Failure to find symmetry in pigeons after multiple exemplar training

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Abstract

Background: An experiment with pigeons was conducted for 46 months in order to test the multiple-exemplar training (MET) hypothesis of symmetry derivation. According to this hypothesis, symmetry is progressively derived after an extensive training of multiple examples of direct and inverse relations among arbitrary stimuli. **Method:** Four pigeons were given extensive training in direct (e.g., A1-B1; A2-B2) and inverse (e.g., B1-A1; B2-A2) arbitrary conditional discriminations. Once pigeons learned a complete reversal (e.g., AB and BA), a new reversal with different stimuli was trained (e.g., CD and DC, etc.). Subjects were assigned to two different stimulus sets, and sample-comparison order was counterbalanced. **Results:** Pigeons learned between 4 and 24 conditional discriminations, but none showed evidence of symmetry. Discriminability of samples and comparisons was identified as an important factor because it affected direct and inverse discriminations differently. **Conclusions:** Despite the negative results reported, this study provides some insights that might help to improve current research on MET and symmetry: We describe some lessons learned about the design of long-term experiments involving a high number of stimuli and finally, we discuss some control strategies for stimulus discriminability that might also contribute to facilitate symmetry derivation in pigeons.

Keywords: conditional discrimination, multiple-exemplar training, symmetry, stimulus discriminability, pigeons.

Resumen

Ausencia de evidencia de simetría en palomas tras entrenamiento en múltiples ejemplares. **Antecedentes:** se realizó un experimento con palomas durante 46 meses para contrastar la hipótesis del entrenamiento en múltiples ejemplares (MET) en la derivación de simetría. Según esta hipótesis, la simetría se deriva progresivamente después de entrenar múltiples ejemplos de relaciones directas e inversas entre estímulos arbitrarios. **Método:** cuatro palomas fueron entrenadas en discriminaciones condicionales arbitrarias directas (ej., A1-B1, A2-B2) e inversas (ej., B1-A1; B2-A2). Una vez que aprendieron una reversión completa (ej., AB y BA), se entrenó otra reversión con estímulos diferentes (ej., CD y DC, etc.). Los sujetos fueron asignados a dos conjuntos de estímulos; el orden de aprendizaje de muestras y comparaciones fue contrabalanceado. **Resultados:** las palomas aprendieron entre 4 y 24 discriminaciones, pero ninguna mostró simetría. La discriminabilidad de las muestras y las comparaciones fue determinante porque afectó a las discriminaciones directas de manera diferente a las discriminaciones inversas. **Conclusiones:** a pesar de los resultados negativos, este estudio puede contribuir al desarrollo de la investigación en MET y simetría: se describen algunas lecciones aprendidas acerca del diseño de experimentos de larga duración con numerosos estímulos y se discuten algunas estrategias para controlar la discriminabilidad de los estímulos que pueden contribuir a facilitar la derivación de simetría.

Palabras clave: discriminación condicional, entrenamiento en múltiples ejemplares, simetría, discriminabilidad, palomas.

According to the most common definition of the term, a subject is said to derive symmetry if, after learning a conditional discrimination where stimulus A1(A2) acts as sample and stimulus B1(B2) is the correct comparison, it is able to choose A1(A2) as comparison in the presence of B1(B2) as sample in a non-reinforced test (Sidman & Tailby, 1982).

Symmetry has been difficult to find in nonverbal organisms. An important research effort has been devoted to finding symmetry in nonhuman animals, with negative or controversial results in most cases (for a review, see Lionello-DeNolf, 2009). For decades, there was no proof of symmetry derivation in pigeons

(Lipkens, Kop, & Matthijs, 1988; Meehan, 1999; Rodewald, 1974). However, some studies reported evidence of symmetry in pigeons, usually involving deviations from the standard conditional discrimination procedure, such as, for example, backward conditioning (Hearst, 1989), the use of biologically relevant stimuli as samples or comparisons (Zentall, Sherburne, & Steirn, 1992), successive conditional discriminations (Frank & Wasserman, 2005) or the discrimination by the pigeon of its own behavior (García & Benjumea, 2006). There is a complex puzzle of species, procedures and pre-experimental histories in studies showing some evidence of symmetry, and no widely accepted hypothesis to account for the origin of this phenomenon is available so far.

