

Initially published as:

Beaugrand, J.P., 1977. Test of magnetic sensitivity in seven species of European birds using a cardiac nociceptive conditioning procedure. Behavioral Processes, 2: 119-127.

TEST OF MAGNETIC SENSITIVITY IN SEVEN SPECIES OF EUROPEAN BIRDS USING A CARDIAC NOCICEPTIVE CONDITIONING PROCEDURE

JACQUES P. BEAUGRAND

Département de Psychologie, Université du Québec à Montréal Box 8888, Québec,
H9C 3P8 (Canada)

(Received 8 March 1977)

ABSTRACT

Beaugrand, J.P., 1977. Test of magnetic sensitivity in seven species of European birds using a cardiac nociceptive conditioning procedure. Behavioral Processes, 2: 119-127.

An attempt was made to show magnetic sensitivity in seven species of European birds captured during their migration. The test was done on the following species: *Streptopelia turtur* (N=8), *Streptopelia decaocto* (N=2), *Corvus monedula* (N=6); one individual of the following: *Corvus corona c.*, *Turdus philomelos*, *Turdus viscivorus*, *Anas penelope*. Most of the individuals were first subjected to conditioning to a light stimulus. They were then subjected to differential nociceptive conditioning to 100 presentations of a magnetic stimulus (CS+) reversing the vertical Z component of the local magnetic field and 100 presentations of a control stimulus for artifacts (CS-). The two stimuli were randomly interdigitated. Cardiac activity was used as an index of reactivity throughout the study. Results indicate that the magnetic stimuli were not used by the birds as a cue presaging the forthcoming shock. We discuss the validity of the stimuli and paradigms used to demonstrate magnetic sensitivity in birds. These negative findings are related to possible artifactual effects explaining suggestive results in homing and zugunruhe experiments, such as the lord processing of magnetic effects without access to higher processes such as learning and arousal regulations.

INTRODUCTION

The view that the earth's magnetic field may be a source of directional information for some migrating birds and for the homing pigeon is one that is becoming quite accepted. The effects of magnetic fields on the spontaneous directional behavior of birds in arenas or octagonal cages has been demonstrated experimentally for the European robin (*Erithacus rubecula*) and three species of Sylviidae (Wiltschko and Wiltschko, 1972, 1976a, 1976b, 1976) for the ring-billed gull (*Larus delawarensis*) by Southern (1970, 1972) and more recently for the indigo bunting (*Passerine cyanea*) by Emlen et al. (1976). On the other hand, Keeton (1974a, 1974b) has reported that young pigeons carrying bar magnets when released under total overcast showed a significantly perturbed homing performance as compared to a brass control group. Even more striking results have been reported by Walcott and Green (1974) who found that pigeons wearing Helmholtz coils reversing the vertical component of the ambient magnetic field (north up) tended to fly in a direction opposite from home when released under overcast. However the problem of showing magnetic sensitivity is completely different from that of demonstrating its use. In fact, information concerning magnetic sensitivity, although considered as being a prerequisite to its use, gives quite a negative picture.

Laboratory experiments using conditioning have failed to show any sensitivity to magnetic stimuli in pigeons (Orgel and Smith, 1954; Meyer and Lambe, 1966). One exception is the report of Reille (1968). This researcher used a nociceptive respondent conditioning procedure and reported that pigeons responded by cardiac accelerations to variations experimentally induced in the local magnetic field. However, an exact replication of Reille's experiment failed to confirm these preliminary results (Kreithen and Keeton, 1974). Our own research (Beaugrand, 1976), using a cardiac orienting response index for detection as well as nociceptive differential conditioning, revealed that pigeons failed to detect any change in the ambient magnetic field. The failure of laboratory behavioral methods to clearly show the existence of

sensitivity to magnetism is puzzling and could be due to the fact that the artificial situation created in the laboratory eliminates important variables which are normally at work in the natural homing or migrating situation. One of these variables may be of motivational origin.

The purpose of the present experiment was to test the existence of magnetic sensitivity in species of wild European birds, some of them captured during their spring migration and presumed to be in a state of *zugunruhe*.

METHODS

Subjects

The subjects used were representatives of seven species of wild birds. They were captured either with mist nets or with a baited trap at the Ornithological Reserve of the Zwin (Knokke, Belgium). That these migrants were in their spring migration toward a presumed northern region of Europe (and not local residents) was known from information given by local banders and the serial numbers of the bands that some of the birds were wearing, as well as the appropriate time of the year.

The birds retained in this research include eight turtle doves (*Streptopelia turtur*), two collared doves (*Streptopelia decaocto*), six jackdaws (*Corvus monedula*), as well as one individual of each of the following species: carrion crow (*Corvus corone corone*), mistle thrush (*Turdus viscivorus*), song thrush (*Turdus philomelos*) and European widgeon (*Anas penelope*). According to plumage, all birds were adults and in good health. In the case of turtle doves, collared doves and jackdaws which were captured in the baited trap a small group at a time, the delay between capture and experimentation was variable but never exceeded two days. All other birds were captured in mist nets which were inspected hourly and served in the experiment within one hour after capture.

