Magnetic Effect on Dancing Bees

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THE BIOLOGIST may be aware of the fact that for billions of years the Earth's magnetic field has offered two important orientation cues to living organisms: (1) compass directions may be derived from it and (2) periodic 24-hour oscillations offer a geophysical time signal that contains constant parameters independent of daylight and temperature.

In this paper we shall try to bring evidence that bees are actually sensitive to the Earth's magnetic field. The sensitivity range will be dealt with and, finally, the question will be posed as to whether magnetoreception is used for orientation by the bees.

DISTURBANCE OF GRAVITY ORIENTATION BY MAGNETIC FIELD

After their return to the hive, successful forager bees inform by the wagging dance other hive mates where food can be found. In this context only the indication of the direction toward the goal is of interest; the angle between the food source and the Sun is transposed with respect to gravity (ref. 1). When comparing the records of more than ½ million dances, it becomes evident that the direction of the wagging line contains regular deviations that follow a typical diurnal pattern (fig. 1A). This daily pattern, in principal, can be reproduced if the azimuth of the goal and the specific geophysical factors (s.b.) remain constant.

However, the misdirection (Missweisung) completely changes when the comb, together with the dancing bees, is turned by 90°, e.g., from an east-west position to a north-south position (fig. 1B). Since the stimulus from the gravity field remained unchanged, we presumed that the Earth's magnetic field may have affected the dancing bees in a different way: In the east-west position the wagging line of the dance can be affected only by the vertical vector of the Earth's magnetic field; in the north-south position by the vertical and the horizontal vector.

The Missweisung completely disappears when the magnetic field is compensated (fig. 2). The dancers now orient exclusively with respect to gravity.

SENSITIVITY RANGE AND ADAPTATION

When analyzing the diurnal curves of the "Missweisung" in more detail, the following correlations become evident:

