.022
	Positive Training AB	0.661	0.037
	Negative Training AB	0.169	0.029
	Positive Training CD	0.642	0.032
	Negative Training CD	0.140	0.021
	Positive Testing AB	0.419	0.049
	Negative Testing AB	0.575	0.069
	Positive Testing CD	0.735	0.061
	Negative Testing CD	0.781	0.065

Table A11. Inferential statistics for all pigeons in Experiment 4.

Pigeon	Source	*df*	F	*p*
28B	Class Trial Type (CTT)	3	9.36	<0.0001
	Pos/Neg (PN)	1	272.25	<0.0001
	CTT x PN	3	47.31	<0.0001
	Error	616	0.36	
97W	Class Trial Type (CTT)	3	12.73	<0.0001
	Pos/Neg (PN)	1	283.28	<0.0001
	CTT x PN	3	27.36	<0.0001
	Error	616	0.10	
85R	Class Trial Type (CTT)	3	26.88	<0.0001
	Pos/Neg (PN)	1	41.76	<0.0001
	CTT x PN	3	32.14	<0.0001
	Error	616	0.12	

Error reported for all pigeons is Mean Square Error.

Table A12. Follow-up results for all pigeons in Experiment 4. Error *df* was 616.

Pigeon	Source	*df*	*t*	*p*
28B	AB PosTrain vs. AB NegTrain	2	15.96	<0.0001
	AB PosTest vs. AB NegTest	2	3.20	0.0014
	AB PosTrain vs. AB PosTest	2	2.79	0.0054
	AB NegTrain vs. AB NegTest	2	-5.96	<0.0001
	CD PosTrain vs. CD NegTrain	2	19.75	<0.0001
	CD PosTest vs. CD NegTest	2	1.04	NS
	CD PosTrain vs. CD PosTest	2	6.26	<0.0001
	CD NegTrain vs. CD NegTest	2	-8.00	<0.0001
	AB PosTest vs. CD PosTest	2	3.32	0.0010
	AB NegTest vs. CD NegTest	2	1.16	NS
97W	AB PosTrain vs. AB NegTrain	2	17.25	<0.0001
	AB PosTest vs. AB NegTest	2	4.57	<0.0001
	AB PosTrain vs. AB PosTest	2	7.43	<0.0001
	AB NegTrain vs. AB NegTest	2	-0.70	NS
	CD PosTrain vs. CD NegTrain	2	15.48	<0.0001
	CD PosTest vs. CD NegTest	2	2.24	0.0257
	CD PosTrain vs. CD PosTest	2	6.84	<0.0001
	CD NegTrain vs. CD NegTest	2	-2.67	0.0077
	AB PosTest vs. CD PosTest	2	1.44	NS
	AB NegTest vs. CD NegTest	2	-0.90	NS
85R	AB PosTrain vs. AB NegTrain	2	10.24	<0.0001
	AB PosTest vs. AB NegTest	2	-2.17	0.0307
	AB PosTrain vs. AB PosTest	2	3.95	<0.0001
	AB NegTrain vs. AB NegTest	2	-6.63	<0.0001
	CD PosTrain vs. CD NegTrain	2	10.44	<0.0001
	CD PosTest vs. CD NegTest	2	-0.64	NS
	CD PosTrain vs. CD PosTest	2	-1.53	NS
	CD NegTrain vs. CD NegTest	2	-10.47	<0.0001
	AB PosTest vs. CD PosTest	2	-4.39	<0.0001
	AB NegTest vs. CD NegTest	2	-2.86	0.0044

