Subunit interactions, even if only stereochemical constraints, apparently are required for the conformational equilibrium of the COOH-terminus.

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Homing in the Harvester Ant Pogonomyrmex badius

Abstract. *During homing, the harvester ant* Pogonomyrmex badius *orients both to the sun and to chemical cues. Visual patterns are generally the less important. Trails laid from the secretion of Dufour's gland comprise the main chemical homing signal. This orientation mechanism assists foraging workers to return precisely to their own nests even when the nest populations are dense.*

Pogonomyrmex badius is a most common ant in southeastern North America (*1*). Near Tampa, Florida, nests were on the average 13.4 m (7.2 to 19.7 m) apart. In this are foragers collected seeds for food up to 10 to 20 m around their nests. Because ants of different colonies, even close neighbors, are hostile to one another, the foragers must find their way back to their own nests very precisely.

The ants follow much the same course both to and from their nests. Ants which were displaced sideways by 1 m while they were about 10 m from their nests, maintained their previous course for 1 to 2 m. At this stage they began to run in circles until they located their original trail. They then returned accurately to their own nest. If, however, their original trail was covered with sand, the ants had great difficulty in homing. A homing ant, shifted from its trail to the trail of a nest mate on the opposite side of the nest would continue to run in the same direction with respect to the sun. If displaced to a homing trail which approaches a different nest from the same direction, it would continue in its original menotactical course. When it came within 30 to 50 cm of the strange nest entrance it stopped, apparently recognizing the different nest odor or odors.

These observations indicate that under natural conditions orientation to both chemical signals and the sun is involved in the precise homing behavior of *Pogonomyrmex badius*. Orientation to visual landmarks appears to be less important. The following experiments were designed to test this interpretation.

Large colonies of *Pogonomyrmex badius* were housed separately in terraria connected to a circular arena (70 cm in diameter) with a sand-covered floor. Foraging ants entered the arena through a small opening at the periphery. Oat flakes were placed in the center of the arena as a food source. Food-laden ants returning to the small opening were observed, and the point at which they reached the edge of the arena was noted. With this arrangement we first analyzed the relative importance of the sun in homing.

An artificial sun (60-watt light bulb) was placed over the edge of the arena 45° above the ants' horizon and 90° around the circumference from the arena entrance. Ants under these conditions home with great precision (Fig. 1). If the light was moved to the opposite side of the arena while a forager was at the food source, then the ant would move away from the nest entrance, holding its initial menotactical course (Fig. 1). These results are not surprising; many ant species show a sun compass orientation (*2*).

When ants were induced to home in the wrong direction as in the above experiment, their orientation was less accurate and it took longer to reach an exit placed opposite the original entrance. This observation suggested that the sun is not the only cue enabling them to locate the true exit. Even when the possibility of optical orientation was excluded (arena surrounded with white walls 100 cm high and diffusely illuminated from above), foragers still homed accurately (Fig. 2A). In a subsequent series of experiments the arena was rotated through 180° with respect to the nest entrance after a forager had entered the arena. In this case the ants' homing course has rotated with the arena (Fig. 2B). If, however, the sand between the food source and the original entrance was covered with fresh sand while the ant was at the center of the arena, the ant was unable to home (Fig. 2C). These results suggest that chemical signals may also be involved in homing of *Pogonomyrmex*. Further experiments proved this.

A colony was provided with a fresh arena (arena surrounded with white

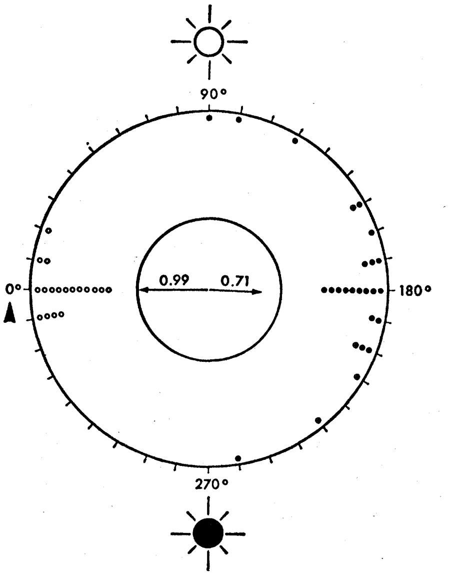

Fig. 1. Direction of homing movements in relation to the sun's position. Open circles indicate position of homing ants with the sun at 90°. Closed circles indicate homing directions with the sun at 270°. A mean vector is shown in each case and its length ($0 < r < 1$) is a measure of the dispersion around the mean direction (*7*).

