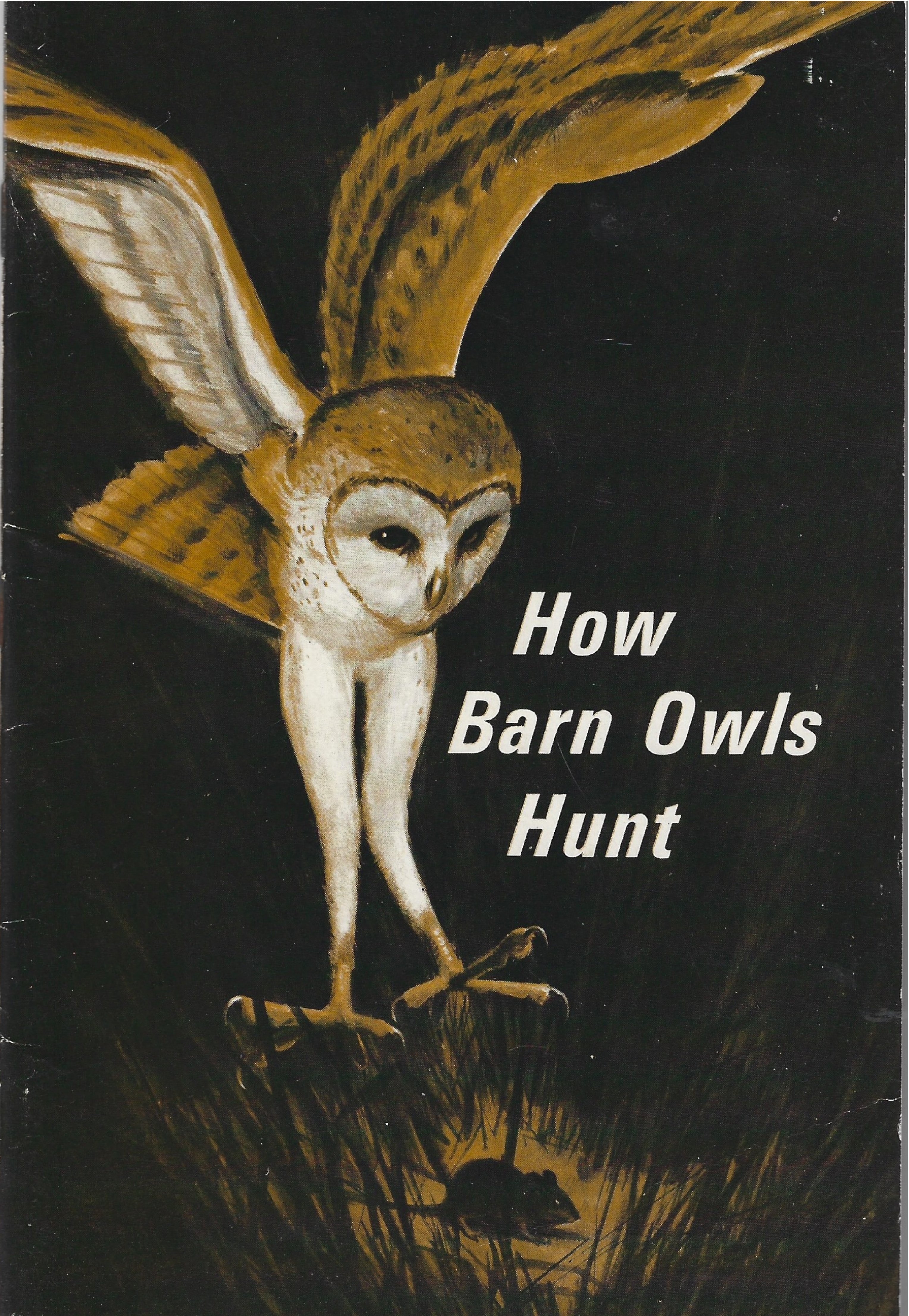
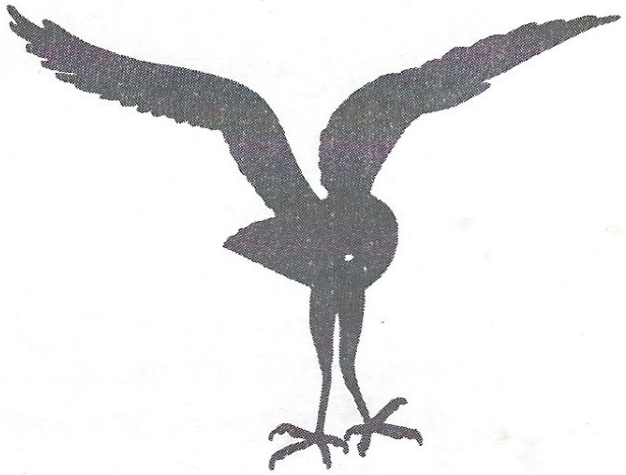
How Barn Owls Hunt



How Barn Owls Hunt

Elementary Science Study



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ACKNOWLEDGMENTS

During the work I have described here, I have been helped by many friends. My greatest debt is to Charles Walcott. Without his guidance, help, equipment, patient advice, and a lot more, the work described here would never have been done, and I would now be employed in some other way — in fact, I should perhaps be most grateful to him for sparing me the knowledge of how grim that alternative might have been. I am also very grateful to William Dilger and Thomas Eisner, both of Cornell University, where I was a graduate student, and to William Drury of the Massachusetts Audubon Society.

