

Transitive responding in pigeons: influences of stimulus frequency and reinforcement history

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Abstract

Fersen et al. (1991) (*J. Exp. Psychol.: Anim. Behav. Process.*, 17: 334–341) trained pigeons to discriminate four overlapping pairs of stimuli A + B – , B + C – , C + D – and D + E – (+ rewarded, – penalized). When subsequently tested with a pair BD the pigeons showed a strong preference for stimulus B. A special value transfer theory was offered as an explanation for this transitive responding. A simpler reinforcement ratio account based on certain inequalities factually affecting the accuracy performance on training pairs is proposed. To explore its implications an experiment employing a novel grit-grain conditioning method was carried out. The presentation frequencies of the training pairs were biased so that the choice accuracies obtained at the end of training were approximately equal for all pairs. Testing with pair BD still yielded high preference for B, documenting the robustness of the transitive responding phenomenon. When suitably adjusted to the training design the reinforcement ratio account was still viable. The transitive responding with the BD and other test pairs could also be simulated with a simple reinforcement based conditioning model. Some of the subjects were then retrained with modified presentation frequencies so that the subjects ended up with an even overall exposure to all training pairs. Test pairs continued to yield strong transitive responding. It is concluded that this behavioral effect is a robust phenomenon which is largely unaffected by training design modifications.

Keywords: Transitive responding; Transitive inference; Discrimination learning; Reinforcement history; Learning model

1. Introduction

Transitive inference is a form of deductive reasoning. If ‘Anna is taller than Mary’ and ‘Mary is taller than Paul’ it can be concluded that ‘Anna is taller than Paul’ (Piaget, 1921). To demonstrate

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analogous transitive responding in very young children and animals it is obviously necessary to use equivalent non-verbal tasks (Bryant and Trabasso, 1971; Boysen et al., 1993; Davis, 1992; Gillan, 1981; McGonigle and Chalmers, 1977, 1992). In a study on the inferential competences of pigeons Fersen et al. (1990) used 5 arbitrary visual stimuli denominated A to E. The birds were trained with repeated randomly ordered presentations of the overlapping pairings A + B -, B + C -, C + D -, D + E -, where choices of the positive stimuli were rewarded with food and the choices of the negative stimuli were penalized with time out. Note that while stimuli A and E were respectively scheduled to be always rewarded and always penalized, the stimuli B, C, D were scheduled to be equally often rewarded and penalized across the pairs. When the pigeons had learned to discriminate all four training pairs, according to simple conditioning principles the stimuli could thus be intuitively expected to be ranked $A > B = C = D > E$. However, when tested with the novel BD pair in unreinforced trials the pigeons were found to respond transitively by strongly preferring stimulus B over stimulus D. This and other test results suggested that the stimuli had instead been ranked $A > B > C > D > E$ in accordance with the inequalities $A > B$, $B > C$, $C > D$ and $D > E$ implied by the training pairs (Fersen et al., 1991).

To explain the formation of such a linear order Fersen et al. proposed a theory that assumed a somewhat unorthodox part-transfer of associative value from the positive to the negative stimuli of the training pairs. This theory is detailed in the Discussion section. Controversy ensued about whether the value transfer model was viable or not (Couvillon and Bitterman, 1992; Wynne et al., 1992; Zentall and Sherburne, 1994). While it is true that certain aspects of this dispute will reappear later in this paper, it was not at all the starting point of the present study which was instead inspired by a plain fact. It had to do with the question whether the training design used by Fersen et al. (1991) had really yielded the assumed equal ratios of rewarded to penalized choices for the critical stimuli B and D. We reexamined the final discriminative performance that their pigeons had shown on the training pairs. The pairs A + B -, B + C -, C + D - and D + E - had yielded respectively a mean 88, 78, 67 and 94% choices correct. These percentages index the rewarded choices of the stimuli A, B, C and D. However, they also specify that 12, 22, 33 and 6% penalized choices of stimuli B, C, D and E had occurred. The reward/penalty ratios for stimuli B and D prior to testing were thus, respectively, $R_b = 78/12 = 6.5$ and $R_d = 94/33 = 2.8$. These ratios, differently from what was generally assumed, were clearly unequal and favored stimulus B. The ratio inequality found of course provided a straightforward, simple account for why Fersen et al.'s pigeons had chosen this stimulus in preference to D (86% of the choices) in the unreinforced BD tests.

