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Abstract-concept learning of difference in pigeons

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Abstract Many species have demonstrated the capacity to learn abstract concepts. Recent studies have shown that the quantity of stimuli used during training plays a critical role in how subjects learn abstract concepts. As the number of stimuli available in the training set increases, so too does performance on novel combinations. The role of set size has been explored with learning the concept of *matching* and *same/different* but not with learning the concept of *difference*. In the present study, pigeons were trained in a non-matching-to-sample task with an initial training set of three stimuli followed by transfer tests to novel stimuli. The training set was progressively doubled eight times with learning and transfer following each expansion. Transfer performance increased from chance level (50 %) at the smallest set size to a level equivalent to asymptotic training performance at the two largest training set sizes (384, 768). This progressive novel-stimulus transfer function of a non-matching (*difference*) rule is discussed in comparison with results from a similar experiment where pigeons were trained on a matching rule.

Keywords Non-matching · Oddity-from-sample · Matching-to-sample · Set-size expansion · Abstract-concept learning

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Introduction

An abstract concept is a relationship that is learned between at least two stimuli that is not bound by perceptual features. This abstract relationship does not rely on perceptual properties of any of the training stimuli; therefore, it may be applied to new stimuli. Unlike natural concepts, which can be acquired through rote memorization and generalization of specific features (Thompson 1995), abstract concepts cannot. In other words, natural concepts can rely on within-class stimulus properties that are used to categorize or classify stimuli. By contrast, abstract concepts are "non-similarity-based" so that simple stimulus generalization is impossible (Wasserman et al. 1992). Because abstract concepts are formed on the basis of the relationships among stimuli, animals may use a concept like "smaller than" or "different from" to solve tasks where stimulus generalization is not readily available or efficient (Wright and Katz 2007).

Conditional discriminations (e.g., matching-to-sample, non-matching-to-sample, same/different) are frequently used for conducting research on abstract-concept learning. Evidence of abstract-concept learning has been found in a wide variety of animals, including baboons (Bovet and Vauclair 2001; Wasserman et al. 2001), bumblebee colonies (Brown and Sayde 2013), chimpanzees (Premack 1978, 1983), dolphins (Herman et al. 1989), humans (Bukatko and Daehler 2011; Gentner 1988; Piaget and Inhelder 1969), monkeys (e.g., Katz et al. 2002; Wright et al. 2003), parrots (Pepperberg 1987), pigeons (Wasserman et al. 1995; Wright 1997), rats (April et al. 2013), and sea lions (Kastak and Schusterman 1994). While the above examples of concept learning involve the abstract concept of *sameness* (or matching) and *same/different*, demonstrations of the concept of *difference* (i.e., non-matching or "different from") have been conspicuously absent from the literature (Aust and Steurer 2012; Lazareva and Wasserman 2010).

To date, there has been an absence of conclusive evidence for the *difference* concept in non-human animals based on the standards dictated in Katz et al. (2007). While classic references such as Moon and Harlow (1955) and Mishkin and Delacour (1975) presented increased rates of acquisition in a non-match-to-sample (NMTS) task, neither study demonstrated full transfer with novel stimuli. Additionally, neither study provided evidence of concept learning on the first presentation of the trial-unique transfer tests. In regard to pigeons, previous studies (Lombardi 2008; Urcuioli 1977; Zentall et al. 1981) have provided evidence indicating the possibility of NMTS concept learning, but the presence of confounding testing procedures (e.g., repeated transfer stimuli) and the absence of full transfer have limited their conclusions. In addition to reusing transfer stimuli, other studies have demonstrated transfer that is above chance but lower than baseline (Lombardi et al. 1984; Zentall and Hogan 1974), a partial-concept learning result that is inconclusive. If subjects were employing abstract relational rules, one would expect performance with novel stimuli to be equivalent to baseline performance with training stimuli, a finding that henceforth will be referred to as full-concept learning.

Only one study has shown full-concept learning in a NMTS discrimination by pigeons (Wright and Delius 2005). The Wright and Delius experiments used a gravel-digging task in which pigeons searched for grain buried in colored gravel. With this task, pigeons rapidly learned NMTS and transferred to novel colors of gravel. This demonstration of *difference* is not explainable through the memorization of specific exemplars, learning by exclusion (Kastak and Shusterman 1994), or neophilia, the non-associative preference for novelty (e.g., Day et al. 2003; Kaulfuß and Mills 2008).

