SENSORY MECHANISMS AND ENVIRONMENTAL CLUES USED BY THE AMERICAN ROBIN IN LOCATING EARTHWORMS

By FRANK HEPPNER

The familiar sight of the American Robin (*Turdus migratorius*) foraging for earthworms on a lawn has not prompted a detailed investigation of the sensory mechanisms and environmental clues employed by the birds when finding worms, although several workers have commented on and made speculations about this behavior. Tyler (*in* Bent, 1949) has supplied a good general description of the behavior of robins foraging for worms. Polyak (1957) and Allen (1934) assume that robins are definitely employing vision to find worms. Bent (1949) mentions the possible use of hearing while foraging but thinks that vision is the more important sense.

Earthworms make up a significant part of robins' diet. Howell (1943) found that earthworms comprised 15 per cent of the diet of American Robins examined. Kalmbach (1914) reported that the diet of the western race of the robin (*T. m. propinquus*) is composed of 8.68 per cent earthworms in summer, the percentage going up to 20 per cent in July.

Several approaches were taken in the present study to determine what sense or senses robins might be using to detect worms. Observations were made in the field to determine if there were favored times or locations for finding worms. I conducted experiments to investigate the importance of vision, audition, and olfaction in worm finding by robins.

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METHODS AND MATERIALS

Field observations were made from March 11, 1961, to May 22, 1962, in Berkeley, California, on the campus of the University of California and at Tilden Regional Park.

For experimentation, wild birds were captured with mist nets on the football field of San Francisco State College from May to November, 1963. Although 13 birds were caught, only six survived to the end of experimentation.

The experimental birds were kept individually in outdoor cages measuring two feet by three feet by two feet high. There was free access to water, and the birds often drank after feeding. For several days following the initial capture, the birds were extremely restless when approached, and frequently they would fly into the screen walls of the cage. But after one or two weeks in captivity they settled down, and when disturbed during feeding operations, they would merely run back and forth in their cage without colliding with the screening.

The caged robins were found to have individual food preferences. Some birds would take up to one quarter of a banana a day, whereas others would not accept bananas even if no other food was offered. A diet which was acceptable to all birds consisted of a gruel composed of one-half minced apple thickened with Gerber's high protein baby food, one-eighth cup of raisins, and two drops of Stewart's vitamin formula. The birds preferred minced apples to sliced apples. Each bird was given

