

Magnets Interfere with Pigeon Homing

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ABSTRACT Magnets glued to the backs of experienced pigeons often resulted in disorientation when the birds were released from distances of 17-31 miles (27-50 km) under total overcast, whereas no such disorientation occurred during similar releases under clear skies. The magnets did, however, often cause disorientation when first-flight birds were released under sun, and there was some indication of disturbance to experienced pigeons released under sun at longer distances.

The possibility that homing pigeons may use the earth's magnetic field as one source of navigational information has been suggested for more than a century (1-4). However, several writers have objected on theoretical grounds (5), and others who have attempted to detect a sensitivity of birds to magnetic stimuli or condition birds to respond to such stimuli (6) have been unsuccessful. Furthermore, though Yeagley (2) reported that in one test release pigeons that carried magnets were disoriented, whereas controls carrying brasses were not, he did not get the same result in tests reported later (3), nor were other investigators (7) able to find any disorienting effect of magnets. Consequently, the idea that magnetic cues are used in avian orientation fell into general disfavor.

Recently, however, several Russian workers (8) have noted a general increase in locomotor activity when birds are placed in artificial magnetic fields. Reille (9) has reported success in conditioning pigeons to respond by heart-rate changes to changes in the strength of an artificial magnetic field only slightly stronger than the earth's. Merkel (10), and his colleagues Wiltshko and Fromme, have reported that European Robins can maintain migratory directional preferences in the absence of visual cues, and that alteration of the directional component of the magnetic field surrounding their cages produces predictable deviations in their orientation, though Perdeck (11) has been unable to repeat these experiments. Southern (12) has reported a correlation between the accuracy of the orientation of Ring-billed Gulls and fluctuations in the strength of the earth's magnetic field. Lindauer and Martin (13) have clearly shown that terrestrial magnetism effects the orientation of the "waggle run" in the dance of honeybees. A number of authors have claimed to find orientational responses to artificial magnetic fields in several other invertebrates (14). And, Lissmann and Machin (15), by demonstrating that the electric fish *Gymnarchus niloticus* can respond to a magnet that induces a gradient in the fish's body of only $0.15 \mu\text{V}/\text{cm}$, have made much less convincing the traditional theoretical objection that the earth's magnetic field is too weak to be detected by organisms.

In view of these recent reports, and in view of our own (16) demonstration that there is redundancy of cues in the pigeon orientational system, it seemed appropriate to reinvestigate the effect of magnets on the homing behavior of pigeons.

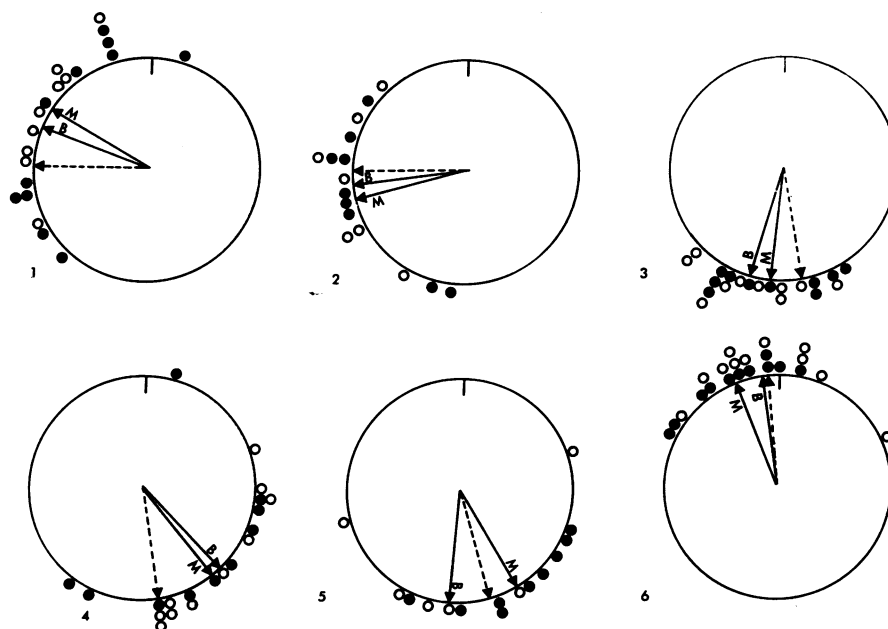
Each of our tests consisted of releasing, alternately, individual pigeons from two groups; the birds for the two groups were selected randomly from a flock housed in a single pen, where they had experienced identical feeding, exercise, and training schedules. The birds of the experimental group wore a magnet bar glued, just before release, to the back at the base of the neck, and the birds of the control group wore a brass bar. Both kinds of bars were about $2.5 \times 0.6 \times 0.3$ cm and weighed 2.7-3.2 g. The strength of the magnets was about 255 gauss at the poles; the field strength at the bird's head was roughly 0.45 gauss. The bars were glued to the skin using veterinary Branding Cement (Victor Business Forms Co., Lincoln, Nebr.), which is completely nontoxic and nonirritating; only in a few cases, when birds were lost for several weeks, did a bar ever fall off.