Relational frame theory (Hayes, Barnes-Holmes, & Roche, 2001; Hayes, Hayes, & Chase, 1991) proposed an ontogenetic hypothesis for the origin of symmetry which relies on multiple-exemplar training (MET) of symmetric relations (e.g., AB-BA; CD-DC, etc. See also Boelens, 1994).

Some experiments in nonhuman subjects pointed to the influence of MET in the derivation of symmetry, although not unequivocally. Schusterman and Kastak (1993) found reflexivity, symmetry and transitivity in a California sea lion after training a total of 30 conditional discriminations (but see Horne & Lowe, 1996; Lowe & Horne, 1996). Importantly for the MET hypothesis, symmetry did not show up until 6 conditional discriminations and their respective reversals were explicitly trained. Yamazaki (2002, cit. in Yamazaki, 2004) tried to partially replicate this experiment with pigeons, but with negative results.

Extraneous stimulus control has been offered as an explanation of some failures to derive symmetry. Spatial and temporal position of stimuli does change from training to test conditions, as well as their behavioral function as sample or comparison. Lionello and Urcuioli (1998) showed that unintended control by sample location could prevent the emergence of symmetry in pigeons. Unintended control by temporal position of samples and comparisons has been also been proposed as an explanation of the failure to find symmetry in nonhuman animals (Frank & Wasserman, 2005).

Given that MET involves presenting several stimuli in different temporal and spatial positions, it can function as abstraction training, eliminating (extinguishing) non- relevant sources of stimulus control (Hayes et al., 2001). According to Velasco et al. (2010), MET could also provide all the necessary successive and simultaneous discriminations between samples and comparisons (Saunders & Green, 1999). The MET hypothesis predicts that a large (but undetermined) number of exemplars will be required, and that symmetry derivation should be gradual rather than immediate (e.g., Luciano, Becerra, & Valverde, 2007).

The actual disparity of procedures, species and training conditions makes it difficult to test these predictions in non-human animals and evaluate the separate influence of these factors in the derivation of symmetry. For that reason, we designed a procedure to systematically train several conditional discriminations and their respective inversions to test whether subsequent reversals were learnt progressively faster than direct ones.

Method

Subjects

Four rock pigeons (*Columba livia*) were kept at approximately 80% of their free-feeding weight. Water and pigeon grit were always available. The temperature and humidity of the room were maintained stable and a 12:12 hour light - dark cycle was employed during the whole experiment.

Instruments

Four modified operant chambers with a tactile PC screen were used. Each chamber was 43.5 cm high, 64 cm long and 45 cm wide. The front of the chamber was equipped with a feeder providing a mix of grain. In the middle of the rear side, a 35 watt white light provided illumination. A touch screen monitor was installed in the left panel of the chamber (ELO Touchsystems ETL 121-C-75WB-1). The monitor displayed 800 × 600 pixels (60Hz, SVGA) and was divided into a grid of 4 × 2 rectangular regions. Only the six positions most distant from the feeder were used (Figure 1).

Operant chambers were enclosed in sound-attenuating hulls. A ventilation fan produced a white noise.
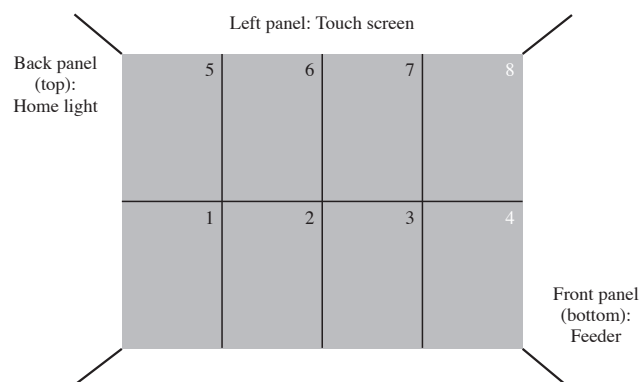
Figure 1. Schematic view of the modified operant chambers. Black numbers indicate active regions, while grey numbers indicate inactive ones

Each touch screen was connected to a PC. A tailor-made program (DV) controlled the presentation of stimuli and recorded responses. Each PC was connected to a MED R/M interface SG-6001C-SN controlled by a central PC. The software used to run the experiments was MedPC 2.0 for Windows.

