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SEZIONE III

(Botanica, zoologia, fisiologia e patologia)

Zoologia. — *Sun spots and homing performances in pigeons. A correlation* (*). Nota di BRUNO SCHREIBER e ORAZIO ROSSI (**), presentata (***) dal Socio S. RANZI.

RIASSUNTO. — Una mole notevole di ricerche ha recentemente dimostrato in maniera inequivocabile che l'organismo animale in genere reagisce a variazioni del campo magnetico, anche di valore di molto inferiore a quello del campo magnetico terrestre. In particolare gli uccelli risentono di queste variazioni nell'ambito dei meccanismi che presiedono all'orientamento spaziale correlato alla navigazione durante le migrazioni. Lo provano chiaramente le alterazioni della direzione della « attività pre-migratoria » studiata in gabbie poste in un campo magnetico variato, come pure le deviazioni della rotta in volo degli animali sui quali vengono adattati magneti o spirali di Helmholtz attivate da correnti appropriate. Questo ci ha indotti a studiare l'eventuale azione sull'orientamento degli uccelli delle variazioni « naturali » del campo magnetico terrestre quali le tempeste magnetiche determinate dall'aumento della attività solare. La ricerca è stata condotta mediante lo studio della correlazione fra il numero delle macchie solari e la velocità del ritorno in gara dei colombi viaggiatori, assumendo come indicazione di questa, la percentuale dei rientri in sede entro la prima giornata di gara. Il periodo delle osservazioni riferite in questa Nota va dal 1932 al 1957 mentre sono in corso di elaborazione i dati che si riferiscono a periodi successivi fino ad oggi. Osservazioni fatte su complessivamente 12 mila animali in 18 gare sul percorso dalla Calabria a Parma hanno dimostrato mediante una statistica particolarmente elaborata che esiste una correlazione negativa altamente significativa ($r = -0.7$) fra i due fatti nel senso che l'aumento del numero di macchie solari nei giorni della gara influisce decisamente in modo negativo sui meccanismi di orientamento dei piccioni viaggiatori.

INTRODUCTION

Among the different mechanisms by which birds find their way in migration flights, those based on the capability of perceiving the earth's magnetic field have in recent years been considered the most probable.

This statement does not exclude that other mechanisms, such as visual landmark recognition in short-range flights and astronomical (sun or stars) navigation, the demonstration of which seems very probative, can cooperate and alternate with the geomagnetic mechanism.

Among these phenomena, the "homing" of pigeons represents a particular case in the general problem of migration, as a consequence of the taming of this species.

The possibility of a geomagnetic sensitivity, which was proposed by Yeagly in the past, has been reconsidered after many facts have been observed

(*) A summary of this work was presented at the XLIVth meeting of the "Unione Zoologica Italiana" held in Camerino, Sept. 1976 [17].

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(***) Nella seduta del 14 maggio 1977.

in different animals. In fact, variations in the magnetic field, even if much smaller than the value of the earth magnetic field, could produce an effect on several biological activities [1]. Long before experimental research was started on this subject, empirical observations pointed out evidence of disturbances in birds' seasonal migrations coinciding with magnetic storms following the aurora borealis. Moreover, the command of the " homing pigeon service " of the Italian Army made exact observations of the relevant impossibility of establishing links with some regions, such as Valle d'Aosta, Isle of Elba, Sardinia, in which changes of the local geomagnetic coordinates were produced by the presence of ferromagnetic mines [2]. Yeagley [3] thought up an elegant natural experiment, belonging to the same class of facts as above, in which he used the existence of the " conjugate point " (Pennsylvania/Nebraska) given by the intersection of geodetical and magnetic parallels. These points, having equal values of magnetic and geodetic (Coriolis effect) forces, could cheat pigeons which had been released at a point equally far from them. Only recently, however, have significant results been obtained thanks to more precise experimental techniques for both the statistical monitoring of flight in natural conditions and the application of the artificial variation of magnetic field during flight or by means of testing the pre-migratory exicitement that birds show in cages in the period immediately prior to bearing.

We want to mention only the most significant experiments done by changing the intensity and the direction of the earth magnetic field components. By means of Helmholtz coils acting on a recording cage, Wiltschko and Coll. [4, 5, 6] notice da rotation of the mean direction of the preflight excitement owing to a pre-determinated rotation of the magnetic North, or a complete inversion of movements caused by an inversion of the vertical component of the magnetic field itself. Analogous results have been obtained by Emlen *et al.* [7] with Emberizia.

Similarly, a deep magnetic screening could severely affect the escape direction recorded in cages [8].