Apparatus

The immobilized animal was placed in a small wooden cage (1 x 0.5 x 0.5 m) situated outdoors, 30 m from the control room. The restraint was imposed by wrapping the bird wearing the cardiac and shock electrodes in an elastic bandage that permitted movements of the neck and head only. The bird was then placed on a plexiglass hammock and stabilized into place by additional turns of vinyl tape around both the animal and the hammock. The unconditional stimulus (UCS) was a 0.2-0.5 sec of a 0.3-2.0 mA footshock (90V, DC, drycell) delivered between a footpad needle electrode and a metal ring fastened around the metatarsal region of the opposite leg. When the animal was too small, a second needle electrode was used instead and impaled subcutaneously in the thigh of the opposite leg. Shock levels were administered to individual birds at the minimal level required to induce tachycardia. Cardiac activity was constantly monitored by three breast electrodes and the picked signal was fed to an R peak detector (Tobin et al., 1970).

Stimuli

Three conditional stimuli (CSs) were used. One was a luminous stimulus produced by a 24 V DC incandescent lamp placed on the floor 10 cm in front of the animal during phase one of the experiment. The other two stimuli were differential magnetic stimuli produced by two pairs of Helmholtz coils mounted in series. These coils were placed on two parallel aluminum cylinders (diameter 1 m) 50 cm from each other and mounted on a wooden frame. Each pair of coils consisted of four turns of a flat ribbon containing 12 copper conductors. Odd and even conductors were soldered together in order to form two coils of 24 turns. The coils were connected in series and could be activated in unison or in an opposed way. They were placed respectively under and above the experimental box in such a way that their axis was vertical (Fig. 1). The north of the generated artificial field was up. It was produced by the application of a rapidly growing current (10ms of leading edge) of 1 ampere to the coils, thus generating a force of 86,304 gammas (γ) directly opposed to the vertical component Z of the local magnetic field (local $Z = 43,372 \gamma$). The magnetic Z resultant was thus reversed while leaving total intensity predominantly undisturbed. This situation is similar to the one used by Wiltschko and Wiltschko (1972) and would correspond (if their hypothesis is correct) for the bird to a phenomenological reversal of the North and South Poles.

Control procedures for responses to heat, to vibrations and to other artifacts produced by the coils were provided by the use of the same two pairs of coils producing sham fields. Opposed coils were used by Reille (1968) in order to control for

artifacts but new coils were added to the original ones in a post-experimental test for artifact detection. Kreithen and Keeton (1974) have used a resistor instead of coils in order to control for instrumental artifacts. In the present experiment, the sham field was produced by having the same coils mounted in series in such a way that the current of IA circulated in an opposite direction in the two coils of 12 turns of each adjacent pair. The same heat and vibrations were produced as in the magnetic situation but no magnetic total component was generated; thus no magnetic variations were introduced in the local magnetic field. The sham and magnetic stimuli were selected by an appropriate driving of electromagnetic relays and were presented in a random interdigitated way. The sequence of stimuli and the random temporal distribution of the trials were programmed by means of a magnetic tape recorder (UHER 2400, stereophonic) on which pulses had been previously recorded. These pulses, when detected, triggered a trial presentation and selected the appropriate stimulus.

