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Domain is a Moving Target for Relational Learning

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Abstract

The domain for relational learning was manipulated by varying the training set size for pigeons that had learned the *same/different* (S/D) concept. Six pigeons that had learned a S/D task with pairs of pictures with a set size of 1,024 picture items had their training set size reduced to 8 items. Training on the reduced 8-item set was followed by transfer testing that was repeated four times. Transfer performance following reduction of the training set to 8 items was less than it had been when the pigeons were trained with the 1,024-item set, but 25.8% above chance. This partial abstract-concept learning remained constant over the four tests with novel stimuli. The results show that a broad domain established by a large expanding training set can once again become restricted by further training with a small training set.

Tasks that can be learned in different ways open the possibility to explore the underlying strategies for these different types of learning (Katz, Wright, & Bodily, 2007; Piaget & Inhelder, 1966/1969; Siegler & Alibali, 2004; Terrace,1979,1993,2005a; Thorndike, 1911/1998). A major division of learning strategies, and the division that will be adopted here, is dividing learning into item-specific learning vs. relational learning. Item-specific learning involves learning based on the absolute properties of stimuli, including features. On the other hand, relational learning involves learning the relationship between/among stimuli. Relational learning is the basis of novel-stimulus transfer and hence abstract-concept learning. The challenge for scientists is to develop tests for these different types of learning in order to understand the underlying processes and mechanisms of learning.

Our research has focused on conditions that promote either item-specific or relational learning in human and nonhuman species (e.g., Elmore, Wright, Rivera, & Katz, 2009; Katz et al., 2007; Wright & Katz, 2006; Wright & Katz, 2009). To explore these conditions, we have utilized matching-to-sample and *same/different* (S/D) tasks. In our S/D research, subjects are typically presented with two pictures (one right above the other) and a white rectangle on a

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computer monitor. If the two pictures are the *same*, the correct choice is to touch the bottom picture; if the two pictures are *different*, the correct choice is to touch the white rectangle (see Figure 1). Initially, we trained pigeons, capuchin monkeys, and rhesus monkeys with a small training set of 8 pictures (Katz & Wright, 2006; Katz, Wright, & Bachevalier, 2002; Wright, Rivera, Katz, & Bachevalier, 2003).

One way the subjects could have learned this S/D task was to memorize (i.e., learn item-specifically) each of the 64 pairs (8 *same*, 56 *different* pairs) and their appropriate response. Another way they could have learned this task was to learn the *relationship* between the two items presented each trial. Because novel-item transfer is based upon relational learning, transfer to novel pairs is evidence that they must have learned the task relationally. On the other hand, if subjects do not transfer to novel pairs, then most researchers have concluded that the subjects *must* have learned item-specifically (e.g., Carter & Werner, 1978; Premack, 1978; Zentall & Hogan, 1974). It should be noted, however, that the former outcome is a necessary and sufficient condition for relational learning, but the latter outcome is only a necessary condition for item-specific learning.

While all of our subjects learned the 8-item S/D task, none transferred to novel pictures. Certainly, most researchers at that time would have concluded that these subjects (pigeons and monkeys) had learned this S/D task item-specifically. We followed this learning with a gradual expansion of the subjects' training sets (16, 32, 64, etc.). After re-acquisition with each expanded set, subjects were retested with novel stimuli for relational learning and hence abstract-concept learning. We found gradually improving transfer with increasing set size to the point where all subjects showed transfer equivalent to baseline, which we have termed full concept learning. One interpretation of these results would be that subjects initially learned the S/D task item-specifically and then later shifted to relational learning, as shown by improving novel-stimulus transfer. This interpretation is, of course, the assumption of item-specific learning when abstract-concept learning fails.

Several findings from our experiments caused us to doubt the assumption that failures of abstract-concept learning indicated item-specific learning in our task. First, when the training set size was expanded, there was no abrupt change in transfer that might be expected from a strategy shift to relational learning. Such a shift would have been indicated by a sudden increase in transfer performance. But instead, transfer increased regularly and linearly with set-size expansion. A second bit of evidence was that the increase in transfer with training set size was much more rapid than any generalization account (Wright & Katz, 2007). A third bit of evidence was that the degree of transfer depended upon prior training set sizes, in addition to the size of the current training set (Nakamura, Wright, Katz, Bodily, & Sturz, 2009). Experimentally naïve pigeons initially trained with a 32-item set size transferred significantly better to novel stimuli than pigeons trained and tested with the same 32-items following training with 8-and 16-item sets. Thus, training with a small set hampers transfer at larger sets (i.e., a negative carryover effect). A fourth bit of evidence was that pigeons initially trained with half the pairs from a 3-item set transferred to stimulus inversions of the training items, to pairs not used in training, and to swirls of the training stimuli (like a caramel concoction). Such transfer suggested relational learning despite a lack of novel-stimulus transfer or abstract-concept learning (Elmore et al., 2009). A fifth bit of evidence was that pigeons and rhesus monkeys initially trained with half the pairs from an 8-item set transferred to stimulus inversions of the training items and to pairs not used in training despite a lack of novel-stimulus transfer or abstract-concept learning (Wright & Katz, 2009).

