THE EFFECTS OF SUPERIMPOSED MAGNETIC FIELDS ON GULL ORIENTATION

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In previous studies on orientation in the Ring-billed Gull (*Larus delawarensis*), I (Southern, 1967, 1969, 1971, 1972a, 1972b) have shown that: 1, chicks and juveniles give oriented directional responses when tested in orientation cages; 2, their preferred bearing corresponds to the mean angle between the nesting and wintering grounds as indicated by band recovery data; and, 3, geomagnetic cues may be associated with their ability to select a preferred heading under test conditions. During the summers of 1971 through 1973, I undertook additional studies on the effects of geomagnetism on orientation in chicks of this species. Recent publications by Keeton (1971), Merkel (1971), Wiltschko (1968), and Wiltschko and his colleagues (1971, 1972), dealing with pigeons (*Columba livia*) and European Robins (*Erithacus rubecula*), provide support for conclusions from my studies and those of Yeagley (1947, 1951) and Merkel and Wiltschko (1965). However, despite these findings it is impossible to state unequivocally that any avian species orients by geomagnetic cues.

Almost every investigator in this field has his own apparatus design, uses different species, and often prefers different statistical procedures. As a consequence, direct comparison of results is extremely difficult if not impossible. The directional tendencies reported in some studies, particularly those relying on grouped responses for a small number of subjects (i.e., second order means) to designate 'preferred bearings,' may be statistically significant, but their biological significance is subject to question. Further work on this subject is essential, as the data supporting a hypothesis of migrational orientation by geomagnetic cues are not as convincing as those for the use of some other more readily accepted cue systems, e.g., stars.

This study was designed to provide a more accurate measure of the response of Ring-billed Gull chicks to alterations in the earth's magnetic field. In the first place, I am assuming that gull chicks do have a sense of orientation and that such orientation is a net direction toward the first migrational movement they will experience, i.e., south-southeast. My reasons for these assumptions are based on: 1, band encounter analysis for juveniles from the population studied; 2, results from experiments with free-flying juveniles; and 3, data from replication trials with chicks. The rationale behind this experimental approach has been discussed in a separate paper (Southern, in press). Experiments were designed to collect data for answering three basic questions: 1, will a magnetic field, when superimposed upon the geomagnetic field, cause gull chicks to become disoriented?; 2, will a significant reduction in the earth's magnetic field result in disorientation?; 3, are gull chicks able to obtain directional information from artificially produced magnetic fields having various characteristics, particularly ones resembling the earth's components? Naturally occurring magnetic disturbances (i.e., geomagnetic storms) and sky conditions were also considered during field experiments.

METHODS

Ring-billed Gull chicks ranging in age between 3 and 10 days were obtained from the Calcite colony at the Michigan Limestone Division of the U.S. Steel Corporation near Rogers City, Presque Isle County, Michigan. The birds were transported by automobile to the research area located about 0.3 km from the colony. The age of each chick (in days) was recorded at the onset of the experiment and data for each age class were analyzed separately and also by three-day groupings, i.e., 3–6 days. This analysis indicated that chicks ranging between 3 and 10 days old responded similarly in the experimental apparatus. As a result, I am assuming that differences in age had no effect on orientation ability and the data have been combined for discussion in this paper.

Birds from this colony were selected because their migratory behavior had been studied more thoroughly than that of any other gull population of the Great Lakes Region (Southern, 1974). Analysis of encounter data for about 25,000 banded or wing-marked gulls has shown the mean direction travelled during fall migration to be approximately 165°. This bearing was used as the hypothesized preferred heading during statistical analysis of my orientation data. Headings taken by experimental gull chicks were tested to determine if they were consistent with the actual migratory behavior recorded for individuals from this population. Chicks from this colony also were used in my earlier experiments (1967, 1969, 1972a), so their adaptability to the experimental procedure had been documented. Because of the mainland location of this colony, it was possible to place test equipment far enough from adult gulls to avoid possible auditory contact between them and chicks used in trials.

Each year experiments were conducted throughout June and occasionally into early July. During the three summers my assistants and I conducted approximately 4,700 orientation-cage trials in addition to a group of free-flight trials (Southern, 1972b). Results directly applicable to the three basic questions posed above will be presented at this time. Data from the remaining trials have been omitted from this paper because similar material has been published earlier (Southern 1969, 1971, 1972a). Field trials were conducted by several observers, various assistants, and myself over the three-year period thereby verifying that the results are repeatable and not simply the interpretation of one person.

Each gull chick (3 to 10 days old) was used in only one orientation-cage trial. Therefore, the mean headings used in the text are based on this single choice-reaction by the number of birds tested under those particular conditions. This approach increased the likelihood that the calculated preferred headings were representative of the population studied rather than simply preferences of individual birds that were expressed repeatedly during additional trials.

