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27 June 1969; revised 11 August 1969

Attention Shifts in a Maintained Discrimination

Abstract. *Pigeons received lights of varying wavelengths paired with sounds of varying frequencies; pecking was reinforced only at one stimulus combination. Then either the light or the sound was held constant at its reinforced value, while the other stimulus continued to vary. Subsequent tests showed that the constant stimulus had lost much of its control over the birds' responses.*

"We know a lot more about the conditions which make a stimulus 'relevant' than about those which make a stimulus 'irrelevant'." This remark by Thomas (*1*) is justified by the animal literature on attention, partly because most of this research has used a learning paradigm. Typically, naive subjects learn a task involving several stimuli; then they are tested to see which stimuli control their behavior. This paradigm emphasizes variables that favor the development of stimulus control, but it may obscure variables that affect loss of control or shifts in attention. Such matters have been clarified in human subjects by the use of difficult but well-learned discriminations that involve several classes of stimuli (*2*). My study applies some aspects of this approach to animal experimentation.

The subjects, three white Carneaux pigeons, were maintained at approximately 80 percent of their free-feeding weight. All had a long history of visual discrimination training, and prior to this experiment they had, for 6 months, daily sessions on variations of the visual and auditory tasks required in this study. The pigeon pecked at a plastic disk in an insulated chamber. Pecking produced reinforcement (2-second access to mixed grain) intermittently in the presence of one specific combination of visual and auditory stimuli. The visual stimuli were provided by a spot of monochromatic light about 0.9 cm in diameter on the plastic disk. This spot assumed one of seven wavelengths (576 to 582 nm in 1-nm steps), with a half-width dispersion of 6.6 nm and a luminance of about 7.0 millilamberts. The auditory stimuli were provided by tones from a 7.6-cm loudspeaker set in one side of the chamber. The tone assumed seven frequencies (3370 to 3990 hz in approximately equal steps) of somewhat distorted sinusoidal form. Though the chamber walls were lined with absorbent material, standing waves were prominent in the chamber; the stimulus intensity varied over a range of about 6 db near the pigeon's head, with a mean of 92 db. In addition to these variable stimuli, a small bulb dimly illuminated the chamber with indirect light, and a white noise at about 90 db was supplied through the stimulus loudspeaker at all times except during the presentation of tone stimuli.

Each day the pigeons received many brief trials during which a light and a sound came on simultaneously. On an average of 78 of these trials, a peck at the plastic disk produced reinforcement. On these trials, the sound was always set at 3990 hz and the light at 582 nm. The first trial in a session was a reinforced trial; thereafter, such trials occurred randomly, with a probability of 1/32. The remainder of the session comprised 2499 unreinforced trials. These consisted, in most sessions, of all 49 possible combinations of the seven tones and seven lights. The combination to occur on a given trial was chosen randomly, except that no combination reappeared until the entire series of 49 had appeared. This series was repeated 51 times.

During some sessions, as noted below, either the visual or the auditory stimulus remained at its reinforced value on all trials. In all other respects the procedure was the same as before. In particular, the birds were reinforced equally often and at the same stimulus

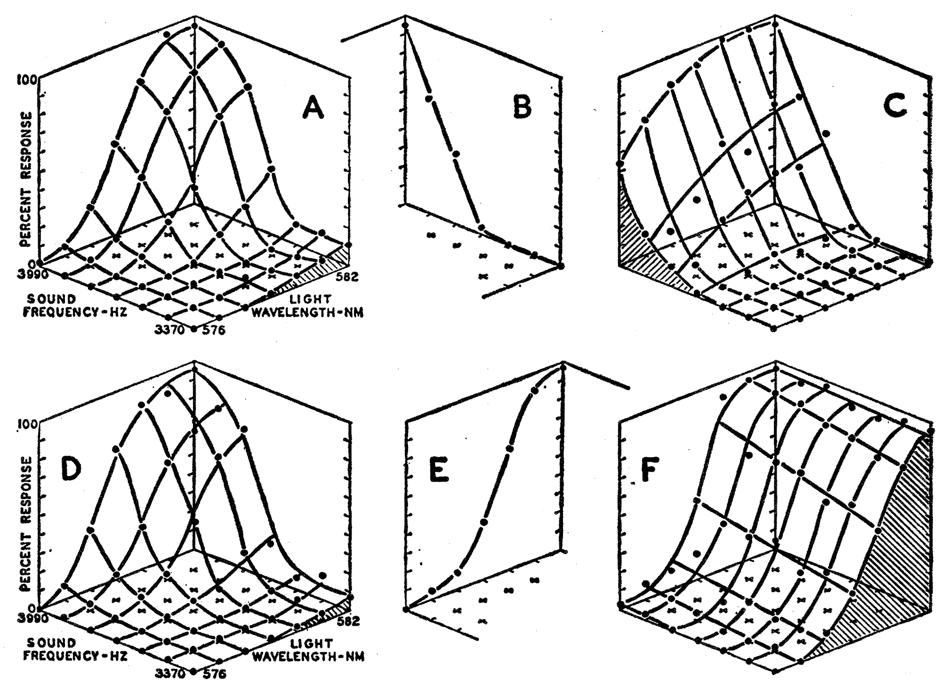

Fig. 1. Discrimination data from a single bird. (A) Mean of the last two sessions on the base-line two-dimensional discrimination; (B) last two sessions on auditory discrimination with visual stimulus constant at its reinforced value (582 nm); (C) first session on base-line procedure after visual constant training; (D) last two sessions on second base-line series; (E) last two sessions on visual discrimination with auditory stimulus constant at its reinforced value (3990 hz); (F) first session on base-line procedure after auditory constant training.

values in all phases of the experiment.