Other types of abstract-concept learning have been successfully demonstrated in non-human animals (including pigeons) by using a set-size expansion procedure (Bodily et al. 2008; Katz et al. 2002; Wright et al. 2003; Katz and Wright 2006). This method systematically increases the number of training exemplars. Following stable performance after each training set expansion, transfer tests to novel stimuli are used to assess the degree of concept learning. The training set is then doubled and the process is repeated. Using a 2-item same/different (S/D) procedure, pigeons successfully transferred to novel images as the training set expanded (Katz and Wright 2006). During early testing sessions, pigeons showed no transfer suggesting that their accurate training performance was tied to those particular training stimuli. However, as the training set was systematically doubled, performance on transfer tests gradually increased until it became equivalent with baseline performance—showing full-concept learning of the *same/different*. Using similar procedures, pigeons were also shown capable of fully learning the matching concept (Bodily et al. 2008).

The purpose of the current study was to determine whether pigeons would fully learn the abstract concept of *difference*. Using a set-size expansion method identical to Bodily et al. (2008), we substituted the MTS task with NMTS so that pigeons were rewarded for pecking the non-matching, different stimuli. All other aspects of the procedure were identical including sessions, apparatus, and stimuli. By controlling and matching these two tasks, we have the opportunity to compare the role of the training set size across NMTS, MTS, and S/D tasks for pigeons.

Methods

Subjects

Four male pigeons (*Columba livia*) from the Palmetto Pigeon Plant served as subjects. All subjects had been trained and tested in an S/D procedure similar to the Katz and Wright (2006) procedure previously described, and they all demonstrated full-concept learning (Schmidtke et al. 2010). Stimuli used in the S/D procedure were photographs of realistic imagery and differed from the cartoon stimuli used in the present study (see Wright and Katz 2006, for the complete training set). Subjects were maintained 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-h light/day cycle and were housed individually with free water and grit access.

Apparatus

Pigeons were tested using custom wood (35.9 cm wide × 45.7 cm deep × 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 detected pecks via an infrared touch screen (17" Unitouch, Carroll Touch, Round Rock, TX). This pressure-fit touch screen sat within a 40.6 × 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, illuminated the chamber during intertrial intervals (ITI). A custom hopper containing mixed grain was accessed through an opening (5.1 × 5.7 cm) centered in the front panel 3.8 cm above the chamber floor.

Custom software written with Visual Basic 6.0 on a Dell Optiplex GX110 recorded and controlled all events in the operant chamber. A video card controlled graphics generated by the computer. A computer-controlled relay interface (Model no. PI0-12, Metrabyte, Taunton, MA) maintained operation of the grain hopper and the lights to both the hopper and the chamber.

Stimuli

Visual stimuli were computer-created, color cartoon JPEG images that were 2.5 cm high × 3 cm wide at 28 pixel/cm (cf. Katz et al. 2008; Fig. 2). Stimuli were arranged in the display such that the sample and comparisons formed a triangle (8 cm high × 19 cm wide) with the comparison stimuli symmetrically placed around the sample. Each sample stimulus appeared centered horizontally at approximately 8 cm above the bottom of the monitor. Comparison stimuli appeared 4 cm above the bottom of the monitor, with the center of the left and right comparison stimuli 8.5 cm from the center or the sample.

Training

Daily sessions were conducted 5–7 days a week, with each session comprised of 96 trials (48 left responses and 48 right responses). Pigeons were initially trained in NMTS with a set size of three stimuli. Trials began with a sample stimulus displayed on the monitor. Pigeons pecked the sample ten times; this FR requirement began with one peck but was systematically increased over seven sessions to ten pecks. After subjects performed the response requirement, two comparison stimuli were presented; one comparison stimulus matched the sample, and the other was randomly selected from the training set. A response to the non-matching comparison resulted in grain reinforcement with the non-matching comparison displayed for 4 s. Grain access was between 2 and 3.5 s of mixed grain depending on the pigeon's body weight prior to the session. A response to the matching comparison resulted in an 8-s timeout where the sample and matching comparison stimulus were removed. All trials were followed by a 15-s ITI whether the response was correct or incorrect. With a set size of three stimuli, there were 12 possible combinations; these combinations appeared eight times per 96-trial session. Stimuli were counterbalanced to ensure that a combination would not directly repeat itself on 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. The correction procedure forced subjects to repeat any incorrect trials until a correct response was made, but only the first response to each trial was counted and computed for accuracy. After this performance-based criterion was met, the subjects were required to perform 85 % accuracy on one session without the correction procedure before proceeding to transfer testing.

