cell to receive a 25-second model presentation. Behavior was considered shaped after the fish showed at least ten responses per hour on a 100 percent reinforcement schedule.

Training was confined to four 30-minute sessions daily, with a 45-minute intersession interval. At the beginning of each session, two 100-watt overhead lights were turned on, and an initial reinforcement was triggered by the experimenter. Training was on a 7-second fixed interval schedule. Fish were trained for 2 days and then subjected to 2 days of extinction sessions, during which occluding the photocell had no effect. The number of correct responses per session (maximum of 60) was recorded on an event recorder.

Nine individuals were trained and subjected to extinction once. The number of responses per session was analyzed by a three-way analysis of variance for differences between training and extinction, between days 1 and 2 of training or extinction, and between individuals (Table 1). The comparison between training and extinction showed the greatest difference. The mean numbers of responses per session (30.2 and 35.0 for days 1 and 2 of training, respectively, and 15.8 and 7.1 for days 1 and 2 of extinction) resulted in the expected interaction between day and training-extinction. Differences between individuals were significant, with a range of 7.2 to 26.6 for the mean number of responses per session under all conditions. Correction for the multiple testing procedure indicated that the interaction between individuals and training-extinction was not statistically significant (*5*), but considerable individual variability was evident.

The moving model was sufficient reinforcement for conditioning of the photocell-crossing response. The natural posing behavior of the hosts probably facilitated formation of this conditioned response. Several of the fish posed in front of the photocell. Others merely swam past or developed persistent adventitious behavior such as swimming across the tank before crossing the photocell. Many of the differences between individuals were probably due to this variability in behavior.

During reinforcement, the fish almost always positioned itself next to the model so that the model repeatedly contacted the fish's side. This behavior, as well as response to a variety of models, suggests that the tactile portion of this stimulus is primarily responsible for the reinforcing value. Cleaner fishes

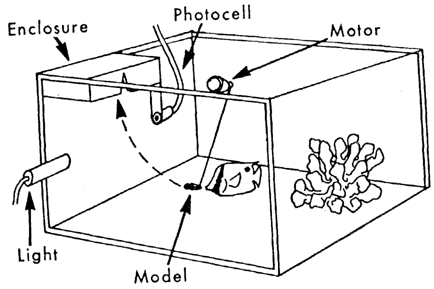

Fig. 1. Apparatus used for conditioning *C. auriga*. The cleaner model is pictured in the reinforcement position.

of the genus *Labroides* deliver similar stimulation by rubbing the host with their pelvic fins and prodding them with their jaws. This study demonstrates how the frequently reported cleaning in captivity between normally allopatric species [for example (*1*)] might come about: Hosts might quickly learn to recognize any new cleaner as a source of tactile stimulation. This explanation avoids the need to hypothesize worldwide characteristics or "guild signs" for cleaners (*6*) to account for this recognition.

Presentation of models to a variety of reef fish species during the development of these techniques indicated that this reinforcement method might be applied to discrimination and classical conditioning studies in reef fishes. This might provide a valuable check for research in which food has traditionally been used as a positive reinforcer for fishes. Tactile reinforcement may also avoid many problems of satiation during training: Fish can be tested for several hours per day with little decrement in performance.

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28 September 1973

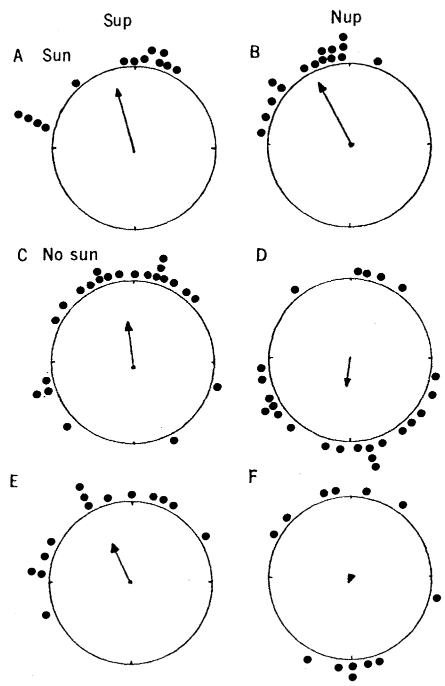
Orientation of Homing Pigeons Altered by a Change in the Direction of an Applied Magnetic Field

Abstract. *Homing pigeons were equipped with a pair of small coils around their heads. Birds with an induced field of 0.6 gauss and the south magnetic pole up, oriented toward home normally under both sun and overcast. Birds with the polarity reversed oriented toward home when the sun was visible but often flew away from home under overcast.*

Evidence has accumulated that magnetic fields may be involved in the orientation of birds. The directional preferences of ring-billed gull chicks are upset during periods when the magnetic field of the earth is disturbed (*1*). European robins show a tendency to orient in relation to a real or artificial earth field (*2*). The initial orientation of tactile stimulation. This explanation small bar magnets attached to the pigeon's backs (*3*). We present evidence here suggesting that the orientation of pigeons is altered by changing the polarity of the applied magnetic field.