The birds were carried to the release sites in closed vehicles. They were tossed from the hand in random directions. Two observers watched each bird with 10×50 binoculars until it vanished from sight, and a compass bearing for the vanishing point was recorded to the nearest five degrees. The vanishing interval, i.e. the interval between toss and vanishing, was timed with a stop watch.

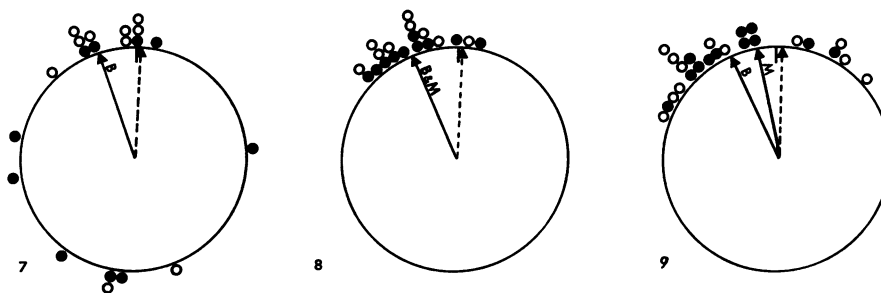
The circular mean for each group of vanishing bearings was calculated by vector analysis (17). The V test (18) was used to determine whether the bearings were significantly homeward-oriented. The vanishing intervals and homing speeds of experimental and control birds were compared by means of the matched-pairs signed-ranks test (19).

In a first series of 6 tests, conducted in 1969, experienced pigeons were released under sun both at familiar sites (Figs. 1-3) and at sites where they had never previously been released (Figs. 4-6). In all 6 tests, both the controls and the experimental birds were well-oriented homeward. In none of these tests was there a significant difference between the controls and experimental birds in homing speeds, and in only one test (Fig. 4) was there a significant difference in vanishing intervals, the birds with magnets taking longer ($P = 0.042$). Thus, these results agreed with those published by most other workers (3, 7).

However, the results were somewhat different in a second series, which consisted of three tests conducted under clear skies at an unfamiliar site, 52.5 miles (about 85 km) from the loft, in 1970. The birds with magnets in the first of these tests vanished randomly, whereas the control birds were oriented



