SHORT COMMUNICATION

FURTHER EFFORTS AT TRAINING PIGEONS TO DISCRIMINATE CHANGES IN THE GEOMAGNETIC FIELD

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Although magnetic sensitivity in pigeons can reasonably be inferred from the impairment of homing by magnetic attachments to their heads (e.g. Keeton, 1971; Walcott and Green, 1974), which have been found to contain magnetite (Walcott *et al.* 1979), attempts to develop training methods suitable for systematic psychophysical analysis have been largely unsuccessful. Of four classical conditioning experiments with magnetic change as the conditioned stimulus, shock as the unconditioned stimulus and overt activity (Orgel and Smith, 1954) or cardiac acceleration (Beaugrand, 1976; Kreithen and Keeton, 1974; Reille, 1968) as the conditioned response, only one (Reille's) gave any indication of conditioning. Of three experiments in which pigeons were rewarded with food or water for pecking a target in response to magnetic change (Alsop, 1987; Meyer and Lambe, 1966; Moore *et al.* 1987), all gave negative results. Bookman (1977) had some success with a flight tunnel in which his animals were rewarded for going to one or the other of two food boxes depending on the prevailing magnetic field, but the results of similar experiments by subsequent investigators were negative (Carman *et al.* 1987; McIsaac and Kreithen, 1987).

This further training effort with pigeons was encouraged by the finding in recent work on magnetoreception in honeybees (Walker and Bitterman, 1989; Walker *et al.* 1990) that the detection of earth-strength anomalies could be facilitated by prior training with a very strong anomaly. Except for the early experiment on classical activity conditioning (Orgel and Smith, 1954), pigeons had always before been trained with earth-strength anomalies, and it seemed reasonable, therefore, to try again with an intense anomaly, using the versatile and highly efficient pecking technique.

The anomaly was produced with two coplanar, concentric, double-wrapped coils constructed for the measurement of honeybee magnetic thresholds. The coils were set not in a laboratory window as before, but in one wall of a plastic and aluminum pigeon chamber. The inner coil was wound around a piece of Plexiglas tubing, 2.5 cm long and 2.5 cm in diameter, that now invited the entrance not of a honeybee seeking sucrose, but of the beak of a pigeon pecking at an illuminated plastic target directly behind it. A

current of 1 A through the coils produced a sharply focused anomaly of 30 times earth strength in the area of beak insertion (see Walker and Bitterman, 1989, Fig. 1, p. 490, for details).

As a check on the adequacy of the training procedure to be used with the magnetic anomaly, nine experienced pigeons were trained first to discriminate the presence or absence of an 80-dB, 600-Hz tone from a speaker in the roof of the chamber. Each trial in 10 daily sessions of 40 trials began (after an intertrial interval of 30 s) with the onset of a white light behind the translucent pecking target. On half the trials (S+ trials), the first peck at the target after an interval of 15 s turned off the target light and produced the reward (4-s access to a tray filled with mixed grain). On the remaining (S−) trials, the first peck after 15 s started a 5-s penalty timer that was reset by each subsequent peck, and the trial ended (without reward) only after the animal refrained from pecking for 5 s. The measure of performance on each trial was the number of pecks in the first 15 s. For four of the nine animals, each peck on an S+ trial turned on the tone for 1 s; that is, the birds had to peck the target in order to hear the tone, just as in the following magnetic discrimination problem they would have to peck the target to encounter the strong field in its immediate vicinity. On S− trials, there was no tone. For the remaining five animals, the tone was produced by pecking on S− but not on S+ trials.

