

Oddity-from-Sample Abstract-Concept Learning by Pigeons

by

Thomas A. Daniel

A thesis proposal submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 7, 2012

Keywords: Non-matching, relational learning, training set, concept formation, item-specific

Copyright 2012 by Thomas A. Daniel

Jeffrey S. Katz, Chair, Alumni Professor of Psychology
Martha C. Escobar, Associate Professor of Psychology
Ana Franco-Watkins, Associate Professor of Psychology

Abstract

The ability to determine whether or not objects are the same has been established as an ability essential to human cognition (James, 1890). Concept formation, such as that of sameness, has been shown to rely on the number of training exemplars for humans and nonhumans. For example, by systematically increasing the number of training items pigeons acquired, performance on completely novel items increased. This shift indicates an early reliance on stimulus features to the relationship between the stimuli. This function of training set-size has been previously shown in same/different (Katz & Wright, 2006) and matching-to-sample (Bodily, Katz, & Wright, 2008) conditional discrimination tasks, but it has yet to be shown in an oddity-from-sample task. Pigeons trained with a set size of 3 cartoon items were required to respond to the sample item (FR 10) and select which of the two comparison items differed from the sample item. Once the pigeons demonstrated consistent performance with this task (85% accuracy), novel items were presented systematically in a series of transfer sessions to test for abstract-concept learning. During these transfer sessions, 12 of the 96 trials presented trial-unique pairings. The set-size was then systematically doubled (8 times), increasing the set-size from 3 to 768 items. With an increase in set-size, performance on novel items became equivalent with that of trained items, suggesting that pigeons use the same strategy across these sessions. This transfer performance suggests the first evidence of the oddity concept formation in the pigeon. The function relationship of set size was different than that of the identity concept

learned during matching-to-sample, indicating different factors that influence how pigeons learn these two abstract concepts.

Acknowledgments

I would like to thank Dr. Jeffrey Katz for his assistance in programming, analysis, editing, and many other pigeon-related activities. More thanks go out to my committee, Dr. Franco-Watkins and Dr. Escobar for their insight and helpful guidance. Special thanks go out to members of my lab: John Magnotti for coffee and whiteboard discussions, Adam Goodman for continuous (or categorical?) support, and (former lab member) Dr. Kent Bodily for paving the way. Finally, thanks go out to my cohort, who have proven to be a formidable trivia team and reminded me that with hard-earned knowledge comes the possibility of (up to \$45 worth of) free food.

Table of Contents

Abstract.....	ii
Acknowledgments.....	iv
List of Figures.....	vii
List of Abbreviations.....	viii
Introduction.....	1
Item-Specific Versus Relational Rule Learning.....	2
Past Research in Oddity Concept Learning.....	6
Proposed Directions	13
Method	17
Subjects	17
Apparatus	17
Stimuli	19
Procedure	20
Pretraining.....	20
Training.....	21
Transfer Testing	22
Set-Size Expansion.....	22

Results.....	23
Acquisition	23
Testing.....	27
Discussion.....	29
Acquisition Comparisons: MTS and OFS.....	31
Transfer Comparison: MTS, OFS, and S/D	34
Conclusion.....	36
References.....	38

List of Figures

Figure 1: Same/Different Configuration Example.....	3
Figure 2: MTS/OFS Configuration Example.....	4
Figure 3: Moon & Harlow (1954) Acquisition.....	7
Figure 4: Comparison of MTS and S/D across Set Size.....	15
Figure 5: Operant Chamber Display.....	18
Figure 6: Video-Picture Stimuli Example.....	19
Figure 7: Initial Set Size Acquisition.....	23
Figure 8: Trials-to-Criterion across Set Size.....	24
Figure 9: First Session Acquisition across Set Size.....	26
Figure 10: Baseline vs. Transfer across Set Size.....	27
Figure 11: Trials-to-Criterion Comparison: MTS/OFS.....	32
Figure 12: First Session Acquisition Comparison: MTS/OFS.....	34
Figure 13: Novel Transfer Performance Comparison: MTS/OFS/S/D.....	35

List of Abbreviations

ANOVA	Analysis of Variance
CP	Correction Procedure
DF	Degrees of Freedom
FR	Fixed Response
ITI	Intertrial Interval
MTS	Matching-to-Sample
OFS	Oddity-from-Sample
OPE	Oddity Preference Effect
S/D	Same/Different
ST-OT	Sample-Trained, Oddity Trained
ST-OU	Sample-Trained, Oddity Untrained
SU-OT	Sample-Untrained, Oddity-Trained
SU-OU	Sample-Untrained, Oddity-Untrained

INTRODUCTION

An abstract concept is a relationship that is learned between at least two stimuli that is not bound by perceptual features. Abstract concepts are used to infer relationships between stimuli because they do not solely rely on perceptual properties; by using relational rules, an animal can apply previous learning in completely new environments or situations. Animals may use the concept of “heavier than,” “smaller than,” or “different than” to solve a task where instances of generalization are impossible and only the relationship between the stimuli can be used (Wright & Katz, 2007). When testing abstract and relational learning, the concept of sameness may be the most commonly studied (Zentall et al, 2008). This concept requires an animal to make the distinction of which stimuli are the same and which are not, essentially asking the question “are they the same?” William James referred to this sense of sameness as “the most important of all features of our mental structure,” (1890, p.460). The ability to form such concepts has been a point of interest in human cognitive development (Piaget & Inhelder, 1966/1969; Daehler & Bukatko, 1992), but this interest has also spread to the arena of nonhuman research. Evidence of abstract-concept learning has been found in a wide variety of animals, including baboons (Bovet & Vauclair, 2001), chimpanzees (Premack, 1978, 1983), dolphins (Herman, Hovancik, Gory, & Bradshaw, 1989), monkeys (e.g., Katz, Wright, & Bachevalier, 2002; Wright, Rivera, Katz, & Bachevalier, 2003), parrots (Pepperburg, 1987), pigeons (Wright, 1997), and sea lions (Kastak & Schusterman, 1994). Abstract relationships should not be confused with categorical learning, known as natural concepts. Relational concepts differ from natural concepts because natural

concepts depend on rote memorization of specific features to categorize stimuli (Thompson, 1995). In other words, natural concepts rely on specific within-class stimulus properties that are used to make judgments about a category or stimulus classification. While the above examples of concept learning involve the concept of identity, or matching, demonstrations of the concept of oddity have been conspicuously absent from the literature.

The use of pigeons in a non-matching task may shed light on how concepts are learned in the absence of language and to what extent nonhuman animals can learn such tasks. To date, there has not been conclusive evidence that pigeons can successfully solve an oddity task by using relational rules, or by answering the question “which of these items is different?” The goal of the present study is to provide the first demonstration of oddity concept-learning in a nonhuman species. While several previous studies have attempted to demonstrate this ability, their results have either been confounded or inconclusive. By using techniques that both facilitate the learning of relational-rules and discourage the maintenance of stimulus-dependent learning, pigeons may be able to form the abstract-concept of oddity.

Item-Specific Versus Relational Rule Learning

Abstract-concept learning has been studied primarily with three types of conditional discriminations: *same/different* (S/D), matching-to-sample (MTS), and oddity-from-sample (OFS; Zentall et al., 2008). The S/D procedure requires subjects to distinguish if two stimuli are identical or if they are not. One example of this procedure is as follows: an initial stimulus is observed before a comparison is introduced – an observation to the comparison is reinforced if the two stimuli are the same, and an observation to an off-centered white box is reinforced if the stimuli are different. If an animal is presented with a picture of an orangutan, and the comparison stimulus is a picture of a house, reinforcement is provided for observing the white box because

the two items are different. If the comparison was identical to the original orangutan, then reinforcement would be provided for selecting the comparison orangutan (Figure 1). The MTS procedure requires subjects to respond to a comparison stimulus that is identical to an original sample stimulus. Different from S/D, MTS offers a foil stimulus, and reinforcement is provided for selecting the matching item. If an animal is presented a picture of a duck, an example of a



Figure 1. These two configurations represent two possible contingencies of the same/different task. The left panel presents a comparison stimulus that is the same as the sample stimulus; in this case, reinforcement is provided for observing the bottom orangutan. The right panel presents a comparison stimulus that is different as the sample stimulus; in this case, reinforcement is provided for observing the white box.

pair of comparison stimuli would be an apple and a duck. In this instance, observing the duck comparison would be reinforced because it matches the original sample. The last, and perhaps least common of these methodologies to be studied is OFS, or non-matching as it has also been referred in other work. The task is similar to MTS, but reinforcement is provided for selecting the odd, non-identical item of the comparison array. In the OFS paradigm, reinforcement would

be provided for selecting the apple instead of the duck because it does not match the sample (Figure 2). While S/D and MTS have both successfully demonstrated abstract-concept learning in nonhuman species (Bodily, Katz & Wright, 2008; Katz & Wright, 2006), OFS has yet to provide sufficient evidence of abstract-concept learning.

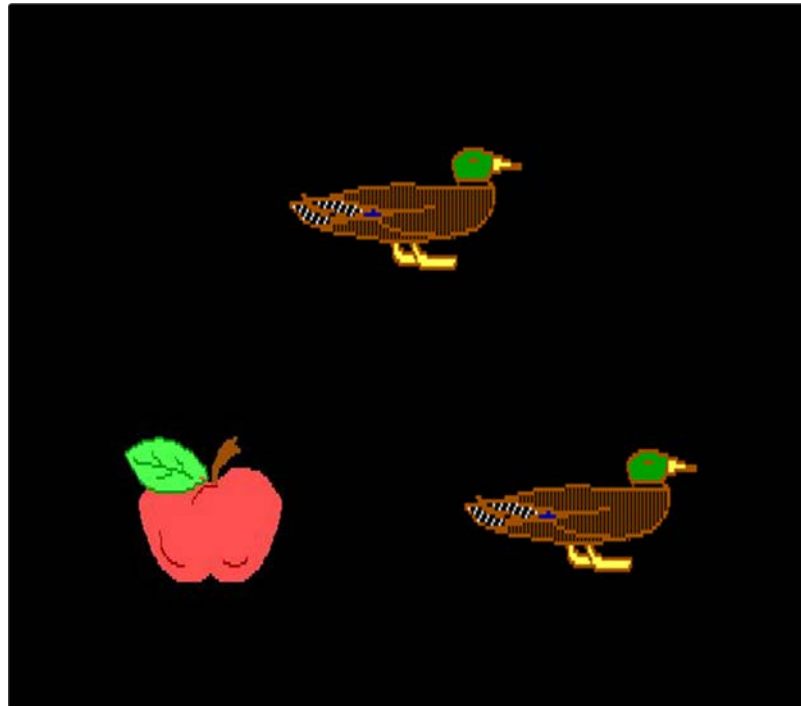


Figure 2. This configuration can serve as an example of an MTS or OFS task depending on which comparison provides a reward. To begin the task, the animal must peck at the top duck. This response will present the two comparison items, the bottom duck and the apple. In an MTS task, reinforcement will be provided for a response to the bottom duck because it matches the sample stimulus. In an OFS task, reinforcement will be provided for a response to the bottom apple because it does not match the sample stimulus.