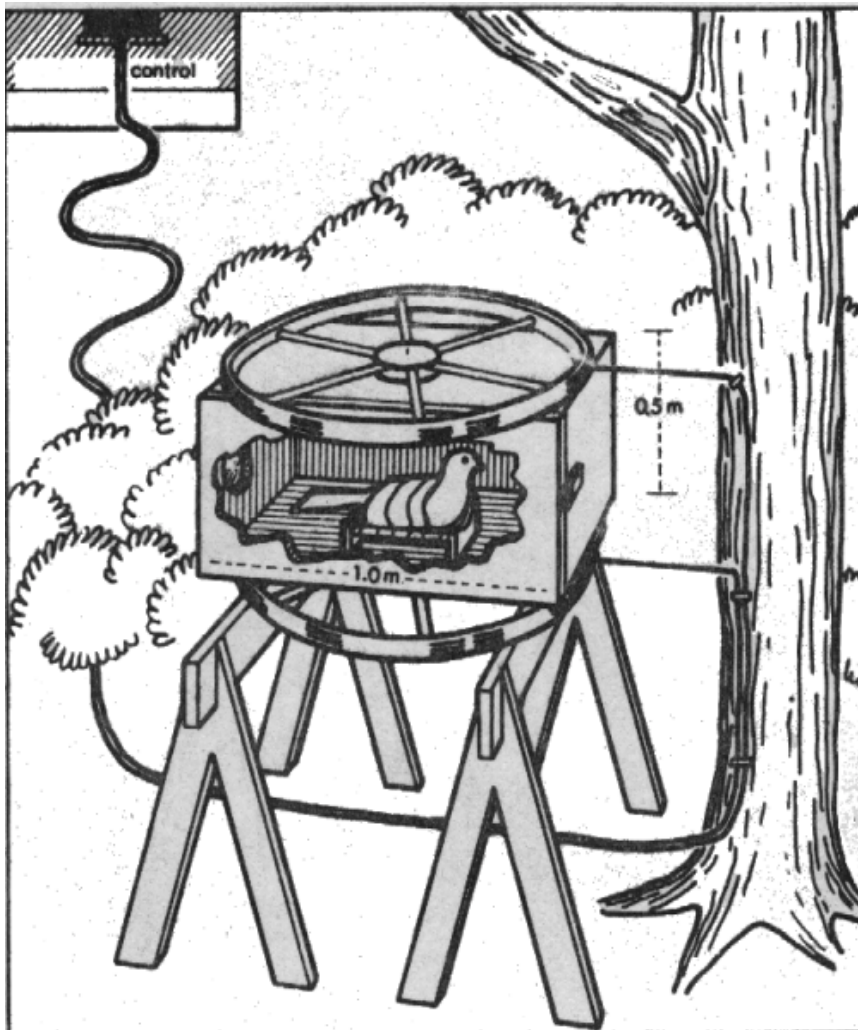


Fig. 1. Experimental cage receiving the immobilized bird. The subject is placed between the four coils of 24 turns needed to produce the magnetic and control (sham) stimuli. Cardiac activity is monitored and recorded in a control room situated 30 m away from the subject. The cardiac amplifier and shocker (not shown) are placed in the experimental box with the subject. The axis of the coils is perpendicular and passing a current of IA through them generates a magnetic field that reverses the vertical component Z of the local magnetic field. In the control-sham stimulus, the current circulates in an opposed direction in the two coils of each adjacent pair, introducing no variation in the local resultant magnetic field.

A trial consisted of 60 consecutive heart beats electronically counted by blocks of five beats. The CS onset coincided with the R peak of the 30th beat and was maintained for the following 30 beats; the footshock-UCS was

optionally given 0.4 sec after CS+ offset. The duration of each block of five beats was printed in the intertrial interval. The heart beats were also recorded on an audio tape recorder (SONY TC252W, stereophonic) to be fed into, processed and analyzed by a PDP-12 computer (Digital Equipment Co.).

Procedures

Depending on the number of subjects captured between one and three subjects were run daily. The experiment itself was divided into two consecutive phases. The first one was a simple conditioning using a luminous CS and footshock as UCS. The second phase consisted of differential conditioning using the magnetic stimulus as CS+ and the sham stimulus as CS-. The footshock-UCS followed the CS+. At least 20 light CSs were presented according to a random temporal program and were used to give a comparative basis in order to evaluate the effects of the other two stimuli. In the following phase, all subjects received a minimum of 100 magnetic CSs+ and 100 CSs-, randomly interdigitated and presented on a random temporal basis. In all phases, the mean intertrial interval was 101 sec (range: 70-120). The session began by a 15 min settling period. The interstimulus interval during conditioning as well as the duration of all stimuli used as CSs were variable and relative to the momentary heart rate of the subjects (=30 beats).

Data quantification

The dependent variable used was the cardiac response to the various stimuli. This response was measured by comparison with its baseline recorded immediately before stimulus onset.

In the case of the turtle doves, the analyses were done on the 29 cardiac inter-beat intervals obtained during 10 trials under each stimulus condition. In order to analyze cardiac reactivity to stimulation, a PDP-12 computer reduced cardiac recordings for each trial to 59 cardiac periods, with an accuracy of 1 ms (1000 Hz oscillator). The first appearance of each CS+ and CS- as well as nine other pairs sequentially and evenly spaced in the subsequent recordings were retained for analysis. A similar procedure was used in order to choose the light CSs presentations. Trials presenting missing beats, artifacts, or marked responses (either acceleration or deceleration) during the basal-level sampling were automatically discarded and the next occurrence of the same stimulus retained.

The cardiac periods were converted into difference scores in order to minimize the effects of individual differences in basal levels. The four periods immediately preceding any given CS were used as the basal level by taking a mean across the four periods. The corresponding mean was then subtracted from each data point and the digit 200 added to the difference. Analyses of data for all other species were done on the blocks of five beats printed after each trial. Each block was taken with a precision of one hundredth of a sec (100 Hz oscillator). The last block of the epoch preceding the stimulation was used as baseline. The six blocks obtained during the stimulus presentation were subtracted from this baseline and the digit 200 added to the difference. Unless otherwise specified, all analyses were done on the 29 or 6 adjusted differences.

Analyses of variance (ANOVAs) were run on the difference scores using options of the BMD08V program (Dixon, 1973). For several of the species the number of subjects was too small for the above-mentioned analyses. Therefore, the data regarding these subjects were analyzed using χ^2 and the results are presented as tentative or suggestive.

RESULTS

Cardiac response curves for the group *Streptopelia turtur* (N=8) are presented in Fig. 2. Units are ms of difference of time interval between successive beats and the basal level. Acceleration responses are presented by a downward curve. Fig. 2 represents scores for period changes during stimulus presentations for the 10 trials retained for analysis under each stimulus condition. The response curves to magnetic and sham stimuli for the group *Corvus monedula* (N=6) are presented in Fig. 3. In this case, each curve represents the deviations of six blocks of five successive beat intervals averaged over 10 trials. Figs. 4 and 5 are mean deviations of blocks of five beat intervals based on 20 presentations under each stimulus condition for the other species used in the present experiment.

Inspection of Fig. 2 suggests that *Streptopelia turtur* responded only to the light CS. This is confirmed by an ANOVA comparing simultaneously the three stimulus conditions ($F(2/14) = 6.6225$, $P = 0.0095$ for stimuli; $F(56/392) = 1.2411$, $P = 0.1268$ for the interaction between the stimuli and the successive cardiac periods). An ANOVA comparing magnetic and sham responses suggests also that the birds did not respond differentially to the stimuli ($F(1/196) = 0.028$, $P > 0.1$).

However, the response to the light stimulus is significantly different from that to both magnetic and sham stimuli (smallest $F(1/7) = 7.5727$, $P = 0.027$). Although successive periods (each two points) of this response to light do not approach significance ($F(14/98) = 1.2992$, $P = 0.2256$), periods 15-17 are significantly different from the last three points of the basal level ($F(1/5) = 8.5709$, $P = 0.0215$). These results suggest that *S. turtur* responded only to the light stimulus.