The asymptotic performance of the animals is shown in Fig. 1A, which is based on the pooled data of the last four training sessions. The two curves, which are plotted in terms of the mean rate of response on each of 20 S+ and 20 S− trials, give clear evidence of discrimination [$F(1,7)=19.35$, $P=0.0032$]. Whether the tone was S+ or S− made no
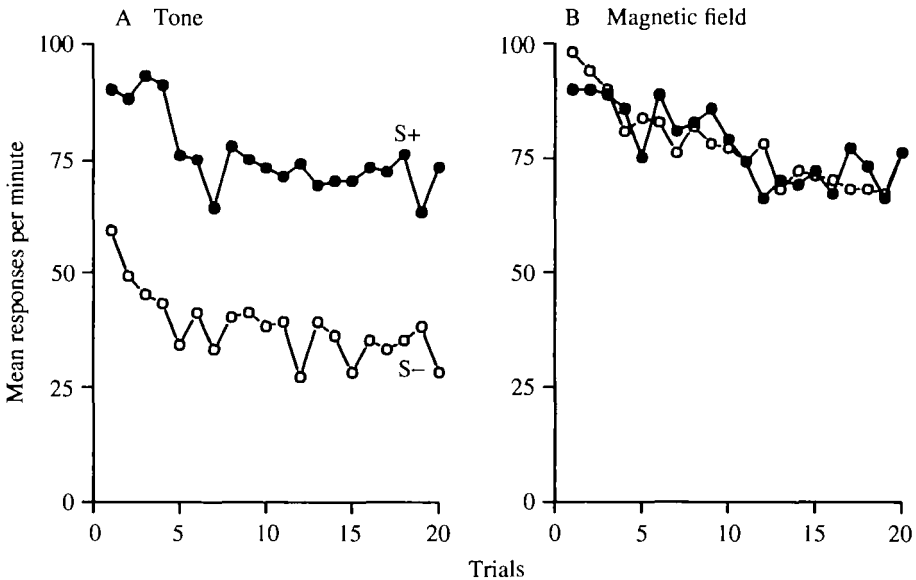

Fig. 1. Mean rate of responding in successive trials within sessions to the rewarded (S+) and nonrewarded alternative (S−) in training to detect (A) a 600-Hz tone and (B) a marked increase in magnetic field intensity.

difference ($F<1$). The gradual decline in the rate of responding over trials within sessions that is evident in the curves is common in training of this kind.

The next step was to introduce the magnetic anomaly along with the tone. The coils were energized at the start of every tone trial (whether S+ or S−) and remained so for the duration of the trial. Over the first four sessions, the tone was 'faded out', which is to say that its intensity was reduced in stepwise fashion (a standard procedure for transferring control of discriminative performance from one set of stimuli to another), and in the next 16 sessions the tone was eliminated altogether. As the intensity of the tone was reduced, differential performance (difference in rate of responding on trials with tone-plus-anomaly *vs* no tone in the ambient geomagnetic field) was reduced, disappearing altogether in the fourth session at the intensity of 62.5 dB. In the next 16 sessions, there was no indication of differential response in the presence *vs* the absence of the anomaly alone. Pooled performance in the last four sessions is plotted in Fig. 1B, which shows that the animals responded both to S+ and to S− at the same rate as to S+ in the tone *vs* no tone discrimination.

On subsequent days, there was refresher training on the tone *vs* no tone discrimination until performance like that shown in Fig. 1A was re-established, following which there was further training on the anomaly *vs* ambient field discrimination, but now the anomaly was time-varying in a 1-Hz square wave. (The coils were energized once each second for a period of 0.5 s.) No sign of magnetic discrimination appeared in more than 20 training sessions, during which the performance of the animals resembled that shown in Fig. 1B.