Conditional discrimination tasks, like OFS can be solved in a variety of ways. Carter and Werner (1978) described three separate strategies that could be used to solve these tasks: configural learning, if-then rules, and relational rules. If an animal used configural learning strategies to solve the task, the sample and choice stimuli form an array that is learned as a

whole; the response made to the configuration will be based on stimulus-dependent cues. If any element of this configural array is changed, predictions would be that the animal could not accurately complete the task. Accordingly, if choice stimuli are given different position or if novel items are used, the animal will make responses equivalent to chance-level performance. If-then strategies govern behavior by subjects having learned the sample stimulus and the correct corresponding choice stimulus (for example: if apple, then pick grape). This strategy will theoretically not work if the animal is presented with novel stimuli, because it will not have had any prior experience with the stimuli. For this reason, if-then strategies are also stimulus-dependent. Performance on trained items will not transfer to novel items under these two learning strategies. Relational rules differ from the previous forms of learning because they are not bound by the perceptual qualities of the stimuli. When an animal uses a relational rule, it uses the relationship between the sample and choice stimuli (e.g., pick the odd item of the configuration) to solve the task. If an animal is using relational rules, it should be able to successfully solve the task with stimuli that it has never previously experienced. This level of performance to novel items should be equivalent with performance on trained items if relational strategies are implemented. One of the goals of this study is to test if pigeons can use these relational judgments to solve a conditional oddity discrimination task.

For a pigeon or an animal to be qualified as using an abstract-concept, it must meet the five following standard criteria based on previous research (e.g., Cook, 2002; Katz, Wright, & Bodily, 2007; Premack, 1978) and detailed previously by Bodily, Katz, & Wright (2008); first, stimuli that are used for the testing of concept learning must be completely different from the stimuli used for training acquisition. Abstract-concept learning must be stimulus-independent, so in using novel stimuli, the organism is unable to make a response based on feature-specific

strategies. Second, instances in which testing occurs should not use both novel and trained items. Previous experience to these trained items (or neophobia of novel items) may influence a response to that particular array of items. Third, during testing trials, contingencies should remain the same as during training trials; differential treatment of reinforcement or punishment could alter behavior for novel stimuli. Because the goal of testing is to demonstrate a transfer of performance, the discrepancy of reinforcement between trained and untrained items could affect the way a response is made. Fourth, the results of responses made to novel testing items must not extend beyond the initial presentation of these items. Once the testing items are presented to the animal, they are no longer novel; if a testing item is shown again, it may be impossible to know if the response is based on a transfer of an abstract-concept or on previous experience with said item. Finally, for abstract-concept learning to take place, an organism would need to perform on new items as well it did on trained items. If performance on novel items is equivalent to performance on trained items and reliably above chance, then it may be inferred that the animal is using the same relational strategy to solve the task. An experimental design needs to meet all of these criteria in order to be considered for evidence of abstract-concept learning, and to date, there has been no study that has demonstrated oddity concept learning while actively maintaining these standards.

Past Research in Oddity Concept Learning

There has been much research on concept learning, but as of yet, there has been no conclusive evidence put forth for oddity learning in nonhumans. Because previous research has not been able to establish oddity as a concept, studies in the field have done much to highlight the peculiarities of oddity as a discrimination task. One of the most common and robust findings

is that acquisition rates in oddity learning surpasses that of its converse matching performance (Wright & Delius, 2005). Major findings and results are discussed next.

Early studies in conceptual behavior used primates (rhesus monkeys) to examine both matching (Harlow, 1943; Nissen, Blum & Blum, 1947) and oddity (Moon & Harlow, 1954). Moon and Harlow's work with primates used the Wisconsin General Test Apparatus to deliver and record responses. By using 256 pairs of stimuli grouped into 4 separate learning sets, oddity learning curves were obtained and compared to matching performance. The study did not implement novel transfer stimuli to compare against previously trained items; it measured rate of oddity discrimination acquisition. Moon and Harlow concluded that rhesus monkeys were able to

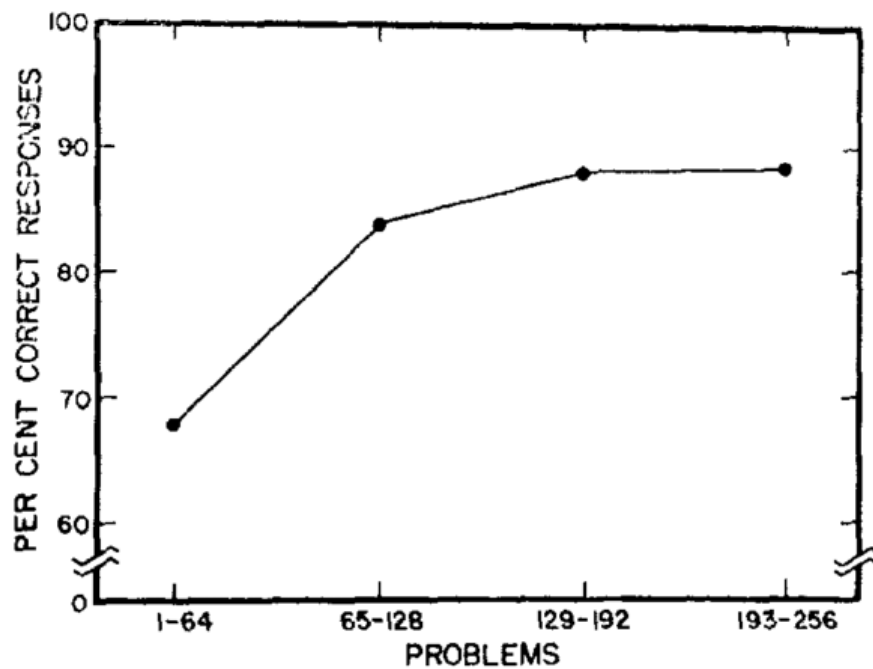


Figure 3. Accuracy performance for Moon and Harlow's 1954 study with rhesus monkeys. Acquisition performance on the non-matching task gradually increased with exposure to the task.

use “oddy learning” to solve the task, and while the primates’ performance was well above chance, it is impossible to conclude that an oddity concept was being used to solve the task. Without the use of novel stimuli to demonstrate a transfer of learning, the results found by Moon and Harlow may be accounted for by previous experience with the stimuli, rather than a relational rule governing subjects’ behavior. Above figure 3 graphically represents the data original published by the study. While the rhesus monkeys were able to learn the discrimination, performance on the task asymptotes around 90% accuracy.

After the attempts made by Harlow and colleagues, attempts at concept learning began to enter other laboratories with different species. Ginsburg (1957) investigated pigeons’ ability to form matching and oddity concepts using color hues. Three groups were trained on MTS, OFS, and a control paradigm not based on a relational rule. Results obtained for these three groups suggest that subjects trained on oddity reach criterion performance before those trained on matching. While this work suggested that nonhuman animals have the capacity to discriminate matching and oddity, it did not successfully demonstrate accurate performance on novel items. The number of trials needed to reach criterion performance was measured, but no transfer performance was ever recorded. Because novel stimuli were never introduced in the paradigm, it is impossible to determine if subjects made use of any relational rules to solve the task. Accordingly, this study cannot be considered sufficient evidence of the oddity concept in pigeons.

Berryman et al. (1965) utilized colored light hues to investigate oddity concept learning. Unlike Ginsburg, this study attempted to implement a novel stimulus to provide evidence of concept learning transfer. Pigeons were trained on red, green, and blue stimulus hues, and for transfer tests, instances of the blue hue were substituted for a yellow hue. Consequently, either

the sample was novel, or the comparison was novel, but never both. The results obtained from this study are not conclusive because transfer stimuli were mixed with previously experienced items. It is impossible to ascertain the effects of any form of conceptual learning with already established acquisition. Further confounding matters, these transfer trials were not limited to one presentation, so any response made may not have been truly due to a transfer of performance. Due to the prior experience with the old stimuli in the task, these results cannot be considered as a reliable demonstration of abstract-concept learning. Because truly novel configurations were never tested, it is likely that subjects relied on item-specific strategies to solve the oddity task.

Zentall and Hogan (1974) attempted to improve upon Berryman et al.'s design by providing trials that included novel samples and novel comparisons. This implementation would allow for novel configurations, possibly offering a more accurate depiction of how subjects transfer performance. Pigeons were trained on red and green hues until performance was consistently above chance. To test for transfer, sessions were created so that all instances of red and green hues were substituted for yellow and blue respectively. Across all subjects, performance on this initial transfer session appeared well below baseline-training performance and no different than chance. Much like previous studies, these findings do not provide evidence for concept learning; while the color hues may be novel upon first presentation, they were used on more than one occasion in a series of eleven sessions. This repetition facilitates stimulus-dependent learning and cannot be put forth as evidence for abstract concept learning in animals. Furthermore, because performance on novel configurations was below that of training performance, it cannot be concluded that subjects used a relational rule to solve the task.

Urcuioli (1977) offers another attempt at demonstrating the oddity concept in pigeons. The study made use of colored light panels, much like the previously recounted studies. The use

of colored hues as stimuli in concept-learning presented a potential confound: it limited the ability to display novel stimuli. Not only were transfer stimuli presented more than once, allowing pigeons to make stimulus-dependent discriminations possible, but transfer stimuli were presented alongside trained items. Because transfer trials were not completely novel, any responses made may be confounded by past history or neophobia of a new stimulus. Further, no statistical test was used to correct for this repetition of stimuli. Performance on novel items recorded by subjects was not equivalent to performance on trained items. These findings can be explained as behavior controlled by using stimulus-dependent learning strategies, such as configural or if-then rules rather than the oddity concept.

Most non-matching designs feature only two comparison stimuli; Zentall, Hogan, Edwards & Hearst (1981) made an attempt to better characterize oddity discrimination by manipulating the amount of possible comparisons available in a comparison array. Throughout the course of their work, comparison arrays increased to the point in which some pigeons were exposed to as many as 24 incorrect alternatives in the OFS task. In this case, the incorrect alternatives would be lighted panels that match the original sample stimulus. The main finding suggests that when subjects are offered more incorrect alternatives, acquisition to the task increases dramatically in speed. When only one or two incorrect alternatives are offered in the comparison array, pigeons take much longer to perform at asymptotic levels, if they reach that level of performance at all. Juxtaposed with MTS, this finding may be unique to the OFS literature. Using a matching target search design, Blough (1979) discovered that as the number of incorrect alternatives increased, so too did rates of error. In this case, pigeons trained in matching actually performed worse when more items were displayed on the subject's screen. While Blough's target search design functions as a delayed version of MTS, the differences that

arise between matching and oddity discrimination are glaring. Zentall et al.'s study, while never explicitly stated to be about the subject of concept learning, does not provide evidence of relational learning; subjects were only exposed to red and green colored discs as stimuli, and testing involved shifting the amount of available comparisons available during choice responding.