FIGS. 1-6. Series 1—tests of experienced birds under sun at familiar release sites (Figs. 1-3) and at unfamiliar release sites (Figs. 4-6). Fig. 1. Marathon, N.Y., 21 May 1969, 20.8 miles, home direction 269°; mean bearing of control birds 290° (oriented, $P = .0002$), mean bearing of birds with magnets 300° (oriented, $P = .007$). Fig. 2. Marathon, 22 May 1969; mean bearing of control birds 262° (oriented, $P = .0006$), mean bearing of birds with magnets 255° (oriented, $P = .002$). Fig. 3. Locke, N.Y., 26 May 1969, 16.6 miles, home direction 171°; mean bearing of control birds 194° (oriented, $P = .0001$), mean bearing of birds with magnets 185° (oriented, $P < .0001$). Fig. 4. Locke, N.Y., 25 Aug. 1969; mean bearing of control birds 134° (oriented, $P = .002$), mean bearing of birds with magnets 138° (oriented, $P = .010$). Fig. 5. Fleming, N.Y., 8 Sept. 1969, 30.4 miles, home direction 164°; mean bearing of control birds 186° (oriented, $P = .027$), mean bearing of birds with magnets 148° (oriented, $P = .0003$). Fig. 6. Near Nichols, N.Y., 29 Oct. 1969, 30.7 miles, home direction 355°; mean bearing of control birds 353° (oriented, $P < .0001$), mean bearing of birds with magnets 337° (oriented, $P < .0001$). [In these and all later figures, true north is indicated by a line at the top of the circle, the home direction by an unlabeled dashed arrow, and the mean bearings by solid arrows labeled B (brass) or M (magnet). Each open symbol on the periphery of the large circle indicates the vanishing bearing of one control bird, and each solid symbol the bearing of one bird with magnet.]



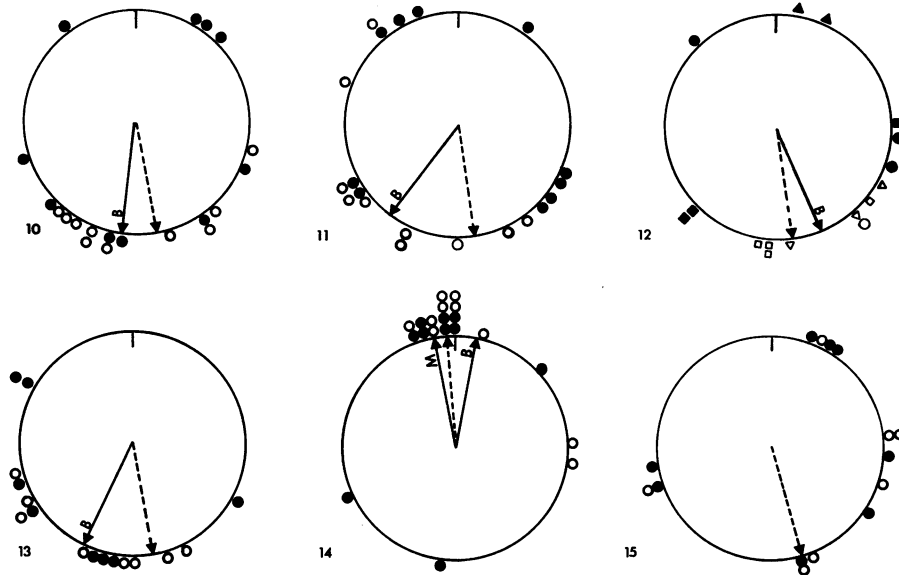
FIGS. 7-9. Series 2—tests of experienced birds under sun at Kellogg Fire Tower, Pa. (an unfamiliar site), 52.5 miles, home direction 3°. Fig. 7. 20 May 1970; mean bearing of control birds 341° (oriented, $P = .009$), birds with magnets not homeward oriented ($P = .34$). Fig. 8. 21 May 1970; mean bearing of control birds 338° (oriented, $P < .0001$), mean bearing of birds with magnets 338° (oriented, $P < .0001$). Fig. 9. 8 July 1970; mean bearing of control birds 337° (oriented, $P = .0005$), mean bearing of birds with magnets 350° (oriented, $P < .0001$).

homeward (Fig. 7); the birds with magnets also had significantly slower homing speeds ($P = 0.022$). In the second and third tests, both groups were homeward oriented (Figs. 8 and 9), but the birds with magnets of both tests had significantly longer vanishing intervals ($P = 0.023, < 0.005$) and in the second test had slower homing speeds ($P = 0.009$).