Inspection of Fig. 3 shows that in the case of *Corvus monedula* no systematic response developed to magnetic and sham stimulus presentations. This is confirmed by an ANOVA comparing the two curves ($F(1/5) = 1.4815$, $P = 0.277$).

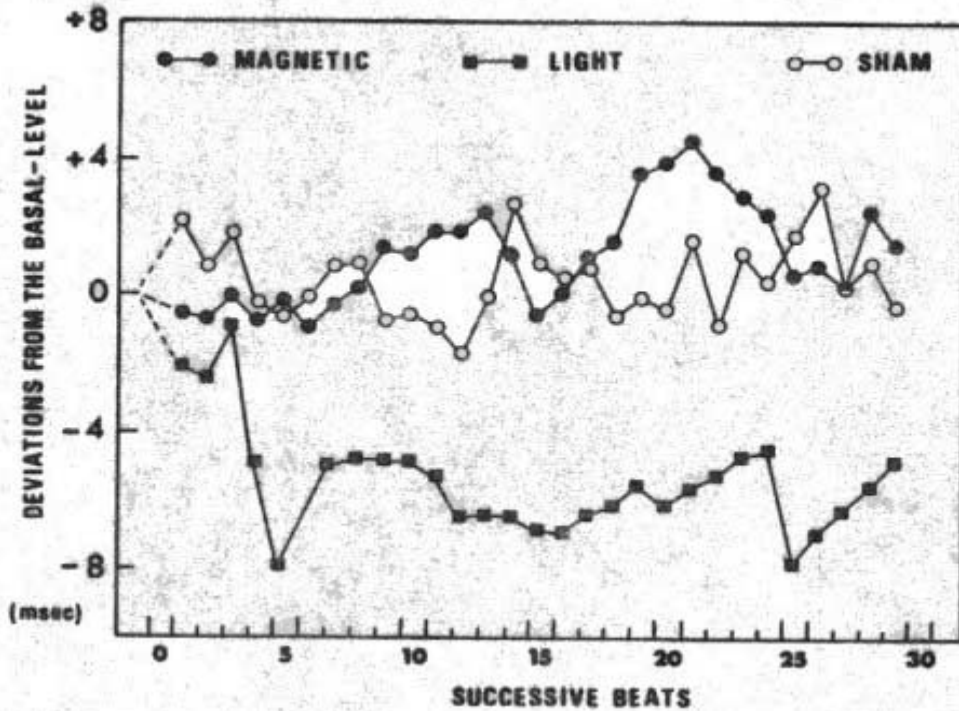


Fig. 2. Cardiac conditioned responses in *Streptopelia turtur* (N=8) to magnetic, sham and light stimuli. The cardiac responses are averaged over 10 trials for each stimulus presented. Units are ms of difference of time interval between 30 successive beats and the pre stimulus basal level. An accelerative response corresponds to a downward curve.

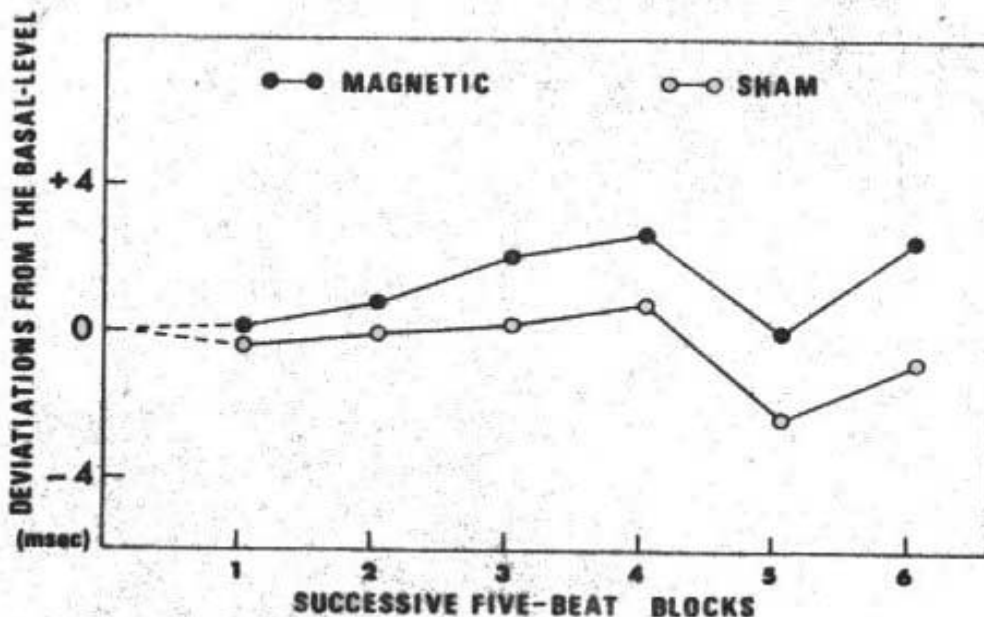


Fig. 3. Cardiac conditioned responses in *Corvus monedula* (N=6) to magnetic and sham stimuli. Each curve is the average of 20 trials of each stimulus presentation. Units are msec of difference of time interval between successive blocks of five beats and the pre stimulus basal level.

Figs. 4 and 5 represent the mean deviations for 20 trials under each stimulus condition for the other species used in the experiment. The number of subjects being far too limited to use the ANOVA, χ^2 were tentatively used to analyze the data. The tests were done on the frequency counts of the deviations in each curve (two sets of data points for the two subjects *Streptopelia decaocto*) that lie above its average basal level.