Lombardi, Fachinelli, and Delius (1984) substituted the colored hues often used in the comparative literature for black and white stimulus polygonal patterns. Pigeons were divided into two groups: one received a small stimulus set size (20 possible configurations), and the other received a larger training set (380 possible configurations). Testing began after 57 sessions of training and contained stimuli that were “unknown to subjects but similar in geometric style to those used for training.” These testing items were created to be perceptually similar to trained items, therefore any conclusions drawn from these results must account for the possibility of past experience accounting for variability in performance. These transfer stimuli were not reinforced, but the novel stimuli in a subsequent testing phase were. The inconsistent treatment of transfer stimuli may have influence over the way the animals solve the task. When pigeons were given completely novel and intentionally dissimilar patterns for testing, their performance, while above chance, was not equivalent to performance levels on trained items. Because performance levels between experienced and inexperienced items were not equivalent, relational rules were not used to solve the OFS task.

Lombardi (2008) recently attempted to demonstrate conceptual oddity performance in pigeons using a small colored polygonal stimulus training set-size and a horizontal image display. Subjects were trained with two stimuli, and once performance was consistently above chance, transfer tests were administered. Within each transfer session, novel stimuli were

presented twice: once in one configuration and again in a reversed-order configuration. While performance during these transfer sessions were equivalent to performance during training sessions, the use of transfer stimuli that were not always truly novel presents a potential confound to the findings. The past experience a subject may have with the stimuli may affect how it responds to it upon a second viewing, even if the configuration is flipped. If the subject is accustomed to using if-then rules, transfer of this performance is likely. Further, during these transfer trials, responses made to either correct or incorrect choices were non-differentially reinforced.

Lombardi's study and those performed in past years have documented discrimination learning in nonhumans well, but they have failed to provide sufficient evidence for abstract-concept learning in an oddity task. By not using novel transfer stimuli, it is impossible to tell if behavior is being confounded and controlled by past experience with the stimuli. The mix of transfer and training stimuli within the same trial presents a similar problem; previously experienced items influence the responses being made to novel ones. To prevent this problem of preferential responding, all transfer items should be treated the same as training stimuli to avoid effects of differential reinforcement. While other studies may have demonstrated performance on transfer items above chance, subjects cannot be considered to use a relational rule unless performance on novel items is equivalent to performance on training items. The proposed methodology for the current study will attempt to provide the first demonstration of the oddity concept in a nonhuman animal by using techniques that facilitate relational rules and discourage perceptual-bound learning strategies. These techniques include increased observance of the sample item (Wright, 1997), large stimulus sets (Wright et al., 1988), and increasing training set-sizes (Katz & Wright, 2006).

Proposed Directions

By using a match-to-sample paradigm, Wright (1997) demonstrated that pigeons could successfully transfer training performance to novel items by manipulating the amount of responses required to a sample stimulus. Pigeons performed equally well on training trials as they did on novel trials when the sample stimulus required 10 or more observing responses. Not only did this finding highlight the role of the sample stimulus observing response, but it provided evidence that pigeons could use a relational rule, or a learning strategy not dependent on stimulus specific properties of the stimuli, to solve the task. By having the pigeon attend to the sample stimulus, relationships were learned between the items in the configuration instead of the configuration as a whole.

The importance of training sets was first shown in pigeons by Wright et al. (1988). By manipulating the amount of exemplars a pigeon experienced, differences in transfer performance were found. Trained with a horizontal display, one group of pigeons was trained with only 2 computer-created stimuli; the other group was trained on 152 trial-unique stimuli within a session. After pigeons acquired the task, they were tested on completely novel items. Pigeons that had been trained with only 2 items performed around chance level when presented with novel items. The group that was trained with the trial-unique set performed significantly higher than chance. This finding suggests that the presence of additional exemplars stresses the relationship between the item rather than the stimulus specific properties.

Katz & Wright (2006) provided evidence for abstract-concept learning in pigeons using a set-size expansion method in a same/different procedure. By using a performance-based criterion (85% accuracy) on training items, novel items were tested and compared to the original training

set. This method systematically increased the number of training exemplars used by doubling the size of the training set after each testing period (8, 16, 32, 64, 128, 256, 512, 1024). Their research found that when given a small number of exemplars, such as 8, pigeons would not be able to perform accurately on novel items. When pigeons were trained with 256 images, however, performance on novel items became equivalent to performance on trained items. Figure 3 offers a representation of these results. As the set-size expanded and the number of training exemplars increased, baseline performance on trained items remained relatively high. Transfer performance on completely novel items, however, gradually increased across manipulations. With the earliest set-size, pigeons transferred to chance performance (50%). As the training set increased, performance on novel items gradually increased so that pigeons performed as well on novel items as they did on trained items. These results suggest two major findings: pigeons use item-specific learning when trained with a few items, and a shift from item-specific to abstract-concept learning (relational rules) occurs as set-size increases.

The set-size expansion method was adapted to the matching-to-sample procedure by Bodily, Katz, & Wright (2008). Again, pigeons were required to meet a specific performance criterion on training items before tested with novel items. After these transfer testing sessions, the amount of images used in the training set increased by doubling in quantity (3, 6, 12, 24, 48, 96, 192, 384, 768). In testing sessions, pigeons performed significantly above chance on the 3 items they had been trained on but performed at chance when tested with novel stimuli. As the training set of images increased in quantity, transfer performance rose above chance level and became equivalent with baseline performance (see Figure 4). Similar to Katz & Wright's (2006) results, pigeons initially transferred to chance on early set-sizes. The expansion of training set slightly decreased baseline performance, but transfer performance gradually increased until

pigeons performed equally well on baseline and transfer conditions. The data suggest that pigeons were able to successfully use relational rules to solve a matching-to-sample task as the number of exemplars increased. The current study will be applying the oddity-from-sample paradigm to the set-size expansion method. By using the same stimuli, sessions, and performance criteria, our results will be directly comparable to Bodily et al.

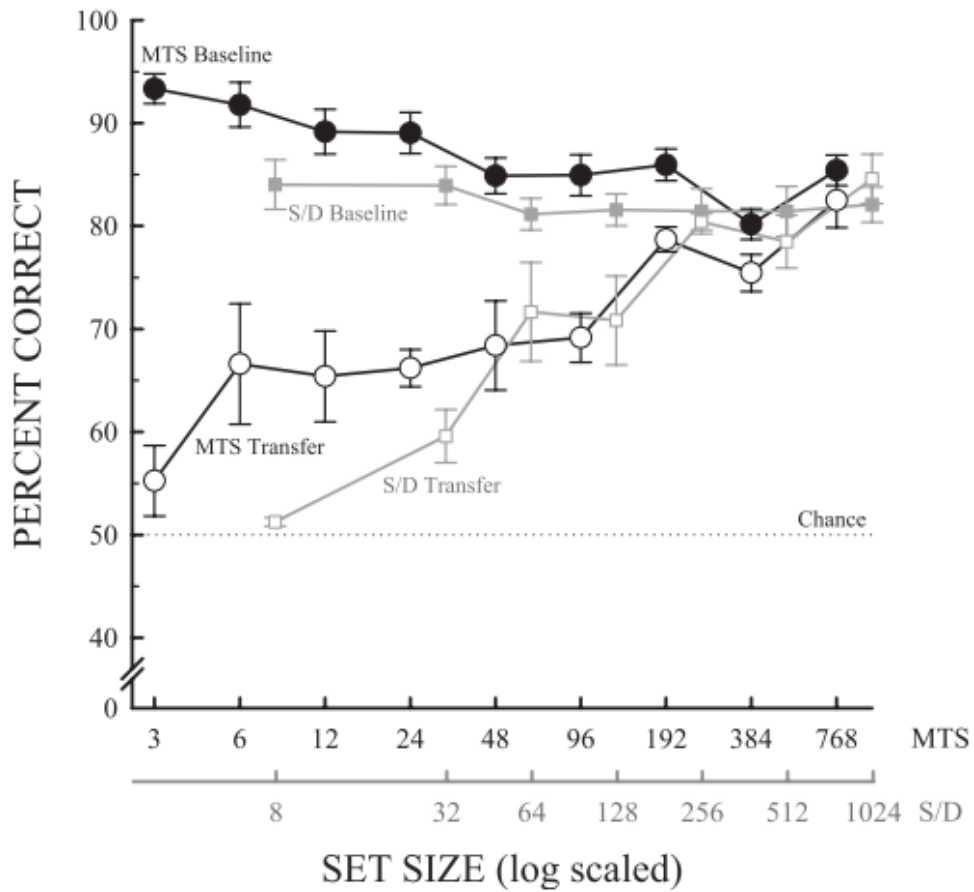


Figure 4. Results from Bodily et al. (2008) show the function of set-size and matching performance. As the number of exemplars in the training set doubles, transfer performance on MTS becomes equivalent to performance on trained items. It is hypothesized that oddity performance will show a similar function over set-size expansion.

The primary purpose of this study is to attempt to test the role of training-set size on an OFS conditional discrimination task. By using the techniques established for matching performance (Bodily et al., 2008), it was predicted that if these animals have the ability to form an oddity concept, this procedure would be able to demonstrate oddity concept formation. Performance in this task is directly comparable to Bodily et al.'s (2008) MTS work. Through identical methodology, apparatuses, and stimuli, the present study's results may be juxtaposed with MTS to further understand the similarities and differences in identity and oddity concept formation. It was hypothesized that not only will pigeons learn the oddity concept, but the set-size function will be similar to that of S/D and MTS tasks: as the number of training items increases, performance on completely novel items will steadily rise and eventually become equivalent to performance on trained items.

METHOD

Subjects

Four naive male pigeons (*Columba livia*) from the Palmetto Pigeon Plant served as subjects. Subjects were kept within 80-85% of their free-feeding body weight throughout the study; in the event that a subject's weight fell above or below this range for the day, it did not participate in that day's session. Subjects resided in a colony room governed by a 12 hour light/day cycle and were housed individually with free water and grit access.

