20 bean seeds were randomly oriented in preweighed aluminium-screen trays, weighed to the nearest cg, and submerged in temperature-equilibrated tap water at 1-min intervals around a table. 4 h later, always over the noon h, all the samples were individually wet-weighed and the amount of water absorbed was determined as the difference between final wet-weight and initial dry weight + 15 cg (= wetting). The percentage weight increase by water uptake was calculated for each of the 4 pairs on a table and the values for the 2nd, 3rd and 4th pairs were converted to differences from the 1st pair submerged. In view of the mutuality of interactions[5,6] the 3 differences from the 1st pair, without sign, were each added to obtain the sum of the positive and negative differences for unit sequences of about 30 and 180 days.

Results and discussion. The data, including all 5 experimental conditions, are shown in tables 1–3 along with starting dates and numbers of days. The mean results for longer periods, about 180 days, are depicted in figure 2. Employing a 2×3 χ^2-test, no significant difference was found between the 2 runs on the CW rotating tables, on the CCW rotating tables, or with the CCW rotating magnet, nor was any difference found among the 1st 3 stationary-table runs. For the CW rotating magnet, despite the A to C difference being the smallest in both cases, there was a 5% probability that these differed from one another. Among the stationary-table results a significant difference ($p < 0.01$) occurred only between the 3rd and 4th series.

Now examining for possible statistical significance the differences from their means for the 3 values for all data for each of the 5 experimental conditions, p-value differences from random were: CW magnet, $p < 0.05$; CCW magnet, $p < 0.001$; CW table, $p < 0.02$; and CCW table, $p < 0.05$. For the 1st 402 days for the stationary table there was no difference, but for the last 393 days, $p < 0.01$.

Again with all data, the inversion of the mean pattern for the 3 consecutive sums between CW and CCW rotating magnets was highly significant ($p < 0.001$), as was similarly the difference between the CW table and the CCW magnet ($p < 0.001$). The beans on the stationary table differed from those on the CW rotating table ($p < 0.01$) and from those on the CW magnet table ($p < 0.005$). The mean pattern for the stationary table resembled the mean of the 2 CCW fields.

It is postulated that 1 basic pattern for the 4 pairs on each circular table conforms to a negative correlation between the successive pairs around the periphery of the table, with the 1st and 4th pairs interacting in a consistent fashion because of the even number of pairs. This could be predicted to be the dominant pattern of interactions when the range of field effects is shorter (CW table and magnet). On the other hand, when the interactional range is longer (CCW table and magnet, and stationary table) the 3rd pair would tend to become negatively correlated (deviate most) with the 1st pair while the 2nd and 4th either remained positively correlated (CCW magnet), or, the 3rd and 4th pairs become negatively correlated with the 1st 2 pairs (CCW table). On the stationary table the beans span the gamut of interactions seen for the 2 CCW fields. The 2 CCW rotating fields appear to press toward opposite extremes the interactional patterns observed under the control conditions.

The 2 directions of either table or magnet rotation have been reported to produce different effects on plant growth[8,9], bean water uptake[10], planarian orientation to light[11], and hamster-rhythm manifestations[12]. It is notable that this differential effect of rotation, postulated to be an adaptation of life to a spinning planet[10], should also apply to magnetic interactions.

Opposite effects of table and magnetic rotation such· as noted here for the CCW fields on interactions have been interpreted to establish geomagnetism as the reference for rotation in studies of bean water uptake[10]. The apparent absence of a differential effect between CW table and CW magnet rotation is unexpected.