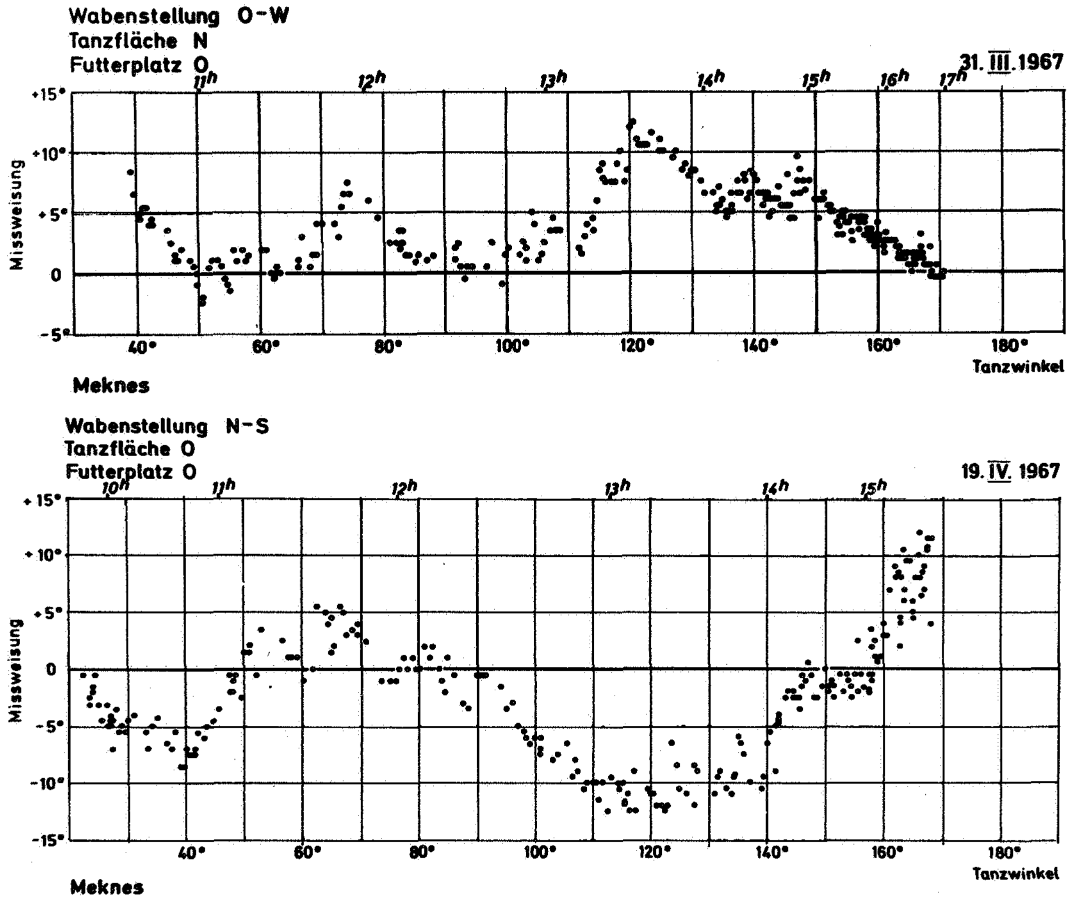

FIGURE 1. Dancing bees had visited a food source 400 m eastward of the hive. In the wagging dance they transpose the angle between Sun and goal into the gravity field. This angle has to be changed all day long corresponding with the Sun's movement (abscissa). Each spot indicates average of 10 records in one dance, whereby only spots on the zero line correspond to dances without mistake. Deviations are not randomly scattered above and below zero line but follow a diurnal curve depending on position of the dance floor in the Earth's magnetic field. (A) Hive position east-west; dance floor facing northwards. (B) Hive position north-south; dance floor facing eastwards.

(1) The curves pass through zero when the wagging line corresponds to the plane of inclination. Thus the position of the dancing area must be taken into consideration. In the first position the comb is directed north-south with the dancing area on the east side; zero points are found at 25° and 205° (fig. 3). In the second position the dancing area is on the west side and the zero points at 155° and 335° (fig. 4). In the third and forth position, the beehive is directed toward the east-west. In this case the dancing area (south or north) is always vertical to the plane of inclination with the zero points at 180° and 360°