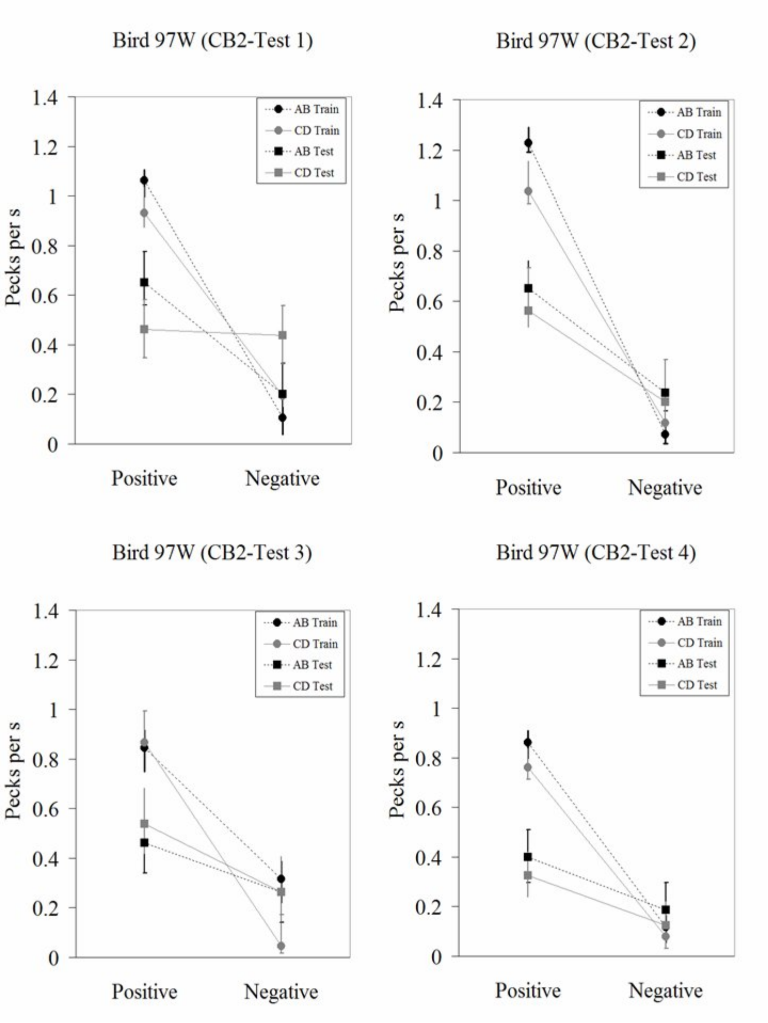


Figure A5. The first four days of testing for Pigeon 97W.

Depicted are pecks per s for the first four test session for Pigeon 97W in Experiment 4. The black lines represent the pecks per s for the AB Set of stimuli for the positive and negative training and testing trials and the light grey lines represent the pecks per s for the CD Set of stimuli for the positive and negative training and testing trials.

APPENDIX B

This Appendix contains data from all of the pigeons from all of the dissertation experiments for Test Day 1. There were no substantial differences between Test Day 1 and Test Days 1-6 for any of the pigeons in Experiment 1 or Experiment 2. In Experiment 3 there were two significant changes between Test Day 1 and Test Days 1-6. Bird #57B does not show evidence of emergent symmetry on Test Day 1, but shows very good evidence of emergent symmetry on Test Days 1-6. Bird #12W shows very good evidence of emergent symmetry on Test Day 1, but does not show very convincing evidence of emergent symmetry on Test Days 1-6. In Experiment 4 there are also two changes between Test Day 1 and Test Days 1-6. Bird #97W does not show evidence of symmetry for the CD Set on Test Day 1, but does show evidence of symmetry for the CD Set on Test Days 1-6. Additionally, Bird #28B does not show statistical evidence of symmetry for the AB or CD Sets on Test Day 1, but does show evidence of symmetry for Test Days 1-6 with the AB Set.