As to the experiments during flight, results obtained on applying magnetic rods to the backs of Larus [9] and Columba [10] are highly meaningful since they show significant angular variations in the vanishing route. The experiments using Helmholtz coils placed on the head of the pigeons [11], in which the magnetic field can be inverted by inverting the direction of the electric current, resulting in a complete inversion of the flight route, are very elegant. The results of applying anomalous magnetic fields are mentioned because these experiments gave the clearest evidence of a magnetic sensitivity and the values of the variations which can be perceived. Even though to a lesser extent, also observations made in " natural conditions of geomagnetic variations " clearly confirm the above mentioned results.

So the demonstration of the problems brought to the flight of pigeons by anomalous situations of the natural state of the magnetic field [2] and the sporadic observations on the bewilderment of migrations during aurora borealis preceeded the more documented knowledge on the phenomena.

However we must remember that since 1972 Southern [12] has been able to record clear angular displacements in the mean direction of the preflight movements in the cages of young seagulls caused by changes in the values of the geomagnetic activity due to solar storms (evident from $K = 4$ to $K = 7$). This finding, together with that of Keeton, Larkin and Windsor [13], is the most strictly connected to the present work. The above-mentioned Authors correlated the values of the mean vector and the direction of the fading route of homing pigeons with the sum of four K values of the earth magnetic field for the 12-hour period ending at the time of competition.

The meaningful positive correlation between the two phenomena is clear also for the leftward displacement of the bearing direction of pigeons, particularly in those times in which the K index was constantly settled at high values.

EXPERIMENTAL RESEARCH PLAN

In this study we wanted to set up research on the possible influence of magnetic storms correlated to sun spots, in an opposite way to that followed by Keeton *et al.* [13]. We wanted to investigate the homing pigeons' ability to returning home during games, in conditions of geomagnetic changes, by recording the percentage of pigeons returned " before the first nightfall ", instead of recording the displacement of the mean vanishing bearing as made by the above mentioned Authors.

The " Federazione Colombofila Italiana " have a unified race organisation system making exact data available on release and arrival times, which can be obtained from official registers. The races are repeated twice a year, always in the same season and on standardized routes along which pigeons are trained by their owners. The Parma section of the F.C.I. runs races on two long-range routes, one towards Calabria through the Appennines, the other all along the Adriatic coast up to Brindisi. In this paper we report on races held from 1932 to 1957 with pigeons bred in Parma and released at Belvedere (Calabria) 736 km away (1).

Release was if possible the day after arrival by train or car, in good weather conditions, just after sunrise and singly for each bird. The total number was 12066 pigeons in 18 releases. On arrival at Parma, the ring was removed and placed in a " recording clock " which marked the official arrival time. The flight speed resulting from the two data is about 50 km/h.

(1) We limit ourselves to this period because the observation was made some 20 years ago together with D. Mainardi and for work reasons the study was interrupted and never resumed again. Only the publication of the above-mentioned works in recent years has induced me to publish the results of these peliminary observations since they seem to clearly confirm the thesis. It is our aim to report in a future work data we have for the period from 1957 to 1971 and after, which are currently being processed.

We also took into account the total number of pigeons released and the « release order », and the percentages of pigeons which arrived " before the first nightfall " with respect to the pigeons released. This is the datum we wanted to correlate with the values of the " sun activity " because we thought it was the most representative of the natural trouble factors on the bump of the locality of pigeons caused by magnetic perturbation following it.

The other factor considered, the number of sun spots, is represented by the Wolf Number which is regularly recorded by many observatories. This is given by the formula: $R = k(10 + s)$, in which:

g = number of sets of spot clusters

s = number of single spots

k = constant.

As to the r variations in the period of time considered, they range from 0 to 200 corresponding to a Gauss variation of about 2/1000, equal to 0.5 % of the terrestrial magnetic field value at our latitude.

We are aware of the fact that it would have been better to refer directly to the geomagnetic changes (number R) but, since we began referring directly to the sun activity we have been following this system. The relation between the two phenomena, however, is well established [14] even if some displacement can occur in the synchronism, which could also explain some disagreement existing in our problem.

An analogous formulation was given by Yeagly [15] in his " vertical magnetic-coriolis " theory, correlating the mean return speed of pigeons with the solar spots of the day before the race. His fig. 8 seems meaningful to that purpose, though there is no statistical treatment in such an observation.

It is clear, in any case, that there are many factors which can affect the return speed and which have nothing in common with the thesis we support, i.e. bad weather encountered on the route after the start, contrasting wind, excessive heat, etc. These factors, which oppose the return in a completely random way, caused us to make a very careful statistical analysis of the results.