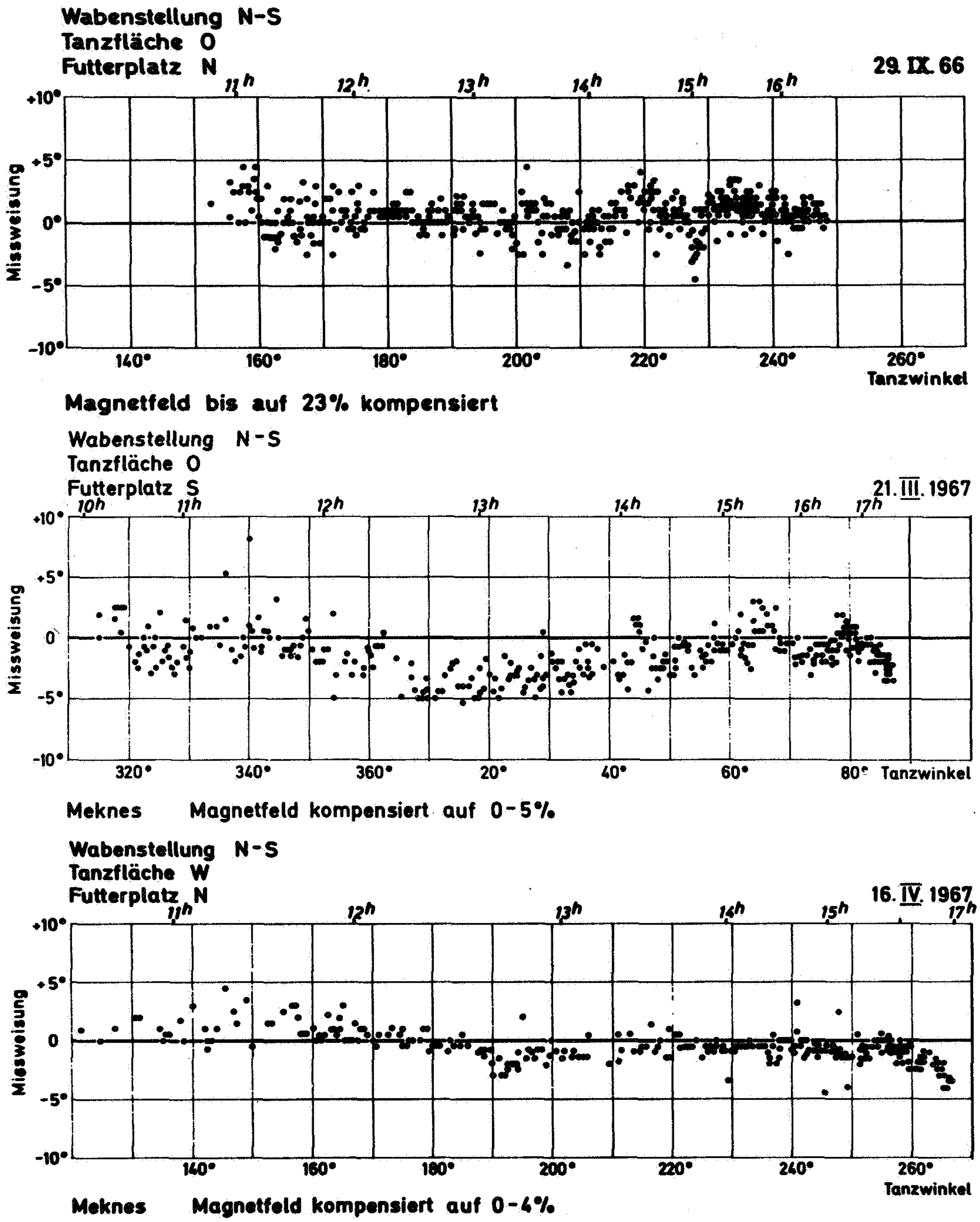

FIGURE 2. A dance floor was put in center of a Helmholtz-coil and the Earth's magnetic field was compensated up to <23 percent, <5 percent and <4 percent respectively. Diurnal curve of the "Missweisung" is flattened; dancing bees now transpose the angle between goal and Sun exclusively with respect to gravity.

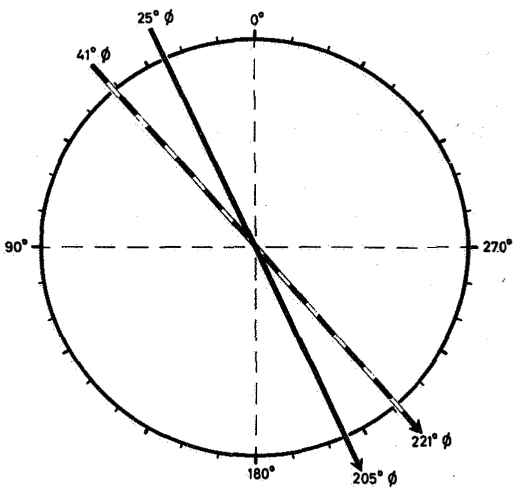

FIGURE 3. Beehive is in north-south position; dancing area ("Tanzboden") faces east. In this situation inclination in Frankfurt is identical with dancing angles 25° (to the left upwards) and 205° (to the right downwards) (solid arrow). In Meknes, Morocco, the inclination passes 41° and 201°. "Missweisung" disappears in this section of the gravity field.