A flock of approximately 50 homing pigeons was kept in a small loft on the university campus at Stony Brook, New York. These birds were progressively trained along a line to the east of the loft under both sunny and overcast conditions. Experimental releases were made from three locations: Cunningham Park, 68 km, 251° (compass direction, from the loft); Hempstead, 59 km, 242°; and Spring Valley, 92 km, 287°. At the release site each pigeon was equipped with a pair of coils. One coil, 35 mm in diameter, was fitted around the pigeon's neck like a collar and the other, 23 mm in diameter, was glued to the top of the head like a hat. Each coil was made of 200 turns of No. 36 enameled wire, and the two coils were connected in series with a 1.4-volt mercury battery. This combination produced a relatively uniform magnetic field of about 0.6 gauss around the pigeon's head. A

Fig. 1. Vanishing bearings of pigeons equipped with Helmholtz coils. Each dot represents the direction of a pigeon at 10 miles from the release point. Home is at the top of the circle, and the arrow is the mean vector of the distribution; its length is proportional to the degree of clumping of the vanishing bearings. In diagrams A and B, the birds were released under sun. In C and D the birds were released under total overcast for the first time at this release point; E and F are the vanishing directions of the same birds as in C and D but with opposite treatments released for the second time at this release point.



gaussmeter (Bell model 620) showed that the field between the coils varied from 1.4 gauss at either coil to 0.5 gauss in the center of the space between them. The life of the battery was 2 to 3 hours. By simply reversing the battery in its holder it was possible to reverse the flow of current through the coils and, thus, the direction of the magnetic field surrounding the bird's head. When a magnetic compass was placed between the two coils with the north seeking end of the needle pointed toward the coil glued to the top of the bird's head, we defined the coil as a Nup (north-up). A coil with the opposite polarity was a Sup. In addition to the two coils and battery, each bird carried a small radio beacon. The vanishing bearings reported here are the direction in which the radio signal was lost when the pigeon was approximately 16 km from the release point (*4*). Nups and Sups were released alternately.

Under sunny conditions the vanishing directions of the two groups, Nups and Sups, appeared to be well oriented toward the home loft (Table 1 and Fig. 1). Surprisingly, a significance test for the mean direction (*5*) shows that the Nups chose a direction that differed at the 1 percent level from home. A Watson test (*5*) shows that the two distributions of vanishing points differ ($P = .005$) although the mean vectors are only 11° apart. Despite these statistical measures, we had the impression that the orientation of Nups and Sups under sunny conditions was quite similar.

When the sun was not visible through heavy overcast, the difference in the behavior of the two groups was much more pronounced. Neither group was as well oriented toward the loft as the group released under sun. As Fig. 1 shows, birds with Sup coils vanished predominantly toward home [*V*-test, $P = .008$ (*5*)], whereas birds with Nup coils were oriented away from the direction toward home. The Watson test gives the probability that the two samples were drawn from the same distribution as less than .005. Despite this difference in initial orientation, the homing performance of the two groups was similar (Table 2). Considering the relatively short life of the battery when compared to the long time it took the birds to home this is not surprising.

Pigeons that returned from these overcast releases were now taken to the same release point for a second time. Birds that had worn Sup coils before were equipped with Nup coils, and birds that had worn Nup coils were now given Sup coils. Once again when released under total overcast the Sup birds were oriented toward home. About half the Nup birds oriented toward home, and about half flew in the opposite direction. This result demonstrates that the behavior of at least half of the birds could be altered by reversing the magnetic field. It also suggests that previous experience at the release site may have reduced the tendency of Nup birds to fly in the wrong direction.

Taken together these results indicate that varying the direction of an artificial magnetic field around a pigeon's head has an effect on its initial orientation although it has little apparent effect on its total homing performance.

Since each pigeon had identical apparatus that differed only in the direction of current flow, it is hard to see how the results could be an artifact of the experimental arrangement. Furthermore, since the effect of differing fields is more pronounced on overcast than on sunny days, it may be that pigeons are, in some way, using the earth's magnetic field as a compass when the sun is not visible.

It is interesting to compare these re-

Table 1. The results of each release under the various experimental conditions. *N* is the number of birds tracked, *B* is the 10-mile vanishing bearing (degrees) relative to the direction to the loft; *l* is the length of the unit vector (arbitrary units), and *P* is the probability that the sample was drawn from a random distribution.