Much as I am thankful to people like Walcott, Dilger, Eisner, and Drury for helping me find a way to spend my life studying animals, I owe a still greater debt to my wife for tolerating it. The life of a biologist is erratic, and his family often gets dragged along with all of the care exhibited by a lioness carrying her kill. Finally, I am grateful to the people at ESS, particularly Adeline Naiman, who have helped to bring this book into being. Their patience has been truly extraordinary.

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PREFACE

The Elementary Science Study is one of many curriculum development programs in the fields of science, social studies, and mathematics, under preparation at Education Development Center, Inc. EDC (a private nonprofit organization, incorporating the Institute for Educational Innovation and Educational Services Incorporated) began in 1958 to develop new ideas and methods for improving the content and process of education.

ESS has been supported primarily by grants from the National Science Foundation. Development of materials for teaching science from kindergarten through eighth grade started on a small scale in 1960. The work of the project has since involved more than a hundred scientists and educators in the conception and design of its units of study. Among these scholars have been biologists, physicists, mathematicians, engineers, and teachers experienced in working with children of all ages from kindergarten through college.

Equipment, films, and printed materials are produced with the help of staff specialists, the film studio, the photographic laboratory, and the production shops of EDC. At every stage of development, ideas and materials are taken into actual classrooms, where children help shape the form and content of each unit before it is released to schools everywhere.

FOREWORD

One of the reasons this book was written was to try to give you some idea of how a scientist—in this case a biologist—tries to solve a problem that interests him. When I set out to write it, I hoped that it would be possible to get rid of the myth that scientists are all-knowing people with immensely complex minds. In fact, they are simply people who think, in an uncomplicated fashion, about what they most enjoy doing.

Many people imagine a biologist as an old man hunched over a dusty microscope in a musty office lit by one bare bulb. He is working on a scrap of tissue that he has pried off a formless blob which is still sinking slowly to the bottom of an evil-smelling jar of fluid by his elbow, giving off a few bubbles as it goes. Everything in the stale room has been kept for years, even the air, and what excites him is something that only he and two other people (both of them on their deathbeds in some Middle European country) can understand. The worst part of this picture is that the man's work must be relied on, and that he and all of his chums have arrived at their discoveries by methods so obscure and hard to understand that the only thing a student can do is memorize their results, with no understanding of how they were obtained.

How such opinions are formed is a mystery to me—because I am a biologist. I went into biology because I like animals and plants, the out-of-doors, woods, meadows, mountains, rivers, and oceans. Biology offered a chance to spend a lifetime in those places, doing what I like best. The people I have met in biology are anything but the sort described above. Young or old, most of them are really happy in what they are doing. For example, one of my biologist friends is at this very moment circling in a small airplane chasing homing pigeons that have small radios strapped to their backs. He learned to fly a plane so that he could follow birds and find out how they navigate. Another friend is at present camped on a mountaintop in British Columbia, about twenty miles from the nearest house, in some of the wildest country left in North America. Last summer he was charged by a grizzly bear and barely lived to tell of it. He is there because he is fascinated by

mountain goats. He wants to know how they live. Every day there he sees things that no one else ever sees, and though I will not meet him until several months from now, when I do, he will have more to say than many others who have stayed in the city all year.

I have biologist friends who are collecting bats in caves in Central America, in order to study how they find their way home after an evening of hunting insects. Another friend is off to New Guinea to study birds in the jungle, and still another is attempting to train birds to fly in wind tunnels, so that he can find out how they stay up. The list could go on for pages but would cover only a small number of the many aspects of biology.

The sort of research I have done may seem less exciting than the work of many other people, but it interests me a lot. If you like owls, perhaps you will find it interesting, too.

When I was your age, I loved owls. I have always loved owls. That is not to say that I thought of nothing else. In fact, months could pass during which owls never crossed my mind and there were lots of other things to think about. But whenever I saw a good picture of an owl (a rare thing) or noticed an owl in a picture of something quite different, I had a special feeling. It would hit me that here was something I really cared about, that if I could only be free of the daily routine, I would spend some time in a forest where owls lived.

I also thought about what it would be like to see an owl in the woods, but dismissed that thought early because it was clear that only people who really did not care whether or not they saw an owl got to see one. I remember reading a short newspaper article about an owl. It had flown into a screened porch in someone's log cabin, and the owners had called the police to get "the thing" out.