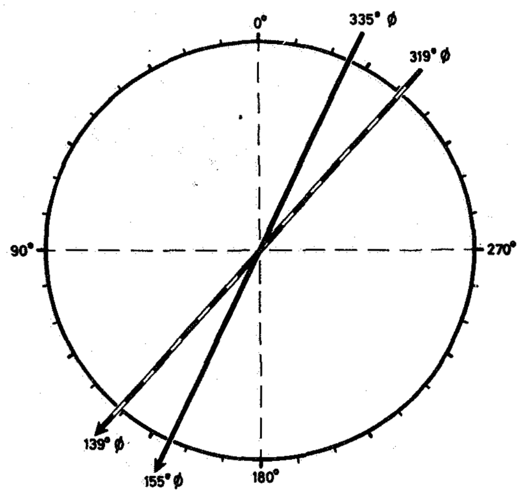

FIGURE 4. Beehive in north-south position; dancing area faces to west. "Missweisung" disappears at 335° and 155° (Frankfurt), or 319° and 139° (Meknes).

corresponding to the vertical component on the northern as well as on the southern side of the comb. Of all 62 diurnal curves of the "Missweisung" available to date, only one does not fit with our theory. On that day a gale of wind had partly removed the double cover of the tent and had caused an uncontrolled disturbing influence of incident light.

The daily curves of the "Missweisung" obtained in Morocco in 1967 were also checked with respect to the rules observed. Owing to the inclination of 49°, the zero points were now 41° (221°, respectively) on the eastern side and 139° (319°, respectively) on the western side of the comb. All curves from Morocco were in full accord with our expectations. Furthermore, we can state that the daily curves only deviate by 0.2° from the expected values, taking into account all dance angles from 2° before, to 2° after, the calculated zero points (standard deviation $\sigma = \pm 3.7°$). We concluded that bees, dancing parallel to the direction of the magnetic field lines, orient themselves without error and exclusively in respect to gravity.

(2) In all other directions, the influence of the magnetic field may be described by the following function (fig. 5):

$$Mi = \log (\sin \alpha \therefore \Delta\gamma)$$

$\alpha =$ direction of the wagging line with respect to the gravity field

$\gamma = 10^{-5}$ oersted

$\Delta\gamma =$ variations of the magnetic field in time units

This rule applies to the north-south comb directions. Experiments with the combs oriented east-west are now being carried out.

The data given, so far, show that bees are sensitive to variations of the magnetic field in the range from 0 to 300 γ. However, only dynamic changes are of importance. When a static artificial magnetic field is produced (3 to 10 times stronger then the Earth's magnetic field), only the dispersion of the "Missweisung" becomes higher.

Furthermore, error free dances only begin 30 to 45 min after the magnetic field is artificially compensated (fig. 6). On the other hand, when the magnetic field whether natural or artificial changes rapidly (by more than 1 $\gamma/1°$ of azimuth of the Sun's path) the bee reacts to this rapid rise or fall with only about one tenth of the normally observed "Missweisung." We thus have a process of adaptation that appears to be like hysteresis or magnetic lag effects.

COMPETING GRAVITY AND MAGNETIC FIELDS

By tilting the comb as far as the horizontal, the orienting force of gravity can be continously diminished. The effect of the magnetic field now becomes more apparent. The dancing bees become more and more confused. The dispersion in indicating the grav-