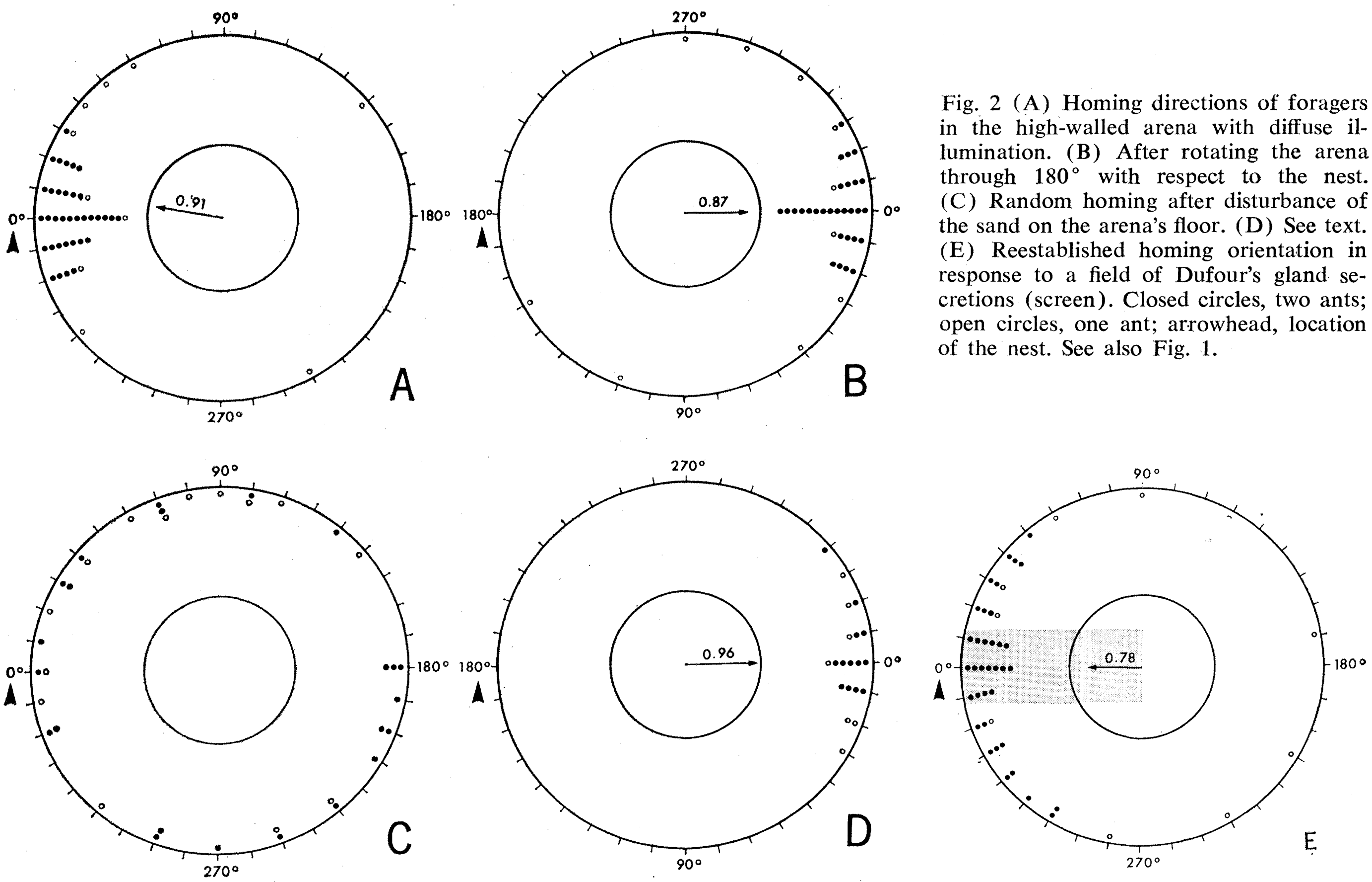

Fig. 2 (A) Homing directions of foragers in the high-walled arena with diffuse illumination. (B) After rotating the arena through 180° with respect to the nest. (C) Random homing after disturbance of the sand on the arena's floor. (D) See text. (E) Reestablished homing orientation in response to a field of Dufour's gland secretions (screen). Closed circles, two ants; open circles, one ant; arrowhead, location of the nest. See also Fig. 1.