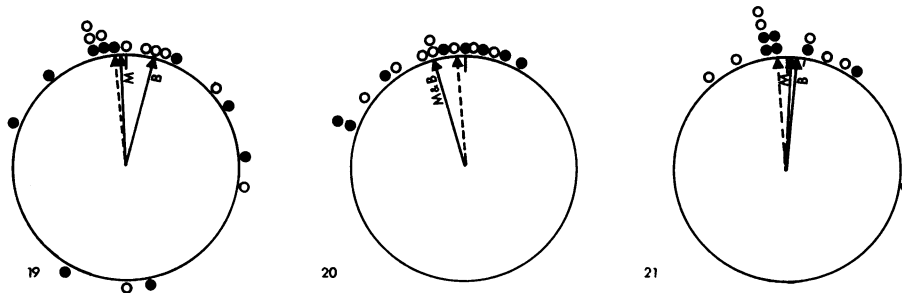
In a third series, consisting of 7 tests, experienced birds were released at unfamiliar sites under total overcast. In five of these tests (Figs. 10-13), the results were strikingly different from those obtained in 8 of the 9 releases under sunny conditions; the control birds were homeward oriented, whereas

the birds with magnets were not.* In the release shown in Fig. 10, the birds with magnets had significantly slower homing speeds ($P = < 0.025$), and in the releases shown in Figs. 12 and 13 they had significantly longer vanishing intervals ($P =$

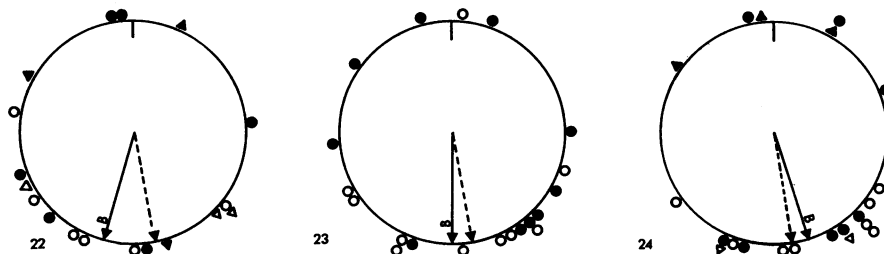
* The magnet birds in the test of Fig. 13 were not statistically homeward oriented, but they were not as scattered as those in the tests of Figs. 10-12. It may be important to record that these birds had accidentally been given a flock training release from a point only three miles southwest of the test site during the week preceding the test.



FIGS. 10-15. Series 3—tests of experienced birds under total overcast at unfamiliar release sites. Fig. 10. Locke, N.Y., 23 May 1969, 16.6 miles, home direction 171° ; mean bearing of control birds 181° (oriented, $P = .0003$), birds with magnets not homeward oriented ($P = .29$). Fig. 11. Locke, N.Y., 10 July 1969; mean bearing of control birds 217° (oriented, $P = .025$), birds with magnets not homeward oriented ($P = .49$). Fig. 12. Locke, N.Y., 2 Sept. 1969 (*triangles*), 5* (*squares*), 6* (*circles*); mean bearing of control birds 158° (oriented, $P = .0005$), birds with magnets random ($P = .604$). Fig. 13. Locke, N.Y., 24 Sept. 1969; mean bearing of control birds 202° (oriented, $P = .003$), birds with magnets not homeward oriented ($P = .085$). Fig. 14. Near Nichols, N.Y., 10 Nov. 1969, 30.7 miles, home direction 355° ; mean bearing of control birds 11° (oriented, $P = .0006$), mean bearing of birds with magnets 348° (oriented, $P = .004$). Fig. 15. Fleming, N.Y., 25 Sept. 1969, 30.4 miles, home direction 164° ; control birds random ($P = .11$), birds with magnets random ($P = .51$).

