Erschienen in: Die Naturwissenschaften ; 77 (1990), 11. - S. 548-549

Deductive Reasoning in Pigeons

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Transitive inference (T.I.) is the ability to rank a series of items having been given information only about the relative values of neighboring items in the series. Given that "Jane is taller than Mary", and "Jane is shorter than Gillian" the T.I.-competent subject concludes that Gillian is the tallest. In this linguistic format T.I. obviously only pertains to humans [1]. T.I. formation is here demonstrated in pigeons in a nonverbal task. We suggest that these birds use here a simple learning mechanism, and that monkeys and children may also behave according to this principle [2].

Six hungry pigeons were trained to discriminate pairs of stimuli in an operant chamber. Five different white-on-black stimuli (Fig. 1) were projected onto two translucent pecking keys. In successive trials they were presented in four overlapping pairs. One of the stimuli of each pair was designated positive (rewarded with food grains) and the other negative (punished with a brief time-out) according to the scheme $A+\ B-$, $B+\ C-$, $C+\ D-$, $D+\ E-$. This implies a sequence from $A+$ to $E-$. Half the subjects received the same stimuli with opposite values ($E+$ .. $A-$); but this led to no differences in performance and the results have been pooled here. Daily sessions consisted of 40 trials in random order. During the last 15 training sessions nonreinforced trials were introduced to prepare the subjects for test trials. The number of such trials was gradually raised to 12 out of 40 daily trials. Four subjects reached a criterion of over 80 % correct choices after 125 training sessions and proceeded to the test phase.

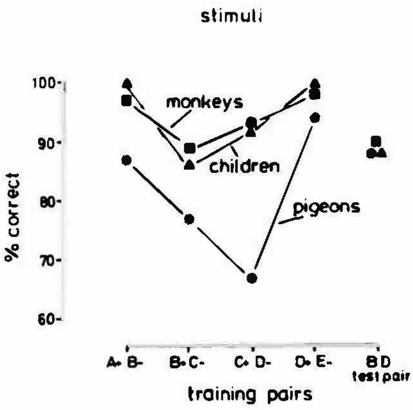

Fig. 1. Mean percent responses to the rewarded stimulus of training pairs during the last ten sessions of training as a function of the position of a stimulus pair in the transitivity series. Also mean percent correct responses to inference test pair *B D*. Pigeon data are from present experiment (insert shows the stimuli employed). The children (5-years-old) and squirrel monkey data were taken from [2] and [3]. The absolute accuracies for the different species cannot be compared because of procedural differences

This phase consisted of 12 sessions each incorporating two additional, randomly inserted test trials. These involved the presentation of the novel, nonreinforced stimulus combination *B D*. Note that during training the stimuli *B* and *D* had as often been positive as negative and were thus equivalent in terms of their reinforcement histories.

Figure 1 shows the pigeons' percent correct performance on the test pair *B D* as well as on the training pairs presented during the test sessions. On this critical test the pigeons chose stimulus *B* transitively on 87.5 % of test trials. Each of the four pigeons yielded a test choice score significantly above chance (100, 91.6, 83.3, 75.0 %; binomial tests, all $p < 0.01$). The pigeons' performances on the *B D* pair are in accordance with T.I. and agree closely with those achieved by monkeys [2] and by young children [3] in analogous tests.

The pigeons performance on the *B D* test pair was actually better than on three of the four training pairs. That items further apart on a T.I. series yield better performance than neighboring items is known as the symbolic distance effect [3]. Additionally, the pigeons' discrimination accuracies on the training pairs display a U-shaped dependency on the pairs' position in the series. A similar trend is apparent in the data from squirrel monkeys and young children, and has been referred to as the symbolic position effect [3].

It seems unlikely that pigeons solve the T.I. problem in terms of the complex symbolic and/or spatial representations

Table 1. Ranks of stimulus values and stimulus differences for a transitivity series according to value transfer theory. Value difference ranks can be compared with accuracies obtained empirically (Fig. 1)

Value	Rank	Value difference	Rank
$V_A = 2$	1	$V_A - V_B = 1 - 2a$	2
$V_B = 1 + 2a$	2	$V_B - V_C = a(1-2a)$	3
$V_C = 1 + a + 2a^2$	3	$V_C - V_D = a^2(1-2a)$	4
$V_D = 1 + a + a^2 + 2a^3$	4	$V_D - V_E = 1 + a^3(1-2a)$	1
$V_E = a + a^2 + a^3 + 2a^4$	5		

that have been proposed to explain human performance [4]. A simpler mechanism, which we term "value transfer theory" (V.T.T.) can account for the results. We assume that during pairwise training each stimulus acquires a composite value. This effective value V of a given stimulus i is determined by the addition of two components ($V_i = R_i + a*V_{i+1}$). The direct value component R_i is the value that reward confers directly to stimulus i. The indirect value component $a*V_{i+1}$ is determined by the effective value V of the stimulus $i+1$ (the stimulus which during training is rewarded when paired with stimulus i), multiplied by a weighting factor a having a magnitude between 0 and 0.5. Setting $R_i = 2$, 1, or 0 depending on whether the relevant stimulus i is respectively always, half of the time, or never rewarded, V.T.T. yields the value rankings shown in Table 1. Choice of the higher-ranked stimulus yields correct response both for training and test pairs. Assuming that choice accuracy is proportional to the value difference between stimuli further allows the theory to predict the symbolic position and symbolic distance effects (Table 1). The theoretical ranking corresponds with that empirically obtained in pigeons (Fig. 1).

These results show that pigeons are capable of behaving according to T.I. Their success, however, can be explained by a simple model. The clear competitive advantage accruing from being able to rank socially and ecologically relevant items according to fitness-conferring values may have brought about the emergence at an early stage of phylogenesis of a simple mechanism capable of yielding T.I. Whether more advanced species, such as our own, also have additional information-processing strategies available to solve T.I. problems needs further examination.

We thank the Deutsche Forschungsgemeinschaft for financial support to J.D.D. and L.v.F. C.D.L.W. was supported by the Science and Engineering Research Council, London and the A. von Humboldt-Stiftung, Bonn; J.E.R.S. was supported by the National Science Foundation, Washington and the A. von Humboldt-Stiftung. We thank A. Lohmann for help in running the experiments, Dr. W. Matthäus for initial motivation, and Drs. B. McGonigle, J. Pearce, H. Terrace, and T. Trabasso for helpful comments on earlier drafts of this paper.

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