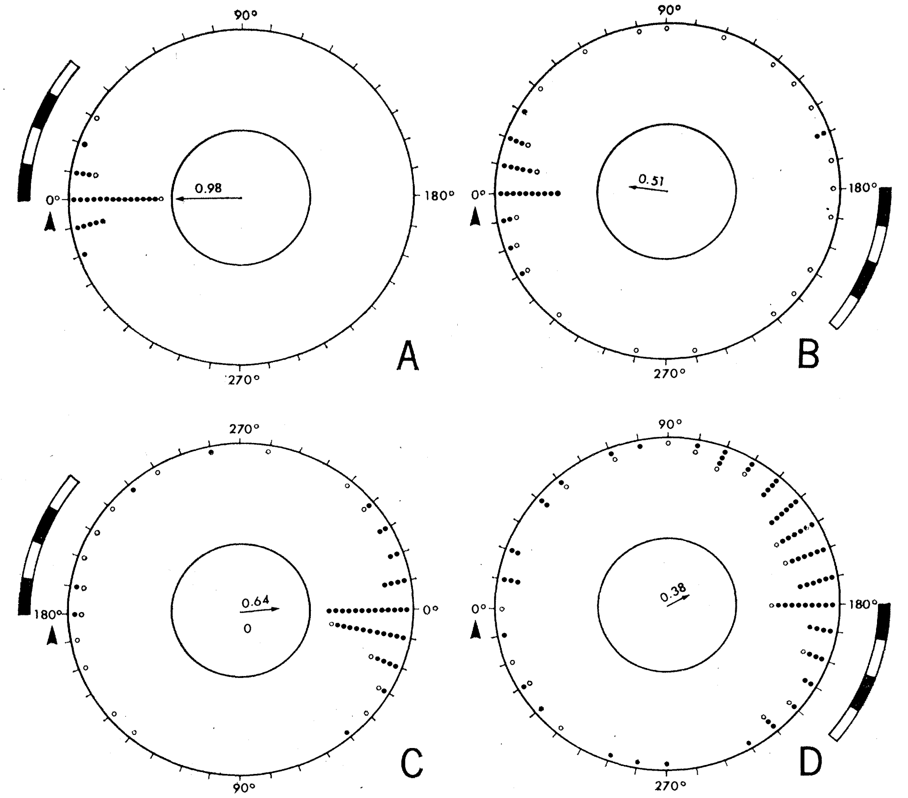

Fig. 3. Interaction of visual and chemical cues in homing in the high-walled arena. (A) Black-and-white striped plate beside nest entrance and the natural chemical field between arena center and nest entrance. In (B) the visual mark is moved to the opposite side of the arena; the homing ants orient to chemical cues. In (C), after turning the arena through 180° with respect to the visual mark, the ants' homing orientation remains with the chemical field. In (D), after disturbance of the chemical field and movement of the visual mark through 180°, the ants orient to the visual cue, but very imprecisely. See also Figs. 1 and 2.

walls 100 cm high and diffusely illuminated from above) and no food was offered for 2 days. During most of this period, from five to ten ants were usually seen in the arena. On the third day the arena was rotated through 180° with respect to the nest entrance, and food was provided. Those ants that were in the arena during its rotation gathered the flakes and carried them toward the original exit, that is, away from the new nest entrance (Fig. 2D). This suggests that a chemical field had been established around the original nest entrance and was being used as a homing cue.

In the laboratory *Pogonomyrmex badius* workers, after being separated from their colony for a day or more, were attracted by air currents carrying the odor of secretions of Dufour's glands. In addition they would follow a trail formed with artificial secretion of Dufour's gland, which indicated that this substance is an important homing signal.

Ants in the high-walled arena were unable to home accurately when the chemical field on the floor of the arena was disturbed (Fig. 2C). However, when offered an artificial odor field (five glands in 0.5 ml of benzine) such ants would reorientate immediately to this field (Fig. 2E), although their movements showed a much stronger zigzag course. As trails formed from secretions of Dufour's glands released almost no nest-mate recruitment but attracted isolated or homing ants strongly, we conclude that it functions essentially as a homing signal (*3*).

Field observations of lasting track trails radiating from nests may be understood in terms of such compounded individual homing trails, which are chemically marked by Dufour's gland secretion. Often the workers leave the nest individually on such tracks and after foraging return to them when homing.

