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The Effect of an Electromagnetic Field on Early Embryogenesis in Quail[1]

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Abstract. Incubating quail embryos in a magnetic field resulted in accelerated somite growth. Twenty % of the experimental embryos in one series of experiments exhibited reversed torsion. The heterogenous magnetic field as opposed to the homogenous magnetic field was more effective in causing these effects. The theory of magnetic action on a biological system is discussed.

The study of life, as it is affected by magnetic fields, proceeded slowly prior to the 1930's, but the discovery of electromagnetic resonance principles stimulated more investigation because of the stronger magnetic fields possible. Much of the new data is equivocal, showing inhibitory and accelerative effects. In addition, relatively little information is available on avian embryos. Therefore, the purpose of this paper is to add information concerning the effects of a magnetic field on avian embryogenesis.

Maximo Valentinuzzi (1966) presented some essential concepts about magnetism's effects. These broad concepts show many possible affectors for biological responses. This may explain the fact that there are many theories accounting for specific results, but no clear reasons can be given for the contradictory data. His concepts were:

1. The effects of a magnetic field occur at the molecular kinetic level.
   (The type of magnetic field, the type of molecule, and its energy state are all interrelated.)
2. Paramagnetism is the basis for the mechanisms.
   (Electric charges on a molecule make it paramagnetic.)
3. Free radicles, which are often paramagnetic, represent the molecular entities which interrelate externally applied magnetic fields and biological actions.
   (Paramagnetic and diamagnetic particles are separated to higher and lower strength magnetic fields respectively.)
4. Molecular, energetic actions, integrated in time and space, are the basis for the effects.
5. Physical forces must have a specific magnitude for biological effects to occur.
   (The magnetic field must have a certain minimum force to overcome the inherent kinetic energy of the system.)

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6. The type of field is important.
(Homogenous fields have uniform intensities over the whole field, while the heterogenous field strength varies from place to place. This variance makes it possible to separate para- and diamagnetic molecules.)
7. Cybernetic mechanisms are important—that is, chemical or mechanical methods of control and communication in living organisms. (A magnetic field can affect a chemical reaction by (a) direct influence or equilibria and rates of reactions; (b) direct influence of magnetic energy on chemical bonding; (c) the indirect effects of fields resulting from physical forces acting on a system (Barnothy, 1964 p. 82).

Starting from these concepts, Valentinuzzi formulated a theory for biological slowdown based on rotating, paramagnetic free radicles controlled by the type and strength of the magnetic field and the chemical make-up of the biological material. He theorized that:

1. Enzymatic reactions are necessary.
2. Intermediate complexes between enzymes and substrates are needed.
3. The complex rotates and is a free radicle.
4. The above complex has specific reactive sites.
5. The complex combines with structures at reactive sites.
6. Cybernetic mechanisms operate. (Valentinuzzi, 1966)

Valentinuzzi's concepts and theories deal with only one parameter of effects—the slowdown of biological activity. The following experiments, recorded in the literature, show a range of effects, but have characteristics that can be related to Valentinuzzi's concepts.

Gross and Smith (1961) reported that in mice subjected to a heterogenous field, wound healing was reduced by 20%. They postulated that RNA and enzyme synthesis was inhibited. This experiment shows that fibroblast proliferation and fibrosis was markedly reduced and may be related to Valentinuzzi's theory of inhibition.

Studies on *Drosophila melanogaster* by Mulay and Mulay (1964) show that a magnetic field causes typical mutations, but they are nongenetic. It is postulated that mutations were created by faulty chemical reactions changed by the same mechanism that caused inhibition.

A magnetic field can affect the genetic code, and Barnothy (1964 p. 81) has lengthened the life expectancy of exposed mice by stabilizing mutation reactions. Presumably, mutation reactions in a magnetic field are stabilized according to quantum mechanics. Thus, fewer cells die, and because normal enzyme-catalyzed reactions can continue, life goes on longer and more efficiently.

Experimental Material

Coturnix coturnix japonica were chosen for this study because of their availability in the Drake University laboratories, and for the small egg size. Eggs average 3.1 cm long by 2.4 cm wide, and are thus suitable for the relatively small size of the magnet's poles.

As seen in Figure 1, the incubator (with cover removed) contained both experimental and control eggs but was large enough so that no stray magnetism reached the control eggs. The control group was surrounded with metal plates similar to the magnet's poles to simulate the conditions existing on the experimental eggs.

The type of magnet used (Fig. 1) was a Cenco Model K (Cat. No. 796375), an air cooled, aluminum-foil electromagnet with a variable gap between the poles. With flat pole faces and a narrow gap, it is capable of approximately 10,000 gauss. With tapered pole faces, which give a heterogenous field, 16,000 gauss are produced at the center of the pole. It is a DC magnet and has a static field traveling from right to left as opposed to an alternating field.