A stimulus pool with different images downloaded from the Internet or specifically created for this experiment was used. All images were 200 × 300 pixels (.bmp format, 24bpp, true colour). The stimulus pool contained photographs of people, objects and landscapes, geometric figures, natural and abstract pictures, and graphic symbols from different alphabets. Stimuli were divided in two random stimulus sets.

Procedure

Pretraining. After magazine training, subjects learnt to peck the touch screen. All pigeons learnt then to peck random stimuli in any of the six positions used in the experiment under a FR 20 schedule.

Experimental design. Two subjects (S13 and S14) were assigned to stimulus set 1, and the rest (S15 and S16) were assigned to set 2. The order of sample and comparison stimulus was counterbalanced. Pigeons S13 and S15 learnt first the conditional discriminations in one direction (e.g., A1-B1, A2-B2; then B1-A1, B2-A2, etc.), and pigeons S14 and S16 in the opposite direction (e.g., B1-A1, B2-A2; then A1-B1, A2-B2, etc.). See Table 1.

The original design included another group of four pigeons for whom stimulus positions randomly varied across the six possible on-screen locations in order to prevent incidental control by stimulus position. Unfortunately, because some pigeons died, this group was cancelled before it produced any significant result.

First conditional discrimination. Regardless of training order for each subject, we will refer to the first conditional discrimination

Table 1 Assignation of pigeons to experimental conditions		
	Stimulus set	
Training order	**Set 1**	**Set 2**
Direct (A-B, then B-A)	S13	S15
Inverse (B-A, then A-B)	S14	S16

as AB direct training. This training consisted of a symbolic delayed conditional discrimination with two sample stimuli (A1, A2) and two comparisons (B1, B2). A trial was preceded by a 12-s inter-trial interval (ITI), during which only the general light was on and the screen was black. After that, a sample stimulus (A1 or A2, with 0.5 probability) was presented in position 3 of the screen. Ten consecutive responses to the sample turned it off, and then, after a 1-s inter-stimulus interval (ISI), two comparisons were presented in positions 6 and 7. The positions of the correct and incorrect comparisons were randomized on every trial. Ten consecutive responses to the correct comparison led to 4-s access to a mix of grain, while all lights, except that of the feeder, were turned off. One response to the incorrect comparison turned the screen black and all lights off for 15 s (timeout). Pecking during timeout restarted the timer. When timeout finished, the pigeon was presented with the same comparison stimuli and position. Only ten consecutive responses to the correct comparison led to the next trial.

Sessions ended after 64 trials or 90 minutes, and were carried out five days a week. The learning criterion was three consecutive sessions with 80% or more correct responses in both stimulus pairs (e.g., A1-B1 and A2-B2).

First inversion and subsequent conditional discriminations. Regardless of stimulus set and training order, we will use the word "direct" for conditional discriminations involving new stimuli (e.g., AB, CD, etc.). The word "inverse" will be used for conditional discriminations involving the opposite sample-comparison relations from a previously learned one (e.g., BA, DC, etc.). Learning a direct conditional discrimination to criterion and its inversion (e g., A1-B1, A2-B2, and B1-A1, B2-A2) will be called a "reversion". Once a subject reached the learning criterion, the next day, sample and comparisons exchanged their roles, and the pigeon started learning the inverse discrimination. All parameters and criteria remained the same. When the inversion had been learned, the next day, subjects had to learn a new conditional discrimination with different, random stimuli, and then its inversion. Further details about the MET procedure employed can be found in Gómez (2009).

Training lasted for 46 months with some scheduled stops during which the animals returned to a free-feeding condition for a few weeks.

Experiment termination criterion. There was no a priori criterion to determine the end of the experiment. First, because the MET hypothesis does not predict how many exemplars should be necessary to derive symmetric relations; and second, because the rate of conditional discrimination learning was subject to several parameters (e.g., modified operant chambers, type of stimuli, training order, etc.) whose exploration was an objective of the present experiment. The experiment finished when one of the subjects completed twelve reversions.

