mains near the middle control station, so also were most recruits collected at the middle site when all stations became more similar in attractiveness. In either experiment 2A or 2B, the recruit distributions more closely correspond with the spatial distribution of dishes than with the results from the first (control) experiment of each series. [Statistical tests have not been employed in this or in other comparisons for various reasons; see note *9* in a related study (*5*).]

The results from the third experiment in each series (Table 1, 3A and 3B), where an equal number of marked dark bees foraged at all four sites (and in which the stations would be even more equal in attractiveness), correlate even better with the linear distance of each site from the geometric center of all sites. The close correspondence between the spatial arrangement of all stations and the distribution of recruited bees persists with little modification by wind conditions, possible interference between bees from the two different hives (*12*), and, perhaps even more important, slight differences in locality odors.

The results of the original fan experiments were interpreted by von Frisch as a demonstration of the precision with which honey bees use direction information. He concluded that the majority of searching bees, after leaving the hive, move within an angle deviating not more than 15° to the left or right of the experimental direction (*13*). While repetitions of such experiments yield data which seem completely consistent with the original results (experiments 1A and 1B), results obtained after the incorporation of essential controls into the experiments indicate that, if recruits use the direction information of the dance, they fail to do so with the precision suggested by the original experiments. Thus, although the waggle-dance maneuver contains relatively precise direction information, it would appear that local cues (including locality odor, food odor, hive odor, and bee odor at the site) dictate the location or locations at which recruits settle to feed.

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References and Notes

1. D. L. Johnson and A. M. Wenner, *Anim. Behav.* **14**, 261 (1966).
2. K. von Frisch, *Naturwissenschaften* **35**, 12, 38 (1948).
3. E. M. Schweiger, *Z. Vergleich. Physiol.* **41**, 272 (1958).
4. H. Kalmus, *Brit. J. Anim. Behav.* **2**, 63 (1954).
5. A. M. Wenner, *Science* **155**, 847 (1967).
6. K. von Frisch, *Bees, Their Vision, Chemical Senses, and Language* (Cornell Univ. Press, New York, 1950).
7. ———, *Sci. Amer.* **207**, 78 (1962).
8. A. M. Wenner, *Bee World* **42**, 8 (1961).
9. K. von Frisch and G. A. Rösch, *Z. Vergleich. Physiol.* **4**, 1 (1926).
10. C. R. Ribbands, H. Kalmus, H. L. Nixon, *Bee World* **33**, 165 (1952).
11. C. R. Ribbands, *Proc. Roy. Soc. London Ser. B* **143**, 367 (1955).
12. H. Kalmus, *Nature* **148**, 228 (1941).
13. K. von Frisch, *Bull. Anim. Behav.* **9**, 10 (1951).
14. Supported by contract NR 301-800, Office of Naval Research and by a PHS graduate fellowship (3-Fl-GM-32, 408, 01S1). This work serves in partial fulfillment of the requirements for the degree of Doctor of Philosophy. I thank N. Barnes, N. Broadston, J. Hand, C. Johnson, and A. Wenner for technical assistance and Drs. D. Davenport, J. Enright, E. Orias, and P. Wells for critically reviewing the manuscript. I also thank H. H. Laidlaw for furnishing the light-colored bees used in these experiments.

2 December 1966

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Honey Bees: Do They Use the Distance Information Contained in Their Dance Maneuver?

Abstract. *Regular visitors at one site (experimental) in a linear series of sites normally recruit inexperienced hive mates to or near that site. If bees from a second hive were allowed to forage at both control sites, however, recruits from the experimental hive, while orienting to these sites, exhibited no evidence of having used any distance information they might have received before leaving their parent hive.*

Important evidence for the theory that bees communicate and use abstract information concerning the distance of a food source comes from the step-experiments (*Stufenversuchen*) of von Frisch and co-workers (*1*). A linear series of stations were placed in one direction from a hive with a known number of marked visitors frequenting only one, the experimental. Repeated round trips by these marked bees, interspersed with waggle dances in the hive, preceded recruitment of new bees to or near the experimental site (*2, 3*). Since the dance maneuver executed by successful bees upon their return to the hive contains information concerning the distance of the food site and since recruited bees generally arrived at the proper distance or close to it, recruited bees were presumed to have used the distance information contained in the dance before finally orienting to the specific odor of the food site.