The fact that the reinforcement ratios for B and D are uneven is directly due to the presence of a so-called end-anchor effect. Much as found in many other transitivity studies (Breslow, 1981) Fersen et al.'s pigeons discriminated the training end pairs AB and DE markedly more accurately (88 and 94% correct choices) than the middle pairs BC and CD (78 and 67% correct choices). The circumstance that the end pairs include stimuli consistently rewarded (A) or penalized (E) seem to make them easier to discriminate than the middle pairs which only contain part rewarded, part penalized stimuli (B, C, D). The obvious question that posed itself was whether a transitive responding on the BD test pair would continue to occur with a training designed to avoid the emergence of any substantial end-anchor effect. Such training could begin with the clearly difficult middle pairs BC and CD, the obviously easier end pairs AB and DE being only added later. Furthermore, the presentation frequencies of these various training pairs could then be manipulated so that those yielding poorer discrimination would be shown relatively more often than those yielding

better discrimination. Judiciously employed, this procedure should lead to a largely even final discrimination performance across the training pairs.

Fersen et al.'s pigeons required an extended training involving more than 5000 trials to learn the premise pairs. In an effort to abbreviate we chose a conditioning procedure expected to be more efficient than their Skinner-box method. The grit-grain procedure was developed and validated for a somewhat different purpose, but with it pigeons learned matching or oddity tasks remarkably fast (Wright and Delius, 1994). It is an adaptation of a grain-among-grit test (Bond, 1983; Dawkins, 1971; Güntürkün and Kesch, 1987; Jäger, 1990) where the grit, and not the grain, serves as discriminative stimulus. The employment of this different method could perhaps contribute to document the robustness of Fersen et al.'s transitive inference findings. A report (Higa-King and Staddon, 1993) had previously suggested that transitive responding in pigeons might be a relatively labile phenomenon, possibly only arising reliably under quite specific conditions.

2. Materials and methods

Ten adult domestic pigeons (*Columba livia*) of local homing stock and selected for low grit consumption served as subjects. They were housed in individual cages located in a well-ventilated room with a 12 h on/12 h off lighting cycle and were kept food-deprived to approximately 80% of their free-feeding weight. Their wire-mesh home cages (40 × 40 × 45 cm) also served as experimental chambers.

The pigeons learned to discriminate 5 varieties of grit clearly differing in particle color (red, green, blue, black, grey), shape (between spherical and polygonal), texture (between smooth and rough), size (between gross and fine) and density (between light and heavy). Care was taken that the stimulus ordering used did not correlate with any physical gradient. The grits were presented in pairs according to the scheme usual in transitive inference studies. The pigeons were trained with the pairs A + B −, B + C −, C + D − and D + E − where the letters stand for the different grits. To control for any spontaneous grit preferences the correspondence of the various grits to the letters was reversed for one half of the birds. As the results from the two groups did not differ in any significant respect they will not be distinguished in the remainder of this paper. The grit variety defined as positive stimulus covered a single food grain (maize or pea) while the grit defined as negative stimulus did not. The grits and the hidden grain making up a pair were presented in two plastic cups (4.3 cm in diameter and 4.3 cm deep) set side-by-side into a horizontal platform (14.5 × 7.5 cm). For a given trial the platform was attached outside and 2.5 cm below a cage-wall opening (10 × 6.5 cm) replacing the normal feeding trough. The trial-to-trial right-left position of the positive stimuli was varied quasi-randomly (Gellermann, 1933). The daily sessions consisted of 64 trials from sessions 1 to 26 and of 72 trials thereafter.