Apparatus

Pigeons were tested using custom wood (35.9-cm wide x 45.7-cm deep x 51.4-cm high) test chambers. A fan (Dayton 5C115A, Niles, IL) located in the back wall of each chamber provides ventilation and white noise. The computer detects pecks via an infrared touch screen (17" Unitouch, Carroll Touch, Round Rock, TX). This pressure-fit touch screen sits within a 40.6 x 32.1-cm cutout in the front panel that was centered 7.7 cm from the top of an operant chamber. A 28-V (No. 1829, Chicago Miniature, Hackensack, NJ) houselight, located in the center of the ceiling, illuminates the chamber during intertrial intervals (ITI). A custom hopper containing mixed grain can be accessed through an opening (5.1 x 5.7 cm) centered in the front panel 3.8-cm above the chamber floor. This hopper allows between 2 to 3.5-seconds access to mixed grain to reinforce a correct response. A tone will be presented along with mixed grain access as a paired reinforcer using desktop speakers (Dell, Round rock, TX) located beneath the monitor and behind the touch screen.

Visual Basic 6.0 on a Dell Dimensions 2100 recorded and controlled all events in the operant chamber. An ATI Xpert 98 video card controlled graphics generated by the computer while a PCI card (Keithley KPCI-PI0) maintained operation of the grain-hopper and the lights to both the hopper and the chamber. This apparatus was used previously by Bodily, Katz, & Wright (2008). Figure 5 shows the front panel of the experimental apparatus used for all subjects.



Figure 5. Operant chamber display. In this picture, the top duck serves as the sample stimulus with the comparison array consisting of a grape and a duck. Below the touch screen is the hopper in which the pigeon has access to grain given a correct trial.

Stimuli

All stimuli were computer-created, cartoon JPEG images. Bodily, Katz, & Wright (2008) previously used this same set of 768 images. All images were 2.5-cm high x 3-cm wide at 28 pixel/cm. Each sample stimulus appeared centered horizontally at approximately 8-cm above the bottom of the display. Comparison stimuli appeared 4-cm above the bottom of the monitor, centered at 4-cm. The left-choice comparison stimulus was presented 9-cm from the left of the display's edge, and the right-choice comparison was presented 13-cm from the left of the left-choice comparison. Figure 6 provides examples of these computer-generated stimuli.

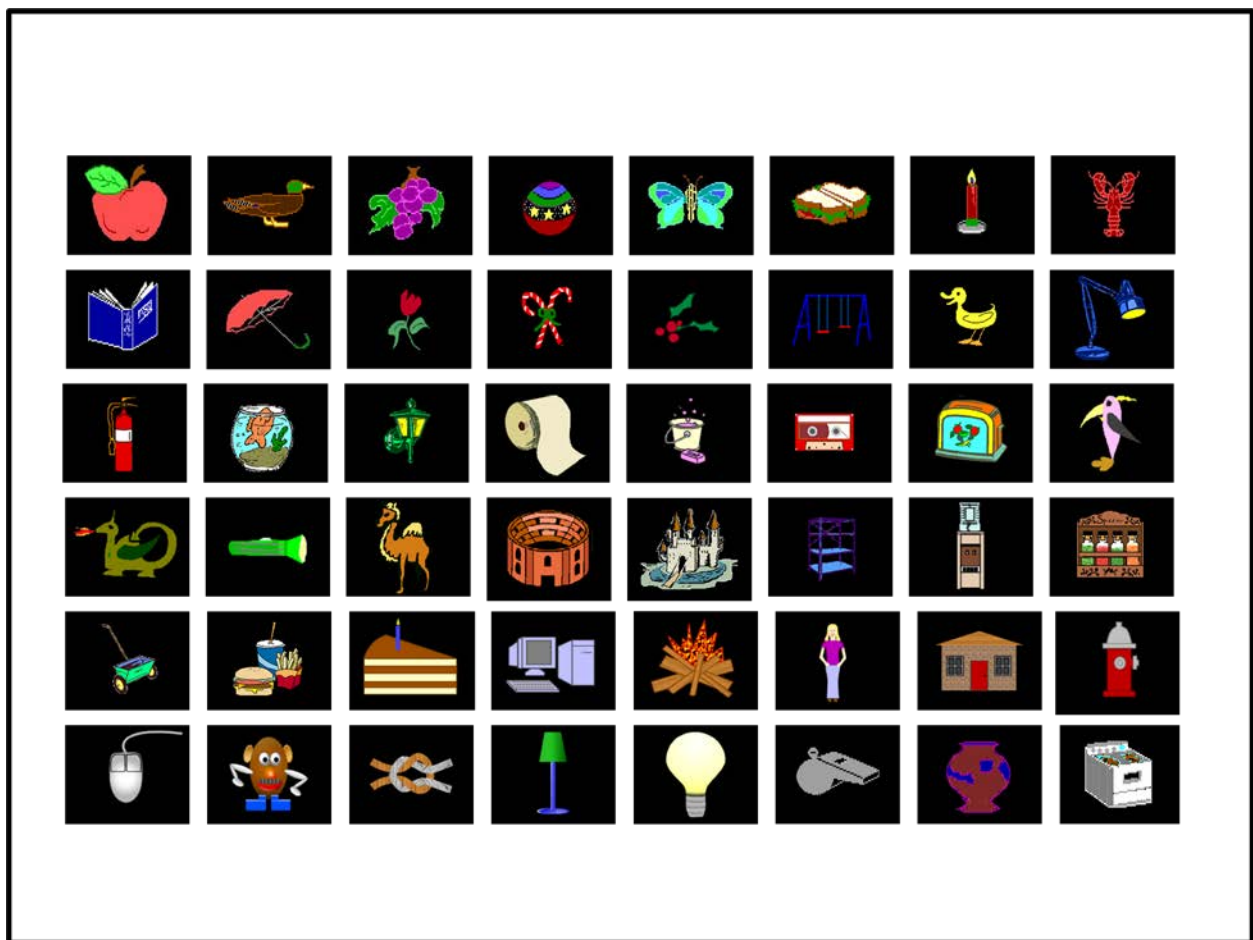


Figure 6. Example of stimuli used in present study. This particular set is representative of the 48-item training set.

PROCEDURE

Pretraining

All subjects learned to peck at the computer monitor using an autoshaping program created using Visual Basic 6.0. This program displayed one of three cartoon stimuli (apple, grape, or duck) in 2 possible stimuli locations: left-comparison and right-comparison. After 10 s of this image being displayed, access was provided to mixed grain for 5 s. This grain access was followed by a 50 s ITI before another stimulus was displayed. Pecking at the present stimulus terminated the cartoon image and immediately raised the hopper. This sequence was repeated for all 96 trials per autoshaping session. Subjects continued autoshaping until at least 80% of the 10 s stimulus presentations received a response. After subjects responded reliably to this response-independent autoshaping session, training began in a response-dependent session that required one peck to a stimulus (FR 1) to provide reinforcement followed by a 15 s ITI. All other details were the same as the response-independent autoshaping session. When subjects completed this session within 2 hours, they advanced to the training phase of the study.

Training

Daily sessions were carried out between 5 and 7 days a week, with each session comprised of 96 trials (48 left responses and 48 right responses). Pigeons were initially trained in the oddity-from-sample task with a set-size of 3 items. This initial set was comprised of the same stimuli used during pretraining (apple, duck, and grape). All trials began with a sample stimulus displayed on the monitor. Pigeons observed a sample stimulus by making 10 responses to the image; this FR requirement began with 1 peck but was systematically increased over 7 sessions to 10. After subjects performed this requirement, two comparison stimuli were presented; one of these images was identical to the sample, and the other image, which does not match the sample, was selected from the training set. A response to the odd comparison resulted in food reinforcement. Grain access was between 2-3.5 s of mixed grain depending on the pigeon's body weight prior to the session. After a correct response, a 15 s ITI followed grain access, and the odd comparison remained on the display for 4 s; an incorrect response resulted in a timeout period of 8 s and the disappearance of the sample and matching comparison stimulus. With a set size of 3, 12 possible configurations can be made; these configurations appeared 8 times per 96-trial session. Stimuli were counterbalanced to ensure that a configuration would not directly repeat itself within the next trial. Correct response locations (left or right) were also counterbalanced so that an equal number of correct left and right responses occurred in any given session.

Training continued until a pigeon reached 85% accuracy across two consecutive sessions with a correction procedure (CP). The CP forced subjects to repeat any incorrect trials until a correct response was made. After this performance-based criterion was met, the subjects were

required to perform 85% accuracy on a session without the CP in place before moving onto the testing phase.

Transfer Testing

The testing phase was comprised of four 96-trial sessions and began directly after a pigeon achieved criteria-based performance. Within each testing session 12 novel stimulus configurations were presented to the subject, creating a total of 24 novel stimuli in one session and 96 (24 X 4) total novel stimuli per testing phase. Stimuli presented in these testing configurations were unique and never viewed prior to the transfer test. None of these testing trials appeared within the first or last 8 trials of the session; at least 5 trials separated any novel stimuli configuration from one another. All testing configurations maintained were reinforced identically to those of training stimuli; a correct response resulted in grain access, and an incorrect response resulted in an 8 s timeout period. These novel configurations were also counterbalanced using the same specifications as those during training.

Set-Size Expansion

After transfer testing, the stimulus set used previously for training doubled in quantity. With this manipulation, the number of images used in training increased from 3 to 6, and systematically to 12, 24, 48, 96, 192, 384, and 768. Each training set size requires the pigeon to achieve criterion performance ($\geq 85\%$ accuracy on one session without CP and a minimum of three sessions) before transfer testing. If a pigeon performed below 75% accuracy, CP was reinstated until two consecutive sessions above 85% accuracy was reached. Subsequent training and testing sessions followed the same structure as the respective sessions used in the initial sessions.