Though I spent summers in the country, I was sure that owls were so special that they would not be living in the woods near our house, so I never looked for them or bothered to ask if there were any around. As it turned out, we were living right in the midst of owl country, but I didn't know this until long after we had moved away.

Years later, I did actually see an owl. It was during late dusk, when I was walking along a back road, and five owls appeared at once — a whole family, ghosting through the branches of a dead apple tree in a deserted orchard. They were visible only for a few seconds, and, when they had vanished, I could hear them calling softly among themselves as they moved off through the woods bordering the back of the orchard. When they were completely gone, I was shattered — first with delight and then with discouragement. My chance had come and gone, and I would never be lucky enough to see a wild owl again.

When I became a senior in college, I found that a course about birds was being taught, and that I could get credit for taking it. That was too good to believe. What was even better, though, was that in this course every student was asked to spend a lot of time reading about one group of birds, to do some research if possible, and then to write about it.

I chose owls before anyone else could beat me to it. As it turned out, nobody else even cared. For the first time, I realized that something I wanted very much to do might be considered work by others — and that was perhaps the most important thing I learned in college.

Since then, I have studied owls for years at a time. I have seen them in the wild, have kept them in captivity (up to fifty owls of fourteen different types at once), and have grown to like them more and more.

Because I am now a biologist, I actually earn a living by studying owls. This has never ceased to amaze me, since I would gladly pay for such a chance if I had the money. One of the strangest — and nicest — things about life is that it is often possible to do what you want to do and earn a living doing it.

When I began to read scientific papers about owls, I was bothered by how little was really known about the lives of owls in the wild and the ways in which they overcome the problems of hunting at night. In the past, people had shot owls and then dissected them to find out what their insides looked like. Such research had exposed several surprising things about the anatomy of owls. For instance, many kinds of owls have left ears that are quite different from their right ears. The two openings may be of different sizes or placed so that one ear is higher on the owl's head than the opposite ear. Such owls also have special feathers on the front edges of their wings. These feathers reduce the amount of noise the wings make when the owls fly, so that their flight is extremely quiet. Neither of these peculiarities is found in other birds. Still, the research said nothing about how owls live, and no one had really tried to find out in what ways the strange ears and silent flight might be of use to an owl — or even whether they are useful at all.

I am not being quite fair, because at least one thing was generally known about the lives of owls in nature: what they eat. For instance, one sort of owl, the barn owl, is known to live almost exclusively on field mice. People discovered this by examining the food pellets made by owls. A food pellet is the undigested remains (chiefly fur and bones) of an owl's

prey, which the owl coughs up after digesting the meat. An owl pellet is a neat, nearly dry, odorless lump. Everything is sorted out so that the bones are on the inside and the fur on the outside. (No one knows how the owl's digestive system performs this trick!) You can collect pellets beneath trees that owls inhabit. If you tear these pellets apart, you can find out what the owl has been eating.

I was quite surprised to read that barn owls eat little besides field mice. I had heard that they ate field mice, but I thought that barn owls must catch lots of other animals, because it would be hard to catch as many field mice as they would need every day. In the summer, moreover, when feeding their young, the owls would have to catch nine times as many field mice, since barn owls have an average of nine young a year. Furthermore, to do this at night, when it must be almost impossible to see the mice, seemed extraordinary. Perhaps field mice are a lot easier to see at night when they are running all about, than in the daytime when they are asleep in their burrows. Still, there are cloudy nights when there is not even starlight to hunt by; and, in the woods, the shade of trees and shrubs must cut down the light which even the most sensitive eyes would need to see a mouse.

Again I went to the library, and again I was discouraged to find that so little was known — this time about the lives of mice. I did find, however, that it would probably be very difficult for the owls to see field mice, even in broad daylight, because the mice build tunnels on top of the ground through the bottoms of grass stems. Traveling in these tunnels, they can move about their home fields without being seen. The mice make the tunnels by pushing a path through the grass stems, chewing off any stems that are in the way, and stuffing the remaining bits into the sides of the paths or into the criss-cross stems that form the roofs. In that way, they end up with paths that have thatched walls and thatched roofs. Unless they have done a really bad job of building, they can move along beneath the winding grass arbors without being seen most of the time.

When I learned this, I felt that I had reached a dead end. It seemed to me that it must be impossible for a barn owl to catch a field mouse, and yet every barn owl in the world catches up to several thousand mice each year. I began to wonder whether the mouse tunnels were really as protective as they seemed. Perhaps they worked against mice as well as for them; if mice could not be seen most of the time, then most of the time they must not be able to see danger approaching. Perhaps, too, the tunnels were not soundproof, even though they were almost sightproof. If sounds could get out of the tunnels, they might give away the mouse's position to a predator like an owl. Moreover, mice could not spend their whole lives in the security of a grass tunnel — they must have to venture out sometimes. Grass tunnels have to be lengthened and cleaned, and new food has to be found, gathered, and eaten. Mates have to be met, battles fought to establish ownership over part of a field, etc. All these activities require leaving the tunnel for a time. Furthermore, it must be very nearly impossible for a mouse to build, gather, chew, explore, or fight, without making noises.