Transfer testing

The testing phase was comprised of four 96-trial sessions and began on the next daily session after a pigeon achieved criterial performance. Within each testing session, 12 novel combinations were pseudorandomly mixed with 84 training trials, resulting in exposure to 24 novel stimuli each testing session and a total of 96 (24 stimuli × 4 sessions) novel stimuli per testing phase. Stimuli presented in these testing combinations were unique and never viewed by the subjects prior to the transfer test. No testing trial appeared within the first or last eight trials of any transfer session; at least five trials separated any testing trial from one another. Responses on testing trials were reinforced similarly to training trials; a correct response resulted in grain access, and an incorrect response resulted in an 8-s timeout period. Testing trials and sessions were also counterbalanced for left and right responses using the same specifications as those during training.

Set-size expansion

Following transfer testing, an equal number of new training stimuli were added to the previous training set. The number of images used in training increased from 3 to 6, 12, 24, 48, 96, 192, 384, and 768. Set-size expansion sessions were 96 trials, counterbalanced for left/right correct. Sample and comparison stimuli were randomly assigned from the stimulus set. Pigeons were required to achieve criterial performance (>85 % accuracy on one session without correction procedure and a minimum of three sessions) with each expanded training set before transfer testing. If a pigeon performed below 75 % accuracy, correction procedure was reinstated until two consecutive sessions above 85 % accuracy were obtained. Training and testing followed the same structure for all set-size expansions.

Results

Acquisition

Set size 3

All subjects reached the performance criterion on the initial set size in about ten sessions ($M = 960$ trials, range

768–1248). Mean percentage correct increased significantly between the first (55.5 %) and last (93.8 %) session of training without response location biases, as confirmed by a two-way repeated measures ANOVA of session (first, last) and response location (left, right) which found a main effect of session, $F(1, 3) = 98.37$, $P < .01$, $\eta^2 = 0.97$, and no effect of response location, $F(1, 3) = 0.03$, $P = .87$, $\eta^2 = 0.1$, or interaction, $F(1, 3) = 0.03$, $P = .87$, $\eta^2 = 0.1$. In addition, subsequent within-session analyses found no systematic trends on a session-by-session basis.

Set-size expansion

The mean trials to acquisition across set size were 960, 672, 792, 888, 792, 816, 1008, 936, and 912, respectively. A one-way repeated measures ANOVA of set size (3, 6, 12, 24, 48, 96, 192, 384, 768) found no differences in trials to acquisition across set size, $F(8, 24) = 0.22$, $P = .98$, $\eta^2 = 0.07$.

Transfer

Figure 1 shows the functional relationships for baseline and transfer performance at the different set sizes. Transfer was close to chance performance (52 % correct) at the initial three-item set size and increased approximately linearly with the logarithm of set size to 87.5 % at the final 768-item set size.

A two-way repeated measures ANOVA of condition (baseline, transfer) and set size (3, 6, 12, 24, 48, 96, 192, 384, 768) confirmed a main effect of condition, $F(1, 3) = 45.40$, $P < .01$, $\eta^2 = 0.94$, set size, $F(8, 24) = 6.02$, $P < .01$, $\eta^2 = 0.67$, and an interaction between the two factors, $F(8, 24) = 14.15$, $P < .01$, $\eta^2 = 0.83$. This interaction was due to a small but significant decrease (4.17 % from 3 to 768) in baseline performance and an increase (34.9 %) in transfer performance across set sizes, as confirmed by significant linear components of separate trend analyses for baseline, $F(1, 3) = 16.2$, $P < .05$, $\eta^2 = 0.84$, and transfer, $F(1, 3) = 66.78$, $P < .01$, $\eta^2 = 0.96$. Transfer percent correct was not significantly different from chance (50 %) at set sizes 3–96 as confirmed by Bonferroni-corrected ($\alpha = 0.05/9 = 0.0056$) one-sample t tests, ts(3) < 5.12, Ps > .01, ds < 5.91, but transfer was significantly greater than chance at all other set sizes, ts(3) > 10.97, Ps < .01, ds > 12.67. Bonferroni-corrected paired samples t tests show that the final two set sizes' (384 and 768) baseline and transfer performances were not different, ts(3) < 0.5, Ps > .72, ds < 0.46. A series of two-way repeated measures ANOVA of side (left, right) × session (1, 2, 3, 4) was conducted on transfer accuracy to test for response biases and acquisition across transfer testing for each set size. At each set size, transfer accuracy did not change across sessions (Ps > .05), indicating performance was constant and no side biases were detected (Ps > .05).