RESULTS

Acquisition

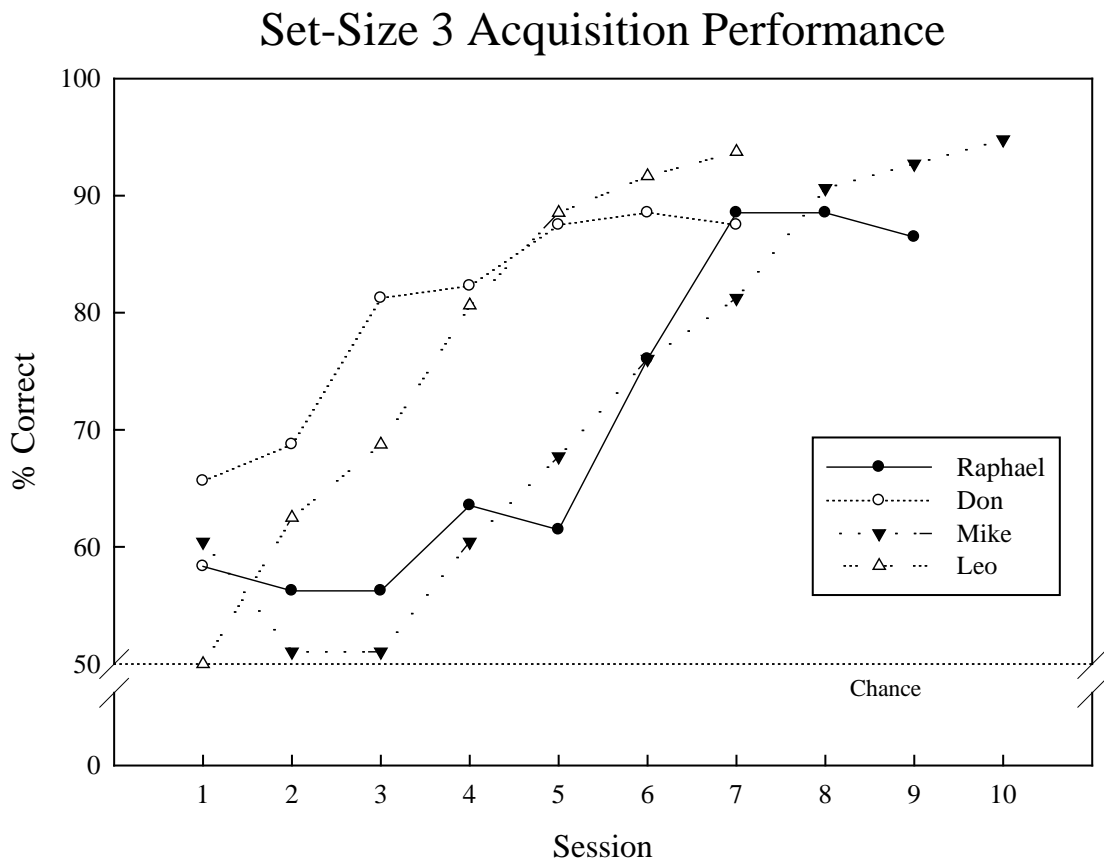


Figure 7. OFS acquisition performance for each subject. All subjects acquired the task as defined by the performance criterion by the tenth session (960 trials). Individual subjects are represented by their marked lines, and chance (50%) is distinguished by the dotted line.

Trials to criterion. Figure 7 shows acquisition across the 96-trial sessions for each pigeon during training of the set-size 3. All subjects reached the initial set-size three performance criterion by the 10th session with a mean of 8.25 sessions. Subjects reached this performance criterion within a range of 672 to 960 trials each. . All pigeons rapidly acquired the OFS task, and some pigeons were even above chance by the end of the first session. This acquisition was confirmed by comparing accuracies for the first and last session during set-size 3 training; a paired-samples *t*-test shows a difference in accuracy after training, $t(3)=6.866, p<.01$. Collapsing across all subjects, a one-sample *t*-test showed that accuracy on the first session of training was not above chance, $p=.07$.

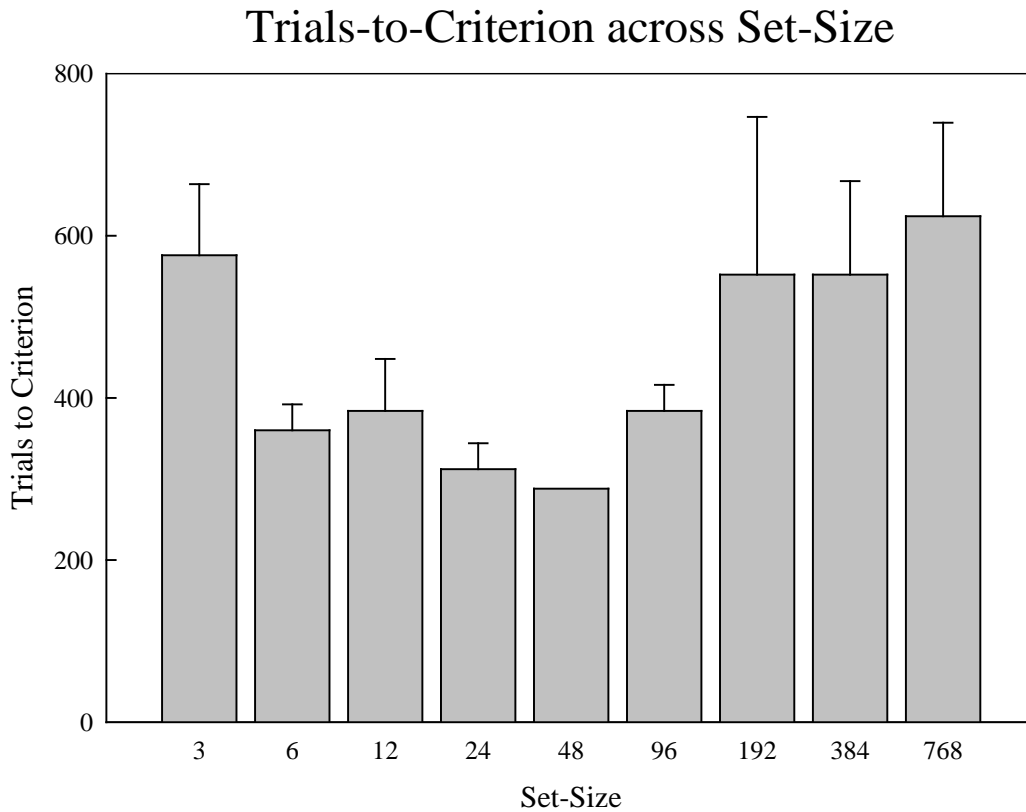


Figure 8. The average total number of trials to reach criterion at each of the expanding set sizes. Error bars represent the standard error of the mean.

Figure 8 shows the trials-to-criterion across all set sizes. Subjects needed fewer trials to reach the performance criterion after the initial training set until reaching some of the higher training sets. That is, the pigeons required more trials to reach criterion at the 3, 192, 384, and 768 than set sizes 6 to 96. This was confirmed by a one-way repeated measures analysis of variance (ANOVA) that revealed an effect of set-size for trials needed to reach criterion performance, $F(8,24)=5.229, p<.01$. A trend analysis found that trials-to-criterion over set size follows a quadratic function, $F(1,3)=38.448, p<.01$.

First-session performance. An effective way to determine how prior history of reinforcement influences how subjects perform in the task is by examining configurations in which items have differing histories of reinforcement. Configurations within the first training session after each set-size expansion were analyzed to more fully understand how pigeons acquired the task. Trials were classified into 4 types based on whether sample and non-matching odd stimulus was novel, previously experienced, or a combination of the two conditions. This categorization creates 4 trial-types: Sample-Trained Oddity-Trained (ST-OT), Sample-Trained Oddity-Untrained (ST-OU), Sample-Untrained Oddity-Trained (SU-OT) and Sample-Untrained Oddity-Untrained (SU-OU). Figure 9 represents first-session performance based on these trial types. While performance on trials in which both the sample and odd image had received previous training (ST-OT) stayed relatively consistent across set-size expansion, the other trial-types exhibited more consistent and more accurate performance as set-size increased. A two-way repeated measures Analysis of Variance of trial-type (ST-OT, ST-OU, SO-UT, SU-OU) and set-size (6, 12, 24, 48, 96, 192, 384, 768) resulted in a main effect of trial-type, $F(3,9)=5.789; p<.05, \eta^2=.659$ and no effect of set-size, $F(7, 21)=1.015; p=.449, \eta^2=.253$. An interaction was found

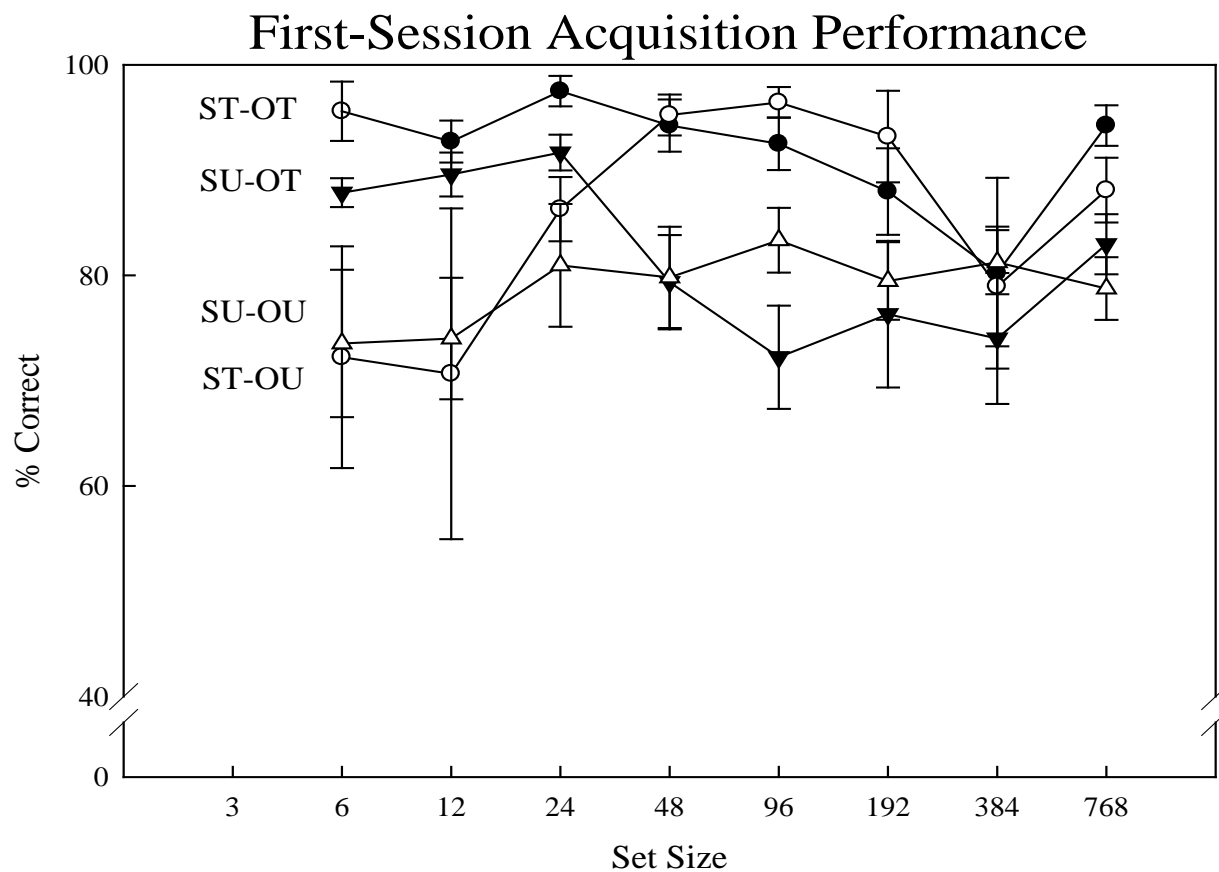


Figure 9. Mean performance of the first-session of each set-size expansion. “ST-OT” represents trials in which the sample and non-matching odd stimuli were items in a previous expansion and have already been trained. “ST-OU” represents trials in which the sample stimulus has been trained, but the non-matching odd stimulus has not. “SU-OT” represents trials in which the sample stimulus is unfamiliar, but the non-matching odd stimulus has had previous training experience. “SU-OU” represents trials in which both stimuli presented have received no prior training. Error bars represent the standard error of the mean.

between trial-type and set-size, $F(21,63)=2.506$, $p<.01$, $\eta^2=.455$. This interaction is due to a change in how the subjects acquired the task. In the first training set, different trial-types led to different levels of performance, but by the last set-size, subjects performed equally regardless of trial-type.