I thought about all of this, and suddenly several things clicked into place: the peculiar ears of owls, their silent flight, and the necessary noisiness of mice. Why shouldn't any animal that wanted to find and catch a field mouse simply follow mouse sounds to their source and grab the noisemaker? To catch anything as small as a mouse, an owl would have to be able to follow its sounds very exactly and, therefore, would need special ears. If the mouse heard an owl approaching, it would probably stop making sounds, and the owl would fail to find it. Thus, the owl would have to fly softly. Also, if the owl did not need to see a mouse at all to catch it, it would make little difference in the owl's life whether its waking hours were spent in light or in darkness. Maybe owls were active at night simply because mice were!

HOW AN OWL LOCATES ITS PREY

Since it all seemed to make sense, I resolved to try some experiments to see whether a barn owl could catch a mouse when I was sure it could not see the mouse, that is, in total darkness. (No matter how sensitive it is, the eye of any animal must have some light in order to see.) I got my start working with Dr. William Drury, the director of research at the Massachusetts Audubon Society. We started experimenting in a building (then deserted) near Dr. Drury's house. After boarding up the windows in one very large room (forty feet long), I spent two weeks with putty and masking tape, plugging cracks until I could see no light — even with full sunlight outside. Then, just to make doubly sure the owl could not see anything, I did my experiments only at night.

I was lucky to get a full-grown barn owl that was quite tame. I decided that I would let the owl become used to the dark room for a few weeks, and then see if it could catch a mouse in total darkness. To be sure that the mouse would make noises when it moved about, I spread dry leaves on the floor of the room. Then, to keep the owl from colliding with anything when it flew, I left the room empty except for a perch at either end.

The first time I offered the owl a chance to catch a mouse in total darkness, nothing happened. I turned on the lights, but even then the owl did not seem to know what to do. Instead of flying down to land directly on the mouse, it landed on the floor and then caught the mouse by running it down. That sight remains in my mind as unforgettably shocking. It suggested what it might have been like to watch a dinosaur run a small, terrified animal to ground, for when an owl runs, it leans far forward and takes very long strides.

Because the owl I was using had been raised in captivity, it had never seen its parents catch mice. I thought that it might, therefore, have to discover for itself how to hunt. For several more days the owl kept running down mice instead of flying directly to them. Then one time it launched itself into the air and came down on a mouse. Every time after that, it flew directly to its target. Now I could turn out the lights.

The next time, I tried the owl with the lights off. Sitting in the still darkness, I could occasionally hear the owl shifting on its perch. I could picture it hesitating to launch itself into the darkness that blocked it from the mouse on the floor. The mouse had apparently not found the bed of leaves to its liking.

After I tossed it gently into the leaves, it waited forty-five minutes before moving at all and then moved with incredible slowness — a step every half minute or so, to judge by the faint and occasional creak of a leaf. It seemed that we three — the mouse, the owl, and I — were all waiting tensely for someone to make the first move, scarcely daring to breath or swallow, alert to any sound.

For fifteen more minutes the suspense was unresolved. Then I heard a slight rasping sound — one I later came to know so well — the sound of the owl's talons scraping off the perch as it started its deathly quiet flight. There was a moment of scarcely bearable silence and then a crash. My hand was on the light switch; I snapped it on. Then, to my amazement, I saw that the owl was grasping the mouse in its claws. I remember little of what happened after that. I was thunderstruck. Everything had exceeded my wildest hopes. I had witnessed, at least with my ears, an owl flying in complete darkness though a room longer than most people's entire houses and pinning to the floor an object smaller than my thumb.

I was also filled with doubts. Had it just been a lucky shot by the owl? Would the owl ever try again? Would it ever succeed again? Was it hearing, as I suspected, or some other sense that had guided the owl to the mouse? I hardly dared to try the experiment again; but unless I did, I could not trust what I had seen.

After an hour the owl had eaten the mouse, fluffed its feathers a few times, and regained its composure. It now seemed to be taking a renewed interest in what was going on, so I released a second mouse. This time the owl struck in darkness with even less hesitation than before. My excitement grew when I realized that, because this owl was raised in captivity, I had proved incidentally that an owl's ability to locate mice in total darkness is a talent it does not have to perfect by hours of practice attempts. If it has had the right experiences and can catch mice in the light, it can succeed on the first try at the exceedingly tricky task of catching mice in total darkness. Since that first day, I have repeated the experiment hundreds of times, using eight different barn

owls. Again and again the same thing has happened — the barn owl catches a moving object without seeing it at all.

Though I had started with the idea that an owl might be locating its prey by hearing it move, my first experiment did not prove this conclusively. The owl might have been using one of several other clues. For instance, mice are very smelly creatures, and perhaps owls could detect them by their odor. Mice are warm-blooded animals, so they might be detected by the heat they give off.