Of doubtless importance with regard to the homogeneity of reply in experiments of this kind is the fact that the pigeons used in the competitions come from dissimilar breeding places, and so are of very variable genetic genealogy. It would be different if the competition animals were highly selected within the same strain, as generally required when an external factor affecting their behaviour is studied.

Statistical methods for the analysis of the results

As we mentioned in the previous section, the aim of the following statistical analysis is to investigate the correlation between the percentage of pigeons which returned within the same day they were released and the Wolf Number resulting from observation of the solar spots.

We shall consider data pertaining to the competitions named " Belvedere 1° " (Table I).

First an evaluation of the linear correlation coefficient between the percentage of returned pigeons and the Wolf Number was made. The result, $r = -0.42$, was not statistically meaningful ($P > 0.05$).

Such a statistical approach, however, is approximate since it does not take into account the fact that each percentage value of returned pigeons weighs more if computed on a large number of released pigeons. The last number, however, changes from release to release.

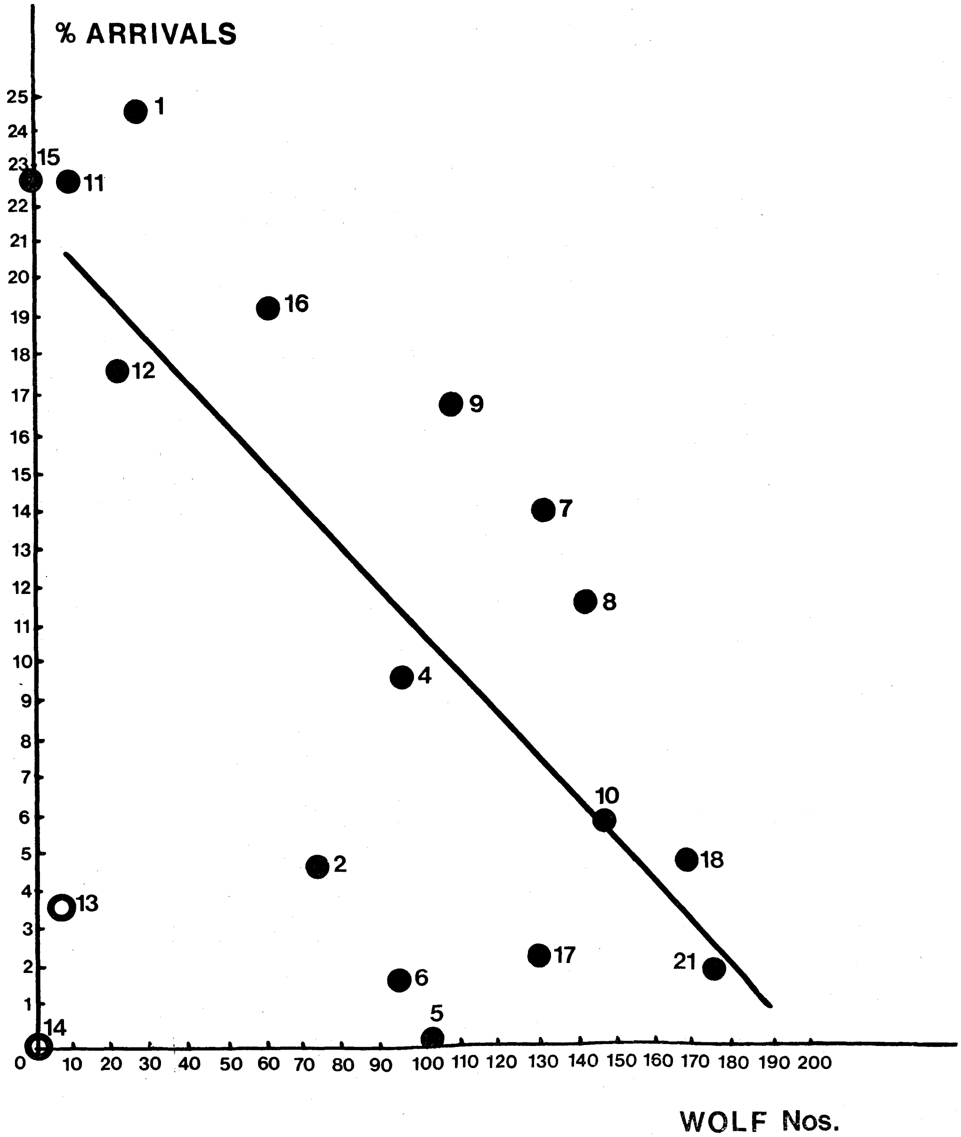

Fig. 1.