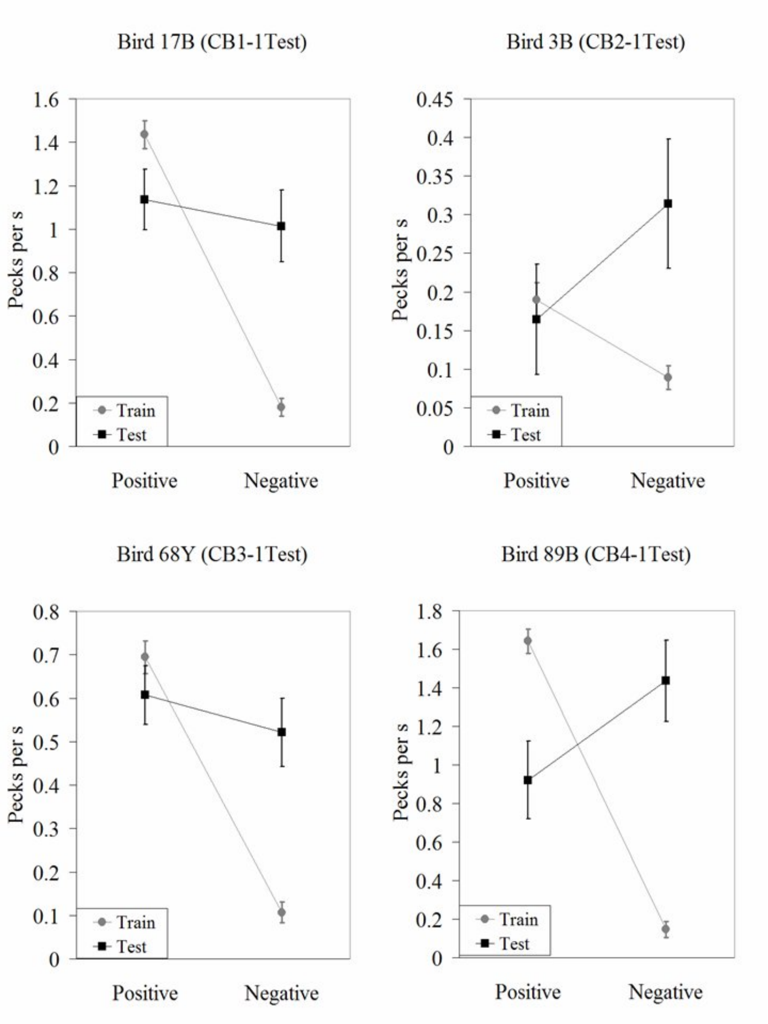


Figure B1. Pecks per s for all pigeons in Experiment 1 for Test Day 1.

Depicted are pecks per s for all four pigeons in Experiment 1. The light grey line represents the pecks per s for the positive and negative arbitrary training combinations and the black line represents the positive and negative testing combinations. Counterbalance (CB) is listed for each bird.

Table B1. Mean response rates and standard error for all pigeons in Experiment 1 for Test Day 1.

Pigeon	Stimulus Combinations	Mean Response Rate	Standard Error
17B	Positive Training	1.435	0.064
	Negative Training	0.180	0.041
	Positive Testing	1.136	0.140
	Negative Testing	1.014	0.164
3B	Positive Training	0.190	0.022
	Negative Training	0.089	0.015
	Positive Testing	0.164	0.072
	Negative Testing	0.314	0.084
68Y	Positive Training	0.695	0.038
	Negative Training	0.107	0.023
	Positive Testing	0.607	0.068
	Negative Testing	0.521	0.079
89B	Positive Training	1.642	0.063
	Negative Training	0.146	0.041
	Positive Testing	0.921	0.201
	Negative Testing	1.436	0.210

Table B2. Inferential statistics results for all pigeons in Experiment 1 for Test Day 1.

Pigeon	Source	*df*	F	*p*
17B	Trial Type (TT)	1	6.75	0.0101
	Pos/Neg (PN)	1	44.64	<0.0001
	TT x PN	1	30.28	<0.0001
	Error	195	0.25	
3B	Trial Type (TT)	1	6.30	0.0129
	Pos/Neg (PN)	1	0.39	NS
	TT x PN	1	9.97	0.0019
	Error	195	0.38	
68Y	Trial Type (TT)	1	7.84	0.0056
	Pos/Neg (PN)	1	33.29	<0.0001
	TT x PN	1	18.50	<0.0001
	Error	195	0.08	
89B	Trial Type (TT)	1	6.79	0.0099
	Pos/Neg (PN)	1	20.23	<0.0001
	TT x PN	1	84.96	<0.0001
	Error	195	0.29	

Error reported for all pigeons is Mean Square Error.

Table B3. Follow-up test results for all pigeons in Experiment 1 for Test Day 1.