A correct choice was recorded if the pigeon began a trial by pecking into the positive grit. It was then allowed to find the hidden grain. If the pigeon began by searching among the grainless grit an error choice was recorded but during the early training phase it was given time to switch to the positive grit and find the reward grain before the trial was ended through removal of the platform. Initially the pigeons often switched repeatedly from one grit to the other before finding the reward grain but this response pattern soon become exceptional. Training began with grit pairs B + C − and

Table 1

Number of per-session presentations of the training pairs during the training and the testing phases. The testing phase sessions included 18 additional test pair presentations (see text)

Phase	Session numbers	Presentations			
		AB	BC	CD	DE
Training	1–10	–	32	32	–
"	11–26	16	24	24	–
"	27–30	16	24	28	4
"	31–40	16	24	28	4
Testing	41–44	12	18	21	3

C + D – . The individual pairs were initially presented in runs, first consisting of 32, then of 16, 8, 4 and 2 repeated trials, but were finally presented in randomized sequences. Next the A + B – pair was added, first presented in 16-trial runs, but then gradually reducing to randomly inserted single trials. Finally pair D + E – was introduced in a similar manner but starting with 4-trial runs. The per-session number of presentation of the various training pairs is detailed in Table 1. As will be recalled the uneven frequencies design was meant to bring about a relatively even discrimination performance across the pairs, avoiding the emergence of an end-anchor effect. Later, under Results it will be shown that the design was successful in achieving this.

From session 31 onwards, error trials ended as soon as two pecks had been delivered to the incorrect grit, correction choices no longer being allowed. A random quarter of the training trials were now not rewarded (both grits of the pair contained no grain) as a preparation for tests to be later conducted in extinction trials. Furthermore, these unreinforced trials served as a control for choices based on unintended cues, the smell of grain for example. On such trials the platform was removed as soon as the pigeon had pecked twice at either of the two grits. The sequencing of the four grit pairs, while constrained by the different frequencies was quasi-random.

Two control sessions for unintended cueing by the experimenter were conducted during the late training phase. A one-way mirror prevented the pigeons from seeing the experimenter. A control test for experimenter bias was conducted during one late training session by an uninformed assistant, who attached the platform and reported the pigeon's choices to the experimenter located elsewhere.

During the test phase all training pair trials involved a grain reward buried beneath the positive grit. Test trials were conducted with stimulus pairs AC, AD, AE, BD, BE and CE randomly interspersed among the training pairs. None of the component grits hid grain (extinction trials) and each of the 6 test pairs was presented 3 times within each session. Correct choices were recorded when the pigeon pecked twice into the grit closest to the head end of the ABCDE sequence, incorrect choices when it did so into the grit closer to the tail end of the sequence.

As a subsidiary check for robustness of the transitivity observed during these tests, 4 of the pigeons which had completed the above regime and had thus experienced the training pairs AB, BC, CD and DE during respectively 528, 1112, 1180 and 68 trials each were subsequently retrained for a further 50 sessions with the same training pairs. The same procedures as above were employed but the pair frequencies were readjusted so that at the end of the retraining these pigeons had altogether experienced each of the four training pairs in exactly 1640 training trials. They were then retested in a manner precisely equivalent to that described above.

3. Results

Seven pigeons learned rapidly. Their choice accuracy on grit pairs B + C – and C + D – was above 80% correct within 10 sessions. Fifteen and 6 sessions were required to reach the same level of accuracy on the A + B and D + E – pairs when these were added later. Three birds were less successful, not reaching this high and even level of performance across all the premise pairs when training terminated. Since they did not fulfil the precondition required for testing they were excluded from the remainder of the experiment. Individualized training programs (compare Higa-King and Staddon, 1993) could perhaps have been successful with them but for reasons of expediency they were not attempted.

Fig. 1 summarizes the mean choice accuracy achieved by the successful pigeons with each of the training pairs averaged over the four testing sessions. The performance differences between the pairs are relatively minor as compared with those reported by Fersen et al. (1991). Also, the ranking of the accuracies obtained with the training pairs (DE > CD > BC > AB) in the present study does clearly not correspond with the end-anchor effect (DE > AB > BC > CD) obtained by these latter authors (Page test; $L = 176$, $n = 7$, $k = 4$, $P > 0.05$; Bortz et al., 1990).