The room I worked in was unheated, and the room temperature was well below freezing during my first experiments. If an owl could see heat rays (which are really just like light rays but below the range in which human eyes see), it might be able to locate mice just because they would be warm objects in contrast with the cold surroundings. In fact, in my reading I had come across an article by someone who suggested that owls' eyes are sensitive to heat, thus enabling them to capture warm-blooded creatures in darkness.

To check these two possible explanations — heat and odor — I needed, essentially, a cold-blooded mouse that had no odor. If an owl could catch such a mouse in darkness, I would be nearer to proving that the owl used its hearing to direct its strike.

I was able to make such a "mouse" by tying thread to a piece of paper crumpled up to mouse size. This I dragged through the leaves on the floor in total darkness. The only truly mouselike thing about this wad of paper was the noise it made as I dragged it through the leaves. Sure enough, the owl caught it in total darkness. I tried this experiment many times, always with the same result, and thereby proved that a barn owl can locate objects using only its ears.

There was still a problem. I could think of two ways that an owl might locate its prey by hearing: (1) it might simply follow a mouse sound to its source — that is to say, it might be homing in on the sounds made by a mouse; or (2) it might locate mice the way some bats find insects — by sending out high-pitched cries (too high for humans to hear), listening to the echoes that come back, and then guiding its flight by the sounds.

To resolve this problem I needed something that made very mouselike noises, but that was shaped utterly unlike a mouse. If the owl could strike such an object in total darkness, I would have proof that it was homing in on sounds, not locating them by echoes. Any very un-mouselike object should give the owl echoes quite different from those that real mice would give.

My solution to this problem was to use a tiny loudspeaker. Through the speaker I broadcast a tape recording of mice running through leaves, and this the owl struck with ease — in total darkness.

As a final test of my case for hearing, I plugged one ear of a barn owl with a small cotton wad and let the owl try to catch a mouse in complete darkness. It missed every time, indicating that when I interfered with its hearing, it could no longer locate mice accurately.

MEASURING THE ACCURACY OF AN OWL'S STRIKE

One thing I never got used to during the course of my experiments was that although the owl could catch the mouse, I found that I was always looking in the wrong place when I switched on the light. The mouse was never where I thought it was, yet the owl always seemed to know where the mouse was. It missed rarely, and then only by inches. I was so impressed by the accuracy of its hearing that I wanted to measure exactly how accurate it really was.

Because I had no way of knowing just where a live mouse would be when the owl struck, I decided not to use live mice for targets in my accuracy measurements. Also, the dry leaves on the floor made it impossible for the owl to leave claw marks or any other sign showing exactly where it landed when it struck. I solved the problem by sweeping away all the leaves and covering the floor with sand.

With the room thus prepared, I turned out the lights so the owl would not see what I was doing. Then I walked to about the middle of the room and placed a dead mouse on

the sand. The mouse had a leaf tied to its tail and a long string tied to its body. I took the end of the string and made my way through the dark to a small hideout I had built in one corner of the owl room. When I could hear that the owl was calm, I pulled gently on my end of the string, moving the dead mouse and the leaf. When it heard the sound of the leaf scraping on the sand, the owl left its perch and struck, and then I turned the lights on quickly.

I did this many times. If the owl missed, I would run in before it had time to pounce on the dead mouse. Then I would record both the position of the dead mouse and the place where the owl's feet had left marks on the sand.

Certain things were wrong with this experiment. It was not a foolproof test of the owl's hearing accuracy for these reasons. *First*, the owl's feet hit the sand hard and spread it around. This made it impossible for me to record the *exact* place where the claws struck the sand. My measurement might be wrong by as much as one and one-half inches, a distance almost as great as the length of a mouse's body.

Second, I could not be positive that the leaf had not changed its position and rustled a little when the owl was in flight. If it did, the noise would give the owl an extra clue. I knew this because I had tried giving extra rustles on purpose while the owl was in flight. Whenever I did that, the owl did not miss the dead mouse target — even when it had to fly the whole forty-foot length of the room. This meant that the owl could correct a faulty reading while flying.

Third, I had no way of knowing what kind of error I was measuring. Was the owl missing the target because it could not hear perfectly? . . . or because it could not fly perfectly in the dark? . . . or both? It seemed to me that it must be at least as difficult for an owl to fly well in pitch darkness as it is for a person to keep his balance and walk in a straight line when he is blindfolded.

In order to eliminate these three weaknesses in the experiment, I decided to use the tiny loudspeaker again. When I wanted the owl to strike it, I broadcast a recording of a mouse rustling leaves through the speaker. I attached a switch to the perch, which automatically turned off the recording when the owl left the perch. This made sure that the owl would not get additional sounds to guide it in flight. On top of the speaker I placed a dead mouse, so that the owl would be rewarded each time it found the speaker correctly.