Orientation-cage Design and Test Procedure.—The Southern-type orientation-cage was used for all trials. The standard cage was circular with 2-foot-high (0.6 m) opaque sides of nonmagnetic materials. The top was open, thereby permitting experimental birds an unobstructed view of the natural sky during trials. It was set up on flat terrain with 360° corresponding to magnetic north. The ground formed the bottom for outdoor cages, but a wooden floor to which coarse sand had been glued was fastened to the elevated indoor models. The supporting upper and lower aluminum rings were marked off in 15° sectors, allowing an observer watching through one of the two portals in the side to plot the bird's course during a trial and its position at the termination of the experiment. The observer periodically switched from one portal to the other between groups of trials to reduce the likelihood that his location biased results. Two cage sizes were used, the diameters of outdoor and indoor models being 8 feet (2.4 m) and 5 feet (1.5 m), respectively. Trials were conducted simultaneously in the adjacent control and experimental chambers thereby assuring that both groups were subjected to the same uncontrolled variables.

Located in the cage center was a 10-inch-diameter (2.5 dm) holding chamber under which one chick was placed at the onset of a trial. This structure was raised above the arena side by means of a string and pulley arrangement attached to an overhead support, thereby providing the bird with an unimpeded choice of headings. Two people were required to operate each test cage. One functioned as the observer, recording existing environmental parameters and each bird's response during a trial on a printed replica of the cage floor. The other placed chicks in the test apparatus and removed them following trials.

A trial consisted of placing a gull chick under the holding chamber, freeing the bird by raising the chamber, and giving it two minutes to select and follow a course toward the cage wall. Trials were terminated when a bird reached the arena wall or when the allotted two-minute period had elapsed. The observer plotted the chick's course on a printed replica of the cage floor pattern. Final headings, the points at which birds reached the wall or their bearing after two minutes, were plotted to the nearest 5°. Final headings were used as indicators of directional preference. Occasionally chicks failed to respond and simply stood in the cage center and looked about. These were recorded as no responses and excluded from calculations. Chicks used in trials were selected at random from those available in the colony. Afterwards each was banded with a Fish and Wildlife Service band, which prevented us from selecting the same individuals for later experiments.

Initial headings, or the direction a chick faced at the onset of a trial, were also tested for significance. As none of these data showed a preferred bearing, I have concluded that the chicks do not elicit an oriented response until after the holding chamber has been raised. Therefore, the associated data have been omitted from this paper.

Production of Superimposed Magnetic Fields.—Three methods were used to alter the geomagnetic field in the immediate vicinity of gull chicks during orientation trials. Each method involved the use of magnets.

Small ceramic disc magnets (12-mm-diameter) were glued to the top of a gull chick's head or to the middle of its back with F-Bar-F Branding Cement (Victor Business Forms Co., 2105 Y St., Lincoln, Nebraska). The magnets produced a 0.5 Oersted field about the head. The direction of the field was perpendicular to the plane of the disc magnet. The polarity of the magnetic field, i.e., whether upward or downward, in relation to the bird's body was determined randomly by the person attaching the magnet. As a result, the differential effect of polarity was not considered during these particular trials although I now realize that it should have been. The two locations on the bird's body were used as an attempt to determine if a superimposed field close to the brain had a different effect than when placed centrally on the body. Brass discs of about the same size and weight were glued to similar locations on controls.

In one set of experiments rows of bar magnets were aligned along radii on the cage floor. This resulted in an irregular field, i.e., of a scalloped design, within the orientation cage. The maximum total field intensity over the cage floor was increased to about 1.5 Oersted. The control cage lacked magnets and the gulls were exposed to an undistorted geomagnetic field during simultaneous trials.

During 1973, a pair of bar magnets was crossed and placed beneath five nests during the incubation stage. The 11 chicks that hatched in these nests were used in trials when three-days-old. This procedure resulted in their being subjected to a superimposed magnetic field (range 1 to 2 Oersted) during about two weeks of development. These birds were exposed to the normal geomagnetic field during trials as were controls. The controls, however, were taken from nests not having superimposed fields during any stage of development.

During all of these trials, consideration was given to the effect of naturally occurring magnetic disturbances. Trials conducted during low, moderate, or severe conditions, indicated by K-indices provided by the World Data Center, were analyzed separately. All of the data presented in this paper pertain to low level disturbances.