Baseline and Transfer Performance across Set-Size

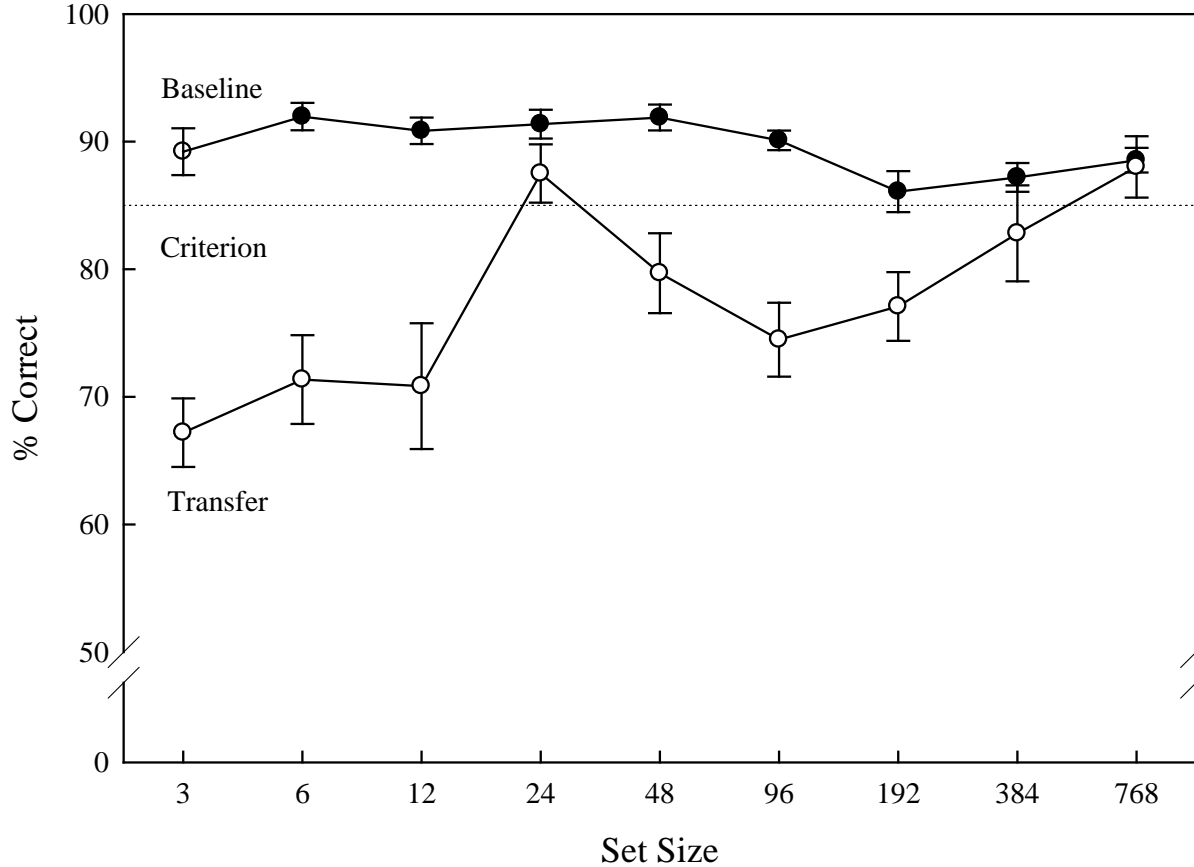


Figure 10. Mean performance accuracy across all subjects for baseline and transfer testing performance across set-size. Baseline, or previously trained items, is represented by the filled symbol circles. Transfer, or novel items, is represented by the opened symbol circles. Criterion (85%) is represented by the dotted line. Error bars represent standard error of the mean.

Testing

Figure 10 illustrates accuracy for baseline and transfer trials for each set size. Mean transfer performance increased while baseline performance remained steady across set-size expansion. This was confirmed by a two-way repeated-measures ANOVA of trial-type (baseline, transfer) and set-size (3, 6, 12, 24, 48, 96, 192, 384, 768) which found a trial type by set size interaction, $F(8,24)=2.658$; $p<.05$. A main effect of trial-type, $F(1,3)=49.49$; $p<.01$, $\eta^2=0.943$ and no effect of set-size, $p=.091$, $\eta^2=.399$. Paired-samples t -tests show no difference

in baseline performance between the first and last set sizes, $t(3)=0.37$, $p=.736$, but a difference in transfer performance for the same set sizes, $t(3)=3.651$, $p<.05$, $d=1.835$. Transfer performance on testing trials increased (18.8%) with set-size expansion.

Transfer testing performance was further evaluated using a series of one-sample t -tests against chance (50%); accuracy was higher than chance on novel items during all training set-sizes, all $t(3)s > 2.71$, $p<.05$, $d's > 1.35$, except at set-size 12, $p=.07$. This effect is due to one bird's poor performance on one transfer session (25% accuracy). When removing this session from the data, the effect was above chance, $t(3)=3.838$, $p<.05$.

DISCUSSION

These results offer the first conclusive evidence of oddity abstract-concept learning in pigeons. Pigeons were able to form relational rules and learn the oddity concept via set-size expansion. With the systematic increase of training exemplars, pigeons transferred high levels of performance to novel items. Accuracy on novel trials increased 18.8% from 72.9% on set-size 3 to 91.7% on the 768-item set-size; this can be contrasted with previously trained baseline trials that remained consistent from the earliest set-size (89.2%) to the final set-size (88.5%). Transfer performance on later set-sizes indicates that subjects' performed equivalently across baseline and transfer trials, suggesting an implementation of relational rules as a strategy to solve the discrimination task; pigeons learned the stimulus relationship and made a response based on that relationship. The shift in strategy from stimulus-dependent rules to relational rules is gradually made across set-size expansion, indicated by transfer performance that is reliably above chance but not equivalent to baseline. Further evidence of this shift in strategy can be seen by looking at how pigeons respond to training stimuli in the first session of each set-size expansion. The first session acquisition analyses presented here and represented in Figure 9 show a qualitative shift of performance between different trial-types. In early set-sizes (3-24), pigeons performed higher on trial-types that the odd comparison had previous training (ST-OT, SU-OT) compared to when the odd comparison was untrained (ST-OU, SU-OU), suggesting that prior learning of the odd comparison controlled behavior. After set-size 24, performance seemed to be highest for trial-types in which the sample received previous training (ST-OT, ST-OU) compared to those that did not (SU-OT, SU-OU). This reversal of responding indicates that as the set size expanded,

subjects changed the way they responded to the task, eventually coming under control of the relational rules. This strategy shift may account for the seemingly anomalous transfer performance at set-size 24. All birds showed 100% transfer for at least one session during this set size but no single session showed 100% transfer across all subjects. Additionally, no transfer configurations during this testing period appeared to receive perfect accuracy across all birds. This further suggests that this high performance was due to a shift in strategy rather than defective sessions or stimuli configurations.

Not only did this methodology establish oddity abstract-concept learning in pigeons, but it did so within strict theoretical guidelines. All testing trials utilized novel images; these images were not just transforms or manipulations of pre-existing stimuli. None of these trials mixed novel and trained images, so prior history with a trained image never confounded transfer responding. Baseline and testing trials administered equivalent contingencies; differential or preferential reinforcement of a certain trial type did not exist between sessions. And lastly, baseline and transfer performance across all pigeons resulted in performance reliably above chance performance. While other previous attempts to establish oddity as an abstract-concept have not been able to successfully demonstrate so within these criteria, the present study offers the first set of results without these confounds.

An interesting trend that the OFS data has offered is the high levels of accuracy and speedy training acquisition achieved within the initial set-sizes. The Oddity Preference Effect (OPE) has been shown to influence behavior in non-matching tasks (Wright & Delius, 2005). The OPE accounts for this initial advantage over matching tasks due to the sample stimulus not presenting direct reinforcement during the initial observing response. This preference for the odd item may have resulted in performance above chance on novel trials in the early set-sizes.

Set-size 24 shows high accuracy on novel items; this is most likely due to the control of the OPE, but by the next set expansion, performance on novel items falls. The decline in novel performance represents a shift in strategy; the pigeons' responses shift from being controlled by a preference to the odd item of the array and item-specific rules to relational judgments of the array. A future avenue of research may be in reinforcing both the sample response and the comparison response in a similar task to determine whether or not the high levels of transfer performance on set-size 24 is an artifact of the OPE, a statistical anomaly, or a different shift in strategy. Figure 9 shows this shift in strategy in terms of how subjects respond to previously experienced stimuli. Performance on configurations in which the non-matching odd item is novel (ST-OU) receives an increase in accuracy during set-size 24. According to the OPE, performance on configurations in which the non-matching odd item has no experience would be given an advantage in comparison to its counterparts. These trial-types do show high levels of performance by set-size 24 and even result in accuracy as great as configurations that are completely trained (ST-OT). After this increase in accuracy, configurations in which the sample is novel but the non-matching odd item is trained (SU-OT) receives a decrease in accuracy during the next set size. Due to the limited number of subjects in our sample pool, there was not enough statistical power to demonstrate these effects.