I mounted the speaker on a board and covered the board with modeling clay except for one small hole above the speaker. When the owl struck at the sound, it would dig its claws into the clay around the speaker hole, and this would give me an accurate record of the landing place.

I left the light on during the experiment. The owl could then use its eyes for flying, if it wanted to. The light did not give the owl any clue about where the loudspeaker and the mouse were, since the whole floor was evenly spread with leaves, and the mouse and the speaker were hidden under them. In addition, I put up a screen between the owl and me, so that the owl never saw me when I was hiding the loudspeaker.

Every time the owl missed the speaker, I recorded the exact position of the speaker and of the claw marks that were left in the clay. My next problem was to figure out a way of describing the owl's accuracy. Suppose I said, "The owl never missed a mouse by more than one inch." Would this statement tell you whether the owl was a good shot or a bad shot? If the owl was a hundred feet away, a one-inch miss would show excellent aiming; but if the mouse was just a foot away, a one-inch miss would indicate very poor aiming. Thus, if I told you that the owl missed a mouse by an inch, it would mean little unless you knew how far away the owl was to begin with. What I needed was not a number of statements about the owl's errors at specific distances, but a general statement from which anyone could figure out by how much the owl would be likely to miss at *any* distance. There is a very good way to arrive at such a statement: to measure the owl's accuracy in angles rather than in inches. An angle is made by drawing two straight lines from the same point (see Figure 1).

Figure 2 shows what I did. Suppose you are looking down at the floor of the owl room from the ceiling. Point *O* is where the owl sat on its perch when it was deciding where the mouse

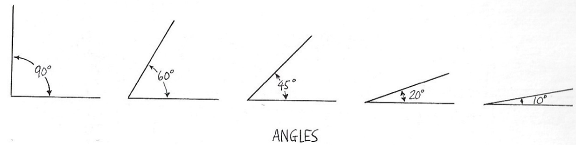


Figure 1.

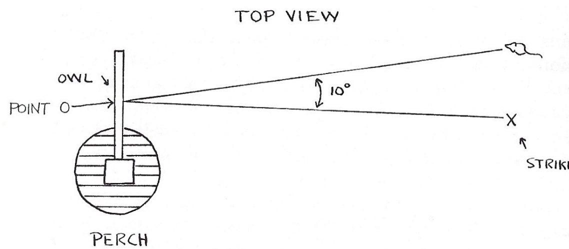


Figure 2.

was; point *X* is where the owl struck (as I could tell from its claw marks). The picture of the mouse shows where the mouse was. You can see that the owl aimed too far to the right in this case. By drawing a line from the mouse to the owl sitting on its perch and another line from the same place on the perch to the claw marks at point *X*, you form an angle that shows the number of degrees to the right by which the owl missed.

Figure 3 is a similar view from above. In an exaggerated way, it records the results of dozens of strike attempts made over a period of several weeks, as an owl tried to catch mice every day.

The mice were tied by threads to one of four little posts, so that they could not wander about, and the posts were set at four different distances from the owl. There were thus

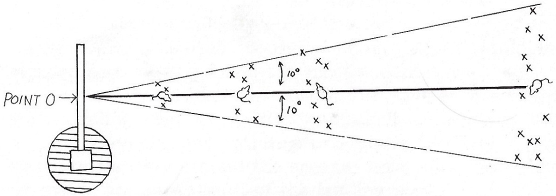


Figure 3.

four different stations where an owl could try to catch food. None of the successful attempts are indicated; I have shown (by *X*'s) only where the owl missed. You can see that each post (indicated by a mouse) has several *X*'s about it. The *X*'s show that even though the owl usually missed more distant mice by a greater number of inches, all of the misses lay within the same angle.

I said before that Figure 3 recorded the results in "an exaggerated way." To be specific, I did not record the *actual* positions of the posts and the places where the owl landed. Instead, I spaced them out to form a wider angle, so that you could see the results more clearly.

In Figure 3, all of the misses lay within a 20° angle (10° to the left and 10° to the right of the line on which the mouse was placed each time). Therefore, one general statement would describe the accuracy of the owl's aim in every attempt shown there: "The barn owl can locate its prey within an angle of 20° (10° left and right)."

Actually, the owl never made an error as large as 20°. In fact, an owl can correctly locate the spot a sound comes from within less than 1° of error. This means, for example, that a barn owl six feet away from you might tell by sound whether you were wiggling your big toe or the one next to it. By any standard, that is good aiming when you are talking about "setting your sights" by hearing.

Figure 4 illustrates an angle of 1°, just to show you how accurate an owl is; it actually does even better than this at left-right aiming.

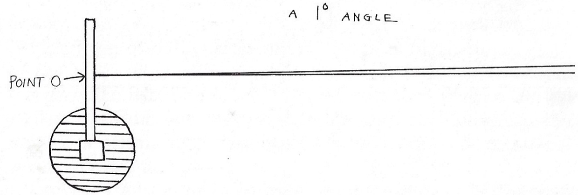


Figure 4.