There were no significant accuracy differences between rewarded and non-rewarded trials with training pairs, implying that the pigeons' discriminative behavior was not based on unintended cues such as grain visibility or smell. Similarly, the control sessions involving a one-way mirror or an uninformed observer yielded no significant performance differences when compared with the preceding and subsequent sessions, showing that experimenter cueing was not a factor. This fully accords with analogous findings of Wright and Delius (1994).

The mean choice percentages corresponding to the test pairs are shown in Fig. 2A. The critical test pair for transitive inference is BD, because the component stimuli both served equally often as rewarded and as non-rewarded stimuli in the premise pairs (A + B –, B + C –, C + D –, D + E –). With 90.5% choices for grit B, it yielded a well above chance transitive responding (t -test; $t = 12.98$, $n = 7$, $P < 0.001$). The remaining test pairs are not as informative on this point because they all

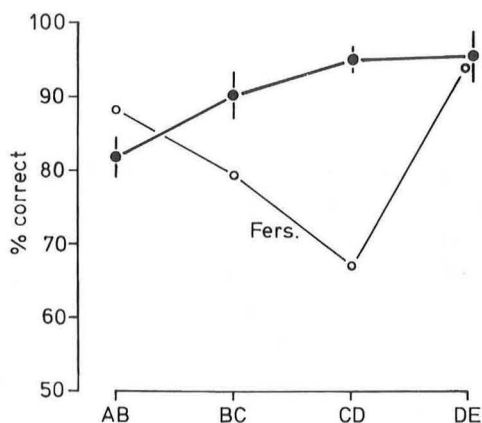


Fig. 1. Average discrimination accuracy (\pm standard errors) on the training pairs during the testing sessions. The equivalent averages from Fersen et al. (1991) is shown for comparison.

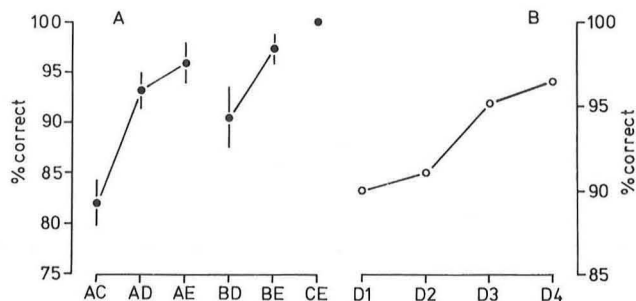


Fig. 2. Discrimination performance on test pairs. **A:** Mean percent correct choices (\pm standard errors) for the various pairs. **B:** Average percent correct for the same pairs and the training pairs grouped according to their symbolic distance (D1: training pairs; D2: AC, BD and CE; D3: AD and BE; D4: AE).

involve either grit A or grit E, respectively consistently rewarded and not rewarded. Nevertheless, none of them contravened transitivity.

Fig. 2B summarizes the test phase results ordered according to their symbolic distance. This dimension refers to the number of ABCDE sequence positions bridged by the stimuli constituting the various pairs. Even considering the test pair data alone, the choice accuracy improves significantly as the symbolic distance increases from D2 to D4 (Page-test; $n = 7$, $k = 3$, $L = 91$; $P = 0.05$), much as reported by Fersen et al. (1991) and others (Breslow, 1981). Note that because of the absence of a substantial end-anchor effect it is quite valid to include the data concerning the pairs containing the end stimuli A and E.

The 4 subjects subsequently retrained to an equal overall training pair exposure and then retested lost the even discrimination performance across premise pairs but without reproducing the usual end-anchor effect. Rather, they produced a surprisingly poor average accuracy on the head premise pair (A + B - : 57%; B + C - : 82%; C + D - : 97%; D + E - : 98% correct). Their retest yielded poor average performances with test pairs AC and AD but on the critical transitivity test pair BD and the remaining test pairs the accuracies did not differ appreciably from those obtained during the original test (AC: 50%; AD: 77%; AE: 98%; BD: 94%; BE: 98%; CE: 95%).