As mentioned above, displaced ants recognized near the nest entrance the area of a strange colony. In addition, *Pogonomyrmex badius* are able to distinguish the odor of their own nest material from that of other nests (*4*). Since olfactometer tests show no colony specificity of Dufour's gland secretions, we conclude that near the nest entrance also a colony-specific chemical factor may be important as a homing signal.

Finally, we have to examine the role of visual landmarks in the homing behavior of *Pogonomyrmex*. In some ant species such cues are important in orientation (*5*). Workers of *Cataglyphis bicolor* orient mainly to visual landmarks and switch over to sun orientation only when the former become ineffective (*6*). In this species Wehner and Menzel found no evidence for chemical orientation (*6*). To investigate the role of visual landmarks in *Pogonomyrmex badius* homing behavior we placed several black- and white-striped plates on the walls of the arenas. These patterns were left in place for a week before experimentation. Chemical signals are dominant over the visual landmarks in homing (Fig. 3). Only when the chemical field is disturbed do the landmarks become significant. We conclude that the precise homing in *Pogonomyrmex badius* is achieved mainly by chemical homing trails and sun orientation, whereas visual landmarks are of minor importance.

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Tumor Detection by Nuclear Magnetic Resonance

Abstract. *Spin echo nuclear magnetic resonance measurements may be used as a method for discriminating between malignant tumors and normal tissue. Measurements of spin-lattice (T_1) and spin-spin (T_2) magnetic relaxation times were made in six normal tissues in the rat (muscle, kidney, stomach, intestine, brain, and liver) and in two malignant solid tumors, Walker sarcoma and Novikoff hepatoma. Relaxation times for the two malignant tumors were distinctly outside the range of values for the normal tissues studied, an indication that the malignant tissues were characterized by an increase in the motional freedom of tissue water molecules. The possibility of using magnetic relaxation methods for rapid discrimination between benign and malignant surgical specimens has also been considered. Spin-lattice relaxation times for two benign fibroadenomas were distinct from those for both malignant tissues and were the same as those of muscle.*

At present, early detection of internal neoplasms is hampered by the relatively high permeability of many tumors to x-rays. In principle, nuclear magnetic resonance (NMR) techniques combine many of the desirable features of an external probe for the detection of internal cancer. Magnetic resonance measurements cause no obvious deleterious effects on biologic tissue (*1*), the incident radiation consisting of common radio frequencies at right angles to a static magnetic field. The detector is external to the sample, and the method permits one to resolve information emitted by the sample to atomic dimensions. Thus the spectroscopist has available for study a wide range of nuclei for evidence of deviant chemical behavior.

The resonance technique selected for this particular application belongs to a group of techniques known as "transient" or induction methods. In this experimental arrangement the sample continues to emit a radio-frequency signal for a brief but measurable period after the incident radiation (pulse) has been removed. This method makes possible the direct measurement of spin-lattice (T_1) and spin-spin (T_2) relaxation times, thus avoiding the uncertainties of estimating them from the line width measurements of steady-state NMR spectra. In addition, it also makes possible the characterization of biologic tissues on the basis of the properties of their emitted radio frequency.

In order to determine whether neoplastic tissues could be recognized from their NMR signals, I studied the proton resonance emissions from cell water. Recent NMR work of Cope (*2*), Hazlewood *et al.* (*3*), and Bratton *et al.* (*4*) has provided fresh insight into the physical nature of cell water. These authors have independently concluded that the decreased NMR relaxation times observed for cell water relative to distilled water (Tables 1 and 2) are due to the existence of a highly ordered fraction of cell water in which the protons of the water molecules have correlation times substantially less than the Larmor period. The reduction of the correlation times is presumably due to the adsorption of water molecules at macromolecular interfaces, findings that are consistent with the proposal by Ling (*5*) that intracellular water (endosolvent) exists as multiple polarized layers adsorbed onto cell proteins.

Two lines of evidence suggested that proton signals from the water in cancerous tissue would be distinct from the radio-frequency emissions of normal tissue. My own experiments with *Escherichia coli* (*6*) suggested that altered selectivity coefficients of alkali cations in biologic tissue, such as occur in neoplastic tissue (*5*), can indicate alterations in tissue water structure. In addition, Hazlewood and his co-workers have recently reported evidence from NMR measurements that growth and maturation of skeletal muscle in the newborn rat is accompanied by simultaneous changes in water structure and