Pigeon	Source	*df*	*t*	*p*
17B	P Training vs. N Training	2	16.11	<0.0001
	P Testing vs. N Testing	2	0.64	NS
	P Training vs. P Testing	2	2.05	0.0413
	N Training vs. N Testing	2	-5.73	<0.0001
	Error	80		
3B	P Training vs. N Training	2	3.35	0.0010
	P Testing vs. N Testing	2	-2.04	0.0427
	P Training vs. P Testing	2	0.46	NS
	N Training vs. N Testing	2	-4.01	<0.0001
	Error	80		
68Y	P Training vs. N Training	2	13.32	<0.0001
	P Testing vs. N Testing	2	0.79	NS
	P Training vs. P Testing	2	1.06	NS
	N Training vs. N Testing	2	-5.02	<0.0001
	Error	80		
89B	P Training vs. N Training	2	18.14	<0.0001
	P Testing vs. N Testing	2	-2.55	0.0117
	P Training vs. P Testing	2	4.67	<0.0001
	N Training vs. N Testing	2	-8.36	<0.0001
	Error	80		

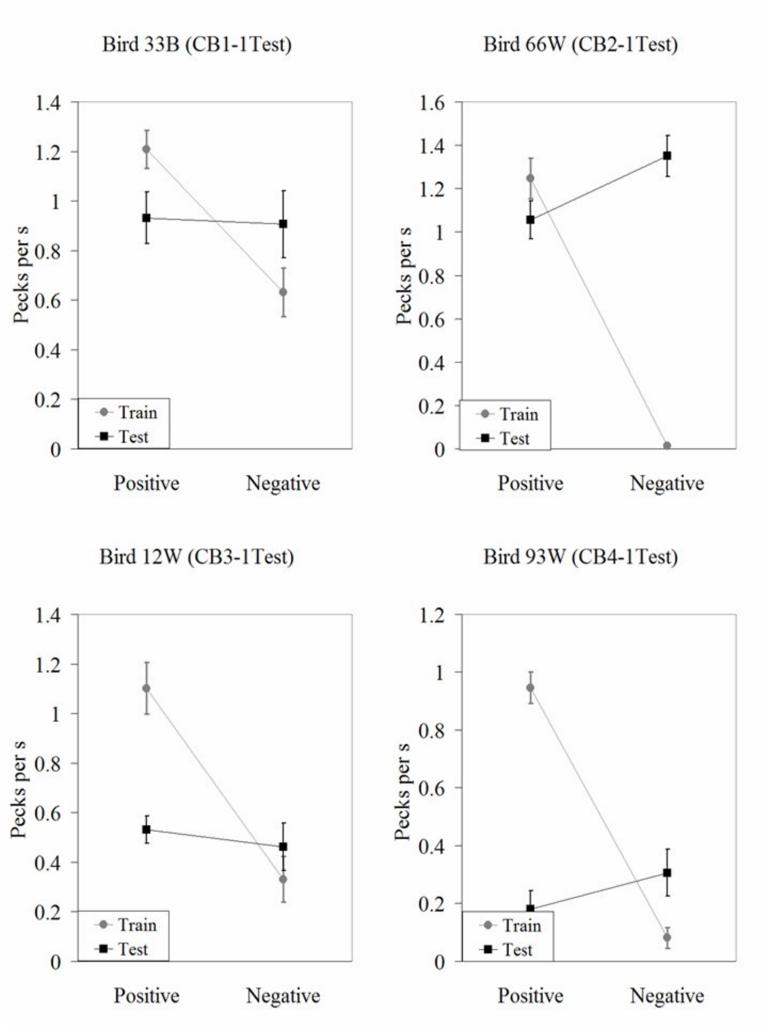


Figure B2. Pecks per s for all pigeons in Experiment 2 for Test Day 1.

Depicted are pecks per s for all four pigeons in Experiment 2 for Test Day 1. The light grey line represents the pecks per s for the positive and negative arbitrary training combinations and the black line represents the positive and negative testing combinations. Counterbalance (CB) is listed for each bird.

Table B4. Mean response rates and standard error for all pigeons in Experiment 2 for Test Day 1.