Collectively, these bits of evidence point to relational learning in the face of abstract-concept learning failure. In lieu of item-specific learning, we propose that such learning is *restricted-domain relational learning* –where the domain is restricted to the particular characteristics of

the training stimuli. As the training set increases in size, so too does the domain of relation learning. Indeed, broadening of the domain rapidly surpasses additional stimuli added to the training set eventually leading to full abstract-concept learning (i.e., encompassing the entire domain).

The purpose of the current experiment was to explore other aspects of restricted-domain relational learning, namely whether regressing in the size of the training set (e.g., returning to the original 8-item training set) would alter the established domain for relational learning, as measured by novel-stimulus transfer. To this end, we retrained and retested pigeons with the 8-item set that had been used to initially train these pigeons and had shown no transfer (Katz & Wright, 2006). At the time, we considered that there were several possible outcomes that would bear upon restricted-domain relational learning. One possibility would be that the full concept learning (i.e., transfer equivalent to baseline performance) would persist. A second possibility would be that the 8-item set might re-restrict the domain of relational learning to that set and replicate the lack of transfer originally obtained. A third possibility would be that training on the 8-item set might reduce the degree of transfer by partially restricting the domain over which the pigeons could apply the S/D concept.

Method

Subjects

Six White Carneaux pigeons (*Columba livia*) 5-6 years old with previous experience in the S/ D task (see Katz & Wright, 2006) from the Palmetto Pigeon Plant in Sumter, South Carolina served as subjects. Pigeons were maintained at 80-85% of their free-feeding weights and were individually housed with a 12-hr light-dark cycle. Testing was conducted 5–7 days a week during the light phase of the cycle.

Apparatus

Chamber—Pigeons were tested in custom wooden chambers (35.9-cm wide × 45.7-cm deep × 51.4-cm high). In each chamber, a custom-built wooden grain hopper allowed a video monitor (Eizo T550, Ishikawa, Japan; 800 × 600 pixel resolution) and infrared touch screen (17″ Unitouch, Carroll Touch, Round Rock, TX) to be better positioned (i.e., lower than commercially available hoppers) on the stimulus panel. Experimental events were controlled and recorded with custom software written in Visual Basic on a Pentium personal computer. A video card (ATI 3D Rage Pro AGP 2X, Ontario, Canada) controlled the monitor. A computer-controlled relay interface (Model PI0-12, Metrabyte, Taunton, MA) operated the food hopper and houselight.

Stimuli—Stimulus displays consisted of two digitized travel-slide color pictures (each 5.7 × 3.8 cm) and a white rectangle (2.6 × 2.3 cm) on a black background. The pictures were vertically aligned with a 1.28-cm gap between them. The top picture was centered 20.63 cm from the left edge and 18.75 cm from the top of the cutout in the front panel. The bottom of the white rectangle was horizontally aligned with the bottom of the lower picture and to the right with a 1.4-cm gap between them. The 8 training stimuli were those used by Katz and Wright (2006) and color reproductions of these stimuli can be seen in Wright and Katz (2006).

Procedure

All pigeons had been previously trained in the simultaneous S/D task and showed full concept learning (Katz & Wright, 2006). Following testing with the 1,024 set of pictures the training set was reduced back to the original 8-item set. There were four training and testing cycles to test for stability of transfer. Training phases were typically 7 sessions, each followed by 6

testing sessions. Three pigeons had an initial 14-session training phase. Training trials and baseline trials during testing employed the original 8 training stimuli.

Training sessions—Sessions consisted of 100 trials (50 *same*, 50 *different*). The sequence of *same* and *different* trials was randomly constructed and varied from session to session. The items used to construct the displays were selected with replacement from the 8-item set. All trials began with presentation of a picture in the upper position. A response requirement of 20 pecks to this picture resulted in presentation of the lower picture and the white rectangle. If the two pictures were *same*, a peck to the lower picture was correct. If the two pictures were *different*, a peck to the white rectangle was correct. Correct responses were reinforced with a 0.5-s, 600.6-Hz tone and food reinforcement (3-5 s access to mixed grain). Food reinforcement or an incorrect response was immediately followed by a 15-s intertrial interval (ITI).