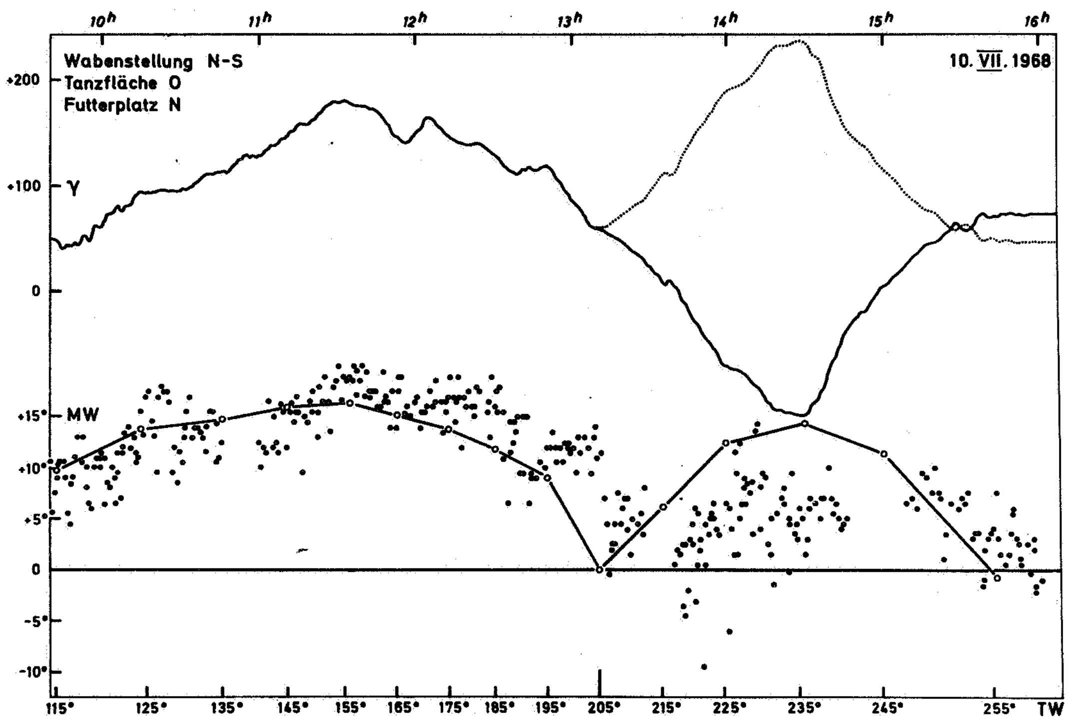

FIGURE 5. Diurnal curve of "Missweisung" follows the function: $Mi = \log(\sin \alpha \cdot \Delta\gamma)$. Curve above is magnetic variation measured during the records of the dances. Curve below is calculated from function above. Curve of the "Missweisung" function fits well into this function. *MW* = "Missweisung."

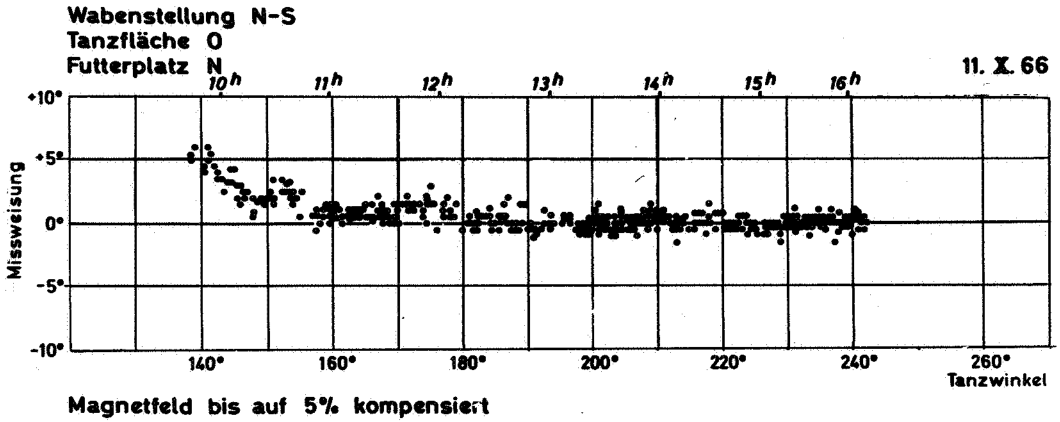

FIGURE 6. In this experiment dances were recorded immediately after magnetic field was compensated. There is a time for adaptation of about 45 min.

ity angles rapidly increases and the bees tend to "cling" to the horizontal components of the magnetic field or to the plane of inclination depending on whether the hive is directed north-south, east-west, northeast-southwest, etc.