During intertrial intervals, the disk was dark and the loudspeaker emitted noise. As a trial began, one of the seven tones replaced the noise, and one of the seven lights illuminated the disk. If the bird did not peck the disk, these stimuli went off after 1.2 seconds. If the bird pecked, the stimuli went off for the remainder of the 1.2-second period and noise resumed. After an intertrial interval of from 1 to 1.5 seconds, randomly chosen, a new stimulus combination appeared. After reinforced trials, the intertrial interval was extended to 3.5 seconds; it was also extended 0.6 second beyond any peck that occurred when the disk was dark. A LINC computer controlled the experiment and recorded the pigeons' responses.

The experiment passed through seven phases. The birds were run for (i) 30 days on the base-line auditory-visual discrimination, (ii) 7 days with the visual stimulus constant at its reinforced value, 582 nm, (iii) 4 days on the base-line conditions, (iv) 11 days with the auditory stimulus constant at its reinforced value, 3990 hz, (v) 13 days on the base-line conditions, (vi) 8 days without any sessions, the birds being fed enough in their home cages to keep their weight constant, and (vii) 4 days on the base-line conditions. The birds' responses on all reinforced trials and also their responses on the first series (49 test trials) from each session were excluded from the data reported below.

Figure 1 shows data collected from one bird just before each stimulus was held constant, during the constant conditions, and just after each return to two-dimensional testing. The other two birds produced similar data, though one bird had a consistently poorer discrimination on both stimulus dimensions. Panels A and D show the base-line two-dimensional discrimination performance. It is clear that on almost all trials the bird must have "attended to" both the visual and the auditory stimuli. This can be seen by considering responses at the two margins of the stimulus matrix along which one stimulus varies while the other is at its reinforced value; these are plotted on the "walls" of the three-dimensional graphs in Fig. 1. On each of these margins in panels A and D, the response percentage goes from about 95 to 10 percent, or less. Since each dimension alone controlled almost the maximal response change, we conclude that (by definition) each dimension was "attended to." ("Perfect attention" would be assured if a stimulus dimension controlled responding over the range of 0 to 100 percent. This observation is a sufficient though not a necessary condition for "attention.")

Figure 1B shows the last 2 days during which the visual stimulus remained constant at its reinforced value. When this curve is compared with the corresponding margin in panel A, it is seen that control by the auditory stimulus has sharpened considerably. On the first day of return to two-dimensional testing, the sharpened auditory control was largely maintained, while visual control suffered severely (Fig. 1C). After 4 days on the two-dimensional procedure, however, the initial base-line performance was almost regained (Fig. 1D). Somewhat better visual control was attained during the auditory-constant procedure; the last 2 days of this appear in panel E. The first day of return to two-dimensional testing after the auditory-constant procedure (Fig. 1F) shows an almost complete loss of control by the changes in the auditory stimulus. This control was only slowly regained; after 13 days it was still somewhat worse than in the earlier base-line sessions. Figure 1 does not show the results of the 8-day rest period. After this break in experimentation, both visual and auditory control were somewhat poorer than the previous base-line performance, but the effects on each were much less than the effects of constant stimulus training. As with the other effects reported here, the magnitude of these changes might have been affected by the order in which the procedures were run, but the birds had such prolonged and varied experience with the stimuli that this seems unlikely.

One account of the results might run as follows. In the base-line condition, slight differences among visual and auditory stimuli control the bird's response and both these classes of stimuli occasion intense analytic activity ("attention"). When only one visual or auditory stimulus appears, and hence this stimulus class is uncorrelated with reinforcement, analysis of these stimuli diminishes. Analysis only gradually resumes when both classes of stimuli are again correlated with reinforcement. This is not the only possible account of these results, and, even if they retained the basic idea, various theorists might alter or reword it in various ways (*3*) that cannot be detailed here. However, a few points of theoretical relevance may be suggested. First, it would be difficult to interpret the effect of constant training as the extinction of an overt observing response. The tone stimulus "filled" the chamber, while the visual stimulus was always on the key when the pigeon pecked. Observations of the birds revealed no significant changes in gross behavior during the experiments. Second, there is some suggestion here of a trading relation between visual and auditory control. Most noticeably, auditory control got better after visual constant training, and worse again on return to two-dimensional training (right margin, Fig. 1, A–D). Third, the results appear to separate the "salience" of the two sets of stimuli from their "discriminability." Auditory control was not as complete as visual in the two-dimensional tests (Fig. 1, A and D); it was lost more completely (Fig. 1F) and regained much more slowly than visual control. Yet, under the present conditions these auditory stimuli were differentiated more accurately than were the visual stimuli (Fig. 1, B and E).

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References and Notes

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Protein Subunits: A Table (Second Edition)

A table containing a list of proteins in which subunits are held together by noncovalent bonds was published in *Science* 2½ years ago (*1*). The wide response from readers indicates that this table was useful for research and teaching purposes. It seems appropriate, therefore, to prepare a revised edition which includes new listings as well as changes that are required to bring the earlier entries up to date.

Decisions with regard to the entries in Table 1, as well as choices of references, have been based on the same criteria described previously (*1*).