1 The author expresses his gratitude to Carol S. Chow and Kate M. Scow who oversaw the collection of most of the data, and to Prof. J.A. Lippincott for helpful discussion of the results. The study was aided by grants from the National Science Foundation, No. GB-41392X, No. BMS73-0191-A01 and No. BMS73-01591-A02.
2 A.J. Kalmijn, J. exp. Biol. *55*, 371 (1971).
3 T.H. Bullock, Am. Sci. *61*, 316 (1973).
4 C.D. Hopkins, Am. Sci. *62*, 426 (1974).
5 F.A. Brown, Jr, and C.S. Chow, Biol. Bull. *144*, 437 (1973).
6 F.A. Brown, Jr, and C.S. Chow, Experientia *33*, 1316 (1977).
7 F.A. Brown, Jr, Experientia *35*, 468 (1979).
8 R.L. Jones, Nature *185*, 775 (1960).
9 W.J. Milton and F.A. Brown, Jr, Int. Soc. Chronobiol., 12 Int. Conf. Proc. 727 (1977).
10 F.A. Brown, Jr, and C.S. Chow, Biol. Bull. *148*, 370 (1975).
11 F.A. Brown, Jr, and C.S. Chow, Physiol. Zool. *48*, 168 (1975).
12 F.A. Brown, Jr, and C.S. Chow, Physiol. Zool. *49*, 263 (1976).

Dynamic biomagnetism associates bean seeds

F.A. Brown, Jr[1]

Department of Biological Sciences, Northwestern University, Evanston (Illinois 60201, USA) 18 July 1978

Summary. Water uptake by bean seeds *(Phaseolus vulgaris)* over 4 h in 4 adjacent Faraday cages and in 4 similar, but mumetal-lined, Faraday cages disclosed comparable interactional patterns among both cage types. This indicates a role of dynamic, or fluctuating, biomagnetic fields. An inverted relationship over time between the 2 cage types is probably due to geomagnetic attenuation.

The discovery that fields responsible for interactions between closely adjacent groups of bean seeds could penetrate from one Faraday cage into another[2] led to the hypothesis that the effective field was magnetic. This hypothesis would require that the seeds generate a biomagnetic field[3,4] and that other nearby seeds receive and exhibit a response to these fields. In a closely apposed series of 4 Faraday cages beans within 1 cage mutually induced in immediately adjacent cages an opposite response to the fluctuations in an atmospheric-field factor. This second factor could be either the geomagnetic field or background radiation, to both of which organisms are extraordinarily sensitive (magnetism[5-11]; high-energy radiation[12-14]. Associations of organisms with others nearby by electromagnet-

ic parameters has been described for electric fishes[15], sharks and their prey[16], as well as among groups of beans absorbing water in adjacent vessels[17].

The current study was designed to learn whether lining of Faraday cages with 0.36 mm sheet mumetal which attenuated the static geomagnetic field to approximately 1%, and any static biomagnetic field passing between 2 cages to about 0.01%, would abolish the interactions.

Material and methods. The same 4 Faraday cages, at the same location as in the earlier study[2], were supplemented by 4 others with mumetal shielding (figure 1). The water uptake, difference between initial dry weight + 15 cg (= wetting) and final wet weight, during 4 h was determined in the same manner as previously for the 2 groups of 16 vessels on 576 days between 10/29/74 and 4/12/77 chiefly in Evanston, Illinois but also in Woods Hole, Mass. Water uptake in each vessel was converted to percentage increase in weight and the mean percentage within each cage was expressed as its deviation from the mean percentage of all 4 cages in its own series.

Considering the 4 consecutive cages of each group to be A, B, C, and D, the percentage water-uptake deviations were then correlated independently for the 2 groups of cages: the adjacents, $A \times B$, $B \times C$, and $C \times D$; the alternates, $A \times C$ and $B \times D$. Since each group of 4 cages was serially correlated by the deviations from a common mean, random expectation from correlating any 2 clusters of 4 vessels would be $r = -0.333$. Finally, to facilitate further analysis, the 576 days of data were subdivided into 20 parallel series of consecutive days with an average number of 28.8.