If the bees are totally deprived of the possibility to orient themselves with respect to gravity by laying the comb flat, the dancers are at first disoriented. If the hive is left in this position for about 3 weeks, orientated dances are observed in increasing number pointing preferably in a north-south or east-west direction (fig. 7). When the magnetic field was then compensated, the dances again were disorientated; when increased three times the Earth's magnetic field, the north-south and east-west directions were even more preferred (figs. 8 and 9).

ORIENTATION IN THE MAGNETIC FIELD

The results reported to date seem to indicate that the Earth's magnetic field is only disturbing the orientation of the bees. M. Oehmke, our student, has found a situation in bees revealing true orientation to the Earth's magnetic field. When a swarm of bees is encased in an empty cylindrical box with a central entrance in the bottom, the bees start sticking small lumps of wax all over the box lid. Finally the building bees, 600 to 1000 or even more, all start building one, two, or three pieces of comb in a defined direction (fig. 10). In the first series of experiments, eight colonies were used of known origin which had, for generations, built their combs in a north-south direction. Daughter swarms were taken from these colonies and permitted to build their combs in the round boxes. All these colonies, without exception, built their combs in the same direction as they had done in the hives from which they originated (standard deviation $S_{\bar{x}} = \pm 2°$) (fig. 11). Neither gravity nor incident light could have given any orientation clues. If the declination of the magnetic field is changed artificially, the direction of the combs is changed in the same sense. We consider the magnetic field as a potential parameter by which the bees could orientate under these circumstances.

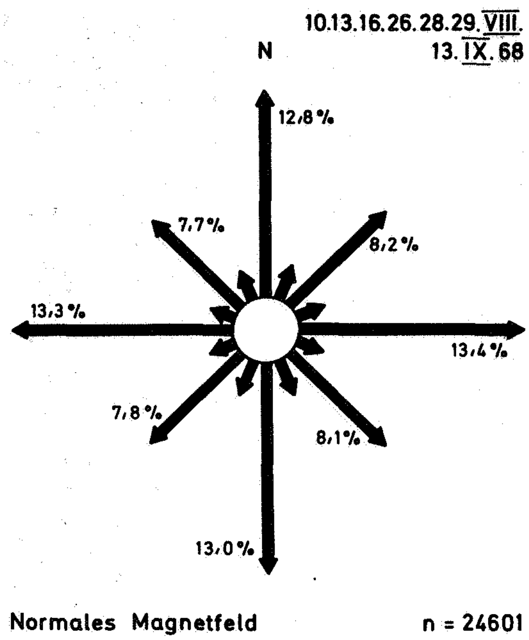

FIGURE 7. When dancing area is in a horizontal position, dances at first are completely disoriented. After 3 weeks, however, a preference was given to N-, S-, E-, W-direction.

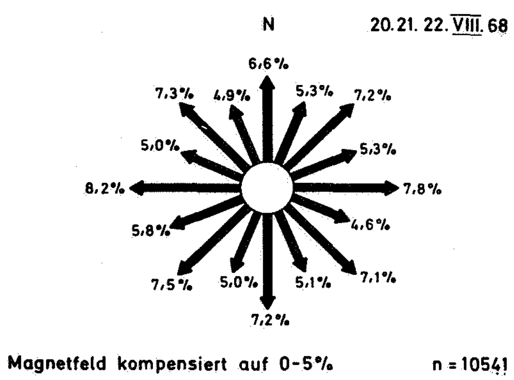

FIGURE 8. In compensated magnetic field, dances remained disoriented in this horizontal position.