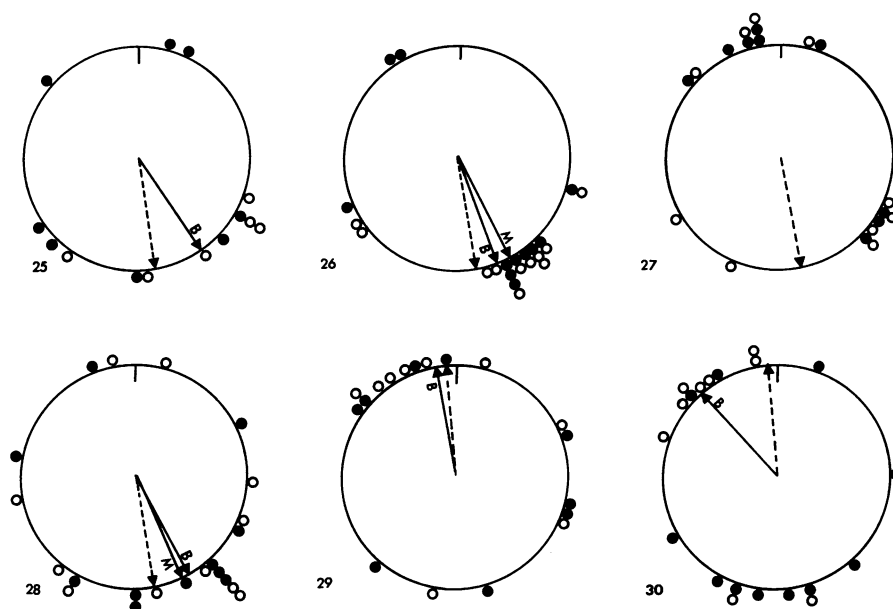


FIGS. 19-21. Series 5—tests, under total overcast, from near Nichols, N.Y., 30.7 miles, home direction 355° . Fig. 19. 3 Oct. 1969; mean bearing of control birds 17° (oriented, $P = .004$), mean bearing of birds with magnets 358° (oriented, $P = .049$). Fig. 20. 14 Oct. 1969; mean bearing of control birds 345° (oriented, $P = .0002$), mean bearing of birds with magnets 345° (oriented, $P = .001$). Fig. 21. 17 Oct. 1969, mean bearing of control birds 6° (oriented, $P = .002$), mean bearing of birds with magnets 3° (oriented, $P = .0009$).



FIGS. 22-24. Series 6—tests of very young, first-flight birds under sun, from Locke, N.Y., 16.6 miles, home direction 171° . Fig. 22. 20 Oct. 1969 (*circles*), 24 (*triangles*); mean bearing of control birds 195° (oriented, $P = .008$), birds with magnets not homeward oriented ($P = .61$). Fig. 23. 30 Oct. 1969; mean bearing of control birds 179° (oriented, $P = .006$), birds with magnets not homeward oriented ($P = .23$). Fig. 24. 13 Nov. 1969 (*triangles*), 25 (*circles*); mean bearing of control birds 164° (oriented, $P = .0004$), birds with magnets not homeward oriented ($P = .51$).

* Although it is always preferable to use in a test only birds released the same day, in this test and in the tests of Figs. 22 and 24 changing weather conditions made it necessary to discontinue releases before the test was completed and to resume on the earliest day (as indicated) of appropriate weather.



FIGS. 25-30. Series 7—tests of fully mature, first-flight birds under sun. Fig. 25. Locke, N.Y., 30 June 1969, 16.6 miles, home direction 171° ; mean bearing of control birds 145° (oriented, $P = .008$), birds with magnets not homeward oriented ($P = .31$). Fig. 26. Locke, N.Y., 28 April 1970; mean bearing of control birds 157° (oriented, $P = .0002$), mean bearing of birds with magnets 151° (oriented, $P = .014$). Fig. 27. Locke, N.Y., 1 May 1970; control birds not homeward oriented ($P = .46$), birds with magnets not homeward oriented ($P = .93$). Fig. 28. Locke, N.Y., 11 May 1970; mean bearing of control birds 152° (oriented, $P = .046$), mean bearing of birds with magnets 156° (oriented, $P = .012$). Fig. 29. Near Nichols, N.Y., 27 April, 1970, 30.7 miles, home direction 355° ; mean bearing of control birds 350° (oriented, $P = .026$), birds with magnets not homeward oriented ($P = .32$). Fig. 30. Near Nichols, N.Y., 2 June 1970; mean bearing of control birds 318° (oriented, $P = .05$), birds with magnets not homeward oriented ($P = .94$).

0.021 and 0.009). Two tests in this series gave results different from those of the other five. In one, both groups of birds were homeward oriented (Fig. 14); in the other neither group was oriented (Fig. 15).