Magnetically-shielded Room (MSR).—The MSR, with interior dimensions of 8×8 ft (2.5×2.5 m) on the floor and 6 ft (1.8 m) in height, was constructed by nailing and gluing 0.25-inch (6 mm) marine plywood over both sides of a framework of 2×2 inch (2.5×2.5 cm) struts. The interior walls were covered with 0.031 inch (0.8 mm) thick, Co-Netic magnetic shielding alloy (Perfection Mica Co., Bensonville, Ill.). This material had been hydrogen anneled to provide minimum degradation in magnetic shielding properties due to cold working. All joints were covered with seam strips held down with aluminum channel screwed to the wooden frame. This procedure provided magnetic shielding continuity between adjacent sheets. All fasteners were of nonmagnetic material (either aluminum or brass). The structure could be dismantled into six pieces for transport to a new test location.

An 8-inch (2 dm) hole was cut in the center of the ceiling and a 10-inch (2.5 dm) stack was constructed from shielding material to vent combustion gasses from propane lanterns used for interior lighting. A 2.5 foot (0.75 m) door was cut in one side. Overlapping strips of shielding around the door maintained magnetic continuity when the door was closed.

The MSR disturbed the ambient magnetic field for a distance of about 100 feet in any direction. Measurements were taken with a RFL Model 101 magnetometer to obtain a maximum field reading in space and a maximum field reading in the horizontal plane. The total maximum field outside the influence of the MSR was 60,000 gamma (60k $\Gamma =$ 0.6 Oersted). The horizontal component was in the range of 13 to 14k Γ. All of the other test and control apparatuses were placed at locations far enough from the MSR to insure normal ambient readings.

Interior field measurements were made at two-foot intervals throughout the volume of the MSR. The mean magnetic field was 2317 Γ. If the ambient external field was taken as 60k Γ, then the mean attenuation factor is 0.04, and the ambient field was reduced by a factor of 25. In the 15 cm horizontal plane (centered on a point halfway between the floor and ceiling) the field variation was 24 percent and the gradient was 6.4 Γ/cm. The 5-foot-diameter orientation-cage used in the MSR was placed on legs so that the floor was within this level of field uniformity.

A control room of similar dimensions but without magnetic shielding was located about 150 feet from the MSR. The test cage in this structure was similarly positioned on legs.

Lighting in each chamber was by two propane lamps (about 300 watts/lamp). The light provided was below optimum levels but a better source was not available, because the use of AC power sources involved further shielding and design problems that could not be resolved under current budget limitations. Because of this, chicks were tested at light intensities far below that outside the chambers.

Simulation of Geomagnetic Field Conditions.—The coil configurations for the MSR are based on modifications of a Rubens' coil set that consisted of five separate coils, each wound around the four of the six sides of a cube (see Rubens, 1945). Using Rubens' technique, equations were derived to determine the magnetic field due to a rectangular coil anywhere in space. As several coils are used, each wound around the z-axis, one may adjust the number of turns in each set of two coils symmetrical about the x-y plane (i.e., the plane of the central coil) to obtain maximum magnetic field homogeneity along the z-axis. The magnetic field at a given point within the Rubens' set is the vector sum of the fields due to each individual coil. Computer simulation indicated that the horizontal component of the desired field could be produced with a 5 coil Rubens' set whose turns ratio was 37:12:20:12:37. This set, wound over a 6×8 foot (1.8×2.5 m) rectangle with individual coils spaced two feet (0.6 m) apart, produced a field in the MSR's horizontal median plane (3 feet off the floor) that varied by no more than 11 percent in the 5-foot-diameter (1.5 m) test cage.

As gulls in the orientation cage were confined more or less to a horizontal plane, the demand for field homogeneity in the vertical direction was less stringent. The vertical field component was produced with a 3 coil Rubens' set, having a turns ratio of 23:10:23, wound over an 8×8 foot (2.5×2.5 m) square, with individual coils 3 feet (0.9 m) apart. Maximum field variation in the median horizontal plane was 7.3 percent for the 5-foot-diameter cage. When simulating the earth's magnetic field, both in magnitude and direction with the two coil sets, the maximum combined variation for a five foot diameter cage was 7.8 percent. Each coil was mounted in a frame of aluminum channel which was screwed to the channel covering the seam strips in the MSR. In addition to serving as support and protection for the coil windings, the channel also provided additional cooling area for the coils when operated with large currents.

Current was provided by two 12-volt heavy duty car batteries connected either in series or parallel, depending upon the range of field magnitude desired. It was possible to produce horizontal fields ranging between zero and 0.374 Oersted and vertical fields ranging between zero and 1.410 Oersted. Inclination of the field is changed from zero to 90° by adjusting the magnitude of the two field components. The batteries and controls (potential dividers, etc.) were located outside of the MSR.

Two fluxgate magnetometer probes were mounted just under the orientation cage floor, one oriented along the vertical coil axis and the other parallel to the horizontal coil axis. Leads from the probes were connected to a magnetometer located near the control box. Field settings were checked and adjusted several times during operation to offset voltage decrease due to battery discharge and/or resistance increase due to coil heating.