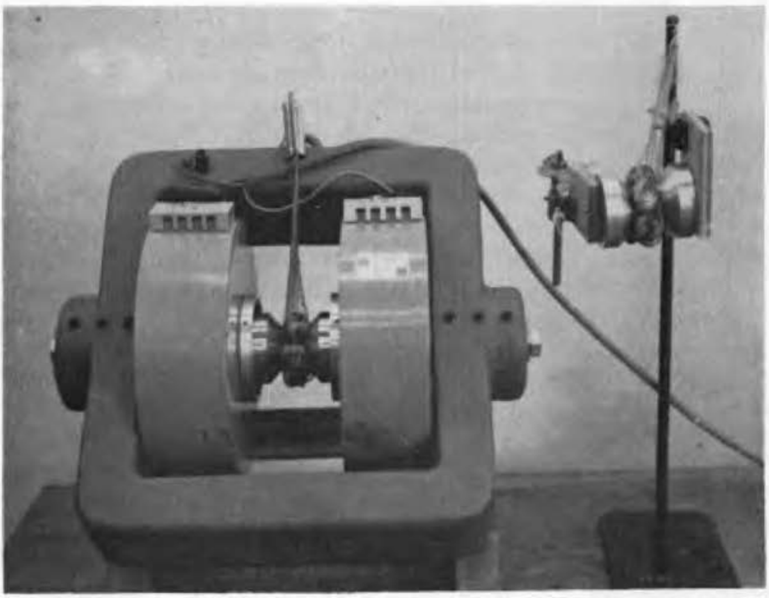

Fig. 1. The incubator (shown with cover removed) contains both experimental (left) and control eggs (right) but is large enough so that no magnetism reaches the control eggs. The heterogenous pole pieces are shown.

Methods

Embryos were incubated in a magnetic field for 48 hours and then observed. If an effect was noticed, other embryos were incubated for forty-eight hours but were kept in the magnetic field only for 0-12, 12-24, 24-36, or 36-48 hours. This tested the effects of magnetism at specific periods. Homogenous fields were tested first, but no significant results were observed. The heterogenous field was then tested.

Standardization tests involved incubating experimental and control eggs in position without turning on the magnet. In magnetism tests, a control group was incubated at the same time as the experimental group. Control groups were always compared to their corresponding experimental groups to eliminate error from temperature variation. Both groups had separate thermostats; their temperatures were equal (± .5C) but varied within a range of 36.5-39.5°C from day to day.

Discussion

The data (Table 1) reveals that a homogenous magnetic field up to 9,000 gauss does not affect the development of the embryos as much as a heterogenous field. To get effects in incubated embryos with a homogenous field, one must provide a high field intensity because of the increased kinetic energy associated with the incubation temperatures (Reno and Nutini, 1963).

It was not possible to create very strong homogenous fields, but in heterogenous fields, field gradients of 1,500 to 7,000 guass/cm induced effects. A 5.6% increase in the somite number of experimental embryos was observed in homogenous fields, but this is not as significant as the 13.2% increase in the heterogenous fields. Experimental eggs used for standardization tests had 2.2% fewer somites than the controls. Embryos exposed to the heterogenous

Table 1

I. % Somite Growth of Experimental as Compared to Control Embryos

Standardization tests (no magnetic field)	—2.2%
Homogenous field tests (up to 9,000 gauss)	+5.6%
Heterogenous field tests (up to 12,000 gauss)	+13.2%

II. Torsion Reversals

Standardization		2 of 26	= 7.7%
Homogenous Fields	control	0 of 42	= 0.0%
	expt.	1 of 46	= 2.1%
Heterogenous Fields			
All heterogenous field tests:	control	2 of 86	= 2.3%
	expt.	10 of 100	= 10.0%
48 hours in magnetic field:	control	2 of 38	= 5.2%
	expt.	8 of 40	= 20.0%
12 hours out of 48 in field:	control	0 of 48	= 0.0%
	expt.	2 of 60	= 3.3%
All controls		4 of 154	= 2.6%

field for a 0-12 hour or 12-24 hour period during 48 hours of incubation show an acceleration of growth even though no, or only a few, somites were formed while the magnet was on. A similar latency was seen in nervous system effects (Kholodov, 1964). It is suggested that the system is changed chemically and does not return to normal immediately after the magnetic field is turned off. Therefore, when an event like somite formation occurs, the changed system develops differently for a time. The 0-12 and 12-24 hour tests show about a 10% somite acceleration while the 24-36 hour test shows a 16% increase. The 36-48 hour exposures showed a