4. Discussion

We begin by noting that the grit and grain method promoted by Wright and Delius (1994) has again proved to be an effective discrimination teaching procedure with pigeons. The only difficulty experienced with it was that a proportion of our pigeon stock exhibited an exaggerated ingestion of grit that interfered with the intended task. As such animals were excluded the progress of acquisition was smooth and rapid. Our subjects needed about half as many training trials to learn the premise stimulus pairs as those of Fersen et al. (1991) with a conventional instrumental conditioning procedure. Apart from mimicking the normal foraging situation, to which pigeons can be assumed to be particularly adapted (Siemann and Delius, 1992), the grit and grain method supports a close temporal and spatial contiguity between stimulus, response and reward that is generally thought to be conducive to efficient learning.

Table 2

Percent correct discrimination on training and test pairs observed during the test phase. Also, percent discriminations derived for test pairs with the value estimation procedure and percent discriminations for training and test pairs simulated with Luce's conditioning model

	Training pairs				Test pairs					
	AB	BC	CD	DE	AC	AD	AE	BD	BE	CE
Observed	82	90	95	95	82	93	96	91	98	100
Derived	–	–	–	–	98	100	100	99	100	100
Simulated	91	89	100	100	99	100	100	100	100	100

The differential training pair frequencies used during the original training had the desired effect of yielding a relatively even performance. The final training pair accuracies did not exhibit any obvious end-anchor effect. This however did not prevent strongly transitive choices with the critical BD pair. Hence, at first sight, the reward/non-reward ratio explanation for transitive responding proposed as an explanation for transitive responding in the Introduction does not seem to apply here. During the test phase stimulus B was rewarded on 90% of B + C – trials and not rewarded on 18% of the A + B trials ($R_b = 5.0$) whereas choices of D were rewarded on 95% of the D + E – trials and not rewarded on 5% of C + D – trials ($R_d = 19.0$). Thus, according to this account pigeons should have preferred stimulus D over stimulus B during the test trials, quite contrary to their factual choice behavior (91% choices of B). If this contrast between reinforcement evaluations and empirical observations could stand it would go some way in favoring a value transfer interpretation such as that proposed by Fersen et al. (1991).

However, the above computation does not take into account the varying relative frequencies with which the different premise pairs were presented during the testing phase ($4 \times AB$, $6 \times BC$, $7 \times CD$, $1 \times DE$; see Table 1). These frequencies obviously affect the absolute number of times the choice of a given grit yielded reward and non-reward and they have to be therefore taken into account. The corrected ratios thus really amount to $R_b = (90 * 6) / (18 * 4) = 7.5$ and $R_d = (95 * 1) / (5 * 7) = 2.7$. This then puts again stimulus B at an advantage over stimulus D bringing about an agreement with the transitive choice factually shown by the pigeons. There is thus no need to invoke a value transfer process in the present case.

It has been argued that if the testing phase had been run with even training pair frequencies the latter correction would not have been necessary and a D over B advantage as predicted by the earlier computation could possibly have emerged. But some reflection reveals that such procedure is highly unlikely to have altered the basic situation. Ratio calculations based on such a testing phase would be ignoring the uneven pair frequencies needed to achieve the no-anchor effect performance during the preceding training phase. As soon as these unequal training frequencies would be computationally allowed for, the reinforcement ratio explanation of transitive responding would be bound to reemerge. Quite generally, an equalization of choice accuracies across the training pairs while using a quasi-randomized pair presentation sequences can only be attained with pair frequencies biased so as to compensate the different difficulties that the animals have with learning the end and middle training pairs. This forcibly will yield a reinforcement ratio imbalance favouring stimulus B vis-à-vis stimulus D.