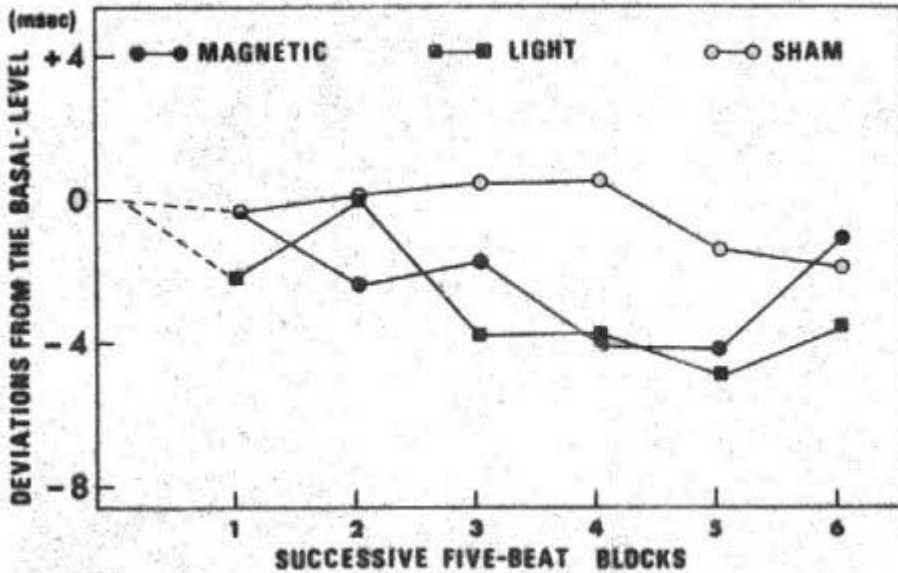


Fig. 4. Cardiac conditioned responses in *Streptopelia decaocto* (N=2) to magnetic, sham and light stimuli. Each curve is the result of the averaging of 20 trials of each stimulus presentation. Units are ms of difference of time interval between successive blocks of five beats and the pre stimulus basal level.

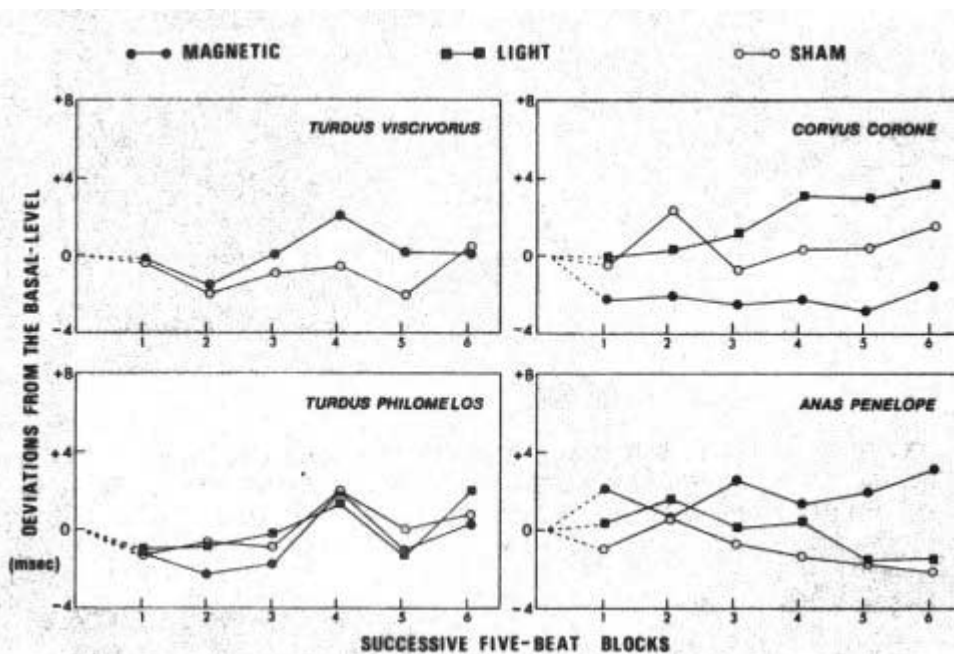


Fig. 5. Cardiac conditioned responses in subjects *Turdus viscivorus*, *T. philomelos*, *Corvus corone c*, and *Anas penelope* to magnetic, sham and light stimuli. Each curve is averaged from 20 presentations of each stimulus. Units are ms of difference of time interval between successive blocks of five beats and the pre-stimulus basal level.

Comparison between magnetic and sham conditions suggests no difference between the two except for subject *Corvus corone* ($\text{Chi}^2 = 16.307$, $\text{df} = 1$, $P < 0.001$). On the other hand, difference between magnetic or sham and luminous conditions reaches significance for *S. decaocto* ($\text{Chi}^2 = 11.093$ and 22.742 , $\text{df} = 1$, $P < 0.01$) and *C. corone*, where a difference also appears between the sham stimulus and the luminous one ($\text{Chi}^2 = 28.4$, $\text{df} = 1$, $P < 0.001$).

These results indicate that, except for the individual *Corvus corone*, none of the six species used in the present experiment responded differentially to magnetic and sham stimulus presentations. They also suggest that the magnetic stimuli were not used by these birds as CSs for the forthcoming shock, and most probably not detected.