Statistical Treatment of Data.—Final headings and the parameters pertaining to each trial were punched on computer cards for analysis by an IBM 360/67. The mean angle, standard angular deviation, and the Rayleigh test (Batschelet, 1965; Zar, 1974) were calculated by means of a program prepared by Dr. J. H. Zar. Calculation of the probability of Rayleigh's statistic z and the modified Rayleigh test (V-test of circular uniformity) (Batschelet, 1972; Zar, 1974) were performed on a Hewlett-Packard Model

9100B programmable calculator. The null hypothesis of the standard Rayleigh test states that the theoretical distribution is uniform. When the test statistic z (tabular presentation of vector length) exceeds a certain critical value, the null hypothesis is rejected. The V-test is used when a particular direction is expected to be the preferred direction in advance of the experiment. In the case of Ring-billed Gulls from Rogers City, Michigan, the preferred heading of 165°, corresponding to the direction of fall migration, is already known in advance. The null hypothesis to be tested is randomness, meaning that the angles of the sample are independent observations from a uniform distribution. Use of the V-test is preferable when knowledge of a predicted direction is available, as it provides a more powerful test. The V-test leads to significance only if there is a sufficient clustering around the predicted direction. In contrast, the Rayleigh test is less powerful in this case but remains powerful for clustering on any part of the circle (Batschelet, 1972).

RESULTS

Standard-cage Controls

Inconsistencies exist in the control data for specific years. In some cases clear sky trials showed significant mean headings, whereas the overcast trials did not. Occasionally the reverse is true. In other instances the mean heading represents a significant sample mean rather than a significant population mean. The presence of conflicting results for the controls has made it even more difficult to evaluate the data for experimental groups. No explanation for the inconsistencies is available at this time.

TABLE 1

STATISTICS FOR STANDARD CAGE CONTROL TRIALS, 1971–1973

	N	Mean angle	Angular deviation	Rayleigh z	Prob. z	V-test 165°	Signif. level	Number of no responses (percent)
1971–73								
Clear sky	357	162.59	74.95	7.45	.0005	51.52	.0005	46 (11)
Overcast	312	169.41	78.43	1.24	.2885	19.64	not (.10)	44 (12)
1971								
Clear sky	94	191.86	74.19	5.07	.0062	27.97	.0005	9 (9)
Overcast	96	225.80	75.98	2.27	.1032	9.18	not (.10)	10 (9)
1972								
Clear sky	180	190.16	72.03	12.06	.00001	52.05	.0005	20 (10)
Overcast	133	89.30	78.51	0.90	.4067	3.36	not	17 (11)
1973								
Clear sky	83	73.90	66.79	8.53	.0001	− 0.51	not	17 (17)
Overcast	83	131.80	72.47	3.32	.0355	13.90	.025	17 (17)

In Table 1, test statistics for each of the three years have been presented separately for clear and overcast sky conditions. In addition, the grouped data for the three years have been plotted according to sky condition. All 669 trials were conducted during low intensity disturbances in the geomagnetic field (K-indices 0–3). The clear sky results for 1971, 1972, and 1971–73 (combined) were significant according to the Rayleigh and V-tests. The mean angles ranged between 163 and 192° for these three sets of data. In contrast, the overcast headings were not significant. The reverse was true for 1973, except that the clear sky heading was significant by the Rayleigh test but not so according to the V-test. This means that a significant sample mean existed in the 1973 data, but that the birds failed to show a preference for the hypothesized population mean. The fact that the 1973 controls exhibited a significant direction preference (132°) during overcast conditions makes it appear unlikely that the discrepancies for the other years are the result of chicks using solar cues.