Taken as a whole, the tests of series 1 and 2 seemed to indicate that magnets do not usually disorient experienced birds when the sun is visible (at least at short distances), but that they usually do cause disorientation at unfamiliar release sites when the sun is not visible. This might mean that the birds can use sun cues or magnetic cues interchangeably, but that both together are seldom needed.

[The description of a fourth test series, together with Figs. 16-18, was deleted in proof due to space limitations.]

Since it had previously been demonstrated that experienced pigeons can orient under total overcast at unfamiliar release sites (16) but that first-flight birds require the sun to orient (20), and since it had been demonstrated in the tests of series 3 (above) that magnets often interfere with orientation of experienced birds under overcast, we thought it possible that early training makes pigeons responsive to magnetic cues and thus able to use these as a substitute for sun cues. To test this possibility, we put magnets or brass bars on a large number of young birds when they first began to fly, and left these on throughout early training. The training consisted of a number of flock releases (birds with magnets and brass bars together, so that we would not lose the birds with magnets) at distances of from one to ten miles (1.6-16 km) in all directions; our earlier experience had shown that this was sufficient training to enable normal birds to orient under overcast skies at distant unfamiliar sites. We then used these birds in a series of 3 test releases under total overcast at a site 30.7 miles (50 km) south of the loft; no bird was used in more than

1 test. Just before each bird was released in a test, its magnet or brass was removed. Our thought was that the control birds might have learned to use magnetic cues during their training, whereas the magnet birds might not have been able to do so; if this were true, then on their first flight under overcast without magnets or brasses, the birds that had until now worn brasses should be able to orient but the birds that had worn magnets should not. However, this was not what happened. In each of the 3 test releases in this fifth series, both groups were oriented homeward (Figs. 19-21), but in each of the 3 tests the birds formerly wearing magnets took significantly longer to vanish ($P = 0.046, 0.035, 0.014$); there were no significant differences in homing speeds.† Contrary to our expectations, then, the birds with magnets had apparently learned, during training, whatever is necessary to orient homeward under total overcast at an unfamiliar release site, but the experience of wearing the magnets had apparently made them somewhat slower in choosing their bearings.

The results of the fifth series of tests forced us to reconsider our ideas concerning the effects of training, and suggested that we should look closer at the orientation behavior of first-flight birds. Accordingly, we conducted a sixth series of tests, under sun, using first-flight youngsters (i.e. birds about 3 months old, that had been given daily exercise flights at the loft but had never before been taken away from the loft). In all 3 tests in this series, the birds with magnets vanished randomly, whereas the control birds were oriented homeward

† The good orientation shown by our pigeons in the 3 releases of series 5, together with the good orientation of the controls in the releases of Figs. 10-13, 16, and both groups in the releases of Figs. 14 and 17, provide examples of homeward orientation under total overcast to supplement those given in (16) and (20).

(Figs. 22–24). There were no significant differences in vanishing intervals. In the test of Fig. 23, the birds with magnets had significantly slower homing speeds ($P = 0.022$). The returns were so few in the tests of Figs. 22 and 24 that no meaningful comparison of speeds was possible.

In view of the fact that first-flight birds require the sun for orientation (20), and that the tests of series 6 seemed to indicate that they also require magnetic cues, whereas experienced birds seem usually to need only one of these two kinds of cues, it seemed to us that perhaps training makes the pigeons sufficiently adept at homing so that they can orient with less information than they need on their first flight.

The situation became more confusing, however, when we conducted a seventh series of tests (Figs. 25–30) again using first-flight birds under sun. These birds were considerably older (8 or 9 months) than the ones used in series 6. In 3 of the 6 tests of this series (Fig. 25, 29, 30), the control birds were oriented homeward and the birds with magnets were not, thus agreeing with the results of series 6. But in 2 tests (Figs. 27, 28) both groups were homeward oriented, and in 1 test (Fig. 26) both groups were random. There was no significant difference in vanishing intervals or homing speeds in this series.