A specific reinforcement ratio associated with a given stimulus can be expected to confer to it a proportional choice determining value. When an organism chooses stimulus X in preference to stimulus Y it can be reasonably assumed to do so based on their values V_x and V_y according to the straightforward percent choice equation $P_{xy} = V_x * 100 / (V_x + V_y)$. Given this, it is feasible to estimate relative values for our 5 stimulus grits on the basis of the empirical percent choices on the 4 training pairs. To begin with, some arbitrary value V_e must be assigned to the tail stimulus E, the actual value chosen being totally immaterial for the final percent derivations that are of interest. The relative value of stimulus D can then be derived from the actually observed choice percent P_{de} , using the expression $V_d = P_{de} * V_e / (100 - P_{de})$, a conveniently rearranged version of the above mentioned choice equation. Numerically, finding $P_{de} = 95$ (Table 2) and setting $V_e = 0.1$ one obtains $V_d = 95 * 0.1 / (100 - 95) = 1.9$. The so-obtained value V_d is then used analogously to calculate $V_c = P_{cd} * V_d / (100 - P_{cd})$, and so forth for V_b and V_a . Once these relative values V_e to V_a for the stimuli E to A have been numerically determined in this way, it is a simple matter to calculate expected choice percents for the test pairs AC, AD, AE, etc. according to the earlier mentioned percent choice function ($P_{ac} = V_a / (V_a + V_c)$, etc.). These percents are listed in Table 2 as derived scores and can be compared with the actually observed percent scores. Even if this calculation overestimates transitive responding somewhat, it serves to show that a minimal model based on stimulus values derived from the performance on the training pairs does predict transitive responding for test pairs.

Several well-known mathematical learning theories operate with stimulus values V of the kind postulated here. Some have been shown to actually predict transitive test choices, at least when the training pairs are presented with equal frequencies throughout (Couvillon and Bitterman, 1992; Siemann and Delius, 1993; Werner and Delius, 1992; Wynne, 1995; Wynne et al., 1992). Whether at least one of these models also would do so when premise pairs are presented with unequal frequencies, was examined here by running a simulation of our experiment with the particularly simple Luce model (Luce, 1959; Wynne et al., 1992). The model assumes that when a training pair $X + Y -$ is presented and stimulus X is chosen on trial $i + 1$, its value $V_{x,i}$ will be increased by a factor β_+ (reward effect). A choice of Y on the same trial will instead lead to a decrease of $V_{y,i}$ by a factor β_- (non-reward effect). The percent probability of choosing X is then determined by the above choice equation, $P_{xy} = V_x * 100 / (V_x + V_y)$, with $P_{yx} = 100 - P_x$ being the converse percent probability of choosing Y. Across a population of subjects the presentation of the pair $X + Y -$ on trial $i + 1$ accordingly will have the mean effects $V_{x,i+1} = V_{x,i} + \beta_+ * V_{x,i} * P_{xy,i} / 100$ and $V_{y,i+1} = V_{y,i} - \beta_- * V_{x,i} * (100 - P_{xy,i}) / 100$.

The numerical simulation involved setting all initial V_a to V_e values equal to 0.10, running it approximately for the same total number of trials (2700 trials) and with the same training pair frequencies as in the actual experiment (Table 1). The parameters $\beta_+ = 0.10$ and $\beta_- = 0.45$ yielded the best match with the final training pair percent accuracies. Table 2 lists the averaged percent scores obtained across the last 216 (test phase) trials of the simulation. Much as the earlier value estimation procedure, the Luce model correctly forecasts transitive choices, although again at a somewhat higher level than that empirically observed. The reasons for these recurring overestimations have been tracked down at some length in another study to which the reader is referred (Siemann and Delius, 1996a). Leaving aside this detail the results underline the basic power of the conditioning model: it can account for transitive responding even when training with unequal pair frequencies prevents the emergence of an end-anchor effect.

The stimulus value derivation procedure can in fact also grossly reproduce the test pair percent

scores obtained after the frequency equalizing retraining in the subsidiary experiment extension. However, the almost chance level performance on the AB pair could not be simulated with Luce's model, regardless of parameter values choice. We believe that the model fails in this instance because of the subject's peculiar training history. To achieve the overall exposure equalization the relative frequency of the AB pair was kept quite low during the last phase of retraining. Conditioning models that give more weight to the most recent training experience than does Luce's simple model (see, for example, Belke, 1992; Davies et al., 1993) may be better at explaining the AB performance decay but the exploration of these complex models is well beyond the scope of this paper.