The relative frequency of final headings under clear and overcast skies are

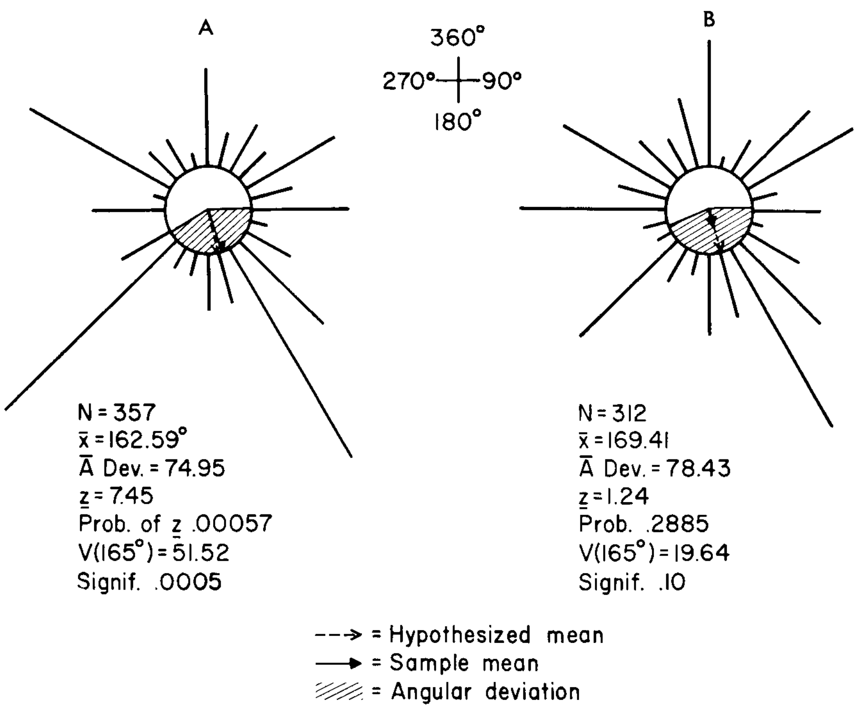

FIG. 1. A. Relative frequency of responses for chicks tested as controls in standard-cage under clear skies, 1971–73. B. Similar data for chicks tested under overcast skies.

present for the combined years (1971–73) in Figure 1. The mean angle for overcast trials is similar to that for clear trials, but it is significant at only the 90 percent level. Although the distribution of these final headings is approaching randomness, the overall pattern is still very different from that for trials involving superimposed magnetic fields. Similar discrepancies had not been present in clear versus overcast data from previous years of inquiry (Southern, 1969, 1972a). An explanation for the change is not apparent at this time. I do not interpret it as an indication that sun cues are being used by chicks, because there is no consistent response pattern in relation to the availability of solar cues.

TABLE 2

STATISTICS FOR STANDARD CAGE EXPERIMENTALS—SUPERIMPOSED FIELDS

	N	Mean angle	Angular deviation	Rayleigh z	Prob. z	V-test 165°	Signif. level	Number of no responses (percent)
1971–73								
Clear sky	388	29.88	78.19	1.83	.1598	–18.90	not	71 (15)
Overcast	327	331.68	79.79	0.30	.7413	– 9.63	not	43 (12)
1971								
Clear sky	118	58.95	80.57	0.01	.9899	– 0.25	not	21 (15)
Overcast	91	293.92	76.86	0.91	.4020	– 5.73	not	19 (17)
1972								
Clear sky	180	110.22	76.06	0.34	.7130	5.81	not	30 (14)
Overcast	148	292.27	72.32	0.45	.6390	– 6.41	not	12 (8)
1973								
Clear sky	90	8.22	67.85	8.03	.0002	–24.71	not	20 (18)
Overcast	88	51.40	77.16	0.72	.4873	– 3.10	not	12 (12)
BODY MAGNETS								
1971								
Clear sky	137	13.76	79.58	0.17	.8416	– 4.27	not	13 (9)
Overcast	79	182.27	78.38	0.33	.7224	4.85	not (.25)	21 (21)
FLOOR MAGNETS								
1971								
Clear sky	97	74.10	79.64	0.11	.8939	– 0.05	not	13 (12)
Overcast	85	228.81	68.26	7.16	.0007	10.89	.05	15 (15)
NEST MAGNETS								
1973								
Clear sky	11	324.97	68.96	0.84	.4433	2.85	not (.25)	0 (0)

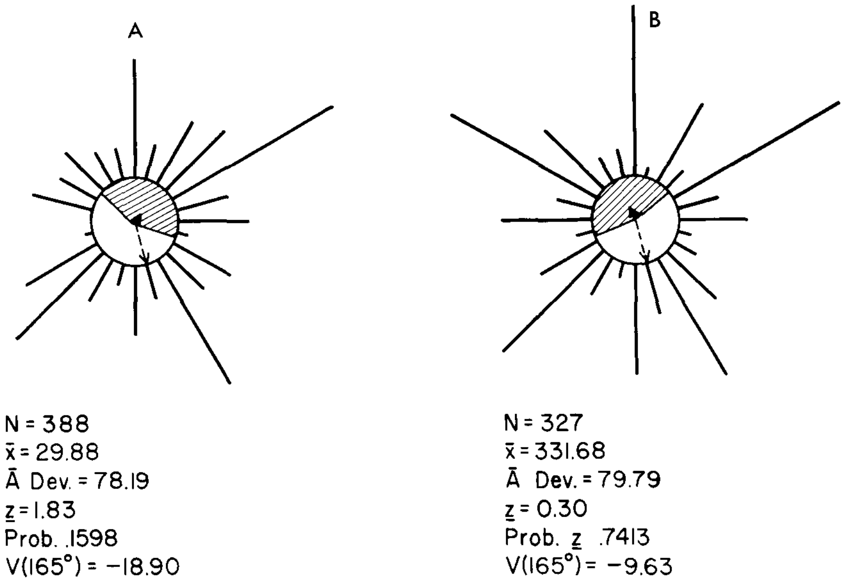

FIG. 2. A. Relative frequency of responses for chicks tested under clear skies in a standard-cage while wearing head magnets, 1971–73. B. Similar data for trials conducted under overcast conditions.