The evidence gathered in support of distance communication in the dance "language" hypothesis might be an artifact of the experimental design rather than an indication that bees use distance information contained in the dance maneuver (see *2, 4*). If not, and if recruited bees use the distance information furnished by regular foragers (and only secondarily use scent of food and of location upon their arrival at the approximate distance), then making both control and experimental sites more uniform in terms of bee visitation should not influence the overall distribution of recruits. I have studied the distribution of recruits both before and after bees foraged at control sites as well as at the experimental site.

All experiments in this series were conducted at the golf course of the Santa Barbara campus of the University of California, on an area largely devoid of living vegetation at that time of the year. One or two different hives provided the bees for each experiment, depending on the particular conditions required. One hive containing dark bees (*Apis mellifera*, Italian strain) was always used as the experimental hive to test the distance-communication hypothesis, whereas another hive of light bees [Italian strain, cordovan gene (*cd*) for body color] served as the control hive when needed (*5*). At the time of the experiments, the hives contained at least 30,000 and 10,000 bees, respectively.

The darker bees from the experimental hive were trained (*6*) to forage at only one of four possible sites in each of the experiments. The other three sites served as controls for this hive (Fig. 1). These sites were linearly arranged in an east-southeast direction from the hive so that the prevailing wind (from the south or southwest) was generally at right angles to the line of flight of bees from the experimental hive during each experiment. Placement of the sites 100 m apart insured that most recruits from the experimental hive would be exposed to relatively accurate information concerning the distance of the experimental site (*2, 7*).

All foragers visiting the experimental site were individually marked before they returned to the hive. Since increasing the total number of foragers at each site increased the number of recruits caught, the number of foragers was adjusted before each experiment to insure an adequate number of recruits but not so many as to deplete the recruit pool of the experimental hive or to make difficult the capture of all unmarked bees as soon as they arrived. After the desired number of regular foragers at the experimental site was attained, new unmarked arrivals were routinely killed until an experiment was started.

Regular visitation of bees from the control hive was adjusted in a similar manner. The use of light-colored bees from the cordovan hive permitted foraging and recruitment at the various sites when desired without causing confusion about the origin of unmarked foragers at each site (I know of no pertinent differences in the behavior of these two colors of bees). This control hive was placed about 150 m downwind from the line of stations between the sites at 200 and 300 m (Fig. 1).

At the beginning of each experiment (after experienced dark foragers had regularly visited the experimental station for at least an hour), a clean dish was provided at each site and filled with lavender-scented sucrose solution (1.5*M* sucrose with four droplets of lavender oil per 500 ml of solution). Only the trained foragers at each site were permitted to forage and return to their respective hives.

A total of five persons gathered data at the four sites. At the end of each 10-minute period, the free person replaced the investigator (and station, including dish) at the 500-m site, who in turn replaced the 400-m station, and so forth. After each complete cycle of station switching, at which time the person at the 200-m site became free, the extra dish was washed before the next cycle. In this manner, the dish that had been frequented by trained dark bees was moved closer to the hive in two or three steps (depending on the experiment) and was then washed. We switched stations to reduce any effect, or effects, of hive odor left at the dish or characteristic human odor present at each site (*8*).

Only the collecting bottle (containing alcohol) remained at each site during the experiment, insuring that each bottle contained bees collected by each of the investigators. Every unmarked bee landing at each station was captured and placed in this bottle during each 2-hour experimental period.

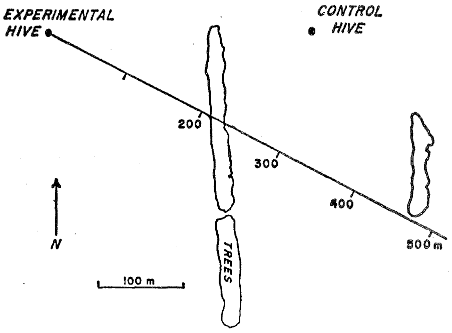

Fig. 1. Map of the experimental area, showing placement of experimental hive (dark-colored bees) and control hive (light-colored bees), in relation to the four training sites. Bees from the experimental hive were trained to forage at either the 400- or 500-m site, depending upon the particular experiment. Trained bees from the control hive foraged at none, three, or four of the sites in different experiments.