Results and discussion. The data are shown in the table along with dates, numbers of days, and differences, alternate minus adjacents r's, for each of the 2 cage types. In figure 2 the differences between the r's are plotted against starting dates for each of the cage types. The differences for beans in the mumetal-lined cages appear essentially to mirror-image those in the unlined ones. A non-parametric estimate using interpoint inflections (3 same, 16 opposite) yielded $\chi^2 = 8.89$, d.f.1, $p < 0.005$. The 20 mean differences for both sets of cages exhibited a significant linear upward trend, $r = 0.60$, $z = 0.69 \pm 0.24$, $p < 0.004$. Expressing each difference as its deviation from the best fitted (by inspection) common linear trend line (broken lines in figure 2), a
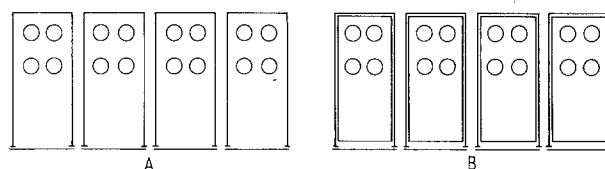

Fig. 1. The arrangement of the 8 Faraday cages during the study: *A* Unlined. *B* Mumetal-lined. The circles indicate the arrangement of plastic vessels each with 20 beans in water. The distance between successive centers of 4 dishes was 35 cm.
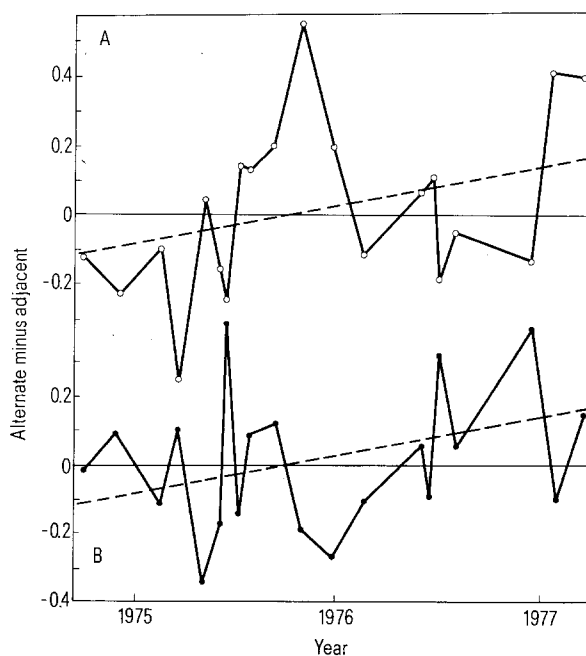

Fig. 2. The differences between coefficients of correlation found between the adjacent cages and the alternate ones for the 20 series of days are plotted against calendar date. *A* Faraday cages alone. *B* Mumetal-lined Faraday cages. The broken diagonal straight lines, drawn by inspection, describe a steady upward trend in the mean differences for the combined cage types over the period of the study.

The coefficients of correlation (r) between beans in adjacent cages, and in alternate ones, for each of the 2 sets of cages over the 20 series of days

Dates	Days	Faraday cages alone			With mumetal lining		
		Adjacent	Alternate	Differences	Adjacent	Alternate	Differences
10/29–12/26, 1974	38	− 0.258	− 0.375	− 0.117	− 0.302	− 0.319	− 0.017
12/30–2/16, 1975	34	− 0.233	− 0.453	− 0.220	− 0.437	− 0.168	+ 0.269
2/17–3/23, 1975	25	− 0.270	− 0.369	− 0.099	− 0.310	− 0.415	− 0.105
3/24–4/25, 1975	25	− 0.136	− 0.614	− 0.478	− 0.406	− 0.301	+ 0.101
4/28–6/9, 1975	30	− 0.291	− 0.237	+ 0.054	− 0.193	− 0.528	− 0.335
6/10–7/18, 1975	29	− 0.271	− 0.423	− 0.152	− 0.192	− 0.368	− 0.176
6/11–7/21, 1975	28	− 0.219	− 0.459	− 0.240	− 0.472	− 0.070	+ 0.402
7/22–8/28, 1975	28	− 0.368	− 0.220	+ 0.148	− 0.337	− 0.478	− 0.141
7/21–9/3, 1975	30	− 0.368	− 0.237	+ 0.131	− 0.319	− 0.237	+ 0.082
9/4–10/21, 1975	33	− 0.364	− 0.164	+ 0.200	− 0.426	− 0.299	+ 0.127
10/22–12/4, 1975	28	− 0.559	− 0.002	+ 0.557	− 0.281	− 0.468	− 0.187
12/19–2/3, 1976	28	− 0.418	− 0.218	+ 0.200	− 0.179	− 0.442	− 0.263
2/4–3/23, 1976	27	− 0.305	− 0.414	− 0.109	− 0.257	− 0.358	− 0.101
6/14–7/15, 1976	25	− 0.319	− 0.259	+ 0.060	− 0.374	− 0.259	+ 0.065
6/14–7/22, 1976	27	− 0.364	− 0.245	+ 0.119	− 0.289	− 0.359	− 0.070
7/18–8/20, 1976	25	− 0.387	− 0.568	− 0.181	− 0.503	− 0.147	+ 0.357
7/23–8/28, 1976	26	− 0.278	− 0.328	− 0.050	− 0.408	− 0.359	+ 0.049
12/2–1/14, 1977	30	− 0.264	− 0.407	− 0.143	− 0.492	− 0.028	+ 0.462
1/17–3/1, 1977	30	− 0.500	− 0.091	+ 0.409	− 0.280	− 0.386	− 0.106
3/2–4/12, 1977	30	− 0.478	− 0.077	+ 0.401	− 0.391	− 0.236	+ 0.155