Moreover, a careful consideration of the data in fig. 1 brings up the suspicion that two data are astray:

Release No.	Date	No. of released pigeons	Wolf No.	Arrivals
13	13.6.53	215	7	3.60
14	9.5.54	165	0	0.00

Therefore we went deeper into the relation between the number of returned pigeons and the Wolf Number by using the multiple regression method, that is by means of the statistical model:

Eq. 1 $$\log_{10}(y+1) = \alpha \log_{10} x_1 + \beta \log_{10}(x_2+1) + \gamma x_3 + \varepsilon$$

where:

$\log(y+1)$ is a dependent variable representing the $\log_{10}$ of the number of pigeons which returned within the first nightfall incremented by one to allow the computation of the logarithm when $y = 0$;

$\log x_1$ is the $\log_{10}$ of the number of released pigeons (first independent variable);

$\log(x_2+1)$ is the $\log_{10}$ of the Wolf Number incremented by one to allow the computation of the logarithm when $x_2 = 0$ (second independent variable);

x_3 is the release order. It can be given values $1, 2, \cdots, 18$ corresponding to the release numbers of Table I (third independent variable).

We used the log of the number of released pigeons, of the number of returned pigeons, and of the Wolf Number to better satisfy the additivity condition expressed by the multiple regression equation (Eq. 1).

It can be noticed that on the basis of this statistical model the number of returned pigeons, expressed as $\log_{10}(y+1)$, depends on the number of released pigeons and on the order of release, as well as on the Wolf Number.

Coefficients α, β, γ are evaluated by means of the least squares method. ε represents the "remainder", i.e. the quantity remaining after removing the "effect" of the above independent variables with respect to the dependent variable $\log_{10}(y+1)$.

The β coefficient is particularly important to our aim because it measures the value and the sense of the supposed relation between the number of returned pigeons and the Wolf Number, the number of released pigeons being the same and having cancelled out a possible effect due to release order.

TABLE I

The Belvedere Race I.

N.	Launching date	Number launched	Wolf n.	% arrivals before the first nightfall
1	19/6/32	359	28	24.60
2	26/6/38	522	72	4.78
3	9/7/38	326	175	2.14
4	6/6/40	305	95	9.83
5	30/6/40	954	103	0.10
6	29/6/41	184	94	1.86
7	5/7/47	500	131	14.20
8	12/6/48	465	143	11.60
9	24/6/50	951	108	16.91
10	16/6/51	1.149	147	5.83
11	17/5/52	326	10	22.60
12	14/6/52	1.159	22	17.80
(13)	13/6/53	(915)	(7)	(3.60)
(14)	9/5/54	(165)	(0)	(0.00)
15	12/6/54	878	0	22.90
16	19/6/55	950	61	19.40
17	16/6/56	952	130	2.40
18	22/6/57	1.006	169	4.80
		12.066 total launched		

Computation and analysis of the multiple regression have been carried out with and without the two data which seemed to be astray (Table II and III).

Comparing results from those tables it results that:

1) the multiple regression, deprived of the suspect data, is statistically meaningful, so making the statistical model valid as a whole;

2) the partial regression coefficient between the number of returned pigeons and the Wolf Number is negative and statistically significant within 5 % = — 0.40 (Table III). We must notice (Table II) that the same rela-

tion was very far from the threshold of statistical significance when the two suspect data had been included.

TABLE II

Analysis of multiple regression calculated on total releases in Table I (*see also Eq.* 1).

S.V.	D.F.	Sum of squares	Mean squares	F	P
Multiple regression	3	2.145	0.715	2.55	>0.05
Residual	14	3.931	0.281	—	—
	Variable coefficients		Standard error	F	P
No. released	1.43		0.57	6.38	<0.05
Wolf No.	— 0.044		0.21	0.04	>0.05
Release order	— 0.017		0.03	0.33	>0.05
Constant	— 2.28				

TABLE III

Analysis of multiple regression calculated after omitting releases no. 13 and 14 of Table I.

S.V.	D.F.	Sum of squares	Mean squares	F	P
Multiple regression	3	2.011	0.670	4.13	<0.05
Residual	12	1.948	0.162	—	—
	Variable coefficient		Standard error	F	P
No. released	1.01		0.53	3.67	>0.05
Wolf No.	— 0.40		0.18	4.93	<0.05
Release order	0.003		0.025	0.02	>0.05
Constant	— 0.45				

The problem now is to verify if the two cancelled data are to be considered really astray from a statistical point of view. The background for this evaluation is formed by the following points: 1) one of the suspected anomalous points is cancelled and the multiple regression is calculated again; 2) the multiple regression has its own variance, then its points are dispersed; 3) if the cancelled point is outside the dispersion interval, it does not belong to the " statistical universe " describing the phenomenon, therefore it is astray. Then it can be effectively cancelled.