Table 1. Distribution of recruited bees in three step-experiments, with data for dark and light recruits separated for ease of comparison. In the first experiment, 43 dark bees foraged only at the 400-m site. During the second experiment, 13 dark bees visited only the 400-m site, but 25, 26, and 13 light-colored bees visited the 200-, 300-, and 400-m sites, respectively. For the final experiment of the series, 14 dark bees from the experimental hive foraged only at the 500-m site, while 15, 15, 15, and 5 light-colored bees from the control hive foraged at the 200-, 300-, 400-, and 500-m sites, respectively.

Experiment	Bees recruited to each site (%)				Total recruits caught (No.)	Wind		Time	Date
	200 m	300 m	400 m	500 m		Direction (degrees)	Velocity (knots)		
					Dark-colored				
1	10	14	74	2	123	220	10	1350	13 July
2	18	48	33	1	146	220	9	0935	19 July
3	6	43	42	9	67	180	8	0945	21 July
					Light-colored				
1						220	10	1350	13 July
2	12	62	26	0	448	220	9	0935	19 July
3	2	42	50	4	409	180	8	0945	21 July

Three different types of experiments provided data on the effect of varying the number of dark and light bees that regularly visited each of the four sites (Table 1). The first experiment, in which only dark bees foraged only at the 400-m site, tested whether switching the dishes would alter recruitment distribution from that expected by the distance-communication hypothesis. During this experiment the 43 dark bees could furnish distance information concerning the 400-m site only upon their return to their hive.

As can be seen from the data for the first experiment (Table 1), 74 percent of the unmarked bees collected at the various sites had arrived at the site frequented by the experienced foragers. This distribution does not differ appreciably from what one might expect from the distance-communication hypothesis.

The second experiment assessed recruit distribution at the various sites when three of them (200-, 300-, and 400-m sites) had an equal number of regular visitors (the fourth site, having no regular visitors, served as a control against the first three sites for recruitment from both hives). In this experiment, dark bees again could furnish information on the 400-m distance only upon their return to their hive. Light-colored bees could collectively provide information on three of the sites upon their return. Each hive thus served as a control against the other.

The uniform visitation of experienced foragers at the first three sites markedly altered the distribution of dark recruits. Now only 33 percent of the dark bees caught had arrived at the experimental site and 66 percent of them had arrived at one of the closer sites. In addition, the distribution of light-colored recruits compares well with the distribution of dark recruits.

The third experiment determined the distribution of recruits when all four sites had equal visitation by trained foragers. According to the established theory, dark bees should have recruited their hive mates mostly to the 500-m site (Table 1), and light-colored bees should have recruited hive mates to the first three of the four sites with nearly equal effectiveness. Again, each hive served as a control against the other.

Both dark and light recruits again failed to appear at the four sites in accordance with that information they might have gotten from experienced bees before they left the hive. Furthermore, the distribution of dark recruits once more resembles that of the light recruits, even though recruits from each hive would not have had access to information provided by experienced bees from the other hive.

That trained dark bees from the experimental hive could successfully recruit hive mates to the 500-m site is evident from a tally made after the control hive had been removed from the area. At that time 38 regular foragers succeeded in recruiting 49 new bees in 70 minutes (while only two landed at a control station at 350 m).

Results from the first experiment, in which regular foragers visited only the experimental site and 74 percent of all recruits caught had landed at that site, do not differ markedly from the results of earlier step-experiments of von Frisch and co-workers (*1*). The act of regularly switching the dishes, by itself, did not appreciably alter the distribution from that expected on the basis of the dance-communication hypothesis [in one respect, though, these results are not directly comparable to those reported earlier, because unmarked bees were collected upon landing, whereas von Frisch and co-workers tallied them as they approached the dish (*2*)].

Results from the second experiment (in which three of the four sites were made more similar to each other by having equal and regular visitation at each site), however, show a drastic alteration of the distribution of dark recruits at the various sites. Regular dark foragers from the experimental hive could provide information concerning the location of the 400-m site only, but most of the recruited bees from that hive arrived at nearer sites. Only 33 percent arrived at that site about which information would have been provided in the dance maneuver.

The close correspondence between the distributions of dark and light recruits in the second experiment emerges more clearly in the remarkable similarity between the distributions of dark and light bees obtained in the third experiment (*9*). Again, neither distribution resembles what one might expect on the basis of the dance-communication hypothesis. That is, bees returning to the control hive would be able to collectively furnish direction information concerning all sites, whereas bees returning to the experimental hive would be able to furnish information concerning the distance and direction of the 500-m, experimental, site only.