DISCUSSION

In general, the results of this experiment reinforce those that we have published elsewhere on magnetic sensitivity in the homing pigeon (Beaugrand, 1976). Both results are in agreement with those of several other workers who have failed to directly show magnetic sensitivity in birds using conditioning. Reille's (1968) data are as yet the only exception to this increasing tradition of negative results and must now be considered as doubtful (Kreithen and Keeton, 1974; Beaugrand, 1976).

The apparent responding of the individual *Corvus corone* to magnetic stimuli must be interpreted with caution. Firstly, the data are based on only one individual and the test used, a X', is evidently not appropriate and was used tentatively only. Secondly, the accelerative response to the magnetic stimulus is of the order of 4 ms at peak; for a bird having a typical 300 ms inter-beat interval as basal level, this deviation is much smaller than the 40-60 ms deviation observed in pigeons having a comparable basal level and responding to a light stimulus (Beaugrand, 1976). Although these restrictions cannot completely eliminate the possibility that this individual *C. corone* responded to magnetic stimuli, they rather suggest that this effect be confirmed in a future and systematic experiment on the species. Thus in the discussion we shall assume that this difference between magnetic, sham and light effects on cardiac activity in *C. corone* was due to a chance effect only.

Our results show only that the species tested did not use the magnetic stimuli presented as cues announcing the forthcoming shock when cardiac activity is taken as an index of vegetative responding. It is out of the question here to form any conclusion regarding their magnetic sensitivity.

Negative results are quite difficult to interpret and might correspond to distinct realities. The first possibility is that there is no such magnetic sensitivity in birds. In fact, even if we take into consideration the results that are the most suggestive of magnetic sensitivity in birds (Keeton, 1974b; Walcott and Green, 1974; Wiltschko and Wiltschko, 1975a, 1975b, 1976), these results show only that varying some of the parameters of the surrounding magnetic field modifies orienting behavior accordingly. That these results signify the use of magnetic information by the birds may only be an illusion. It can be argued that the effects attributed to magnetic fields are indirect, global, random or artifactual effects generated either by systematic asymmetries of the instrumental procedure or test used (Howland, 1973) and/or amplified by the way the data are analyzed afterward. Indeed there are design problems with the cages used in some zugunruhe experiments (Emlen, 1975). Also, relying on second-order analysis in order to obtain significant numerical values from data of octagonal experiments is a technique that can be questioned. The use of a single directional vector in an orientation experiment is probably a formally correct mathematical answer to the problem of independence of the data in one experiment, but it can be questioned whether this mathematical answer is respecting the conditions of invariance with behavior in the real world.

On the other hand, it can be argued that the disorientation or reorientation observed after manipulation by experiment or selection of the surrounding magnetic field is to a certain degree systematic and can be controlled and predicted, thus suggesting a direct causal relationship between the magnetic modifications injected into the system and the behavior measured. However, such a fine relationship cannot completely exclude the possibility that the magnetic field has an indirect causal effect by acting on other levels of functioning (such as a biological clock for example) which in turn would provoke a systematic misinterpretation of other cues, visual or hitherto unsuspected. Such an indirect effect is thus congruent with the long history of negative results obtained for sensitivity in the conditioning laboratory.

A second possible explanation of the negative results relies on some kind of methodological failure happening in the laboratory: there may exist magnetic sensitivity in birds we have been working on but the methodology used up to now in order to demonstrate its existence was inadequate or inappropriate for this particular case of sensitivity. The failure to show magnetic sensitivity using conditioning (and evoked cardiac orienting responses) can then be explained by the fact that the experimental situation lacks external validity. We may be introducing or eliminating some intervening variable(s) that otherwise would have permitted detection or may be creating for the animal a non-sense situation. A comparison of conditioning experiments leading to negative results with zugunruhe experiments (octagonal cages and homing experiments) reveals important differences between the two; they concern not only the duration of stimuli used and the relative mobility of the birds in the cages (Kreithen and Keeton, 1974; Keeton, 19745; Beaugrand, 1976) but also differences between the paradigms themselves.

Duration of stimuli

As stressed by Kreithen and Keeton (1974) and by Keeton (19745), all conditioning experiments have presented discrete or short duration magnetic variations (pulses) as stimuli and have failed to show any sensitivity to magnetism. The use of pulses as stimuli is a direct import from the conditioning laboratory where this method of presentation has proven successful for the study of visual or auditory discrimination and detection. No one seems to have realized that, contrary to visual test stimuli, magnetic fields in nature as well as in zugunruhe experiments are continuously and permanently at the disposal of the birds. They are not pulsed by a random external contingency but readily accessed when needed. This property of permanence of magnetic fields suggests that integration (summation of the signal over time) of the signal might be the normal process through which its detection is made possible; this integrative process might be similar to the one suspected for incident light reception by the pineal. The notion of integrative process also fits well with the inertia effects in spontaneous orientation observed following the introduction of significant and sudden changes in the total intensity of magnetic fields in octagonal cages (Wiltschko and Wiltschko, 1972): there is a momentary loss of coherent orientation for several hours.

On the other hand, if there is no integration of the magnetic signal then there must exist some biological mechanism regularly shutting the sensory channel in order to reduce or eliminate habituation to the continuous stimulation. Magnetic use is often qualified as "weak" compared to other known detections and modes of orientation; indeed, it is hard to extract its "significance" from data. But this weakness might reflect an intermittent use or detectability of magnetic signals. Wiltschko and Wiltschko's (1975a, 1975b, 1976) suggestion that the bird proceeds to an early transposition of magnetic directional information to stars reinforces this hypothesis. Magnetic detection or information itself would be somewhat labile or intermittent and that information (obtained from magnetic gradients) would have to be soon transposed to more stable or readily accessed visual cues in order to preserve its directional information.