Dependent variables. Two dependent variables were used: the number of sessions to criterion, and the percentage of sessions needed to learn a direct discrimination compared to the number of sessions needed to learn its inversion. The number of sessions to criterion was not directly comparable across reversions because the design required a high number of stimuli and their discriminability could not be *assessed a priori* (see Honig & Urcuioli, 1981, for a review). Therefore, a systematic reduction in the ratio between the two measures would evidence the progressive derivation of symmetry.

Data analysis

Given the nature of data, its analysis strongly relied on graphic representation and visual analysis. Complementary statistical analysis were used in two occasions: a *t*-test was used to compare the acquisition of direct and inverse discriminations, and a Pearson correlation coefficient was used to compare the acquisition of the same discriminations by different subjects.

Results

Individual acquisition. The number of reversions achieved by the individual pigeons is shown in Table 2.

Pigeon 13 (Figure 2) completed 3 direct discriminations (A-B, C-D and E-F) and their respective inversions after 579 training sessions. Direct discriminations A-B and C-D were learned faster than their respective inversions, B-A and C-D. Discrimination E-F required 239 sessions. This pigeon received 62 training sessions of the inverse relation F-E, but it did not reach criterion when the experiment terminated. Therefore, only 2 complete reversions (AB-BA and CD-DC) can be considered for this subject. Specifically, this pigeon spent 353 sessions (61%) to learn the direct discriminations and 226 (39%) to learn their respective inversions. However, this ratio is mainly determined by the great number of sessions needed to learn the E-F discrimination.
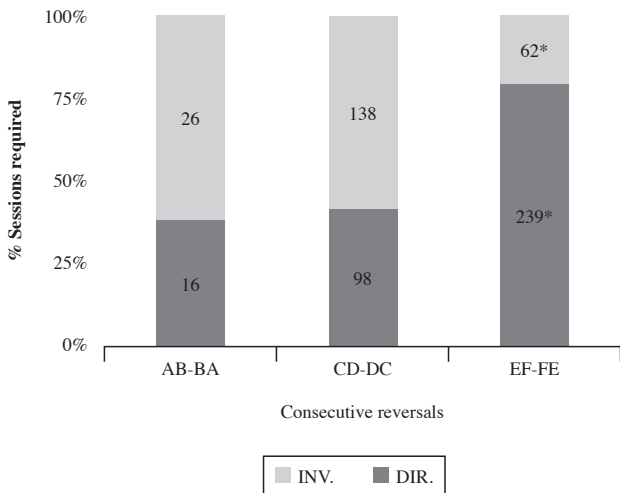
Pigeon 14 (Figure 3) completed 4 direct discriminations (B-A, D-C, F-E and H-G) and their respective reversals after 583 training sessions. The first pair (B-A) was learned slightly slower than its inversion (A-B); the second pair was learned twice as fast in the direct form (D-C) as in the inverse form (C-D); in the third pair, discrimination F-E was learned in 40 sessions and its inversion E-F in 31. Finally, discrimination H-G needed 53 sessions to be learnt, while training with inversion G-H did not reach criterion after 204 sessions. Three complete reversals can be considered for this subject. Overall, this pigeon spent 201 sessions (34.5%) learning the direct discriminations and 382 (65.5%) learning their respective inversions.

Pigeons assigned to stimulus set 1 learned 13 conditional discriminations in 896 sessions. The small number of reversals learned by pigeons 13 and 14 is insufficient to show any trend.
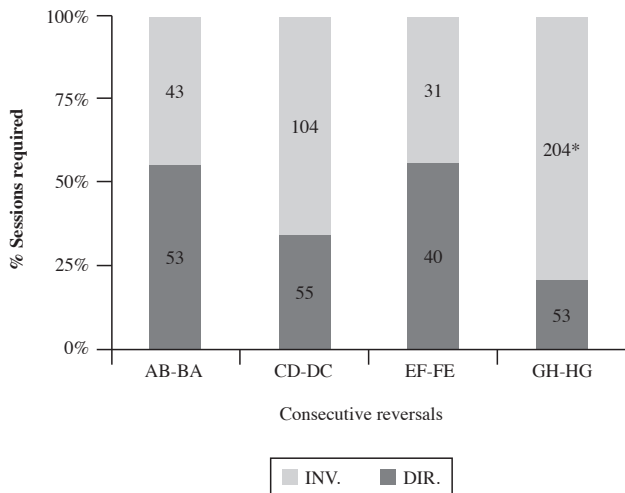
The number of sessions required to reach the learning criterion for discriminations sharing stimuli and training order in both pigeons can be compared in Figure 4. In the first and second discriminations (AB and BA), pigeon 13 reached the criterion faster than pigeon 14. In the third discrimination (CD), both subjects required a similar number of sessions (94 and 104). In discrimination DC, pigeon 13 needed more sessions (138) than pigeon 14 (55) and never reached another learning criterion despite