Furthermore, both distributions obtained in the third experiment exhibit an interesting symmetry about the geometric center of all sites. The percentage of recruited bees arriving at each site from both hives closely correlates with the distance of each site from the center of moment of all sites (*9*). Of all the distributions, that of the dark recruits in this third experiment reveals this most clearly. Whereas only 9 percent of the dark recruits arrived at the experimental site, 85 percent arrived at one of the two sites closest to the center of all sites.

The particular distribution of recruits may well arise from the fact that, even if all stations are equal in attractiveness, they would not necessarily be similar in their spatial relationship. The 300- and 400-m stations have at least one station on either side of them, but the end stations each have other stations in only one direction.

The results from the present experiments indicate that previous step-experiments (which contribute to the interpretation that recruited bees use the distance information contained in the dance maneuver) lack at least two essential controls in their design. For a step-experiment to be properly controlled, experimental and control sites should be as similar to each other as possible. Even if various sites are identical in attractiveness to bees, however, the geometry of the arrangement of various sites apparently funnels recruits toward the center of all sites (*2*).

Clearly, the dance maneuver executed by successful bees contains information related to the distance between the hive and the food source. My results, however, are not consistent with the interpretation that recruited bees use that information in arriving at the appropriate distance from the hive before they orient to the specific odor of the food. These results indicate, instead, that recruited bees apparently use other information after leaving their hive (including odor of hive mates or other bees) in the process of orienting to a particular food site visited by bees.

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References and Notes

1. K. von Frisch and R. Jander, *Z. Vergleich. Physiol.* **40**, 239 (1957).
2. A. M. Wenner, *Anim. Behav.* **10**, 79 (1962).
3. K. von Frisch, *Tanzsprache und Orientierung der Bienen* (Springer-Verlag, New York, 1965).
4. D. L. Johnson and A. M. Wenner, *Anim. Behav.* **14**, 261 (1966).
5. D. L. Johnson, *Science* **155**, 844 (1967).
6. A. M. Wenner, *Bee World* **42**, 8 (1961).
7. E. M. Schweiger, *Z. Vergleich. Physiol.* **41**, 272 (1958).
8. K. von Frisch and G. A. Rösch, *ibid.* **4**, 1 (1926); C. R. Ribbands, *The Behaviour and Social Life of Honeybees* (Dover, New York, 1964).
9. The data published herein were not subjected to a statistical analysis for various reasons, in particular because the most interesting set of comparisons that could be made are not stochastically independent. Without a better understanding of the mechanisms contributing to the distribution of bees at feeding sites, one cannot compute expectations for comparison to the experimental results.
   The data obtained from this type of experiment suggest that the distribution may be multinomial with parameters functionally related to the distance from the geometric center of the stimulus sources. This preliminary notion of the mechanism involved is easily testable. However, we intend to do this by prospective experimentation—not by retrospective tests of goodness of fit to the data presented here. This will give us a probabilistic structure within which we can frame meaningful null hypotheses.
10. Supported by contract NR 301-800, Office of Naval Research. I thank N. Barnes, N. Broadston, J. Hand, and D. Johnson for technical assistance and Drs. J. Connell, D. Davenport, J. Enright, T. Gartner, W. Hamilton III, D. Mertz, J. Walters, and P. Wells for critically reviewing the manuscript. I thank H. H. Laidlaw for furnishing the light-colored bees used in these experiments.

2 December 1966

Effects of Magnesium Pemoline and Dextroamphetamine on Human Learning

Abstract. *Two central nervous system stimulants, magnesium pemoline and dextroamphetamine, were tested to see if they facilitate learning in human subjects. Subjects under placebo learned faster than the subjects under any of the several doses of magnesium pemoline; however, none of these differences reached statistical significance. Subjects who received dextroamphetamine learned significantly more slowly than those who received placebo.*

The stimulant magnesium pemoline has been reported (*1*) to enhance learning and memory in the rat. According to Glasky and Simon (*2*) magnesium pemoline facilitates the synthesis of nucleic acids in the brains of rats. They argue that this finding is relevant to the biochemical findings which suggest that RNA synthesis or protein synthesis, or both, underlie memory and learning. Consonant with Glasky and Simon's biochemical findings is the