Pigeon	Stimulus Combinations	Mean Response Rate	Standard Error
33B	Positive Identity	0.966	0.053
	Negative Identity	0.253	0.045
	Positive Training	1.209	0.076
	Negative Training	0.631	0.098
	Positive Testing	0.931	0.104
	Negative Testing	0.906	0.136
66W	Positive Identity	1.271	0.066
	Negative Identity	0.214	0.061
	Positive Training	1.247	0.093
	Negative Training	0.013	0.006
	Positive Testing	1.056	0.088
	Negative Testing	1.350	0.094
12W	Positive Identity	0.038	0.008
	Negative Identity	1.514	0.064
	Positive Training	1.102	0.104
	Negative Training	0.331	0.093
	Positive Testing	0.531	0.055
	Negative Testing	0.463	0.096
93W	Positive Identity	0.860	0.030
	Negative Identity	0.181	0.036
	Positive Training	0.947	0.055
	Negative Training	0.081	0.035
	Positive Testing	0.181	0.063
	Negative Testing	0.306	0.081

Table B5. Inferential statistics for all pigeons in Experiment 2 for Test Day 1.

Pigeon	Source	*df*	F	*p*
33B	Trial Type (TT)	1	0.00	NS
	Pos/Neg (PN)	1	8.01	0.0057
	TT x PN	1	6.73	0.0110
	Error	92	0.24	
66W	Trial Type (TT)	1	51.06	<0.0001
	Pos/Neg (PN)	1	34.42	<0.0001
	TT x PN	1	90.79	<0.0001
	Error	92	0.14	
12W	Trial Type (TT)	1	4.23	0.0425
	Pos/Neg (PN)	1	15.45	0.0002
	TT x PN	1	10.80	0.0014
	Error	92	0.24	
93W	Trial Type (TT)	1	21.11	<0.0001
	Pos/Neg (PN)	1	39.64	<0.0001
	TT x PN	1	70.93	<0.0001
	Error	92	0.07	

Error reported for all pigeons is Mean Square Error.

Table B6. Follow-up results for all pigeons in Experiment 2 for Test Day 1.

Pigeon	Source	*df*	*t*	*p*
33B	P Training vs. N Training	2	4.70	<0.0001
	P Testing vs. N Testing	2	0.14	NS
	P Training vs. P Testing	2	1.84	NS
	N Training vs. N Testing	2	-1.83	NS
	Error	92		
66W	P Training vs. N Training	2	13.33	<0.0001
	P Testing vs. N Testing	2	-2.24	0.0273
	P Training vs. P Testing	2	1.69	NS
	N Training vs. N Testing	2	-11.79	<0.0001
	Error	92		
12W	P Training vs. N Training	2	6.25	<0.0001
	P Testing vs. N Testing	2	0.39	NS
	P Training vs. P Testing	2	3.78	0.0003
	N Training vs. N Testing	2	-0.87	NS
	Error	92		
93W	P Training vs. N Training	2	12.75	<0.0001
	P Testing vs. N Testing	2	-1.30	NS
	P Training vs. P Testing	2	9.20	<0.0001
	N Training vs. N Testing	2	-2.71	0.0081
	Error	92		