Acquisition Comparisons: MTS and OFS

The present study brings new insight to the formation of not only the concept of oddity but also that of matching and identity. By using the same experimental conditions, apparatus, sessions, and stimuli as Bodily, Katz, & Wright (2008), these results are directly comparable to these earlier works and unbiased by differences in laboratories. These converging lines of evidence point to the role of systematic training-set expansion as the key to formation of

Trials-to-Criterion across Set-Size

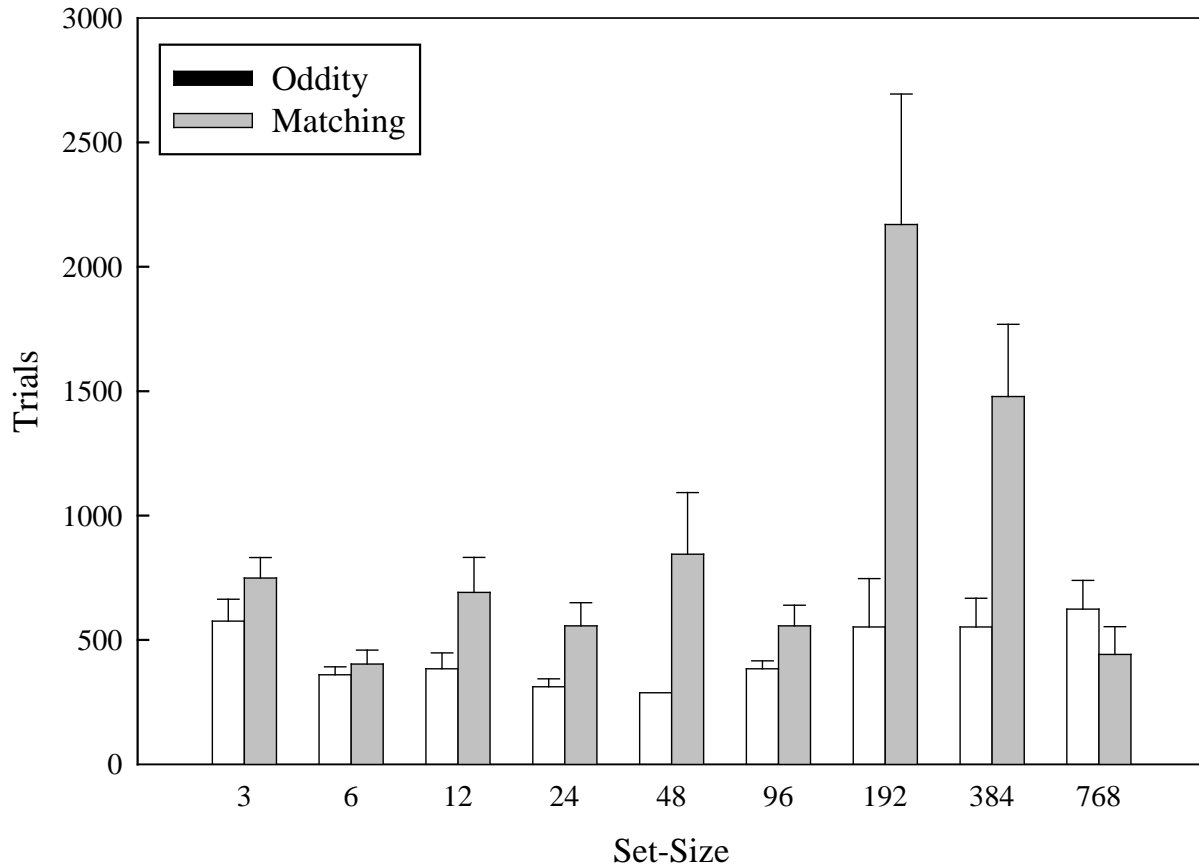


Figure 11. Mean number of trials needed to reach criterion performance between MTS and OFS designs. Black bars represent pigeons trained in the current Oddity-from-Sample and grey bars represent pigeons trained in Matching-to-Sample. Error bars represent the standard error of the mean.

abstract-concepts. While the matching and oddity concepts do manifest themselves similarly across set-size, a closer look at how these tasks are acquired highlights the differences.

An interesting comparison between matching and oddity concepts lies in the way pigeons reached the performance criterion to qualify for testing. With a set-size of 768, there are 589,056 possible stimulus configurations, and if no items were repeated, it would take 6136 trials in order

for all possible configurations to be viewed once. Both studies used the same criterion of performance to qualify for testing, but pigeons performing in the oddity task proved to reach this criterion faster than those in matching. This line of evidence replicates historical findings of faster oddity acquisition due to the OPE (Wilson, Mackintosh & Boakes, 1985). Figure 11 plots the trials needed to reach this criterion across set-size. Subjects trained in MTS take longer to reach 85% criterion than those trained in OFS. A two-way repeated-measures ANOVA of procedure (MTS X OFS) by set-size (3, 6, 12, 24, 48, 96, 192, 384, 768) found a main effect of procedure, $F(1,3)=21.645$, $p<.05$, $\eta^2=.878$, set-size, $F(8,24)=5.833$, $p<.01$, $\eta^2=.66$, and an interaction between the variables, $F(8,24)=6.397$, $p<.01$, $\eta^2=.681$. This analysis suggests that pigeons performing oddity learned to solve the task in general more quickly and needed fewer trials to reach criterion ($M=448$) than pigeons performing in matching ($M=867.8$). The advantage that is perceived from these oddity subjects is likely due to the OPE; pigeons' preference of these novel items in the array may facilitate learning more quickly than matching, evident in set-sizes 192 and 384. Different trends of performance may be observed when contrasting how subjects performed on their respective tasks directly after a set-size expansion. Figure 12 represents these separate trends between discrimination tasks. At early set-sizes, MTS subjects perform better when the sample stimulus had previous exposure (ST-OT and ST-OU); this pattern is consistent until the final set sizes when performance becomes equivalent across trial-types. This is juxtaposed with OFS subjects' performance receiving benefits when the odd comparison received previous experience (ST-OT and SU-OT). This pattern is not held long before subjects begin responding based on different qualities of the configuration. These separate trends demonstrate the differences in how the concepts of identity and oddity are learned.

Across both procedures however, responding was no longer controlled by the history of reinforcement of the specific properties of the stimulus but rather by the abstract relational rules.

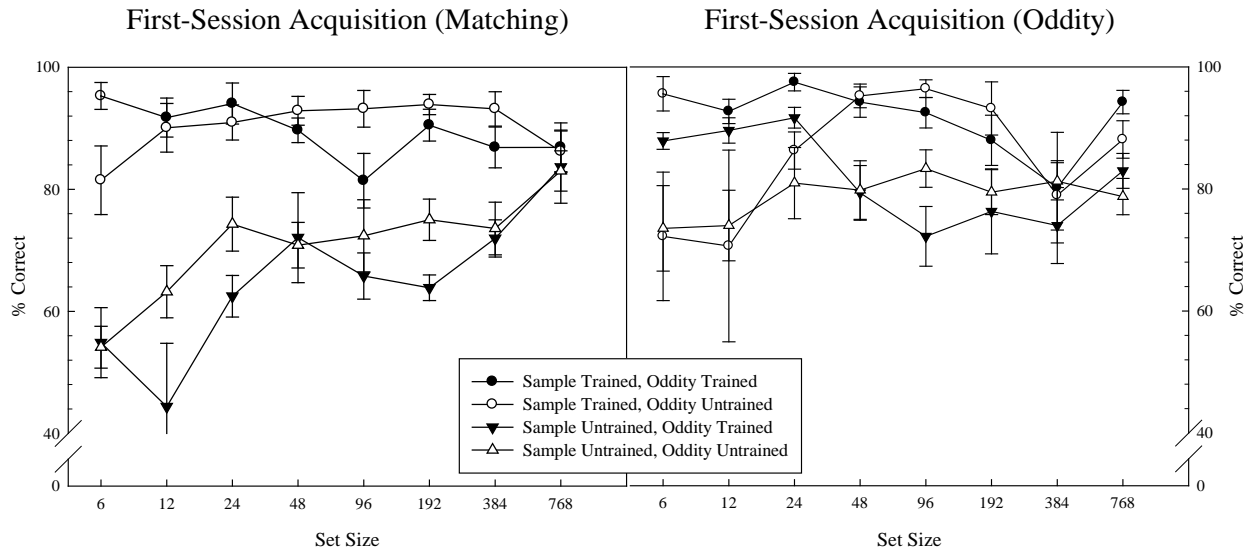


Figure 12. First-session performance across MTS and OFS procedures. The left panel plots the performance of 7 subjects in Bodily, Katz & Wright (2008). The right panel plots the current 4 subjects. Error bars represent standard error of the mean.

Transfer Comparison: MTS, OFS, and S/D

Across all tasks (OFS, MTS, and S/D), baseline performance on trained items remains largely unaffected across set-size, but the transfer of performance on novel items increases until subjects perform just as well on trained items in the same session. This gradual increase in performance is not due to rote experience of the task; as Katz & Wright (2006) discovered, mere experience with a S/D task did not facilitate accuracy on novel items. Nor could it be said that subjects were able to memorize 85% of all 589,056 possible combinations in order to be able to reach criterion performance. The most parsimonious explanation is that subjects are engaging in

Performance on Novel Items

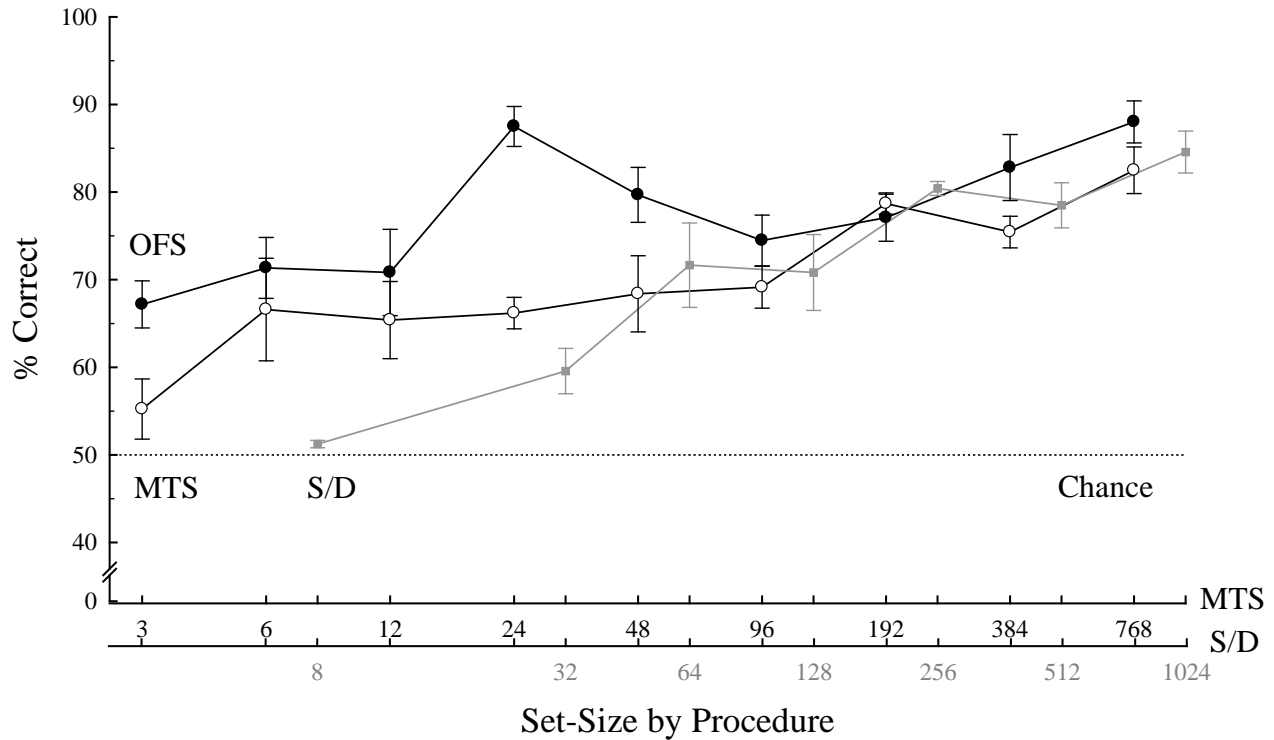


Figure 13. Mean accuracy for novel transfer performance across set-size by experimental design. Due to a different in the initial training set sizes, same/different performance is plotted on a different axis. Both abscissas are log-scaled. The present study's results are represented by the filled circles, matching-to-sample by the open circles, and same/different by the open squares. All error bars represent the standard of the mean.

so called higher-order learning that focuses on the relationship between the items rather than stimulus-dependent cues.