Aiming to the left or right is not all an owl has to do to catch a mouse. The owl might have a perfect left-right aim and still miss the target. For instance, if it aimed too high it would overshoot the mouse, or if it aimed too low it would land short of it. Once again, the best way to express the accuracy of an owl's up-and-down aiming seems to be to use angles.

In the series of pictures in Figure 5 (again showing misses only), I have shown the accuracy of the owl's up-down aiming, as it tried for mice at four different distances, as being always within an angle of 10° above or below the mouse. (In fact, the owl always struck within ½° of the mouse, but I have made the angles wider so that you could see the strikes more clearly.) Again, you can see that even though the owl undershoots or overshoots by more inches when aiming at more distant mice, its accuracy is really the same throughout all trials.

You may also notice that for any mouse at any particular distance, an error of 20° in an owl's up-down aiming covers more ground than is covered by the same error in side-to-side aiming (compare Figures 5 and 3). This means that an owl needs to be even more accurate in up-down aiming than in left-right aiming, or it won't catch a mouse. It was not until I realized this fact that I understood the importance of the discovery that an owl's up-down accuracy of aiming (within ½° of error) is roughly *twice* as good as its side-to-side aiming!

Exactly how does the sort of accuracy I have been describing help a barn owl to catch a mouse? At a distance of twenty

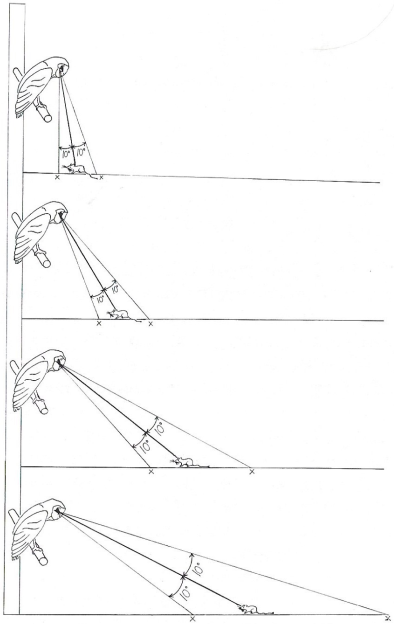


Figure 5.

feet, for instance, the owl should be able to pinpoint the place where a sound is coming from to an area roughly three inches wide and six inches long. This is about the area covered by the spread-out claws of an owl added to the space occupied by an average mouse. Thus, no matter where the mouse is in such an area, the owl should hit it with at least one talon, or claw, when it strikes. The accuracy measurements predict that an owl should be able to catch a mouse every time the mouse is twenty-three feet away or less, and that at greater distances it will miss quite often.

In the light of this, I was very interested to see that beyond twenty-three feet an owl will not try for a direct hit. Instead, it flies down from its perch and lands softly on the floor, short of the place where the sound came from. It holds still for a few seconds, listening for more clues, and then flies on for the strike. It seems not even to attempt a direct hit unless the mouse is within the distance at which the owl is almost certain to get it.

Probably a barn owl's hearing accuracy is even better than I have given it credit for. Remember, in all the experiments I had done up to this time, the owl had flown to the sound in darkness. What bothered me was the possibility that what I considered to be the owl's mistakes in hearing might really be mistakes in flying without the use of sight. To make certain I was measuring *only* the hearing error, I somehow had to separate the two. By using a hidden loudspeaker and allowing the owl to strike at it in the light, I hoped to separate flight errors from hearing errors; but problems are rarely solved by any one experimental method, and this method had its own limitation. The only loudspeaker I could afford was of very low fidelity. As a result, the mouse sounds were distorted when played over the speaker and caused the owl to make errors.

Because of this limitation, I am now planning a completely different sort of experiment. I want to see how accurately an owl can locate a mouse without flying at all.

To do this, I will first have to train an owl to nibble at a piece of wood when it hears a recorded sound. It will not be hard to do this, since an owl spends lots of time nibbling things anyway. All I will have to do is wait until the owl nibbles something and then encourage it with a food reward.

When it has learned to do this, I will encourage it to nibble at a piece of wood near its left foot when it hears the sound coming from its left side, and to nibble at a piece of wood near its right foot when it hears the sound coming from its right side. It will get a food reward only when it nibbles on the correct side. As the owl becomes used to earning its meal in this way, I will begin to play the sounds closer and closer to a spot directly in line with the owl's line of sight. When the owl is unsure which piece of wood to nibble, it may make as many wrong nibbles as right ones. By moving the sounds gradually farther to both the left and the right of the mid-point, I will find out at what point the owl stops having to guess and is able to locate the sound accurately. Then I will draw an angle to illustrate this. It will be the angle within which the owl will make guesses when I move the sound source. In other words, it will be the smallest angle within which an owl can locate the position of a sound source.