The 7 series of test releases reported here seem to provide evidence that under certain conditions magnets can confuse homing pigeons. If we consider only those tests in which the birds of one group were homeward oriented and the birds of the other group were not, we find that in all 12 such cases it was the control birds that were oriented and the birds with magnets that were not. The probability (binomial) of this happening by chance is only 0.0002. Similarly, in all 5 tests where there was a significant difference in homing speeds, it was the birds with magnets that were slower; the chance probability of this is 0.031. And in all 8 tests where there was a significant difference in vanishing intervals, it was the birds with magnets that took longer; chance probability, 0.004. In all 20 tests in which the two treatments differed significantly in at least one of the three variables measured, it was the birds with magnets that performed poorer; chance probability, <0.000001. It seems to me to be unlikely that these results are due simply to some general disturbing effect of the magnets, since the effects are different depending upon whether it is sunny or overcast. I think it more likely that the magnets have a direct effect on the orientation mechanisms used by the pigeons, though I have no evidence to suggest what the effect is or how the magnetism might be detected by the birds. However, the fact that many birds with magnets got home, and that in many releases they travelled as rapidly as the controls, suggests that the birds are often able to compensate for the orientational disturbance the magnets cause. Furthermore, the one test (Fig. 7) in which experienced birds with magnets were disoriented under sun, and the two tests (Figs. 27 and 28) in which first-flight birds carrying magnets were able to orient, show that our hypothesis of the effect of experience is, at best, an oversimplification. If further research proves that magnetic cues are used by orienting birds, it seems clear that such cues, and the solar cues that are already known to be used, will not provide a full explanation of the birds' orientation system. That system surely involves still other cues yet to be discovered.

David H. Niver obtained the magnets and helped with 3 releases. Andre Gobert and Irene Brown helped plan and conduct the releases, as well as train the birds. Jerry F. Downhower,

Melvin Kreithen, Lorraine Pakkala, and Deena Zalkind helped conduct releases. Supported in part by NSF Grant GB 13046 X and in part by Hatch Act funds.