One can also imagine that only a limited number of subjects in a flock of migrating birds need momentarily to have this magnetic signal in an intermittent manner while the group still economically maintains adequate heading. Two functions have to be postulated. One is that directional information once transferred to easily accessed visual cues is systematically maintained in a persistent manner by this minority. Secondly, cohesion in the flock plays in favor of this minority, so that the flock as a whole behaves meaningfully by "averaging". Theoretically, the whole process could be simulated by a series of automata, each automaton running two different programs in an intermittent and exclusive manner: the first series is the minority group stubbornly maintaining a heading; the second group of automata initially is randomly acting except that its individuals have a strong tendency to synchronize (i.e., align) with the most proximal automata in order to keep with the flock. The result would be that after a certain time the whole flock would be synchronized on the minority. The minority could reset its heading individually and regularly and be relayed randomly by subjects of the rest of the flock without affecting the behavior of the whole group.

Mobility of the bird

A second distinction between the conditioning situation and the zugunruhe experiment concerns the mobility of the receptor system as compared to the continuous and relatively stable environment of magnetic stimulation. These conditions of mobility are minimal in the octagonal cage and arenas, optimal in the homing experiments but absent in the conditioning experiments. Although we might see mobility of the animal as essential for detection, detection here does not have to occur through an accessory mechanism such as plumage polarization or buildup of electromotive force on the

mobile animal. Indeed it is hard to conceive how these two mechanisms might have played a role in small arenas and octagonal cages. We are rather suggesting that if movement is an essential element for the detection of magnetic fields by the bird it is through an active scanning of the stimulation by motor adjustments and spatial displacements permitting a feedback between the receptor system and the stimulating source. When such movements are limited by a stationary (or restraining) testing situation like conditioning, detection might be impaired. It is known in the case of vision and audition, for example, that mobility of the dual receptive system (of which binocularity and binaurality are already inbuilt spatio-temporal comparative mechanisms) greatly facilitates complex perception of depth, distance and localization of the stimulating source.

Other differences

There are further differences between the conditioning and zugunruhe paradigms. One of these concerns the internal state of the organism in a test situation. This state depends not only on tonic hormonal changes which are most probably underlying the triggering of zugunruhe in the migrant; it also depends on immediate or phasic effects following the coincidence of environmental or physical influences such as being outside home or off migratory goals. In other words, the detection or use of magnetism could be conditional upon internal states and upon the capacity of the immediate physical situation to trigger and regulate (=orient) behavior.

It is obvious that in an artificial situation such as a conditioning experiment, at least one of these conditions is lacking. In our experiment on migrants captured during their migration we presumed that they were in a state of zugunruhe. However, the physical situation of retraining the animal can have induced such a stress that the animals were probably more in a state of escaping the immediate situation than one of orienting themselves. This is suggested by the fact that sensitivity to a light stimulus was either difficult or even impossible to assess from the cardiac responses. It is also possible that in the octagonal cage stress might generate enough noise to explain the difficulty in obtaining consistent orienting behavior. Since one basic difference between conditioning and arenas experiments is the fact that in the latter the session lasts much longer (a whole night usually), it might be expected that the birds have the opportunity to habituate gradually to the stressful situation and switch to more meaningful behavior as time passes.

Also, processes referred to in both kinds of experiment are of different levels of organization. That in the conditioning paradigm the animal has to learn something is, of course, a statement of the obvious, though it is not hard to find cases where animals were biologically contraprepared to make specific associations or responses and failed to learn. Magnetic fields in nature are not a cue announcing footshock, so it can be argued that it is biological non-sense to include those ingredients in a particular conditioning contingency. However, the fact that magnetic fields presented alone do not trigger a cardiac orienting reflex as light stimuli do (Beaugrand, 1976) is even more puzzling and might suggest that, if there is magnetic sensitivity in the birds so far studied, it does not contribute to their arousal system. In zugunruhe and homing experiments we are referring to associations which are most probably biologically preprogrammed, like an IRM or taxis. It is also possible that magnetic energy impinging on the animal would be detected and processed locally without having access to higher processes such as learning and "arousal" regulations. An example of this unusual biological constraint is provided by Wells (1964) in the denucleated octopus for weight discrimination; his findings suggest that the information concerning weight is used locally for appropriate tentacles adjustments although not available centrally for learning and weight discrimination.

CONCLUSIONS

A negative experimental result is evidence but not proof that a character such as magnetic sensitivity is lacking. Conclusions are limited to the species studied, to the specific biological significance of the test used, to the response tested and to the environmental conditions prevailing during the test. If it is shown that sensitivity is lacking for all responses and situations studied, then one possibility is that the animal's sense organs are not responsive to magnetic fields. Eventually, the most direct technique for studying the ability of an avian organism to detect magnetic fields will involve recording from sense receptors, sensory pathways and brain centers themselves. It is the next step. But where shall we look?

ACKNOWLEDGEMENTS

The author is grateful to the staff of the Ornithological Reserve of the Zwin (Het Zoute, Knokke, Belgium) in allowing us to work on their reserve and especially to Mr. Robert Trio and Mr. Guido Burggraeve for their interest and collaboration in the study. This work was generously supported by the Association Royale Colombophile de Belgique, the Centre de Psychologie Expérimentale et Comparée (Pellenberg, Belgium) and the Université du Québec à Montréal. We are most grateful to Prot G. Thinès and to Dr. René Zayan for helpful discussions at various stages of this project.