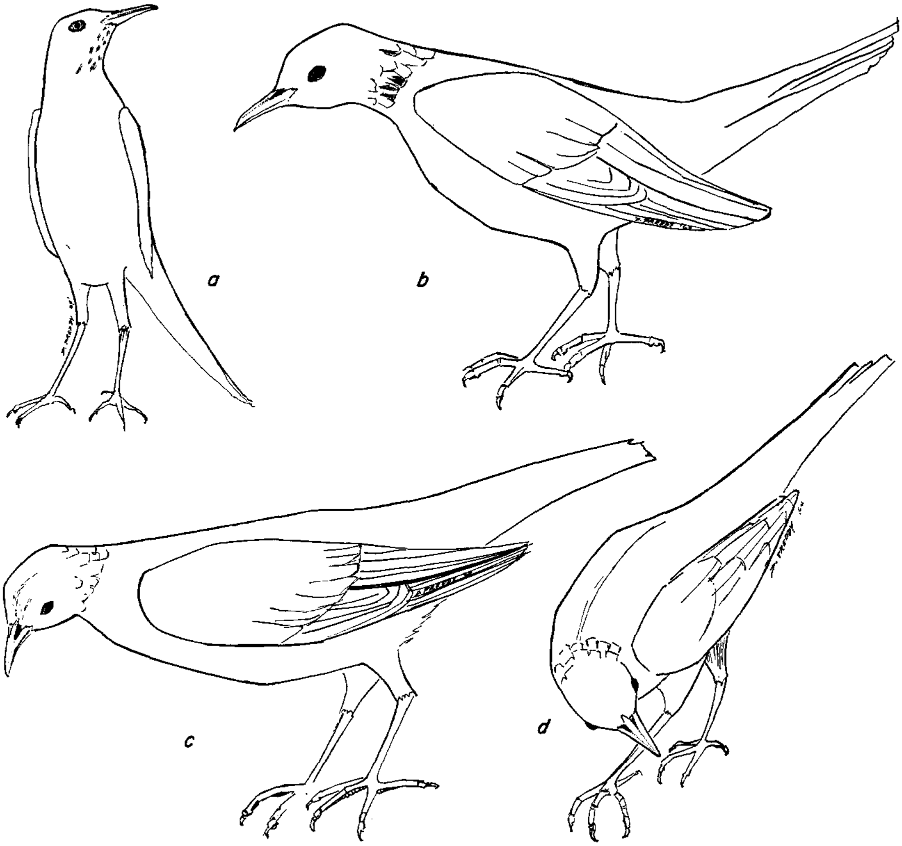

Fig. 1. Foraging postures of the robin. a, standing; b, c, d, stances while running across lawn (from motion pictures).

five to ten mealworms per day. Two birds were maintained for eleven months on this diet, and were released in good condition at the end of the experiments.

A small lawn was specially prepared for foraging experiments. It measured five by nine feet and was initially "seeded" with 80 earthworms, even though worms were naturally abundant in the soil. Robins were restricted to the lawn by a screened cage which was open at the bottom to permit free access to the ground. The lawn was watered and cut at frequent intervals.

FIELD OBSERVATIONS

Robins were most frequently seen finding worms on lawns in the morning just before sunrise, and in the evening from about one-half hour before sunset until dark. At other times during the day birds found worms when it rained or when lawns were watered. At midday a bird would occasionally find a worm, but at this time the more typical food was an insect, berry, or piece of waste fruit thrown on the lawn.

Typical foraging behavior was as follows. A bird would run from five to 15 feet with its body tilted slightly forward from the standing position. Upon stopping the

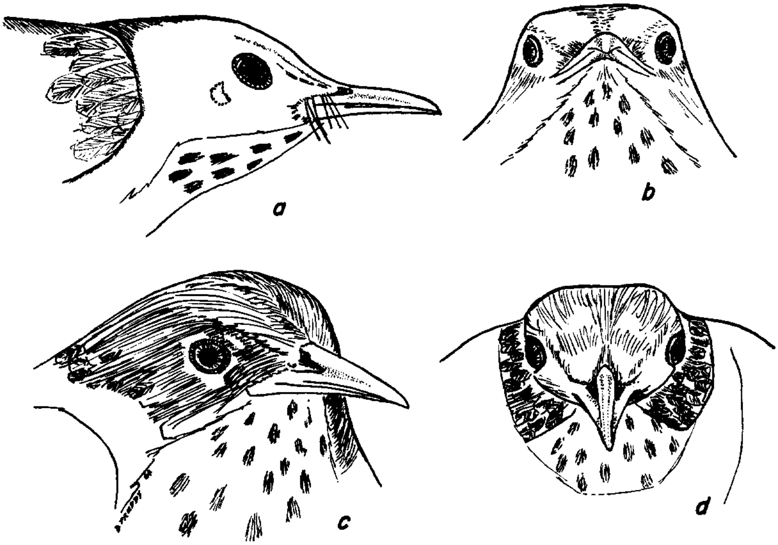

Fig. 2. Head of a robin. a, lateral view, dotted line indicates external auditory meatus; b, frontal view, bill pointed toward observer; c, oblique view; d, frontal view, bill depressed.

bird would usually stand erect (fig. 1a), pause for five to ten seconds, then run off again. Occasionally, the bird would stop short in the run, with the body still tilted forward in the running position (fig. 1b), rotate the head about the longitudinal axis and flex to the left or right (fig. 1c), take a step backward, and thrust the head downward and seize an object in its bill (fig. 1d). Head cocking was observed when the robins examined pieces of fruit or whole berries scattered on the lawn. Robins often would run across the lawn and pick up an insect without cocking the head. It may be seen in figure 2b that the eyes are so positioned that some binocular vision is probable.