Table 2
Number of total essays and sessions per subject and stimulus set

Stimulus set	Pigeon	Total number of essays	Sessions	Number of discriminations learned to criterion
Set 1	P13	38,831	579	5
	P14	37,889	583	7
Set 2	P15	38,942	579	24
	P16	37,982	569	13

Figure 2. Pigeon 13. Percentage of sessions required to complete direct (DIR) versus inverse (INV) conditional discriminations. Asterisk indicates that the learning criterion was not met

Figure 3. Pigeon 14. Percentage of sessions required to complete direct (DIR) versus inverse (INV) conditional discriminations. Asterisk indicates that the learning criterion was not met
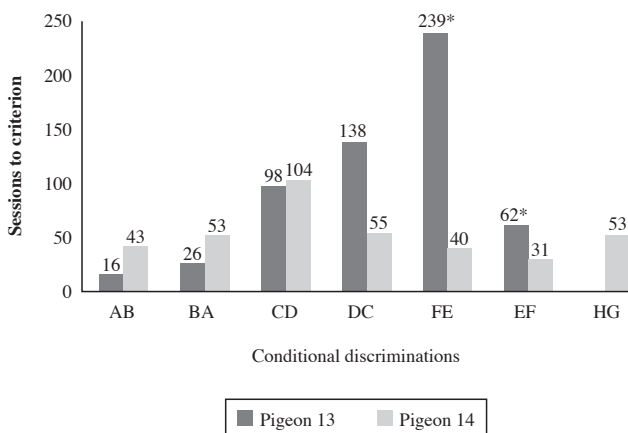

Figure 4. Number of sessions to criterion in comparable discriminations for pigeons assigned to stimulus set 1. For Pigeon 14 sample-comparison order was the opposite. Asterisk indicates that the learning criterion was not met

extensive training. Pigeon 14 spent 40 sessions in discrimination FE, 31 in discrimination EF, and 53 in discrimination HG.

As for the pigeons assigned to stimulus set 2, pigeon 15 (Figure 5) completed 12 reversions after 550 training sessions. The number of sessions required ranged from 7 to 45, and no trend emerged as training progressed. Overall, this pigeon spent 269 sessions (49%) learning the direct discriminations and 283 (51%) learning their respective inversions.