Release site	Date	Sup				Nup			
		N	*B*	*l*	*P*	*N*	*B*	*l*	*P*
			Sun						
Hempstead	17 Oct 71	6	305	.86	.007	6	323	.89	.004
Cunningham Park	27 May 72	3	16	.98	.04	4	314	.91	.03
	22 Oct 72	4	4	.98	.01	5	352	.96	.005
	Summary	13	342	.79	.00007	15	331	.88	6×10^{-7}
			Inexperienced birds under overcast						
Cunningham Park	31 Oct 71	5	358	.92	.009	4	124	.57	.27
Spring Valley	20 Nov 71	5	4	.64	.12	4	228	.89	.03
Cunningham Park	1 Nov 71	4	261	.72	.12	4	73	.17	.89
	13 Nov 72	4	9	.51	.36	5	200	.48	.32
	28 Nov 72	1	10			1	169		
	4 Dec 72	0				2	129	.98	.13
	20 Dec 72	0				1	244		
	30 Mar 73	1	44			0			
	8 May 73	3	39	.56	.39	3	262	.39	.45
	Summary	23	352	.52	.001	24	188	.36	.04
			Experienced birds under overcast						
Cunningham Park	4 Dec 72	2	334	.99	.13	1	179		
	20 Dec 72	3	270	.97	.05	1	169		
	3 Mar 73	3	346	.77	.16	4	216	.14	.92
	30 Mar 73	3	342	.65	.28	4	107	.15	.91
	4 Apr 73	3	1	.92	.07	3	216	.19	.90
	Summary	14	330	.71	.0003	13	207	.09	.91

Table 2. Homing success.

Time	The number of birds which homed on:					
	Sun		Overcast			
			Inexperienced		Experienced	
	Sup	Nup	Sup	Nup	Sup	Nup
Day of release	9	13	3	1	7	7
1 day after	3	1	3	2	3	2
2 days after	0	0	6	7	0	0
3 days after	0	1	6	2	0	0
After 3 days	0	0	0	2	0	0
Never homed	1	0	5	10	4	4

sults with the orientation of European robins (*Erithacus rubecula*) described by Wiltschko (*6*). He reports that his birds use the inclination of the magnetic field of the earth and interpret the direction in which the magnetic field vector and gravity vector make the smallest angle, as north. The earth's magnetic field in the Long Island area has an intensity of about 0.6 gauss and an inclination of 70°. This field would combine with the field from our coils to produce a total field around the pigeon's head. The intensity and inclination of the resulting field would depend on the orientation of the pigeon's head with respect to the earth. This in turn would vary with the direction that the pigeon was flying and with the angle at which it held its head. We have estimated the pigeon's head angle from photographs of flying pigeons; the coils should produce a field oriented from about 10° to 45° above the horizon. We then plotted the net vector resulting from the combination of the earth's field and the field of the coils carried by the pigeon. The resultant obviously depends on the direction in which the bird flies, but the interesting point is that a bird with a Sup coil finds the total magnetic field vector most steeply inclined (the smallest angle between the magnetic field vector and gravity) when flying north, whereas a bird with a Nup coil finds the steepest vector when flying south. If pigeons were using the direction of the steepest inclination of the field to indicate north, then perhaps this would explain why there was a tendency for pigeons with Nup coils to fly 180° away from home when the sun was not visible.

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Inhibition of Cell Metabolism

The use of metabolic inhibitors has been of great value in eukaryotic cell research. However, the interpretation of results is fraught with peril and requires a careful measure of unanticipated side effects. A serious error in interpretation is possible in the type of experiment reported by Grayson and Berry (*1*). They show inhibition of protein synthesis after the administration of cordycepin and conclude that this inhibition is a measure of messenger RNA (mRNA) half-life. However, much the same results are obtained if the drug is administered to HeLa cells, that is, synthesis decays with a half-life of approximately 2 hours; however, the mRNA lifetime in HeLa cells has been determined to be considerably longer than that (*2*). Cordycepin actually appears to have a direct effect on translation rate. In fact, in HeLa cells, after the administration of cordycepin for several hours, normal-looking polyribosomes are obtained, but the ribosomes no longer are functioning. We do not know the nature of the lesion, but it could conceivably involve adenosine triphosphate metabolism or the substitution of cordycepin for the terminal adenosine in cytosine-cytosine-adenosine turnover on transfer RNA.

The use of cordycepin as a differential inhibitor of mRNA metabolism is restricted to comparatively short times (approximately 2 hours or less). At longer times, the drug has other effects on the cells which are difficult to interpret. Certainly the assumption that protein synthesis decline reflects the decrease in available mRNA is unwarranted. While the authors may consider that HeLa cells are not analogous to the insect material they have studied, before they conclude that they have indeed measured a messenger half-life, a direct measurement of mRNA or polyribosomes is necessary.

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28 June 1973

We appreciate Penman's comments about the pitfalls of interpretation of inhibitor experiments. Our report clearly demonstrates that two inhibitors which ought to produce similar estimates of mRNA half-life in intact cells produce very different data. Our suggestion that the cordycepin kinetics for the decay of protein synthesis may be more realistic than those derived from the use of actinomycin D requires more direct confirmation. We are attempting to isolate and characterize the mRNA produced by colleterial secretory cells and hope to gain further insight into the problem of determining messenger half-life.

It is difficult to compare our results with data that are not generally available at present, but it seems important to emphasize the rather considerable differences in the experimental systems being compared. Most obviously, the