Superimposed Magnetic Fields

During all three years, trials were conducted with experimental gulls bearing head magnets. In all, 715 trials were conducted under clear and overcast skies. In no instance did birds wearing head magnets show (Table 2) a significant preference for the hypothesized population mean (165°). A significant sample mean (8.22°) occurred in the data for 90 trials conducted under clear skies in 1973. The relative frequencies of headings for the 1971–73 clear and overcast head magnet trials are plotted in Figure 2. The results for experimental chicks and those for standard controls (Table 1) are obviously different. The almost complete loss of an ability to select a preferred heading indicate that a superimposed magnetic field will disrupt the orientational ability of young Ring-billed Gulls.

Body magnets and nest magnets also resulted in disorientation. In the case of the former, final headings were randomly arranged during clear as well as overcast conditions. Results for nest magnet trials are particularly interesting because in this case chicks were not subjected to a superimposed field during the actual trial. Instead, an experimental field had been applied during embryological development. These results suggest that the magnetic field sur-

TABLE 3

STATISTICS FOR TRIALS IN THE MAGNETICALLY-SHIELDED ROOM (MSR) AND CONTROL CHAMBER

	N	Mean angle	Angular deviation	Rayleigh z	Prob. z	V-test 165°	Signif. level	Number of no responses (percent)
MSR								
1971–73	101	240.19	77.20	0.86	.4240	2.38	not	497 (83)
1971	26	247.44	59.30	5.61	.0029	1.59	not	173 (87)
1972	43	189.46	76.93	0.42	.6614	3.86	not (.25)	157 (79)
1973	32	41.98	73.57	0.99	.3757	– 3.06	not	167 (84)
Controls								
1971–73	122	96.02	72.99	4.34	.0128	8.25	not (.25)	179 (60)
1971	69	111.07	76.37	0.86	.4249	35.13	.0005	31 (31)
1972	32	79.72	65.85	3.69	.0237	0.89	not	69 (68)
1973	21	107.58	70.19	1.31	.2731	2.82	not (.25)	79 (79)
1973[1]	90	197.38	78.36	0.31	.7368	4.44	not	10 (10)

[1] With translucent roof.

rounding a prehatched Ring-billed Gull influences, in some way, its later ability to use ambient geomagnetic cues for orientation purposes.

Results for floor magnet trials were not as conclusive. The clear sky trials (N = 97) lacked a significant heading, whereas trials conducted under overcast conditions (N = 85) had a significant bearing (0.05). Although I am unable to account for this difference, the fact that gulls tested during overcast showed a significant preference for 165° makes it seem unlikely that they were responding to solar cues; therefore, some other factor must be responsible.

Effect of Reduced and Simulated Fields

MSR and Control Room.—The data for this group of trials are presented in Tables 3 and 4. The response rate was poor for trials conducted in the two buildings. I believe that low light intensity in the MSR and control building contributed to the large number of no responses (79–87 percent in the MSR; 31–79 percent in the Control Room). It is also possible that the reduced magnetic field, in the MSR affected the tendency for gull chicks to respond. Support for this possibility is provided by the finding of El'Darov and Kholodov (1964), that the rate of particular motor activities of various passerines is increased as magnetic field intensity is increased to about three times that of the earth. It is possible that reduced field intensity has the opposite effect.

During the three years of MSR trials with reduced field intensity, no

TABLE 4

STATISTICS FOR TRIALS CONDUCTED WITH SIMULATED MAGNETIC FIELDS

	N	Mean angle	Angular deviation	Rayleigh *z*	Prob. *z*	V-test 165°	Signif. level	Number of no responses (percent)
MSR-4A[1]	21	163.49	62.62	3.41	.0312	8.45	not (.25)	29 (58)
MSR-4B[2]	4	214.38	65.27	0.49	.6406	0.91	not	16 (80)
MSR-4C[3]	14	122.25	70.64	0.81	.4545	2.47	not (.25)	21 (60)
MSR-4D[4]	14	185.48	74.49	0.34	.7218	2.03	not (.25)	26 (65)

[1] Field equivalent to earth's, 0.6 Oersted.
[2] Field twice that of earth, 1.2 Oersted.
[3] Field one-half that of earth, 0.3 Oersted.
[4] Experimental north shifted 180° from ambient north.

significant preference was indicated by chicks for the predicted heading of 165°. However, the 26 birds that responded in 1971 had a statistically significant mean bearing of 247°. The combined responses for the three years lack a preferred bearing (Fig. 3B).