Adjacent values, mean of 3; alternate values, mean of 2.

coefficient, r=−0.58, z=−0.66±0.24, p < 0.006, was obtained.

The data of the table were examined to learn whether the differences between alternate and adjacent r's differed significantly from random in their systematic drifts seen in figure 2. The r's were calculated for each of 4 selected time spans (10/29/74 to 7/21/75; 7/22/75 to 2/3/76; 2/4/76 to 1/14/77; and 1/17/77 to 4/12/77) and transformed to z's. For the unlined cages, all except the third of these spans of data showed statistically significant deviations from randomness (z=−0.347) independently for adjacents and alternates. p ranged from < 0.05 to < 0.002. The mumetal cages showed no such significant differences, even when the only 3 consecutive negative or positive values were selected. When the differences are positive the interactions are favoring alternate signs of the differences from means, + − + − or − + − +, and when negative, the same signs, + + − − or − − + +.

Definite interactions must be occurring to permit closely the same pattern, though now inverted, to exist between the 2 4-cage series. Also, interactions must account for the significant systematic upward trend of the differences over the period of this study. Both describe intra-group patterns of association.

Since the effectiveness of a mumetal shield essentially disappears for dynamic, or oscillating, magnetic fields, an oscillating biomagnetic field would pass the shield with relative ease. The results, therefore, suggest strongly that dynamic biomagnetic fields are involved in the interactions. Such low-energy fields not only can be generated readily by living systems but great specificity in their characteristics is theoretically obtainable.

Inversional tendencies between simultaneous studies have been reported between day by day rates of bean water uptake in the open laboratory and under the same conditions except in a ferric-metal sheathed room[17,18]. It seems probable, therefore, that differences in ambient magnetic field levels are responsible for the inverted fluctuations.

This study, together with the earlier[2], demonstrates that significant departures from randomness can occur as a consequence of interactions, with either the adjacents or alternates the more negative. Significant drifts in departure

directions can occur systematically over many months. It is conceivable that biomagnetic fields and the mitogenetic radiation of Gurewitsch[19] may be the same. The inversional propensity demonstrated here could have effected the frequent failures to confirm the phenomenon which led ultimately to cessation of its study.

Should organismic responsiveness to dynamic magnetic fields prove widespread or universal, as seems probable, constant experimental conditions would be virtually unattainable. Current enigmas such as biological senses of time and space could gain new parameters of informational input.