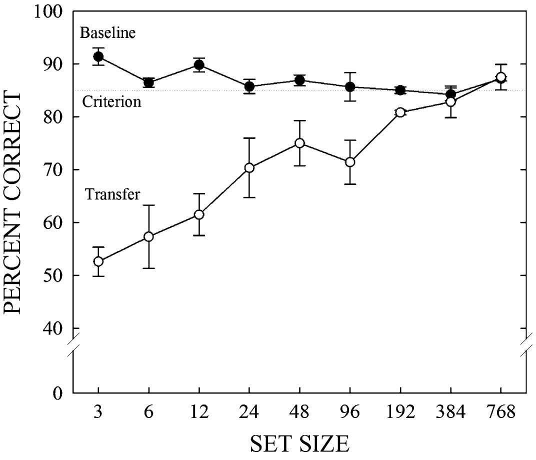

Fig. 1 Mean baseline (*filled symbols*) and transfer (*open symbols*) percent correct across set size. The *horizontal dotted line* represents the 85 % accuracy performance criterion used during acquisition. *Error bars* represent *SEMs*

Discussion

Pigeons were able to acquire the relational rule and learn the *difference* concept via set-size expansion. With the systematic increase in training exemplars, the pigeons transferred this performance to novel stimuli with high levels of accuracy. With the smallest training set, transfer accuracy on trials with novel combinations was at chance ($M = 52.6$ %), but as the training set expanded, accuracy on these transfer trials gradually rose to 87.5 % following training with the largest training set. When trained with a set size of 384 and 768 potential stimuli, pigeons demonstrated full-concept learning by performing equally well on novel and trained combinations. This was an approximately linear transfer function and mirrors that found in MTS and S/D with pigeons (Bodily et al. 2008; Katz and Wright 2006).

Pigeons displayed little or no carryover effects from their prior S/D training as evidenced by their initial three-item acquisition and transfer. The lack of any carryover effect may have been due to the substantial difference in the stimuli used in this NMTS (i.e., cartoons) study compared with stimuli used in the previous S/D (i.e., photographs) study. Additionally, in S/D training, the correct "different" response was a peck to a uniform white rectangle. This contrasts with the current experiment, where pigeons were required to respond to the comparison stimulus that did not match the sample stimuli. Using S/D, Bhatt and Wright (1992) also found no carryover effects when the “different” response was changed from “respond to the white rectangle” to “respond to a different button”.

First session of set-size expansions

During acquisition, training sets were expanded and new training stimuli were introduced resulting in trials that contained both trained and untrained stimuli. We classified trials into four combinations, where the sample and/or comparison was new (untrained) stimuli or old (trained) stimuli (cf., Bodily et al. 2008). When the sample was from a previously trained set, combinations were either sample-trained, non-matching-trained (ST-NMT) or sample-trained, non-matching-untrained (ST-NMU). When the sample was chosen from the newly added stimuli, combinations were either sample-untrained, non-matching-trained (SU-NMT) or sample-untrained, non-matching-untrained (SU-NMU). Accordingly, trial combinations in which all stimuli were experienced in the previous training set would be classified as ST-NMT, and combinations in which all stimuli were first introduced in the newly expanded set would be classified as SU-NMU. If pigeons were using an abstract relational rule to solve the task, it should not have mattered whether the stimuli were previously used in training or were newly added. However, if pigeons learned something other than the abstract relational rule, their pattern of accuracies on these different stimulus combinations should be indicative of what they had learned and how they were performing this NMTS task.