Despite these negative results, it was tempting to look further for evidence of a learned response to magnetic change, now in direction rather than intensity. The goal was to determine whether the birds could detect a simple 90° shift in field direction but with approximately the same intensity. The field direction was shifted by the use of a large pair of square coils, 122 cm to the side and separated by 73 cm – a square analog of circular Helmholtz coils yielding optimal field uniformity (Lee-Whiting, 1957). The coils were so aligned that when activated they produced a NE-to-SW horizontal magnetic component, shifting the field from north to west. In addition, the ambient field intensity increased from 60 to 70 μT (Wiltschko, 1972). The small coils at the pecking target were removed and the entire chamber, with the pigeon facing north, was placed between the large coils. Again, in this situation the animals were trained in two tasks, one to discriminate the presence of a continuous tone (presented independently of response) from its absence, and the other to discriminate change in magnetic field direction (produced by continuously energizing the square coils) from the ambient direction. For the animals previously trained with tone as S+, tone continued to be S+, and for the others the tone was S−; for animals previously trained with the magnetic anomaly as S+, the shift in direction was S+, and for the others the shift was S−.

A simplified, free-operant training procedure was used. In each 30-min training session, 3-min S+ and S− presentations were regularly alternated. In S+ segments, pecks at the target were rewarded with 4 s of mixed grain on the average of once per minute (a VI-1 min schedule); in S− segments, there was no reward. Under these conditions, as before, the animals mastered the tone discrimination but not the magnetic discrimination. In Fig. 2A, asymptotic performance in the tone problem (pooled over the last four
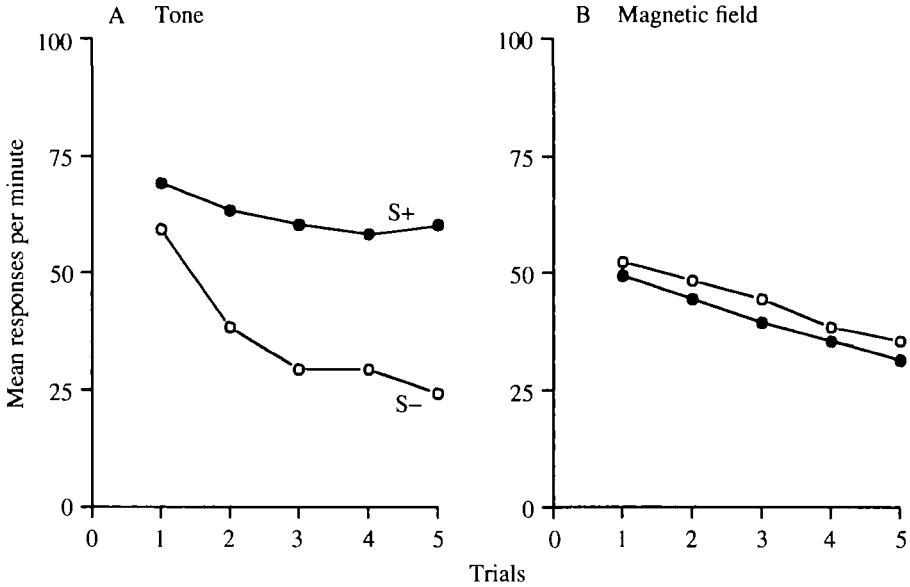
Fig. 2. Mean rate of responding in successive trials within sessions to the rewarded (S+) and nonrewarded alternative (S−) in training to detect (A) a 600-Hz tone and (B) a 90° change in magnetic field direction.

training sessions) is plotted in terms of mean rate of response to S+ and S− in each segment. The difference in response to the two stimuli is highly significant [$F(1,7)=20.37$, $P=0.0028$] regardless of whether the tone was S+ or S− ($F<1$). In the directional problem, the animals gave no evidence of discrimination, even after 40 sessions. Pooled performance in the last four sessions of training in that problem is plotted in Fig. 2B.

Here, then, is another report of failure to train confined pigeons to discriminate changes in the ambient geomagnetic field. To judge from work with honeybees (Walker et al. 1989), these failures may reflect not the absence of magnetoreception in pigeons, but only our ignorance of the circumstances under which magnetic information is processed by the animals, which may be such as to make formal learning studies impractical. Although it would be interesting to try to define those circumstances, the easiest avenue to understanding the magnetosensory system in itself may be found in physiological preparations.

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