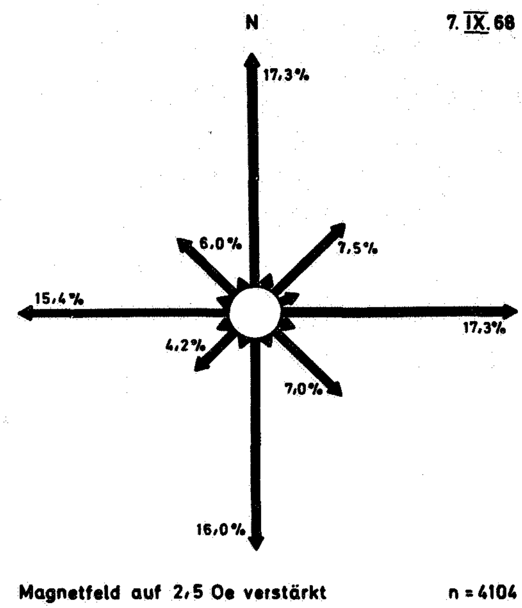

FIGURE 9. In increased magnetic field, main points of compass are still more accentuated.

MECHANISM OF PERCEPTION

The actual mechanism is still not known; it seems improbable that there are any specific receptors. In theory electric induction in the sense organs or in the nerve fibers might be considered as well as paramagnetic effects in the sense organs (e.g., the gravity receptors) or protein molecules acting as dipoles during the wagging dance on which the magnetic force of the magnetic field could act in a specific way. The mechanisms based on paramagnetic effects seem more probable with respect to the phenomenon of adaptation. We hope to test, by experimental analysis, whether this hypothesis is valid.

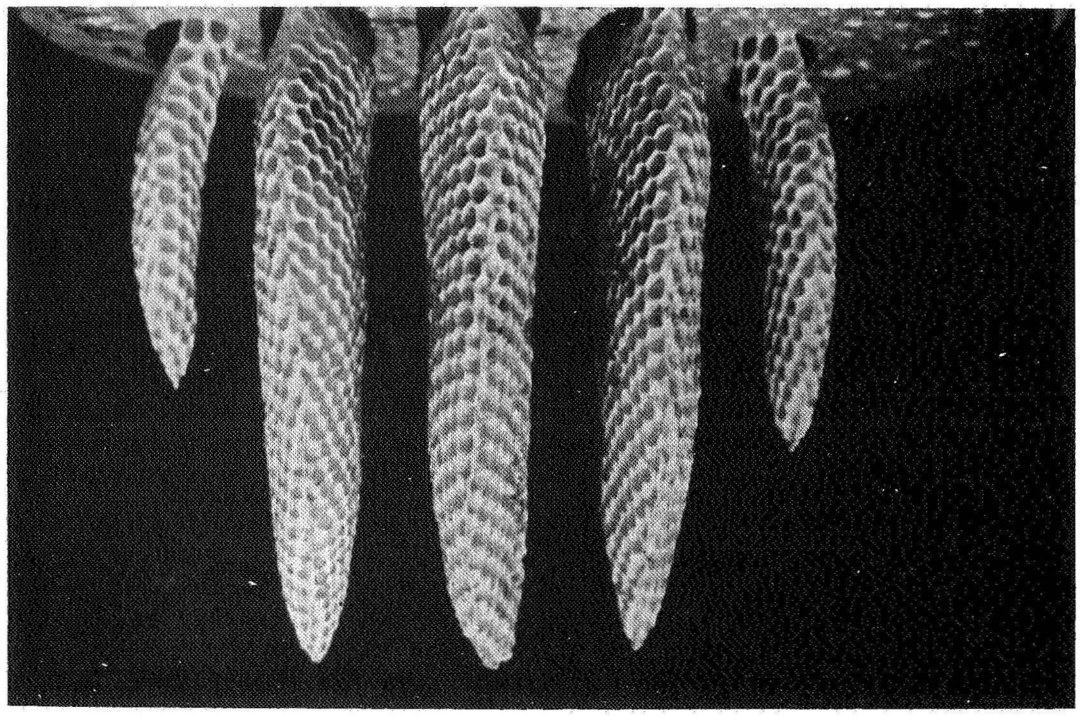

FIGURE 10. Thousands of building bees unanimously start their combs oriented in the same direction.

DISCUSSION

ENRIGHT: How are your angles measured? Is it simply a visual estimate?