Transfer testing sessions—Sessions consisted of 90 baseline training trials (45 *same*, 45 *different*) plus 5 *same* and 5 *different* transfer trials. Novel stimuli, never before seen, were presented on transfer trials. Thus, each transfer test employed 90 trial-unique pictures (15 pictures per session for 6 sessions) with none of the pictures repeated in any of the other transfer tests. Within each session, the 10 transfer trials were pseudorandomly placed following the seventh trial. Performance on transfer trials was reinforced like that on baseline trials. All other details were identical to the training sessions.

Results

Figure 2 shows mean percent correct for the four transfer tests for baseline and transfer performance for all pigeons. Baseline and testing performance remained constant over the four testing cycles. This result was confirmed by a three-way repeated measures analysis of variance (ANOVA) of Trial Type (baseline, transfer) × Testing Cycle (1, 2, 3, 4) × Group (7 training sessions, 14 training sessions) on percentage correct which yielded no Trial Type × Testing Cycle interaction, $F(3, 12) < 1$, $p = .8$. There was a main effect of Trial Type, $F(1, 4) = 77.2$, $p < .02$, as baseline was 16.8% higher than transfer performance, and a main effect of Group, $F(1, 4) = 14.04$, $p < .021$, as there was a 5.4% overall performance difference. The fact that Group did not interact with any other factors, indicates the first training cycle difference of 7 sessions had no measurable influence on performance. We therefore combined the group's testing performance for the following analyses.

The mean percentage correct on the 8-item reduction transfer tests for baseline and transfer performance for the six pigeons from the current experiment is shown on the far right (8 reduction) of Figure 3. These results are compared to data we previously collected for the same pigeons for the 8-item transfer test before set-size expansion and the 1,024 transfer test (from Katz & Wright, 2006). Transfer performance decreased (9.2%) and baseline performance increased (9.3%) compared to the prior results following training with the 1024-item set. These performance changes were confirmed by a two-way repeated measures ANOVA of Trial Type (baseline, transfer) × Testing (1,024 vs. 8 reduction) on percentage correct which yielded an interaction, $F(1, 5) = 35.6$, $p < .003$. Bonferroni correct (alpha = .025) *t*-tests further confirmed that baseline increased and transfer decreased relative to the 1,024 test, $t(5)s > 3.7$, $ps < .02$. For the 8-item reduction, transfer performance was well above chance (50%), as confirmed by a one-sample *t*-test, all $t(5) > 18.9$, $p < .00001$.

Discussion

In this experiment, the training set size was reduced from 1,024 items to the original 8-item picture training set, and four cycles of training and transfer were conducted. Transfer performance decreased relative to the level following training with the 1024-item set, but

nevertheless was 25.8% above chance (i.e., partial transfer). There are several possible explanations for the transfer performance drop. One possibility might have been the contrast in familiarity between the novel transfer stimuli and the training stimuli could have disrupted the subjects. With the 8-item set, all the stimuli and training pairs are seen many times and became very familiar relative to training with the 1024-item set.

Another possibility for the partial transfer during the 8-item reduction test may be the 8-item training stimuli set-the-occasion for the context of the original training but only partially restricted relational learning. Once the subjects enter the context of the original 8-item set they excelled (93.6%) in relationally discriminating the characteristics of these stimuli (baseline performance increased by 9.3%). This occasion reduced the flexibility of relationally discriminating novel stimuli but not to the initial degree that it once was, due to the broadened domain from experience with the larger set sizes. An interesting test of this hypothesis would be to change the 8-item set from the original training set to 8 novel pictures. Relative to the 8-item reduction test, we would expect an initial decrease in baseline performance but an increase in transfer performance.

A final possibility that will be mentioned with regard to the partial drop in transfer performance is that subjects trained with only eight stimuli have to combat proactive interference from trial-to-trial. They see a test item (lower picture) that does not match the sample item (upper picture), so the correct response is "different" (touch the white rectangle). But since they have seen this test item many times recently, maybe in the previous trial, there is a tendency to become confused that it might match the sample item. Training to perform well and combat proactive interference may tap into behaviors that are not best suited to performing well with novel stimuli. Indeed, the increased baseline performance relative to the 1,024-item condition suggests that these pigeons may have become extremely good at combating interference.