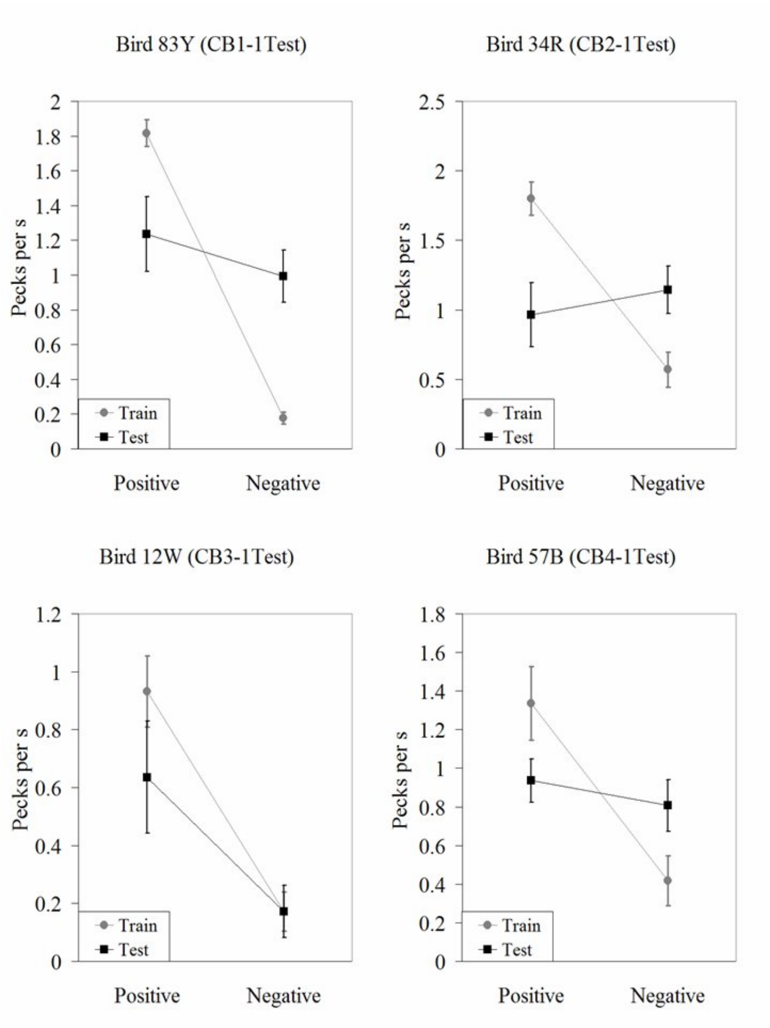


Figure B3. Pecks per s for all pigeons in Experiment 3 for Test Day 1.

Depicted are pecks per s for all four pigeons in Experiment 3 for Test Day 1. The light grey line represents the pecks per s for the positive and negative arbitrary training combinations and the black line represents the positive and negative testing combinations. Counterbalance (CB) is listed for each bird.

Table B7. Mean response rates and standard error for all pigeons in Experiment 3 for Test Day 1.

Pigeon	Stimulus Combinations	Mean Response Rate	Standard Error
83Y	Positive Identity	1.802	0.094
	Negative Identity	0.166	0.041
	Positive Training	1.846	0.136
	Negative Training	0.200	0.059
	Positive Testing	1.236	0.215
	Negative Testing	0.993	0.149
34R	Positive Identity	1.845	0.074
	Negative Identity	0.230	0.052
	Positive Training	1.799	0.119
	Negative Training	0.571	0.126
	Positive Testing	0.964	0.232
	Negative Testing	1.143	0.172
12W	Positive Identity	1.333	0.069
	Negative Identity	0.120	0.034
	Positive Training	0.931	0.123
	Negative Training	0.171	0.067
	Positive Testing	0.636	0.194
	Negative Testing	0.171	0.090
57B	Positive Identity	1.035	0.091
	Negative Identity	0.284	0.062
	Positive Training	1.336	0.190
	Negative Training	0.418	0.128
	Positive Testing	0.936	0.113
	Negative Testing	0.807	0.134

Table B8. Inferential statistics for all pigeons in Experiment 3 for Test Day 1.

Pigeon	Source	*df*	F	*p*
83Y	Trial Type (TT)	1	0.43	NS
	Pos/Neg (PN)	1	45.98	<0.0001
	TT x PN	1	25.37	<0.0001
	Error	80	0.36	
34R	Trial Type (TT)	1	0.68	NS
	Pos/Neg (PN)	1	10.84	0.0015
	TT x PN	1	10.48	<0.0001
	Error	80	0.47	
12W	Trial Type (TT)	1	1.40	NS
	Pos/Neg (PN)	1	24.13	<0.0001
	TT x PN	1	1.40	NS
	Error	80	0.29	
57B	Trial Type (TT)	1	0.00	NS
	Pos/Neg (PN)	1	9.08	0.0035
	TT x PN	1	5.17	0.0257
	Error	80	0.56	

Error reported for all pigeons is Mean Square Error.

Table B9. Follow-up results for all pigeons in Experiment 3 for Test Day 1.