As already mentioned Fersen et al. (1991) proposed that a process of value transfer was necessary for the emergence of transitive responding on test pair AB after the standard A + B -, B + C -, C + D -, D + E - training. They argued that due to straight conditioning, stimulus A (always rewarded) and stimulus E (never rewarded) would respectively end up with the values $V_a = k$ and $V_e = 0$. Stimuli B, C and D (all half rewarded) would instead attain an identical value $V_b = V_c = V_d = k/2$. However, because of the paired stimulus presentation, a fraction of these values was assumed to transfer from the first stimulus X to the second stimulus Y of each pair according to an updating function $V_y \leftarrow V_y + \alpha * V_x$. With $0 > \alpha > 0.5$ this leads to a $V_b > V_d$ inequality thus potentially accounting for transitive responding. Although some evidence for the existence of such value transfer has been obtained in specially designed experiments (Siemann et al., 1996; Steirn et al., 1995; Zentall and Sherburne, 1994) it is unlikely to have played any major role in the standard transitive responding paradigm used by Fersen et al., or indeed in the modified design used by us. The reason is that, as first pointed out by Couvillon and Bitterman (1992) and documented here, the discriminative conditioning during training will not yield anything like the stimulus value equality $V_b = V_c = V_d$ that Fersen et al. (1991) assumed as preceding their value transfer stage. Through an inherent choice-reinforcement biasing process the conditioning will instead automatically produce the value ranking $V_b > V_c > V_d$ needed for transitive responding. Indeed, the capability of Luce's model (and other similar models) to simulate transitive responding relies on precisely this circumstance (Siemann and Delius, 1996a). Elsewhere we have modelled the fractional contribution that value transfer may nevertheless be making to transitive responding (Siemann and Delius, 1996b) but the present experiment cannot, and does not contribute usefully to this issue. As far as we can judge, its results are also neutral with regard to some other theories of transitive inference (Davis, 1992: relational ordering; Harris and McGonigle, 1994: rule stack).

The most salient objective result reported here is that pigeons yielded a strong and consistent evidence of transitive inference-like responding during the critical tests despite the fact that the conditions of training employed differed markedly in several respects from those used by Fersen et al. (1991). The fact that in our experiment considerable alterations in the presentation frequencies of the training pairs had no appreciable effect on the choices during the critical BD tests, suggests that as long as a sufficiently discriminative performance on the training pairs is assured, reinforcement histories may only have minor consequences for transitivity. This indicates that the transitive responding of pigeons first reported by the above authors is a quite robust phenomenon essentially due to the emergence of an almost unavoidable reinforcement ratio inequality between the critical stimuli B and D. It also confirms that pigeons, much as humans, are prone to memorize stimulus sets that they experience in the form of pairwise inequalities as an array of linearly ranked values (Siemann and Delius, 1994). This competence, that also entails the capacity for transitive responding, is thus apparently quite widespread among higher vertebrates (Boysen et al., 1993; Davis, 1992;

McGonigle and Chalmers, 1992). Its commonness agrees with the circumstance that linearly ranked item representation strategies are probably favored by both socioecological demand (Fersen and Delius, 1992) and by computational economy (Carmesin and Schwegler, 1994), and with the fact that they can be implemented with simple conditioning mechanisms (Couvillon and Bitterman, 1992; Siemann and Delius, 1993, 1996b; Wynne, 1995; Wynne et al., 1992).

Whether transitive responding demonstrated with conditioning paradigms is in any way related to the transitive inference competences studied in humans is an as yet disputed matter (Markovits and Dumas, 1992). Traditionally, transitive inference tasks have been presented verbally and have mostly been interpreted within the framework of linguistic and rational abilities of humans. However, more recent experiments show that adult humans exposed to conditioning paradigms similar to those employed with pigeons respond transitively to test pairs much as these animals do (Siemann, 1993; Siemann and Delius, 1993, 1996a; Wynne et al., 1992). The fraction of subjects who can verbalize the strategies they purportedly used, often identify the tasks as transitive inference problems. Interestingly these subjects yield almost exactly the same response profile as task solvers that are unable to rationalize their performance (Siemann and Delius, 1996a). This profile is quite accurately predicted by the same Luce model used here. In any case, regardless of the final outcome of the dispute whether non-verbal transitive responding mechanisms are related to verbal transitive inference processes, conditioned syllogisms are likely to go on providing a strongly experimental and eminently comparative access to the field of deductive cognition.

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