Pigeon 16 (see Figure 6) completed 7 direct discriminations and 6 inversions after 569 training sessions (i.e., 6 complete reversions can be considered for this subject). The number of sessions required ranged from 11 to 94, and as in the previous case, no trend was evident as training progressed. Overall, this pigeon spent 286 sessions (50%) learning the direct discriminations and 286 (50%) learning their respective reversals.
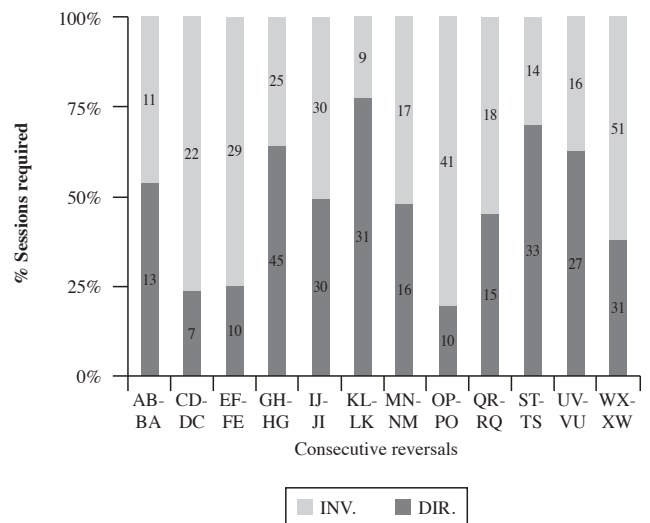
Figure 5. Pigeon 15. Percentage of sessions required to complete direct (DIR) versus inverse (INV) conditional discriminations for every reversal learned
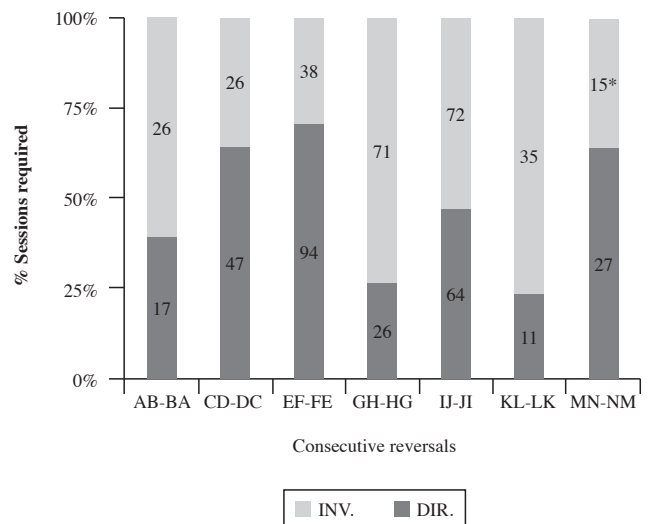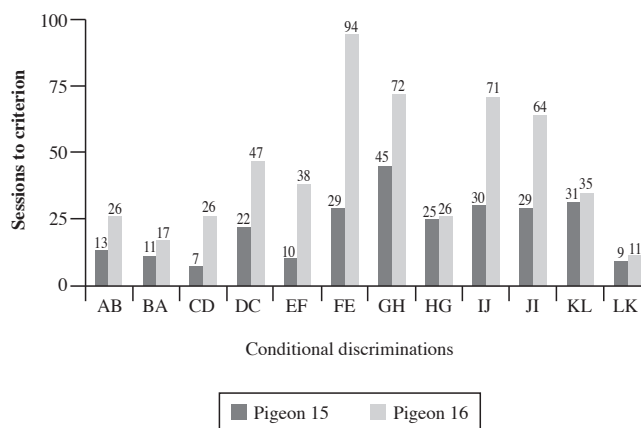

Figure 6. Pigeon 16. Percentage of sessions required to complete direct (DIR) versus inverse (INV) conditional discriminations for every reversal learned. Asterisk indicates that the learning criterion was not met

Pigeons assigned to stimulus set 2 learned 37 conditional discriminations in 1104 sessions (see Figure 7). Discriminations that took more sessions for one pigeon also took more sessions for the other. For the 12 conditional discriminations considered, the correlation coefficient was .73 ($p = .000$).

Considering all subjects, we observed a high variability in the number of sessions to criterion. This effect was found between subjects, ranging from 7 to 239, and also within subjects (Figures 2-6).

Analysis of reversals. The relative number of sessions to criterion in each reversion can be compared between pigeons sharing the same stimulus set but opposite training order (pigeons 13 and 14 on one hand, and 15 and 16 on the other). Only two reversions (AB-BA and CD-DC) can be compared in the case of set one. In the first reversal, subjects spent more time learning one particular stimulus configuration than the other; in the second reversal, the stimulus configuration that was learned faster by one pigeon was learned slower by the other.