REFERENCES

- Beaugrand, J.P., 1976. An attempt to confirm magnetic sensitivity in the pigeon, *Columba livia*. *J. Comp. Physiol.*, 110: 343-365.
- Dixon, W.J., 1973. BMD Biomedical Computer Programs, University of California Press, Los Angeles.
- Emlen, S.T., 1976. Migration: orientation and navigation. In: D.S. Farner, J.R. King, K.C. Parkes (Editors), *Avian Biology*, Vol. V. Academic Press, New York, pp. 129-219.
- Emlen, S.T., Wiltschko, W., Demong, N.J., Wiltschko, R. and Bergman, S., 1976. Magnetic direction finding: evidence for its use in migratory indigo buntings. *Science*, 193:505-607.
- Howland, H.C., 1978. Orientation of European robins to Kramer cages. *Z. Tierpsychol.*, 33: 295-312.
- Keeton, W.T., 1974a. The mystery of pigeon homing. *Sci. Am.*, 231: 93-107.
- Keeton, W.T., 1974b. The orientational and navigational basis of homing in birds. In: D.S. Lehrman, J.S., Rosenblath, R.A. Hinde, E. Shaw (Editors), *Advances in the Study of Behavior*, Vol. 5. Academic Press, New York, pp. 49-132.
- Kreithen, M.L. and Keeton, W.T., 1974. Attempts to condition homing pigeons to magnetic stimuli. *J. Comp. Physiol.*, 91: 355-362.
- Meyer, M.E. and Lambe, D.R., 1966. Sensitivity of the homing pigeon to changes in the magnetic field. *Psychon. Sci.*, 5: 349-350.
- Orgel, A.R. and Smith, S.C., 1954. Test of the magnetic theory of homing. *Science*, 120: 891-892.
- Reille, A., 1968. Essai de mise en évidence d'une sensibilité du pigeon au champ magnétique à l'aide d'un conditionnement nociceptif. *J. Physiol. (Paris)*, 60: 85-92.
- Southern, W.E., 1970. Influences of disturbances in the earth's magnetic field on ring-billed gull orientation. *Am. Zool.*, 10: 23.
- Southern, W.E., 1972. Magnets disrupt the orientation of juvenile ring-billed gulls. *BioScience*, 22: 476-479.
- Tobin, M., Djoletto, B.D. Milkman, N., Kerr, J., Williams, T.A., Khachaturian, Z. and Schachter, J., 1970. The R peak detector and R-R interval counter: a new interface to the PDP-12 computer for on-line analysis and processing of heart rate data. *Proc. 1970 DECUS Spring Symposium*, pp. 265-271.
- Walcott, C. and Green, R., 1974. Orientation in homing pigeons altered by a change in the direction of an applied magnetic field. *Science*, 184: 180-182.
- Wells, M.J., 1964. Learning and movements in octopuses. *Anim. Behav. Suppl.*, 1: 115-128.
- Wiltschko, W. and Wiltschko, R., 1972. Magnetic compass of European robins. *Science*, 176: 62-64.
- Wiltschko, W. and Wiltschko, R., 1975a. The interaction of stars and magnetic field in the orientation system of night migrating birds: I Autumn experiments with European warblers (Gen. *Sylvia*). *Z. Tierpsychol.*, 37: 337-355.
- Wiltschko, W. and Wiltschko, R., 1975b. The interaction of stars and magnetic field in the orientation system of night-migrating birds: II. Spring experiments with European robins (*Erithacus rubecula*). *Z. Tierpsychol.*, 39: 265-282.
- Wiltschko, W. and Wiltschko, R., 1976. Interrelation of magnetic compass and star orientation in night-migrating birds. *J. Comp. Physiol. A*, 109: 91-99.

RÉSUMÉ

Beaugrand, J.P., 1977. Essai de mise en évidence d'une sensibilité magnétique chez sept espèces d'oiseaux européens à l'aide d'un conditionnement nociceptif. *Behavioural Processes*, 2: 113-127 (en anglais).

Nous avons tenté de mettre en évidence une sensibilité magnétique chez des oiseaux capturés durant leur migration. Le test a été effectué sur sept espèces d'oiseaux migrateurs européens (*Streptopelia turtur*, N=8; *Streptopelia decaocto*, N=2; *Corvus monedula*, N=6; un représentant des espèces suivantes: *Corvus corona c.*, *Turdus philomelos*, *Turdus viscivorus*, *Anas penelope*). La plupart des sujets ont en premier lieu été soumis à un conditionnement nociceptif à un voyant lumineux. Ils ont ensuite été soumis à un conditionnement différentiel magnétique comprenant 100 présentations d'un stimulus conditionnel magnétique impliquant une inversion de la composante verticale Z du champ magnétique local, et 100 présentations d'un stimulus contrôle pour les artefacts. Les deux stimuli étaient présentés dans un ordre et sur une base de temps aléatoires. Les variations de l'activité cardiaque des sujets ont été utilisées comme variable dépendante. Nos résultats indiquent l'absence de conditionnement cardiaque au stimulus magnétique. Nous discutons de la validité des stimuli et des paradigmes employés pour la mise en évidence d'une sensibilité magnétique chez les oiseaux.