LINDAUER: We use special equipment: a rectangular plexiglass sheet in which there is a second rotatable plexiglass circular sheet with white parallel lines engraved on it. These lines are adjusted along the wagging lines of the dancing bee.

The accuracy of the measurement amounts to less than ±0.5 degree. However, the following precautions must be taken: (1) The bees must be in a good dancing mood so that they will not interrupt the wagging lines. To ensure this, there must be high quality food available and no competition from other crops in the open field. (2) The feeding table should be more than 400 m away since dancers indicating close goals (less than 300 m) perform wagging lines of slightly divergent angles, which decrease to 0 as the table is moved to 400 or more meters. (3) To ensure exact data, 10 measurements in one individual dance are taken; therefore, each point on the curve indicates 10 records from one single dancing bee.

ENRIGHT: Were the bees single identified individuals?

LINDAUER: For statistical purposes, care is taken to select, by chance, individual bees arriving at the dancing area from the feeding table. A group of 20 to 30 marked bees is kept at the feeding table. This group changes, in part, from day to day.

ENRIGHT: How did you get recruits, when the foragers were dancing in the horizontal position, to tell each other where the food was?

LINDAUER: Since dancers in a horizontal position are disoriented and never indicate the direction toward the food, recruited novices search around the hive randomly. Subsequently very few recruits come to the feeding table.

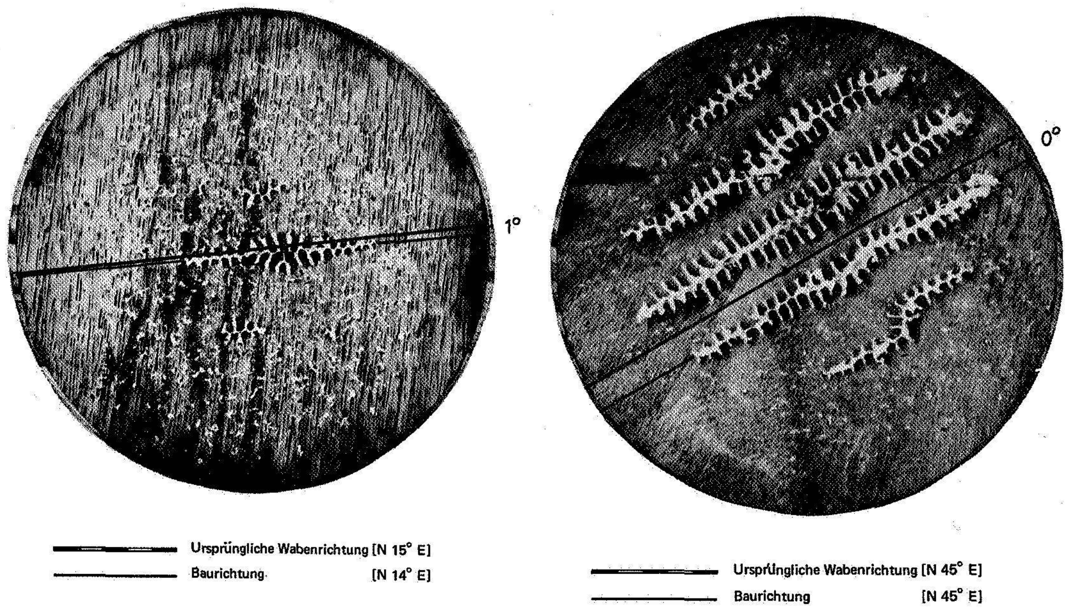

FIGURE 11. Swarm encased in cylindrical box builds new combs in same compass direction as there was in the mother hive. Top: deviation 1°; bottom: deviation 0°.

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2. Lindauer, M.; and Martin, H.: Die Schuereorientierung der Bienen untεr dem Einfluss des Erdmagnetfelds. Z. f. vergl. Phys., vol. 60, 1968, pp. 219–243.