Figure 7. *Number of sessions to criterion in comparable discriminations for pigeons assigned to stimulus set 2. For Pigeon 16 sample-comparison order was the opposite*
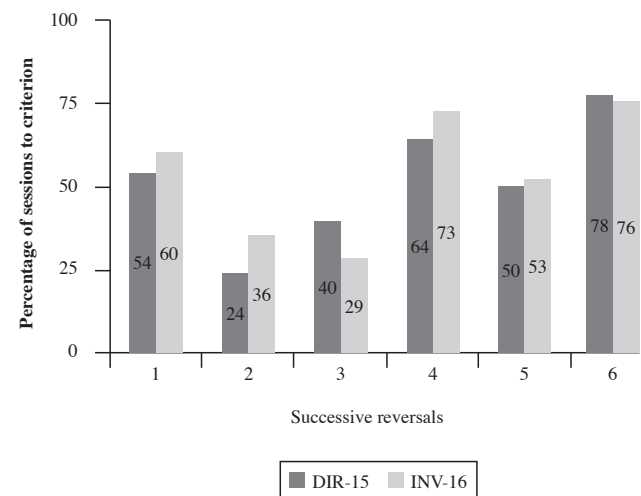
Figure 8. *Percentage of sessions required to complete direct discriminations for pigeon 15 (DIR-15) versus percentage of sessions required to complete inverse discriminations for pigeon 16 (INV-16). Discriminations in each reversal shared identical stimulus and sample-comparison order for both pigeons*

For subjects assigned to set 2, six complete reversals can be compared (Figure 8). There were no differences between the relative speed of acquisition of direct and inverse relations in the reversals considered, $t(1, 11) = 0.12$, $p = .467$.

Pigeon 15 required 261 sessions to complete the first 6 complete reversals, while pigeon 16 required 527. In other words, pigeon 16 required about twice the number of sessions as pigeon 15 (range 1.04 – 3.71). Although the absolute number of sessions required for each subject was different, the percentage of sessions required to reach the learning criterion in each reversal for equal discriminations was similar.

Figure 8 shows that discriminations that required a lower percentage of sessions with a particular sample-comparison order for one subject were also learned faster by the other. The correlation coefficient between the percentages of sessions to criterion for both pigeons was .91 ($p = .000$).

Discussion

In the present experiment, we extensively trained four pigeons in multiple exemplars of direct and inverse arbitrary conditional discriminations. One of the subjects successfully learned 12 reversals, which is an unprecedented number in pigeon conditional discrimination literature. High variability in the number of discriminations learned was found both between and within subjects. The results of this experiment can be summarized in two main conclusions: first, this design did not lead to derived symmetry after MET. Second, particular stimulus pairings and sample-comparison order were the main factors determining the speed of acquisition of conditional discriminations. These results do not allow us to corroborate the MET hypothesis, but with the current data, it cannot be discarded either, at least for two reasons: first, because the number of exemplars trained was limited even in the best case (twelve reversals); and second, because at least one relevant variable, namely stimulus position, was not controlled.

Despite the negative results reported here, this experiment can arguably provide some insights relevant to research on MET and symmetry, and might contribute to the development of an animal model of MET and derived relational responses. The experimental design allowed us to identify some important sources of variability that might contribute to optimize future research.

Some features related to the long-term nature of this design can explain part of this variability. For one, as the experiment lasted for more than four years, some pigeons eventually got sick and were excused from experimental sessions until recovery. But this measure was only taken when the pigeons presented evident signs of illness, which may have been having deleterious effects on operant performance before it was detected. Besides, some pigeons had to be temporarily removed from the experiment more often than others for this reason, and therefore some pigeons experienced more discontinuity in training than others.

Age-related diseases may also explain some results. Pigeon 13 showed a pattern of results that may reflect this problem. After reaching the learning criterion faster than its control in two discriminations, this pigeon spent about the same number of sessions in the third discrimination, then more than twice the number in the fourth, and finally it never reached the learning criterion again (see Figure 4). Rock pigeons usually live between three and five years in the wild and, although its life is longer in captivity (about 15 years), ageing is commonly associated with

diseases like arthritis, loss of equilibrium and visual problems (Gibbs, Barnes, & Cox, 2001). Therefore, results from pigeon 13 and its control, pigeon 14, should be taken with caution. For this reason, the rest of the discussion will be restricted to pigeons 15 and 16.