Accuracy on these four stimulus combinations is shown in Fig. 2 for the first session of training at each expanded set size. A two-way repeated measures ANOVA of stimulus combination (ST-NMT, ST-NMU, SU-NMT, SU-NMU) × set size (6, 12, 24, 48, 96, 192, 384, 768) shows differences in accuracy between stimulus combination, $F(3, 9) = 17.36$, $P < .01$, $\eta^2 = 0.85$, across set size, $F(7, 21) = 6.81$, $P < .01$, $\eta^2 = 0.69$, and an interaction between the two factors, $F(21, 63) = 4.27$, $P < .01$, $\eta^2 = 0.59$. This interaction was due to response biases on the first session following expansion to sets 6 and 12 to select the trained non-matching stimuli (ST-NMT, SU-NMT; $M = 84.72$) rather than the untrained non-matching stimuli (SU-NMU, ST-NMU; $M = 52.89$), as shown by a paired samples t test, $t(3) = 5.51$, $P < .05$. As the set size expanded from sets 96 to 192, this response bias changed. Now, pigeons performed best when the sample stimulus was trained (ST-NMT, ST-NMU; $M = 89.0$) compared with when the sample stimulus was untrained (SU-NMT, SU-NMU; $M = 76.2$), as shown by a paired samples t test, $t(3) = 5.44$, $P < .05$. Similar response biases were shown previously for MTS (Fig. 1 top panel from Bodily et al. 2008; Wright and Lickteig 2010), where accuracy decreased when the non-matching stimulus (the foil in MTS) was trained and the sample was untrained. For the last two training sets, 384 and 768, the response biases between the four stimulus combinations vanished, as shown by separate one-way repeated measures ANOVAs at each set size, $Fs(3, 9) < 1.35$, $P > .32$. This set of analyses corroborates full-concept learning by sets 384 and 768, indicating pigeons solved this task using an abstract concept.

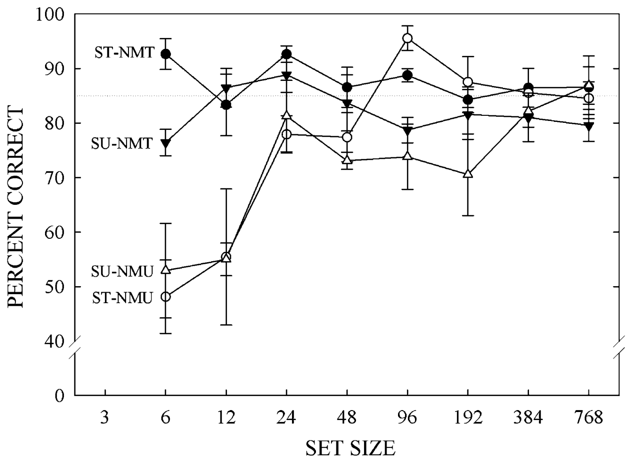

Fig. 2 Mean percent correct on first-session acquisition across set size. Four trial types, sample-trained non-matching-trained (ST-NMT, *filled circles*), sample-untrained non-matching-trained (SU-NMT, *filled triangles*), sample-trained non-matching-untrained (ST-NMU, *open circles*), and sample-untrained non-matching-untrained (SU-NMU, *open triangles*), are plotted across the expanding set size. The *dotted line* represents 85 % accuracy performance criterion used during acquisition. *Error bars* represent *SEMs*

As the set size expanded logarithmically and the number of stimulus pairings grew rapidly, the pigeons’ initial item-specific learning quickly became impractical (e.g., the 768 set size resulted in 589,056 stimulus combinations). However, at the largest set size, it is possible that pigeons were able to memorize all 768 stimuli (von Fersen and Delius 1989; Cook and Fagot 2009), but it is unlikely that pigeons would be able to memorize all 589,056 possible stimulus combinations. Because of the increase in the number of new stimulus combinations, one concern is that pigeons may be generalizing their item-specific rule use to novel combinations. If this was the case, evidence for such stimulus generalization would be visible in the first-session performance of newly expanded training sets depicted in Fig. 2. Accordingly, there would be the most generalization to the ST-NMU combinations, where two stimuli were trained, less generalization to the SU-NMT combinations, where one stimulus was trained, and the least generalization to the SU-NMU combinations, where all three stimuli were untrained. This pattern is not observed in our results, and the ST-NMU trials, which should receive the most