Pigeon	Source	*df*	*t*	*p*
83Y	P Training vs. N Training	2	10.24	<0.0001
	P Testing vs. N Testing	2	1.07	NS
	P Training vs. P Testing	2	3.10	0.0027
	N Training vs. N Testing	2	-4.03	0.0001
	Error	80		
34R	P Training vs. N Training	2	6.67	<0.0001
	P Testing vs. N Testing	2	-0.69	NS
	P Training vs. P Testing	2	3.70	0.0004
	N Training vs. N Testing	2	-2.54	0.0131
	Error	80		
12W	P Training vs. N Training	2	5.28	<0.0001
	P Testing vs. N Testing	2	2.28	0.0251
	P Training vs. P Testing	2	1.68	NS
	N Training vs. N Testing	2	0.00	NS
	Error	80		
57B	P Training vs. N Training	2	4.58	<0.0001
	P Testing vs. N Testing	2	0.45	NS
	P Training vs. P Testing	2	1.63	NS
	N Training vs. N Testing	2	-1.58	NS
	Error	80		

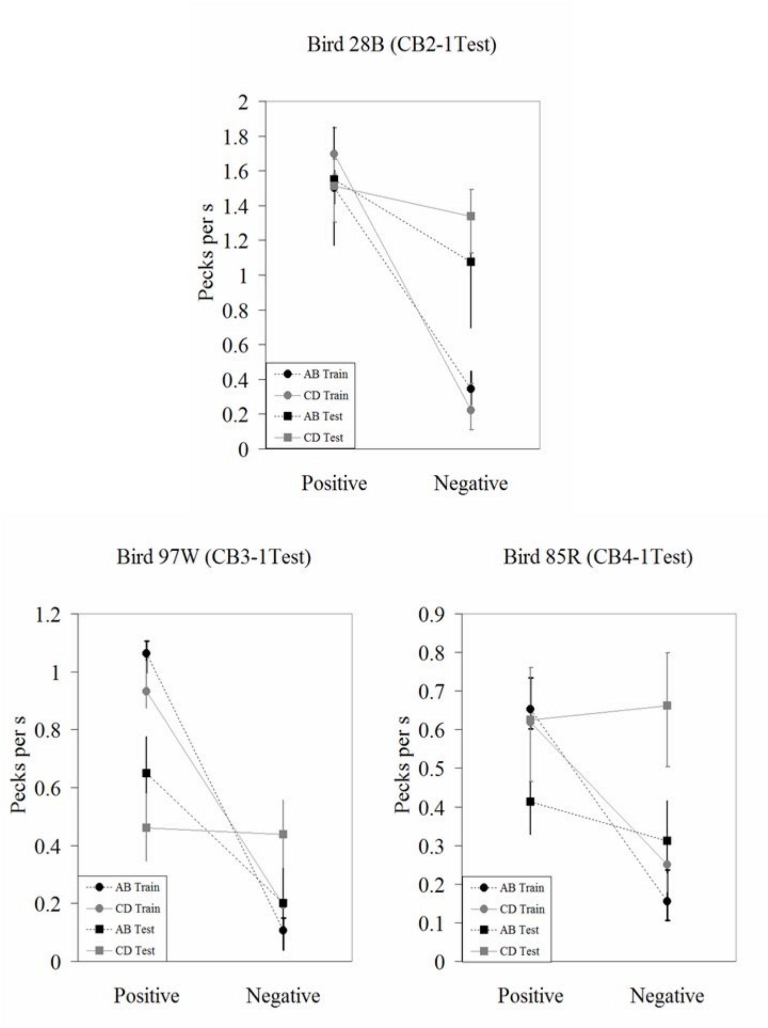


Figure B4. Pecks per s for all pigeons in Experiment 4 for Test Day 1.

Depicted are pecks per s for all four pigeons in Experiment 4 for Test Day 1. The light grey line represents the pecks per s for the positive and negative arbitrary training combinations and the black line represents the positive and negative testing combinations. Counterbalance (CB) is listed for each bird.

Table B10. Mean response rates and standard error for all pigeons in Experiment 4 for Test Day 1.