1   I wish to thank Carol S. Chow and Kate M. Scow for overseeing the collection of data, and Profs J.A. Lippincott and R.C. Gesteland of the Dept. of Biological Sciences and Prof. M.R. Brodwin of the Dept. of Electrical Engineering, Northwestern University, for helpful discussions. This study was aided by grants No. GB-41392X, No. BMS73-0191-A01, and No. BMS73-01591-A02 from the National Science Foundation.
2   F.A. Brown, Jr, and C.S. Chow, Experientia 33, 1316 (1977).
3   M.A. Khedelidze, S.I. Dumbadze and M.Sh. Lomsadze, Soobshch. Akad. Nauk. gruz. SSR 49, 287 (1968).
4   A.P. Dubrov, Zh. obshch. Biol. 34, 440 (1973).
5   F.A. Brown, Jr, Biol. Bull. 123, 264 (1962).
6   F.A. Brown, Jr, F.H. Barnwell and H.M. Webb, Biol. Bull. 127, 221 (1964).
7   G. Becker, Z. vergl. Physiol. 51, 135 (1965).
8   M. Lindauer and H. Martin, Z. vergl. Physiol. 60, 219 (1968).
9   W. Wiltschko and R. Wiltschko, Science 176, 62 (1972).
10 C. Walcott and R.P. Green, Science 184, 180 (1974).
11 F. Schneider, Z. angew. Entomol. 77, 225 (1975).
12 F.A. Brown, Jr, Biol. Bull. 125, 206 (1963).
13 F.A. Brown, Jr, and Y.H. Park, Nature 202, 469 (1964).
14 F.A. Brown, Jr, Y.H. Park and J.R. Zeno, Nature 211, 830 (1966).
15 T.H. Bullock, Am. Sci. 61, 316 (1973).
16 A.J. Kalmijn, J. exp. Biol. 55, 371 (1971).
17 F.A. Brown, Jr, and C.S. Chow, Biol. Bull. 144, 437 (1973).
18 F.A. Brown, Jr, and C.S. Chow, Biol. Bull. 145, 265 (1973).
19 A. Gurewitsch, Die Mitogenetische Strahlung, Springer, Berlin 1932.

Different effects of D-glucose anomers for respiration of bacterial germinated spores

H. Ishihara, I. Miwa, H. Nagano and J. Okuda

Faculty of Pharmacy, Meijō University, Nagoya 468 (Japan), 28 August 1978

Summary. Effects of a- or β-D-glucose on the respiration of germinated spores (only germinated spores not including swollen spores and elongated spores) of *Bacillus subtilis* and *B. megaterium* were studied. In our conditions, net amount of oxygen consumed by 10^{10} germinated spores of *B. subtilis* per min after addition of a- or β-D-glucose was 1.6 µg or 6.6 µg ($\beta/a = 4.13$), while that by *B. megaterium* was 4.5 µg or 6.8 µg ($\beta/a = 1.51$), respectively. However, the net amounts of oxygen consumed by 10^{10} vegetative cells per min after addition of a- or β-D-glucose were identical, for *B. subtilis* in both cases 443.0 µg and for *B. megaterium* in both cases 604.4 µg.

Hachisuka et al. reported in 1956 that dormant spores of *Bacillus subtilis* do not consume oxygen, but that germinated spores rapidly oxidize D-glucose added to a suspension culture of spores[1]. It is well-known that the dormant spores of *B. subtilis* and *B. megaterium* have respiratory enzymes for D-glucose oxidation, but the activities of these enzymes are generally not detected. The activities appear distinctly only after germination[2–7]. We were interested in finding out whether the germinated spores of *B. subtilis* strain NRRL B558 and *B. megaterium* strain QM B1551 can distinguish a- from β-anomers of D-glucose for respiration or not.

Materials and methods. *B. subtilis* strain NRRL B558 and *B. megaterium* strain QM B1551 were used and maintained on nutrient agar slant. Cultures on nutrient broth (liquid), inoculated with a loopfull from an overnight culture on nutrient agar slants, were incubated at 37 °C with vigorous shaking (120 strokes/min). Vegetative cells were harvested by centrifugation (9000 g × 30 min) at 4.5 h after inoculation and washed 3 times with chilled saline.

To prepare dormant spores, growth cultures of the 2 species were inoculated as described above, and *B. subtilis* was grown and sporulated on nutrient agar plates at 37 °C for