An important source of variability identified was the particular sample-comparison configuration. Performance of pigeons 15 and 16 (Figure 7) indicate that the difficulty of each conditional discrimination varied as particular stimulus configuration changed. No differences appeared between direct and inverse discriminations, and no clear pattern emerged as training progressed (Figures 5 and 6). Figure 7 suggests that differences in stimulus discriminability caused the observed differences in the number of sessions required to reach the criterion during the course of the experiment. Although compromised, the results of pigeons 13 and 14 support this explanation in the first three discriminations (Figure 4). Carter and Eckerman (1975) showed that differences in discriminability between colors (more discriminable) and lines (less discriminable) influenced conditional discrimination learning. Hue-hue and hue-line discriminations were learned about twice as fast as line-hue and hue-hue discriminations. Also, pigeons showed greater differences in their acquisition curves with the less discriminable stimuli. In the line - line condition (the least discriminable), two out of four subjects did not reach the learning criterion after 100 sessions.

In addition, stimulus discriminability may have also influenced asymptotic accuracy, interacting with the learning criterion (Chase, Schupak, & Ploog, 2012; Heinemann, 1983). Our learning criterion of three consecutive sessions with 80% correct responses in both samples was lower than typically found in the literature, where up to 90% correct responses are usually required. It seems that easily discriminable stimulus configurations could be learned with our criterion at least as fast as in other experiments. But in the case of the less discriminable stimulus configurations, the number of sessions to criterion might have been artificially extended for this reason.

Furthermore, Figure 8 indicates that the difficulty of the task varied when the sample-comparison order changed. This effect can be explained given that, in conditional discriminations, sample discriminability has a larger effect than comparison discriminability (Carter & Eckerman, 1975; Carter & Werner, 1978). When a particular stimulus configuration (e. g. A1-B1, A2-B2) is trained in a direct order, subjects had to make a successive discrimination between A1 and A2 and a simultaneous discrimination between B1 and B2; but when the relation is inverted (e.g., B1-A1, B2-A2), subjects had to make then a successive discrimination between B1 and B2 and a simultaneous discrimination between A1 and A2. Successive discriminations usually require more training and produce lower asymptotic accuracy than simultaneous

discriminations (Honig, 1962). In our experiment, the differences in discriminability of a particular sample-comparison pair were always the same; but when we changed their role as samples or comparisons, we changed their influence on learning speed, and probably on asymptotic accuracy. Having the rest of conditions controlled (except for training order, which produced no influence), the conclusion that stimulus discriminability explain the observed data seems quite robust. See Gómez (2009) for details about the stimuli used and its discriminability.

However, we only inferred stimulus discriminability from data; ensuring an independent measure of this variable would be a key task for future experiments involving MET and symmetry with pigeons. Animal models are still required to further investigate the role of MET in derived relational responses and its relevant parameters. Studies on symmetry in pigeons usually employ a limited number of stimuli, and the same applies to experiments specifically addressed to investigate stimulus discriminability. To the best of our knowledge, this is the first experiment that combines both research lines. In traditional experiments with pigeons, stimulus discriminability is easily controlled (between or within subjects) or assigned a priori if necessary, given the reduced number of stimuli required (four stimuli are the minimum required to investigate symmetry). External measures of stimulus discriminability such as wavelength or stimulus type (lines vs. colors, for example) can be thus easily operationalized and applied in this kind of design.

But a higher number of stimuli are required to test the MET hypothesis (e.g., 48 stimuli were required to train pigeon 15). In this situation, an a priori control of the discriminability of each potential stimulus pair becomes impossible, and external measures of discriminability cannot be applied. In fact, it is conceptually tricky to speak of stimulus discriminability as a property of the stimulus (Honig & Urcuioli, 1981). Given the high impact of stimulus discriminability in the present design, new control measures appropriate to MET experiments should be designed. One approximate possibility is the independent categorization by human observers (Gómez, 2009), which explained 74% of the variance. However, it is possible that better results could be achieved with within-subjects controls. A convenient solution could be to arrange the potential stimuli in pairs and test the acquisition speed of simple simultaneous and successive discriminations prior to the MET experiment. Given the similar effect of stimulus discriminability in simple and conditional discriminations (Carter & Werner, 1978), this procedure could provide a relatively quick and accurate independent measure of stimulus discriminability to select stimulus pairs. Furthermore, training the successive and simultaneous simple discriminations before the conditional discriminations would contribute to ensure that pigeons learned all the prerequisites of symmetry derivation (Velasco et al., 2010).

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