The familiar behavior associated with worm finding was seen to consist of the "head-cock" and the "bill-pounce." In cocking the head, the body was held horizontally, and the head rotated about the longitudinal axis to a position such that a line drawn between the eyes and extending to the ground would intersect the surface at an angle of 45 to 60 degrees. The head was flexed to the left or to the right with the result that one eye would be pointed toward a spot on the ground, one to two inches directly in front of the bird, along the longitudinal axis of the body. Thus the other eye would be oriented away from the ground. After holding this position for a few seconds, the bird would rotate and flex the head so as to bring the opposite eye into a similar relationship with the ground. The body was held motionless while the head was cocked from one side to the other. As many as four movements from side to side were noted although one or two were more common. The bird would cock its head several times, then either straighten its body to the running position and move off without making a thrust, or straighten its head and jump forward with both feet off the ground, thrusting the bill into the soil at the spot where the eyes had been directed. If a worm was grasped with the bill on the first thrust, the bird would shift its weight back on both feet, much as a tug-of-war player might do when responding to the pull on the rope. The body was held horizontally and the head flexed downward so that the bill was pointed almost vertically toward the worm hole. This position would be held until the worm was pulled from the hole, or until it slipped out of the bill. If the first thrust was not successful, the bird would hop to a new position around the worm hole and make another attempt. Birds were seen to attack the same spot for as long as one minute.

Robins had greater success in finding worms where the grass was sparse, than where the turf was thick and the surface of the ground was obscured. Close examination of the ground revealed a small ragged crater where a worm was found.

An observer is able to see an earthworm in its hole on a wet lawn from a height of six inches. When observations were made within one-half hour after watering, round holes, approximately one-eighth inch in diameter, could be seen flush with the ground surface. Some holes contained worms which were about one-eighth to one-fourth of an inch below the surface of the ground. If the soil next to the hole was tapped sharply with the fingers, the worm would immediately retreat to a lower level in the hole and disappear from view. In dry soil, the hole was as conspicuous as when wet, but the worm was not visible in the hole.

EXPERIMENTAL OBSERVATIONS

Worm finding in captivity.—Birds were allowed to feed for 25 minutes on the experimental lawn. A cage was placed permanently over the lawn to prevent wild birds from removing worms. The lawn was watered at midday, and the trials were made one-half hour before sunset. Only one trial was made each day, and the same number of worms, which were removed from the lawn by a bird during a trial, was replaced immediately after the run. Trials were made under prevailing weather conditions, which included fog, rain, bright sun, and overcast. A test bird was not fed until its run was over. Worm-finding experiments were conducted from July 24 to October 22, 1963.

The results of these runs (table 1) indicate that the mean number of worms

TABLE 1

NUMBER OF WORMS FOUND IN THE FIRST TWENTY-FIVE MINUTES OF FORAGING IN CAPTIVITY

Trial no.	Bird 1	Bird 2	Bird 3	Bird 4	All birds
1	10	0	7	8	–
2	6	9	7	5	–
3	5	5	6	2	–
4	5	4	6	3	–
5	6	5	5	4	–
6	5	10	7	4	–
7	3	4	5	3	–
8	7	5	7	4	–
9	6	4	6	4	–
10	6	5	3	4	–
11	7	4	7	2	–
12	3	5	–	3	–
Mean	5.75	5.00	6.00	3.83	5.13
Standard deviation	± 1.86	± 2.24	± 1.26	± 1.59	± 2.01

TABLE 2

INTENSITY OF RECORDINGS AS RELATED TO BASE LEVEL

Source	Sound pressure relative to base level* (decibels)
Base level	+ 0
Worms in Hartshorne chamber	+ 9.4
Noise on soccer field	+ 26.9
Noise by powerhouse	+ 30.2

* See text below.

found per trial per bird falls within the range of one standard deviation of the mean number of worms found by all birds.

The robins were initially restless when transferred from their holding cages to the experimental lawn, but within five minutes they settled down and began foraging. The birds' behavior on the experimental lawn was similar to the foraging behavior under natural conditions.

Establishment of the base level of sound intensity and the analysis of worm sounds.—All sound recordings were made at a tape speed of 7.5 inches per second with a Kudelski Nagra IIIB tape recorder using an American D-33 microphone. Analysis of frequency distribution was made by transferring recordings to an audiospectrograph (Kay Electric Company Sonagraph) using a Magnecord PT6 tape recorder. Analysis of amplitude range was made by transferring tape recordings into a Textronic 535 Oscilloscope using the Nagra recorder. Polaroid photographs were taken of the oscilloscope tracings.