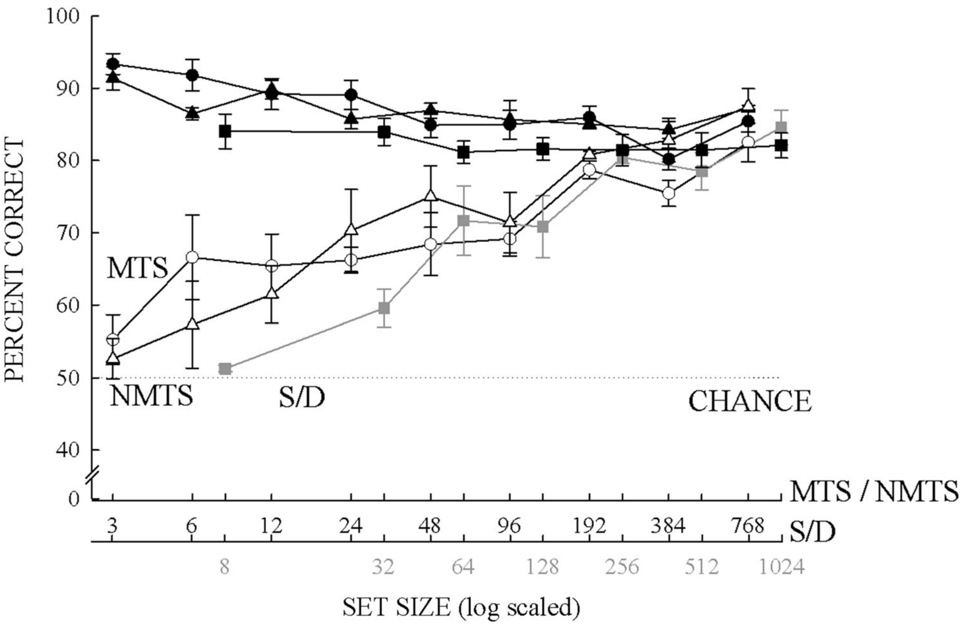

Fig. 3 Mean baseline and transfer accuracy across set size for NMTS (*triangles*), MTS (Bodily et al. 2008; *circles*), and S/D (Katz and Wright 2006; *squares*). *Error bars* represent *SEMs*

generalization, show the lowest level of accuracy early in the experiment when pigeons used memory-based item-specific strategies.

Comparing non-matching, matching, and same/different concept learning

Acquisition

One common finding in NMTS when compared with MTS is that NMTS is often learned more rapidly (e.g., Ginsburg 1957; Wilson et al. 1985; Wright and Delius 2005; Zentall and Hogan 1974). Comparing acquisition at the three-item set in NMTS ($M = 960$ trials) and MTS ($M = 748.8$ trials; data from Bodily et al. 2008), no such advantage was found, $t(8) = 1.62$, $P = .87$. Pigeons acquired NMTS just as quickly as others acquiring MTS. Previous studies that found increased acquisition or transfer in NMTS used experimentally naïve subjects, and it may be possible that naïve subjects would have shown these same hallmarks in the current task.

Transfer

Although the focus of the present study is on *difference* concept learning, it may be instructive to consider how "difference" concept learning compares to "matching" concept learning and "same/different" concept learning. Figure 3 compares the set-size functions for NMTS, MTS (Bodily et al. 2008), and S/D (Katz and Wright 2006). For all discriminations, baseline performance slightly dropped across set size and transfer performance increased linearly in a dramatic manner to the point of full-concept learning. It is clear that increasing the set size for these tasks has the same impact across discriminations. In both NMTS and MTS, pigeons showed full abstract-concept learning at set sizes 384 and above. Overall, the data in Fig. 3 illustrate for NMTS, MTS, and S/D the similar functional relationships of set size on abstract-concept learning.

Conclusion

Discovering which and how species can learn abstract concepts is important for understanding the quantitative and qualitative similarities and differences across species. It has become clear that many diverse species can learn abstract concepts and undoubtedly other species will be added to the growing list. While discovering evidence of *which* animals can learn concepts is important, the functional approach taken here provides insights into *how* these processes likely work. Using an NMTS procedure and an expanding training set, we were able to demonstrate that pigeons *can* learn the concept of *difference*, and importantly we were able to show at least some of the processes of *how* they learn the concept. These data, in conjunction with those of S/D and MTS, stress the importance of training set size; animals require multiple exemplars of the relational rule in order to apply this rule to novel stimuli, and this transfer varies directly as a function of the number of training exemplars clear up to full-concept learning.

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Conflict of interest The authors declare no competing financial interests.

Ethical standard This experiment complied with current US law and following the relevant ethical guidelines for animal research (IACUC approved and conducted in AAALAC approved facilities).

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