1. Middendorf, A. v., *Mem. Acad. Sci. St. Petersburg*, **8**, 1 (1855); Viguier, C., *Rev. Phil.*, **14**, 1 (1882); Thauziés, A., *VI Int. Congr. Psychol.*, pp. 263–280, 834–835 (1910); Stresemann, E., *Ardea*, **24**, 213 (1935); Daanje, A., *Ardea*, **25**, 107 (1936); Daanje, A., *Vogelzug*, **12**, 15 (1941); Schumacher, W. C., *J. Appl. Phys.*, **20**, 123 (1949); Barnothy, J. M., in *Biological Effects of Magnetic Fields*, ed. M. F. Barnothy (Plenum Press, New York, 1964), p. 287; Graue, L. C., *Am. Zool.*, **5**, 704 (1965).
2. Yeagley, H. L., *J. Appl. Phys.*, **18**, 1035 (1947).
3. Yeagley, H. L., *J. Appl. Phys.*, **22**, 746 (1951).
4. Talkington, L., "On Bird Navigation," mimeographed paper distributed at AAAS meeting, Montreal (1964).
5. Rochon-Duvigneaud, A., and C. Maurain, *La Nature*, **51**, 232 (1923); Slepian, J., *J. Appl. Phys.*, **19**, 306 (1948); Varian, R. H., *J. Appl. Phys.*, **19**, 307 (1948); Wilkinson, D. H., *Proc. Linn. Soc. Lond.*, **160**, 94 (1949); Kimm, I. H., *Nature*, **188**, 69 (1960).
6. Griffin, D. R., *Auk*, **57**, 61 (1940); Griffin, D. R., *Biol. Rev.* **27**, 359 (1952); Kramer, G., in *Ornithologie als biologische Wissenschaft*, eds. E. Mayr and E. Schug (C. Wenter, Heidelberg, 1949), p. 269; Kramer, G., *Naturwissenschaften*, **37**, 188 (1950); Clark, C. L., R. A. Peck, and W. F. Hollander, *J. Appl. Phys.*, **19**, 1183 (1948); Orgel, A. R., and J. C. Smith, *Science*, **120**, 891 (1954); Fromme, H. G., *Z. Tierpsychol.*, **18**, 205 (1961); Meyer, M. E., and D. R. Lambe, *Psychonomic Sci.*, **5**, 349 (1966); Emlen, S. T., *Amer. Zool.*, **7**, 806 (1967); Emlen, S. T., *Animal Behav.*, **18**, 215 (1970).
7. Casamajor, J., *Rev. Sci.*, **65**, 554 (1927); Wodzicki, K., W. Puchalski, and H. Liche, *J. Ornithol.*, **87**, 99 (1939); Gordon, D. A., *Science*, **108**, 710 (1948); Matthews, G. V. T., *J. Exp. Biol.*, **28**, 508 (1951); Matthews, G. V. T., *Ibis*, **94**, 243 (1952); Riper, W. V., and E. R. Kalmbach, *Science*, **115**, 577 (1952); Bochenski, Z., M. Dylewska, J. Gieszczykiewicz, and L. Sych, *Zesz. Nauk. Wyzsz. F. Zoologica*, **5**, 125 (1960).
8. Eldarov, A. L., and Y. A. Kholodov, *Zh. Obschch. Biol.*, **25**, 224 (1964); Shumakov, M. E., *Bionica*, **371** (1965); Shumakov, M. E., *Vestn. Leningrad. Univ.*, **Biol.**, 106 (1967).
9. Reille, A., *J. Physiol., Paris*, **60**, 85 (1968).
10. Merkel, F. W., and H. G. Fromme, *Naturwissenschaften*, **45**, 499 (1958); Merkel, F. W., H. G. Fromme, and W. Wiltshcko, *Vogelwarte*, **22**, 168 (1964); Merkel, F. W., and W. Wiltshcko, *Vogelwarte*, **23**, 71 (1965); Wiltshcko, W., and F. W. Merkel, *Verh. Deut. Zool. Ges., Jena 1965*, 362 (1966); Wiltshcko, W., *Z. vergl. Physiol.*, **25**, 537 (1968).
11. Perdeck, A. C., *Ardea*, **51**, 91 (1963).
12. Southern, W. E., *Condor*, **71**, 4 (1969).
13. Lindauer, M., and H. Martin, *Z. vergl. Physiol.*, **60**, 219 (1968).
14. Brown, F. A., W. J. Brett, M. F. Bennett, and F. H. Barnwell, *Biol. Bull.*, **118**, 367 (1960); Barnwell, F. H., and F. A. Brown, *Experientia*, **17**, 513 (1961); Barnwell, F. H., and F. A. Brown, in *Biological Effects of Magnetic Fields*, ed. M. F. Barnothy (Plenum Press, New York, 1964), p. 263; Brown, F. A., *Biol. Bull.*, **123**, 264 (1962); Schneider, F., *Naturforsch. Gesell. Zurich*, **108**, 373 (1963); Becker, G., *Naturwissenschaften*, **50**, 21 (1963); Becker, G., *Naturwissenschaften*, **50**, 218 (1963); Becker, G., and W. Speck, *Z. vergl. Physiol.*, **49**, 301 (1964); Palmer, J. D., *Nature*, **198**, 1061 (1963); Brown, F. A., F. H. Barnwell, and H. M. Webb, *Biol. Bull.*, **127**, 221 (1964); Picton, H. D., *Nature*, **211**, 303 (1966).
15. Lissmann, H. W., and K. E. Machin, *J. Exp. Biol.*, **35**, 451 (1958).
16. Keeton, W. T., *Science*, **165**, 922 (1969).
17. Batschelet, E., *Statistical Methods for the Analysis of Problems in Animal Orientation and Certain Biological Rhythms* (American Institute of Biological Sciences, Washington, D.C., 1965).
18. Durand, D., and J. A. Greenwood, *J. Geol.*, **66**, 229 (1958).
19. Siegel, S., *Nonparametric Statistics for the Behavioral Sciences* (McGraw-Hill, New York, 1956).
20. Keeton, W. T., and A. Gobert, *Proc. Nat. Acad. Sci. USA*, **65**, 853 (1970).