The fact that the 8-item reduction transfer performance did not return to the 50% chance level is noteworthy in itself. This result indicates that the domain did not become as restricted as it originally was following the initial 8-item acquisition. The change in restriction was not altered, even after more than a month of training with the 8-item set and testing. The transfer trials (as they all involved novel pictures) may have helped to stabilize the degree of restriction, but our previous research suggests they have little impact on abstract-concept learning in our task (Katz & Wright, 2006). In the future, an interesting test of domain restriction would be to increase and decrease the training set over successive cycles, for example, between a 1,024 and 8-item set (i.e., an ABAB design). Such a design would further help illuminate how the domain expands and constricts with set size over time.

Restricted-domain relational learning is a new proposal related to abstract-concept learning. While prior failures of transfer to novel stimuli do not necessarily indicate evidence of item-specific learning in our task, we hasten to add this does not mean that failures to transfer to novel stimuli in other research are not evidence of item-specific learning. However, if one does not test for item-specific learning one cannot be sure (Katz, Bodily, & Wright, 2008; Wright, 1997; Wright & Katz, 2009). How the domain becomes restricted is largely unknown for our pigeons or monkeys and will likely vary across species and tasks. As one example, consider ordered serial learning where subjects can learn to produce item specific sequences by rote memorization (e.g., Straub & Terrace, 1981; Swartz, Chen, & Terrace, 1991). In these experiments, subjects are simultaneously presented a list of four picture items and learn to select picture A then select B then select C then select D. Since the order of the sequence is arbitrary, if subjects learn the sequence and learn the serial, linear relationship between the items, then this would be evidence for restricted-domain relational learning. Monkeys apparently do learn in this way, but pigeons do not, as shown by tests with two-item subsets of 4-item lists, replacing an item with a "wild card" stimulus, and substituting an item that

occupied the same position in a previously learned list (for reviews see Terrace 1993, 1995, 2005b). This qualitative species difference suggests that monkeys have learned the simultaneous-chaining paradigm by restricted-domain relational learning whereas pigeons may have learned the task item-specifically. Perhaps, further explorations of restricted-domain relational learning will be a means to explore learning and problem solving by a variety of species.