Pigeon	Stimulus Combinations	Mean Response Rate	Standard Error
28B	Positive Identity	1.850	0.070
	Negative Identity	0.519	0.084
	Positive Training AB	1.502	0.104
	Negative Training AB	0.344	0.093
	Positive Training CD	1.695	0.153
	Negative Training CD	0.222	0.114
	Positive Testing AB	1.550	0.304
	Negative Testing AB	1.075	0.378
	Positive Testing CD	1.513	0.154
	Negative Testing CD	1.338	0.210
97W	Positive Identity	0.775	0.044
	Negative Identity	0.100	0.039
	Positive Training AB	1.063	0.043
	Negative Training AB	0.106	0.067
	Positive Training CD	0.932	0.104
	Negative Training CD	0.194	0.058
	Positive Testing AB	0.650	0.125
	Negative Testing AB	0.200	0.091
	Positive Testing CD	0.463	0.119
	Negative Testing CD	0.438	0.115
85R	Positive Identity	0.744	0.073
	Negative Identity	0.197	0.050
	Positive Training AB	0.653	0.081
	Negative Training AB	0.156	0.050
	Positive Training CD	0.619	0.077
	Negative Training CD	0.250	0.070
	Positive Testing AB	0.413	0.104
	Negative Testing AB	0.313	0.083
	Positive Testing CD	0.625	0.136
	Negative Testing CD	0.663	0.159

Table B11. Inferential statistics for all pigeons in Experiment 4 for Test Day 1.

Pigeon	Source	*df*	F	*p*
28B	Class Trial Type (CTT)	3	3.93	0.0108
	Pos/Neg (PN)	1	42.04	<0.0001
	CTT x PN	3	5.70	0.0012
	Error	96	0.35	
97W	Class Trial Type (CTT)	3	1.48	NS
	Pos/Neg (PN)	1	68.34	<0.0001
	CTT x PN	3	9.22	<0.0001
	Error	96	0.10	
85R	Class Trial Type (CTT)	3	2.69	0.0507
	Pos/Neg (PN)	1	11.95	0.0008
	CTT x PN	3	3.36	0.0220
	Error	96	0.10	

Error reported for all pigeons is Mean Square Error.

Table B12. Follow-up results for all pigeons in Experiment 4 for Test Day 1.

Pigeon	Source	*df*	*t*	*p*
28B	AB PosTrain vs. AB NegTrain	2	5.83	<0.0001
	AB PosTest vs. AB NegTest	2	1.60	NS
	AB PosTrain vs. AB PosTest	2	-0.19	NS
	AB NegTrain vs. AB NegTest	2	-2.89	0.0048
	CD PosTrain vs. CD NegTrain	2	7.42	<0.0001
	CD PosTest vs. CD NegTest	2	0.59	NS
	CD PosTrain vs. CD PosTest	2	0.72	NS
	CD NegTrain vs. CD NegTest	2	-4.41	<0.0001
	AB PosTest vs. CD PosTest	2	-0.13	NS
	AB NegTest vs. CD NegTest	2	0.89	NS
97W	AB PosTrain vs. AB NegTrain	2	9.30	<0.0001
	AB PosTest vs. AB NegTest	2	2.91	0.0044
	AB PosTrain vs. AB PosTest	2	3.14	0.0022
	AB NegTrain vs. AB NegTest	2	-0.72	NS
	CD PosTrain vs. CD NegTrain	2	7.16	<0.0001
	CD PosTest vs. CD NegTest	2	0.16	NS
	CD PosTrain vs. CD PosTest	2	3.58	0.0005
	CD NegTrain vs. CD NegTest	2	-1.85	NS
	AB PosTest vs. CD PosTest	2	-1.21	NS
	AB NegTest vs. CD NegTest	2	1.54	NS
85R	AB PosTrain vs. AB NegTrain	2	4.72	<0.0001
	AB PosTest vs. AB NegTest	2	0.63	NS
	AB PosTrain vs. AB PosTest	2	1.79	NS
	AB NegTrain vs. AB NegTest	2	-1.17	NS
	CD PosTrain vs. CD NegTrain	2	3.50	0.0007
	CD PosTest vs. CD NegTest	2	-0.24	NS
	CD PosTrain vs. CD PosTest	2	-0.05	NS
	CD NegTrain vs. CD NegTest	2	-3.07	0.0028
	AB PosTest vs. CD PosTest	2	1.35	NS
	AB NegTest vs. CD NegTest	2	2.22	0.0291