Sound intensity measurements were referred to a base level of noise inherent in the recording instruments. This level was established by placing the microphone in a modified Hartshorne, triple box, sound-proof chamber and making a recording with the tape recorder input set to the level used in recording worm noises and background noises in the field.

To analyze worm sounds, 60 red earthworms were placed on the surface of moist humus contained in a cardboard box four inches in diameter. The box was placed in the Hartshorne chamber, and a microphone was directed toward the center of the container, two inches above the soil. A recording was made immediately upon release of the worms, continuing until the worms burrowed into the soil.

The intensity of the noise inherent in the recording instruments was below the minimum sensitivity level of the audiospectrograph. Worm sounds were found to be of short duration and had a frequency range of from one to seven kilocycles.

Background noise at worm-finding locations.—Tape recordings were made between four and five in the afternoon on the campus of San Francisco State College at several locations where robins were seen finding worms. The nearest main traffic artery, 19th Avenue, was 700 feet away. The microphone was placed two inches above the ground, at a 45° angle to the surface.

The frequency distribution of the background noise at the soccer field at 4:13 p.m., December 21, 1963, was essentially continuous but contained more energy at the lower frequencies. Table 2 shows that this noise was 26.9 decibels (db.) above the base level, or 17.5 db. above worm noise. Frequency characteristics of the background noise on a small lawn 20 feet away from the boiler room and power house

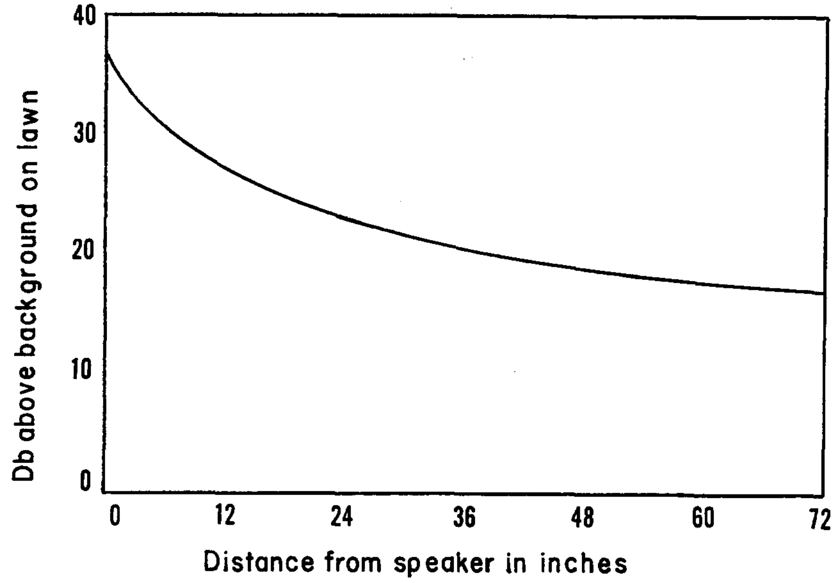

Fig. 3. Intensity of white noise at various distances from speaker.

were similar, but, as can be seen in table 2, this noise was 30.2 db. above the base level, or 20.8 db. above the level of worm noises.

Worm-finding ability in the presence of a high intensity white noise.—A solid state white noise generator was constructed by using a germanium diode as the noise generating element. The signal was amplified with a 10-Watt audio amplifier. The frequency distribution of this system as analyzed by the audiospectrograph was flat over the range of frequencies produced by burrowing worms.

The generator and amplifier were connected to an AR-2A speaker system which was placed at the corner of the experimental lawn. Figure 3 shows the intensity of the sound produced by the entire system when measured with a General Radio 1551-A Sound Level Meter. The intensity of the white noise was calculated with reference to the background noise on the lawn.

A bird was allowed to feed on the lawn under the same conditions prevailing under the control experiments except that the noise generator was turned on five minutes before the beginning of the trial and was kept running during the trial.

No differences in foraging behavior were observed between the control birds and the bird exposed to white noise. If the generator was turned on and off rapidly while the bird was foraging, the bird displayed no interruption of activity. In four trials, the bird found five, seven, five, and eight worms. These figures are all at or above the mean number of worms found by robins foraging in the absence of a masking white noise (table 1). Worms were captured in all quarters of the lawn. Two worms were found within one and one-half feet of the speaker. Typical head-cocking behavior was noted to take place at all distances from the speaker.