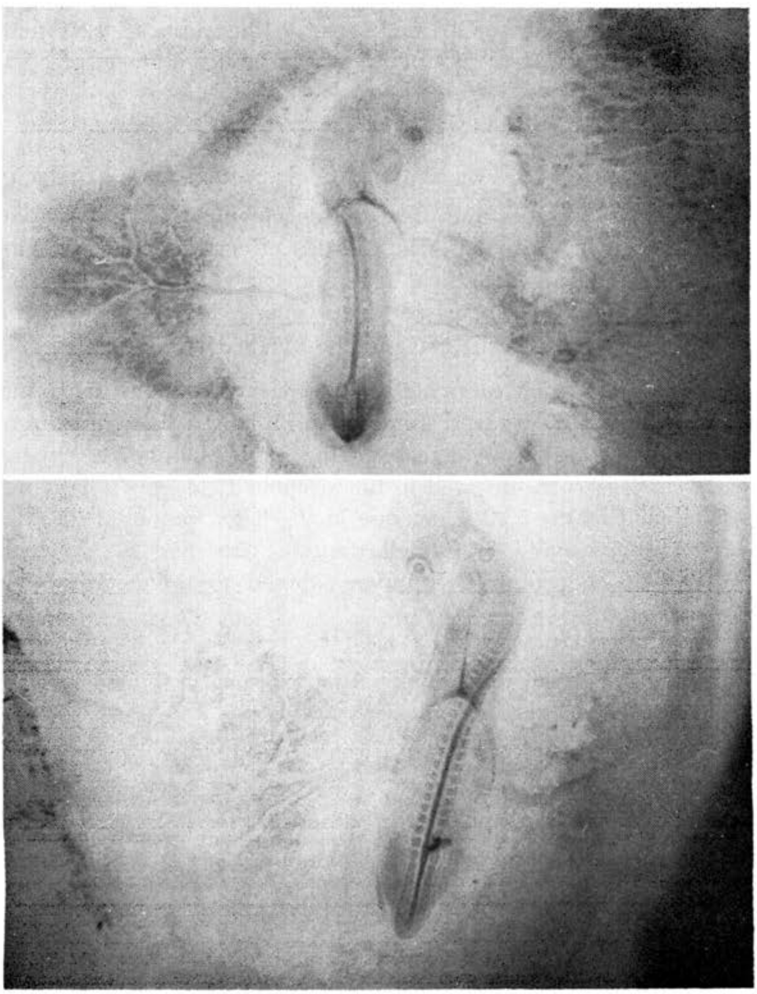

Fig. 2. Embryo Torsion: normal (above), facing right; abnormal (below), facing left.

similar degree of somite increase, but an insufficient number was tested to fix an exact level.

No explanation for growth acceleration has been found in the literature, and little data has been gathered about accelerative effects. Perakis (1947) reported that the *in vitro* growth of chicken embryo heart fibroblasts was stimulated by 24% in an inhomogenous field of 1,000 gauss. Accelerative effects might be explained indirectly by Barnothy's aging delay hypothesis. If the normal growth rate is constant, but fewer cells mutate and die in a magnet field, the growth rate would appear to be increased. This speculation is supported by the fact that actively dividing tissue is generally more susceptible to mutation. Teratological differences between control and experimental groups might indicate fewer mutations in the experimentals, though other causes are also important in teratology.

A number of embryos were seen in a reversed position (Fig. 2). Reversed torsions were caused only by heterogenous fields. Fifty % of the reversals occurred at egg position number 2 (Fig. 3). The importance of egg position in the magnetic field is not understood, but further tests using different egg orientations might clarify this

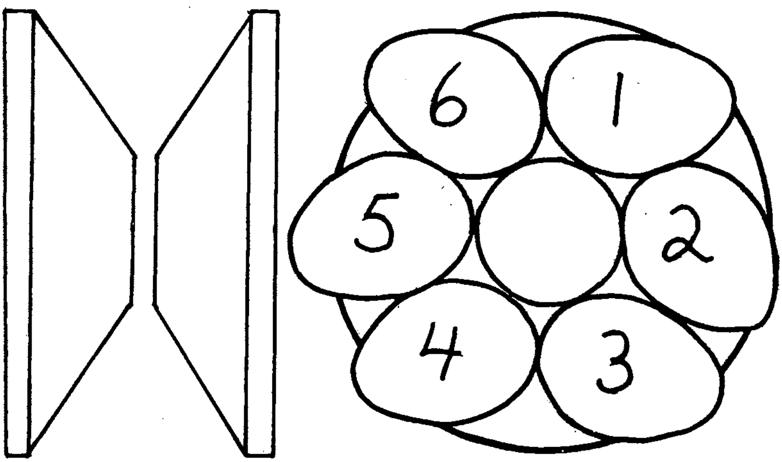

Fig. 3. Heterogenous pole pieces and egg orientation: side view (left) and front view (right). Fifty percent of the torsion reversals occurred at egg position #2. The significance of this distribution is not known.

point. Length of exposure to the field was important; 3.3% of the embryos exposed for 12 hours and 20% of those exposed for 48 hours showed reversed torsion. This suggests that latent effects are not important in this phenomenon. Unless a consistant relation between embryo orientation and the direction of the field can be shown in future tests, a chemical mode of action seems very probable.

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