Therefore, following the Bliss [16] procedure, let $\log_{10}(y' + 1)$ be a value suspected of being astray and let $\log_{10}(Y + 1)$ be its value on the basis of the new multiple regression calculated after having cancelled it. $\text{Log}_{10}(Y + 1)$ is calculated for the independent variable values for which the corresponding dependent variable value is $\log_{10}(Y^* + 1)$.

The variance of the difference between these values, supposing they belong to the same population, is:

Eq. 2 $$V[\log_{10}(Y^* + 1) - \log_{10}(Y + 1)] = S^2 + V\log_{10}(y + 1)$$

where:

S^2 = total sum of squares-sum of squares due to the multiple regression/ D.F. residuals

$$V[\log_{10}(y + 1)] = S^2 \left\{ \frac{1}{N} + C_{11}(\log x_1 - \overline{\log x_1})^2 + 2C_{12}(\log x_1 - \overline{\log x_1}) \cdot (x_2 - \bar{x}_2) + 2C_{13}(\log x_1 - \overline{\log x_1}) \cdot (x_3 - \bar{x}_3) + C_{22}(x_2 - \bar{x}_2)^2 + 2C_{23}(x_2 - \bar{x}_2) \cdot (x_3 - \bar{x}_3) + C_{33}(x_3 - \bar{x}_3)^2 \right\}$$

where:

N is the total number of the $\log(y + 1)$ terms;

C_{ij} is the element of a matrix which can be calculated on the basis of the relation

$$C_{ij} = \frac{r_{ij}\, r^{ij}}{\text{Dev}_{ij}}$$

where r_{ij} is an element of the correlation matrix between two of the independent variables, r^{ij} is the corresponding element of the inverse matrix of r_{ij} and Dev_{ij} is the corresponding element of the deviance–codeviance matrix;

$\overline{\log x_1}$, $\bar{x}_2$, $\bar{x}_3$ are respectively the mean of the first, second and third independent variables.

The expression

$$\frac{[\log_{10}(Y^* + 1) - \log(Y + 1)]}{\sqrt{V[\log_{10}(Y^* + 1) - \log_{10}(y + 1)]}}$$

has a distribution like the Student's test and it can be used to prove our hypothesis: whether or not the examined data must be considered statistically anomalous.

In the case of the release number 13, the value of $\log(y + 1)$, which can be predicted by the multiple regression equation of Table III, is 2.200. $S^2 = 0.162$ (Table III), and the variance $V \log(y + 1)$ is 0.051.

Since the observed value is $\log(Y^* + 1) = 1.531$, $t = 1.55$ corresponding to a P slightly larger than 10%.

Repeating the same calculation for the release number 14, we find $\log(y + 1) + -1.83$ and $V \log(y + 1) = 0.091$ from which $t + 3.66$. The corresponding P value is 0.003.

We notice that, should the value of $\log(y + 1)$ be considered "a posteriori", i.e. the value of P be multiplied by $(N + 1) = 17$, we would get a value of P equal to 0.05.

Therefore we can soundly suspect, on the basis of this statistical test, that the two points considered belong to a different statistical universe than the other points with which the partial regression between the number of returned pigeons and the number of Wolf has been calculated.

On the basis of these results (see Table I) we can reasonably calculate the correlation coefficient between the percentage of arrivals and the Wolf numbers. Such a coefficient is equal to -0.73 and therefore highly meaningful. The "regression line" between the percentage of returned pigeons and the Wolf Number is: $y = -0.11\,x + 21.53$.

With this correction, supported by a rigorous statistical analysis, we feel we have demonstrated the existence of a negative influence of sun activity, represented by an increase in sun spots, on the efficiency of the homing pigeons' ability to return home.

Conclusion

At the end of this study let us express some considerations on the significance of our results: we have found a "correlation" between solar spots and the homing failure of pigeons.

We must however remember that a "correlation" (i.e. the correspondence of values of two variables) does not always necessarily represent a relation of cause and effect, as we would be tempted to consider it.

In the present case, the results of the experiments described (mentioned in the bibliography) on the effect of artificial magnetic variations on the birds' behaviour, remove any possible doubt and we can surely claim that the correlation found by us is definitely the consequence of a natural cause (solar spots) on the homing behaviour of pigeons.

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