Reactions to odor.—Paper toweling soaked in test solutions was placed in the feeding dish along with the food. No substances which have eye irritating effects (with the exception of acetic acid) were used. Tests were made on calm days. Each of six birds was presented with the same odor on the same day to avoid the possibility

TABLE 3

RESPONSES OF A ROBIN TO VACANT AND OCCUPIED ARTIFICIAL WORM HOLES

Trial no.	No. vacant holes	No. pecks at vacant holes	No. holes with "live" ends*	No. "live" ends taken	No. holes with "dead" ends**	No. "dead" ends taken
1	1	0	1	1	0	0
2	2	0	2	1	0	0
3	2	0	2	1	0	0
4	4	0	4	4	0	0
5	4	1	2	2	2	2
6	4	0	4	4	0	0
7	4	0	4	4	0	0
8	4	0	0	0	4	4
Totals:	25	1	19	17	6	6

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* "Live" indicates worm ends freshly cut and inserted in the holes.

** "Dead" indicates worm ends first soaked in ethanol.

of odor masking between cages. Odors tested were butyric acid, acetic acid, mercaptoacetic acid, methyl salicylate, and ammonium sulfide. In all cases, the birds' feeding behavior was normal; no avoidance behavior was detected. The amount of food taken and the time required to consume it were normal.

Reaction to the odor of earthworms was tested by macerating earthworms in a Waring blender and placing the mixture on a piece of paper towel in the food dishes of six birds. Birds were not fed on the day of the test. In no case did the birds display any interest in the food dish or come to the part of the cage containing the dish.

Reactions to simulated worm holes.—A shallow metal baking pan, nine by twelve inches, was covered with soil to a depth of one-half inch. The soil was sifted through a screen to insure that no live earthworms were present. Numerous holes, one-eighth inch in diameter, were made by twirling a small nail in the soil. In the process of making the holes, small mounds of earth piled up around the entrance of the hole, thus giving the appearance of worm castings. The holes, which were randomly distributed over the pan, penetrated the soil layer just short of the metal pan. Some holes were bored vertically, but others were made at various angles to the surface of the soil. The soil was soaked with water, and new holes were made before each trial, the old holes were smoothed over with a trowel.

Into some of the holes were placed one-quarter inch lengths of earthworm tips. These were inserted to a depth of from one-sixteenth to one-eighth inch. In some trials, fresh worm tips were soaked in ethanol, which caused all movements to stop and the colors to fade. In each trial, the pan was placed on the experimental lawn, and a bird was allowed to feed *ad libitum* for twenty-five minutes.

The bird foraged randomly over the entire lawn. There was no tendency to forage on the pan before foraging on the grass. The bird was seen to cock its head when foraging on the pan. On two occasions, the head was cocked in the direction of an empty hole.

Trials 7 and 8 (table 3) were made with the pan two and one-half feet from the speaker and with the white noise generator turned up to maximum intensity.

DISCUSSION AND CONCLUSIONS

The experiments reported here when considered collectively lead to the conclusion that the American Robin locates worms exclusively by visual clues. The olfactory and auditory senses seem not to be involved in worm finding.

Portmann (1961) has noted that the Kiwi (*Apteryx*) appears to locate earthworms by smell. The failure of robins to react either positively or negatively to different odors suggests that olfaction is unimportant in locating worms.

Although worms do produce some sounds when burrowing into soil, the intensity of these sounds is far below the level of background noise at worm-finding locations.

My deduction that the robin does not employ auditory clues to locate worms is supported by the fact that a white noise of high intensity does not prevent the birds from finding worms or cause any changes in the normal foraging behavior. Griffen (1958) reports that bats can echolocate in the presence of high frequency white noise, but the bat is listening for a nonrandom pulsed sound. Worm noises are composed of broad bandwidth sounds of random frequency and amplitude.

The hearing range of passerines, reported by Schwartzkopff (1955), extends from 200 to an extreme of 29,000 cycles per second in the Chaffinch (*Fringilla coelebs*). However, the hearing ability of the bird is not relevant for the following reason. If two sounds, each of the same frequency but of different intensities, are produced simultaneously, the sound of higher intensity will mask the sound of lower intensity (Beranek, 1954). Examples of this phenomenon are frequently encountered in factories where there are background noises of a high intensity and wide spectrum.