As expected, the current design has an initial advantage (11.94%) over early sessions due to the OPE; subjects in the OFS task ($M=67.19$) showed higher levels of transfer to novel items than subjects in MTS ($M=55.25$; see Figure 13). The initial advantage gained over MTS subjects proves to be short-lived, as functions of both tasks across set-size become quantitatively similar

by set-size 96. This similarity may represent a common strategy that subjects perform when a large number of training exemplars must be learned (i.e., using relational rules as a strategy). Similar to MTS, subjects performing in the current OFS design reached higher levels of accuracy than those in an S/D design. It is important to note that S/D provides a few quantitative differences than its MTS and OFS counterparts. Rather than beginning with a set-size of 3 (comprising 12 unique configurations), S/D began with an initial set of 8 (comprising of 64 unique configurations), and the amount of possible configurations between the set-size expansions does not increase linearly between methodologies. With these differences in mind, one may expect functions of S/D performance across set-size to manifest itself in different ways than those of MTS and OFS. This pattern however, is not seen; baseline performance on previously trained items stays relatively consistent across each set-size expansion, and transfer performance to novel items systematically increases until it becomes equivalent to baseline. This trend of baseline and transfer performance coupled with how subjects responded based on prior reinforcement history in acquisition suggests that while all of these tasks are learned differently, by the final set size, all subjects respond based on relational rules.

Conclusion

The present study is the first to show a set-size function for the oddity-from-sample task for any species. The pigeons' ability to perform on novel transfer items at a level that is just as high as with trained items suggests that the same strategy is used for both types of items (Katz, Wright & Bodily, 2007). A complete transfer of performance to novel items indicates that a relational rule is being used by all subjects: in this case, "pick the odd item." The oddity concept, reported in this study as well as others, was learned in a different manner than subjects learning its converse concept (identity) suggesting that these concepts *are* different and not just a

reversal in responding (Wilson, Mackintosh, & Boakes, 1985). This abstract-concept of oddity was learned by all subjects in the present study by parametrically increasing the number of training exemplars. These findings add to the body of evidence that the crux of abstract-concept learning lies with the increased number of potential training exemplars (Cook & Wasserman, 2012). In addition to providing evidence for the oddity concept in nonhuman species, it adds to our understanding of the formation of relationships underlying abstract-concept learning in all species.

REFERENCES

- Berryman, R., Cumming, W. W., Cohen, L. R., & Johnson, D. F. (1965) Acquisition and transfer of simultaneous oddity. *Psychological Reports, 17*, 767- 775.
- Bodily, K. D., Katz, J.S., & Wright, A.A. (2008). Matching-to-sample abstract-concept learning by pigeons. *Journal of Experimental Psychology, 34*, 178-184.
- Blough, D. S. (1979). Effects of the Number and Form of Stimuli on Visual Search in the Pigeon. *Journal of Experimental Psychology: Animal Behavior Processes, 5*(3), 211-223.
- Bovet, D., & Vauclair, J. (2001). Judgment of conceptual identity in monkeys. *Psychonomic Bulletin & Review, 8*, 470-475.
- Carter, D. E., & Werner, T. J. (1978). Complex learning and information processing by pigeons: A critical analysis. *Journal of the Experimental Analysis of Behavior, 29*, 565–601.
- Cook, R. G. (2002). Same-different concept formation in pigeons. In M. Bekoff, C. Allen & G. M. Burghardt (Eds.), *The cognitive animal* (pp.229–237). Cambridge, MA: MIT.
- Cook, R.G. & Wasserman, E.A. (2012) Relational discrimination learning in pigeons. In T.R. Zentall & E.A. Wasserman (Eds.), *The Oxford handbook of cognitive psychology*. (pp.533-551). New York, NY: Oxford University Press.
- Daehler, M. W., & Bukatko, D. (1992). *Child development: A topical approach*. Houghton Mifflin Company.
- Ginsburg, N. (1957). Matching in pigeons. *Journal of Comparative and Physiological Psychology 50*, 261-263.
- Harlow, H. F. (1943) Solution by rhesus monkeys of a problem involving the Weigl principle using the matching-from-sample method. *Journal of Comparative Psychology, 35*, 217-227.

- Herman, L. M., Hovancik, J. R., Gory, J. D. & Bradshaw, G. L. (1989). Generalization of visual matching by a Bottlenosed Dolphin (*Tursiops truncatus*): Evidence for invariance of cognitive performance with visual and auditory materials. *Journal of Experimental Psychology: Animal Behavior Processes*, *15*, 124-136.
- Herrnstein, R. J., Loveland, D. H., & Cable, C. (1976) Natural concepts in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, *2*, 285-302.
- James, W. (1890). *The principles of psychology* (Vol 1). London: Henry Holt & Co.
- Kastak, D., & Schusterman, R. J. (1994). Transfer of visual identity matching-to-sample in two California sea lions (*Zalophus Californians*). *Animal Learning & Behavior*, *22*, 427-435.
- Katz, J. S., & Wright, A. A. (2006). *Same/different* abstract-concept learning by pigeons. *Journal of Experimental Psychology*, *32*, 80-86.
- Katz, J. S., Wright, A. A., & Bachevalier, J. (2002). Mechanisms of *same/different* abstract-concept learning by rhesus monkeys (*Macaca mulatta*). *Journal of Experimental Psychology: Animal Behavior Processes*, *28*, 358-368.
- Katz, J. S., Wright, A. A., & Bodily, K. D. (2007). Issues in the comparative cognition of abstract-concept learning. *Comparative Cognition & Behavior Reviews*, *2*, 79–92.
- Lombardi, C. M., Fachinelli, C. C., & Delius, J. D. (1984). Oddity of visual patterns conceptualized by pigeons. *Animal Learning & Behavior*, *12*(1), 2-6.
- Lombardi, C. M. (2008). Matching and oddity relational learning by pigeons (*Columba livia*): transfer from color to shape. *Animal cognition*, *11*(1), 67-74. doi:10.1007/s10071-007-0087-2
- Moon, L. E. & Harlow, H. F. (1954). Analysis of oddity learning by rhesus monkeys. *Journal of Comparative and Physiological Science*, *48*, 188-194.
- Nissen, H. W., Blum, J. S., & Blum, R. A. (1948). Analysis of matching behavior in chimpanzee. *Journal of Comparative and Physiological Psychology*, *41*, 62-74.
- Pepperberg, I. M. (1987). Acquisition of the same/different concept by an African Grey parrot (*Psittacus erithacus*): Learning with respect to categories of color, shape, and material. *Animal Learning & Behavior*, *15*, 423-432.

- Piaget, J., & Inhelder, B. (1969). *The psychology of the child* (H. Weaver, Trans.). New York: Basic Books. (Original work published 1966).
- Premack, D. (1978). On the abstractness of human concepts: Why it would be difficult to talk to a pigeon. In S.H. Hulse, H. Fowler & W.K. Honig (Eds.), *Cognitive processes in animal behavior* (pp.423-451). Hillsdale, NJ: Erlbaum.
- Premack, D. (1983). The codes of man and beasts. *The Behavioral and Brain Sciences*, 6, 125–167.
- Thompson, R. K. R. (1995). Natural and relational concepts in animals. In H. L. Roitblat & J.-A. Meyer (Eds.), *Comparative approaches to cognitive science* (pp. 175–224). Cambridge, MA: MIT Press.
- Urcuioli, P. J. (1977). Transfer of Oddity-From-Sample Performance in Pigeons. *Journal of the Experimental Analysis of Behavior*, 25, 195-202.
- Wilson, B., Mackintosh, N. J., & Boakes, R. A. (1985). Matching and oddity learning in the pigeon: Transfer effects and the absence of relational learning. *Journal Of Experimental Psychology*, 37(4), 295-311.
- Wright, A. A., Cook, R. G., Rivera, J. J., Sands, S. F., & Delius, J. D. (1988). Concept learning by pigeons: Matching-to-sample with trial-unique video picture stimuli. *Animal Learning & Behavior*, 16(4), 436-444.
- Wright, A. A. (1997). Concept learning and learning strategies. *Psychological Science*, 8, 119-123.
- Wright, A. A., Rivera, J. J., Katz, J. S., & Bachevalier, J. (2003). Abstract-concept learning and list-memory processing by capuchin and rhesus monkeys. *Journal of Experimental Psychology: Animal Behavior Processes*, 29, 184–198.
- Wright, A. A., & Delius, J. D. (2005). Learning processes in matching and oddity: the oddity preference effect and sample reinforcement. *Journal of Experimental Psychology. Animal Behavior Processes*, 31(4), 425-32.
- Wright, A. A., & Katz, J. S. (2007). Generalization Hypothesis of Abstract-Concept Learning : Learning Strategies and Related Issues in Macaca mulatta , Cebus apella , and Columba livia. *Journal of Comparative Psychology*, 121(4), 387-397.

Zentall, T., & Hogan, D. (1974). Abstract concept learning in the pigeon. *Journal of Experimental Psychology*, 102(3), 393-398.

Zentall, T. R., Hogan, D. E., Edwards, C. A., & Hearst, E. (1980). Oddity learning in the pigeon as a function of the number of incorrect alternatives. *Journal of experimental psychology. Animal behavior processes*, 6(3), 278-299.

Zentall, T., Hogan, D., Holder, J. (1974) Comparison of two oddity tasks with pigeons. *Learning and Motivation*, Vol 5(1), 106-117.

Zentall, T. R., Wasserman, E. a, Lazareva, O. F., Thompson, R. K. R., & Rattermann, M. J. (2008). Concept Learning in Animals. *Comparative Cognition & Behavior Reviews*, 3, 13-45.