Response rates in the control chamber were lower than in outdoor trials, but not as low as in the MSR (Table 3). Although the combined results for the three years did not indicate a significant preference for 165°, there was a significant sample mean of 96° (Fig. 3A). In addition, the results for 1971 and 1972 were significant by one statistical test or the other. As with the superimposed field trials, the results are more consistent. In the latter instance, it appears that an alteration in the normal geomagetic field causes an overall response pattern different from that for controls. There seems to be a trend in each data set suggesting that disturbances in the earth's magnetic field will disrupt the ability of Ring-billed Gull chicks to select a preferred bearing. In addition, it appears that a reduction in the opportunity for chicks to see other aspects of their natural environment, e.g., the landscape or sun, may reduce the extent to which their orientation ability is expressed during experimentation.

Various attempts were made to determine if low light levels were associated with the reduced response rates. One method for testing this was to replace the opaque roof (plywood) of the control room with sheets of translucent fiberglass. By doing so, the number of no responses was decreased from 56 percent for the combined years of 1971–73, to 10 percent for 1973 (Table 3). Similar changes could not be made in the MSR ceiling without destroying the shielding effect. The differences in response rates indicate that an improved lighting method for both rooms might have increased the response rate of chicks, as well as the validity of this important group of trials.

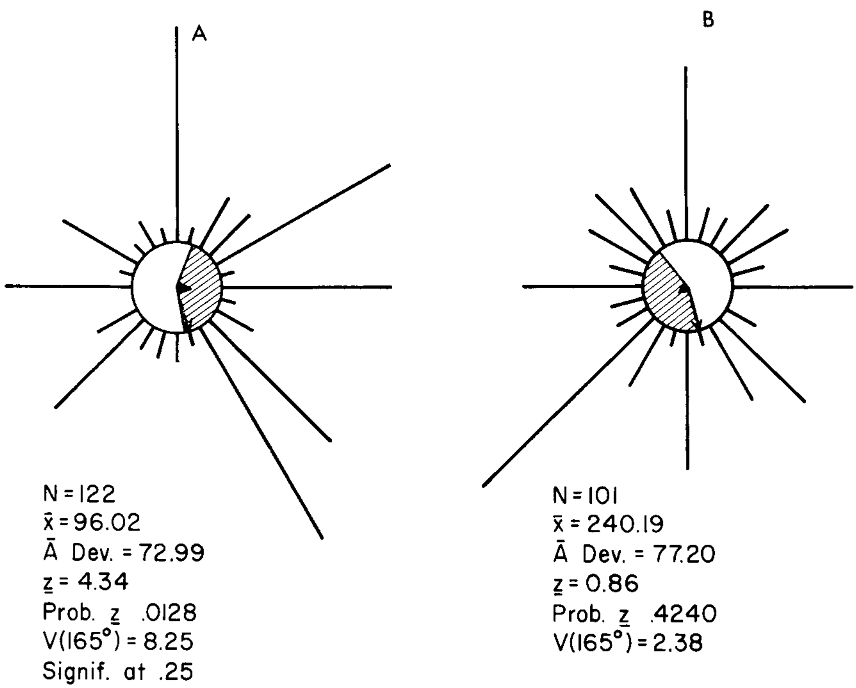

FIG. 3. A. Relative frequency of responses for chicks responding in the unshielded control room during 1971–73. B. Similar data for birds tested in the magnetically-shielded room (MSR).

While it appears that reductions in the total intensity of the geomagnetic field (by a factor of 25) has some effect upon the orientation ability of Ring-billed Gull chicks, data from these experiments are not sufficient for proving such a contention.

Simulated Fields.—Four different magnetic field conditions were produced by the coil system in the MSR. Fifty trials were conducted under the influence of an artificial field having a total intensity equal to that of the Rogers City area (0.6 Oersted). Only 21 (62 percent) of the chicks responded (see MSR-4A in Table 4). The resulting mean angle (163°) represented a significant sample mean, but not a significant predicted mean except at the 0.25 level. These results suggest that Ring-billed Gull chicks may be capable of obtaining directional information from a simulated field having component characteristics similar to those of the geomagnetic field.

Three other artificial magnetic field conditions were used (Table 4), none of which resulted in significant mean headings by chicks. Only four (20 percent) out of 20 chicks responded during tests under the influence of an artificial field having a total intensity about twice (1.2 Oersted) that of the earth (see MSR-4B in Table 4). In another set of trials, 14 (40 percent) of the 35 chicks exposed to a field of one-half (0.3 Oersted) that of the earth at Rogers City responded during trials (see MSR-4C in Table 4). The sample sizes for responding birds were small in both instances, but it appears that gull chicks lack a directional preference when suddenly subjected to fields either significantly higher or lower than the one experienced during development or immediately before the trial. In 1973, 25 chicks were held in the MSR for 15 to 60 minutes before trials; such exposure did not improve response rates.