Schwartzkopff (1949) has found that Herbst corpuscles in the legs of the Bullfinch (*Pyrrhula pyrrhula*) respond to vibrations of from 100 to 3200 cycles per second. The possibility that robins are locating worms by detecting vibrations through the feet cannot be overlooked, but this explanation seems unlikely for a variety of reasons. If the robin senses vibrations through its feet, the question of why the robin cocks its head remains unanswered. The bird would have difficulty in isolating the vibrations of one worm from those of the thousands of others in the foraging area. Masking vibrations of pedestrians, traffic, and machinery in buildings would compound the problem of locating the position of the worm. The fact that no difficulty was encountered in locating killed worms in artificial worm holes tends to rule out this possibility.

The results of the experiments involving simulated earthworm holes suggest that the robin is responding to the sight of the end of a worm in a burrow. If the hole is empty, the bird does not peck at it.

The times of day when robins are most often seen finding worms are those when worms are closest to the surface of the ground (Darwin [1881]). After a rain, worms are forced out of their flooded burrows to the surface of the earth (Wolfson and Ryan, 1955). If the worm is crawling on the surface of the ground, the robin, with its low vantage point, can easily see it. If the worm is in its burrow, the bird can also see it, provided it is not too far beneath the surface.

The visual acuity of robins is probably great. Donner (1951) found that the minimum visual angles of *Turdus merula* and the Fieldfare (*T. pilaris*) are from 0.67 to 1.34 minutes of arc.

The head-cocking behavior of the robin is easily explained if visual clues are being used to find worms. The position of the eyes requires that the head be turned in order for one eye at a time to have a full view of an object on the ground in front of the bird (see fig. 2). Because the eyeballs are relatively immobile in their sockets, the bird must cock its head to make best use of central, rather than peripheral vision.

I would explain the worm-finding behavior as follows: While foraging on the lawn, a robin sights a whole worm on the surface, or some object which resembles the end of a worm in the opening of a burrow. The bird runs over and seizes the worm if it is on the surface. If the bird has been attracted by an object in a hole, it places its body in a position which will enable it to thrust straight ahead. Such an alignment of prey, head, neck and body enables the bird to penetrate the ground with the bill to a greater depth than would be possible if the bird had to jump sideways. To fix exactly the location of the hole, the bird cocks its head so that each eye is pointed, in turn, toward the hole. It is critical that the first thrust be accurate, otherwise the disturbance may cause the worm to retreat into the burrow. Once the bird has determined by visual clues (shape or color) that a worm is in the hole, the bird points its bill toward the hole and thrusts the bill forward. Since the robin's bill is elongate, it readily penetrates the soil around the hole. If the end of the worm is caught between the mandibles, the bird pulls backward, exerting a steady tension, until the worm releases its hold on the walls of the burrow and is extracted.

SUMMARY

This paper reports on a study of the sensory mechanisms employed by the American Robin (*Turdus migratorius*) in locating earthworms.

The foraging behavior of robins in the wild includes the "head-cock" and the "bill-pounce." Robins forage for earthworms more frequently in the early morning and the late afternoon, than at other times. Worms are more often located in bare patches of ground than in dense turf.

Captive robins were allowed to feed on an experimental lawn. In 47 tests using four birds, the mean number of worms captured in 25 minutes was 5.13.

The sounds of earthworms burrowing into soil were analyzed on an audiospectrograph. These sounds were found to be of such a low intensity that they are undoubtedly masked by background noise at locations where robins normally find worms.

Captive robins, which were allowed to forage on an experimental lawn in the presence of a high-intensity white noise, showed no decrease in worm-finding ability or any change in foraging behavior from that typical of natural conditions.

Robins showed no positive or negative response to noxious odors or to the odor of earthworms.

Robins do not peck at unoccupied simulated earthworm holes, but when the ends of killed worms are placed slightly below the surface level in the artificial holes, the robins found 92 per cent of the food.

It is concluded that robins are looking for the visible signs of worms in their burrows, when the worms are forced to the surface by moisture in the ground, or at dawn and dusk when the worms are foraging near or on the surface of the ground.

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