Acknowledgments

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Figure 1.
The stimulus displays used to train the rhesus monkeys, capuchin monkeys, and pigeons. A touch to the bottom picture was correct on *same* trials. A touch to the gray rectangle was correct on *different* trials. The actual stimulus displays did not have labels, were in full color, had black backgrounds, and the gray area to the right was white.
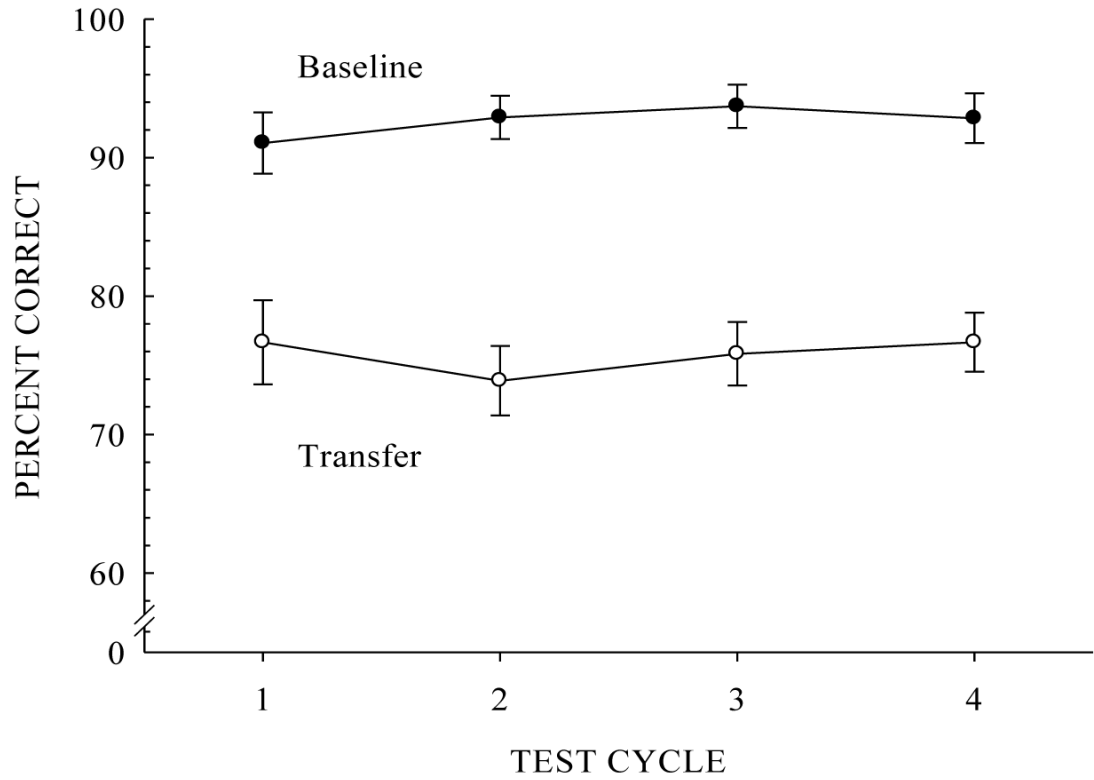
Figure 2.
Mean performance on baseline and transfer trials for transfer testing within the four consecutive testing cycles. Each transfer test lasted six sessions. Error bars represent standard errors of the mean.
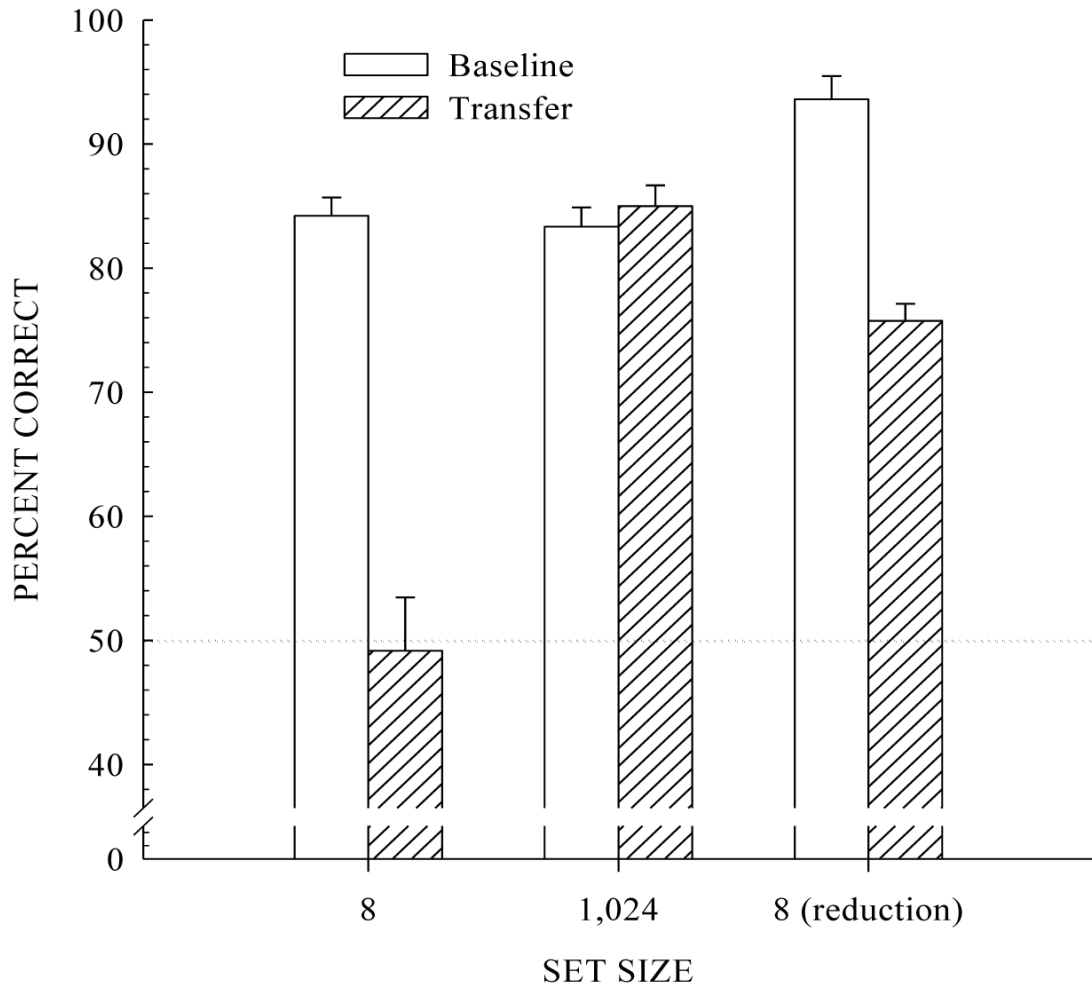
Figure 3.
Mean performance of the six pigeons on baseline and transfer trials during 8-item reduction testing. 8-item transfer testing before set-size expansion and the 1,024 transfer test is also shown for these same pigeons (data from Katz & Wright, 2006). The dashed line represents chance performance, and the error bars represent standard errors of the mean.