I also subjected 40 gull chicks to a field of about equal intensity to the earth's, but having experimental north rotated 180° from geomagnetic north (see MSR-4D in Table 4). Only 14 (35 percent) of the chicks responded, and these showed an almost random pattern of headings (significant at 0.25 level). In general, the results from the trials with simulated fields must be considered inconclusive. The low response rate discouraged me from conducting additional trials, as I consider it inappropriate to base any final decisions about orientational ability on the response of such a small proportion of the available population.

DISCUSSION

From the data presented in this paper, it is impossible to state conclusively whether or not Ring-billed Gulls are using geomagnetic cues for orientation. Part of the difficulty associated with interpretation of results from such studies may rest with our basic methodology.

During orientation experiments we have no assurance that a majority of our test subjects are in the proper endogenous state to do what we expect at a particular moment. We also lack an awareness of the complex of stimuli in existence at any moment or what the priorities might be. Furthermore, the controlled elimination of particular variables may significantly reduce the likelihood of any response, while not having any direct effect on the behavior under study (i.e., orientation). We also are unaware of the effect an experimentor has on the probability that particular individuals will respond in a given way. From past experience with capturing and releasing adult Ring-billed Gulls in homing trials (1967), I know that extensive differences appear in the reaction to being 'manhandled.' Adults used as controls were released at the colony after being subjected to trapping, marking, and the other treatments applied to experimental birds. The response of these birds varied greatly, some immediately abandonded the colony, other stayed away from the nest area for hours, and a proportion returned immediately. In the literature such time intervals have been used to designate poor, average, and outstanding homing performance. Similar types of reactions to the rigors of the experiment should be expected from gull chicks, and probably from other species as well. This sort of information is not usually plugged into data analysis and for good reason, we do not know how to handle it, except that we try to treat controls similarly.

Perhaps we should be more willing to accept substantiated trends as being indicative of what a species can or cannot do. From this baseline, more precise questions can be asked and appropriate techniques developed to give answers regarding the minutia associated with the mechanisms responsible for the varied results. If our level of investigation is going to advance, it is necessary for researchers in the area of avian orientation, and their critics, to accept the existence of variability, to probe its basis, and to acknowledge that the general trends reported for various cue systems are adequate for advancing us to the next stage of inquiry. At this new level of investigation it should be possible to analyze the actual processes and the associated mechanisms.

This is the light in which my current results should be evaluated, and hopefully the preceding comments will serve as adequate justification for so doing. If we compare the results for the experimental groups exposed to superimposed magnetic fields with those for controls tested outdoors in the natural geomagnetic field, it is obvious that differences exist. Most of the test groups lack a preference for the predicted population mean of 165°. In addition, almost all of the experimental groups lacked a preferred mean heading. The trend in the experimental data is that of randomness.

On the other hand, the control groups often had a preferred heading corresponding to the predicted mean, or they indicated a tendency toward a preference for some direction, even though it is not always significant at levels above 95 percent. This strongly suggests that the gull chicks are sensing magnetic stimuli and that spontaneous, or unusual, alterations in the geomagnetic field (or the field they experienced during development) will reduce or cause an elimination of their tendency to exhibit a directional preference. It may be true that Ring-billed Gull chicks are actually deriving directional information from magnetic cues, but my attempts to verify this possibility were unsuccessful. I did not, however, obtain data that negate such a possibility. Further work is essential to explain the extent of such an avian ability and to locate the mechanisms involved.

SUMMARY

A three year study was undertaken to determine the role of geomagnetic cues in Ring-billed Gull orientation. The study was designed to provide data for answering three basic questions: 1, will superimposed magnetic fields cause disorientation?; 2, will reduc-

tions in the geomagnetic field result in disorientation?; 3, are gull chicks able to obtain directional information for artificial magnetic fields?

Orientation-cage experiments were conducted in the natural environment, in a magnetically-shielded room (MSR) equipped with Rubens' coils, and in an unshielded control room. Detailed descriptions of the equipment and test procedures are provided. The resulting data were tested for the presence of a significant sample mean and for the clustering of responses about a predicted population mean. The latter test took into account information based on the migratory history of gulls from the colony under study.

Certain inconsistencies exist in the data and an attempt has been made to account for some of these. In general it appears that any significant alteration in the geomagnetic field will cause Ring-billed Gull chicks to disperse randomly in the test apparatus. In contrast chicks tested as controls usually indicated a preferred heading. It appears that Ring-billed Gulls are capable of perceiving geomagnetic stimuli and that their ability to express a directional preference may be based on such cues.

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