HOW AN OWL STRIKES

Locating a mouse by the sounds it makes is only part of an owl's problem; it must also catch the mouse. I discovered that an owl does several things to improve its chances of catching mice it cannot see. In order to discover these things, I had to watch an owl fly and strike in total darkness, using only its ears for aiming; but first I had to find a way of "seeing" in the dark, so that I could watch what was happening.

Getting Equipped

In the room I placed several lamps completely covered with filters through which no light whatever could pass, but through which heat from the bulbs could escape. By looking through a sniperscope, an instrument that changes heat into light, I could watch the owl hunting a live mouse in darkness.

Roughly speaking, a sniperscope uses the heat that comes from an object in darkness. The heat falls on a light-sensitive surface and releases electrons from it. Each electron is sent down a tube at high speed and hits a screen at a point that corresponds exactly to the electron's former position on the light-sensitive surface. The screen has a fluorescent material that gives off light when an electron hits it. The observer looks at the screen, which is very small, through a built-in magnifying glass and sees what looks like a television picture of whatever the sniperscope is aimed at.

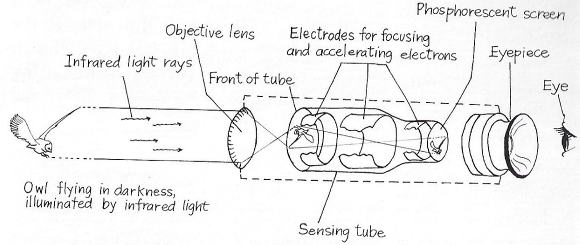


Figure 6.

How the sniperscope works. *Infrared light rays are focused just like visible light rays by the objective lens (like a magnifying glass) onto the front surface of the sensing tube. This surface is coated with a super-thin metal layer with millions of holes in it, which let infrared light through. Because this coating is metal, it can conduct electricity; and, in this case, a high electric charge is transmitted to it from the power supply (not shown). Because of the charge, each light ray knocks off electrons which are speeded down the tube (and also focused) by other electric fields. (These fields come from the circular electrodes which line the tube, attracting or repelling the electrons.) As they are speeded down the tube, the electrons store energy. When they hit the phosphor coating on the smaller screen at the back of the tube, they give up their energy to the coating, making it glow wherever they strike. The phosphor coating glows greenish and yellow. Since those are colors we can see, we are able to see whatever pattern the showering electrons make on the screen. If you realize that the pattern of the showering electrons is fixed by the pattern of infrared light coming from whatever object the infrared viewer is pointed at, you will understand that the shower pattern is always a picture of whatever the viewer is pointing at.*

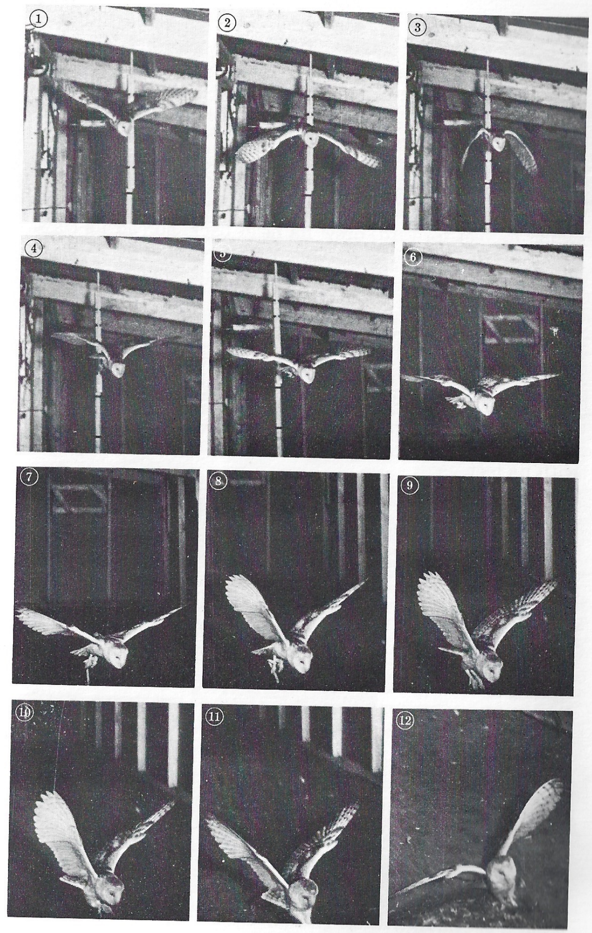
Because everything happens so fast during a strike and because I wanted to be sure I saw exactly what does happen, I made several motion pictures of the owl striking a mouse in the dark. I used heat-sensitive film and aimed the camera with the help of the sniperscope. When heat-sensitive film is developed, it can be shown on a regular movie projector. By running my film slowly, I could study the owl's flight in detail. I also made moving pictures of the same owl hunting in the light, and I found that its behavior during the strike was quite different in light and in darkness.

Strikes in Light

The first motion pictures I made show how a barn owl strikes a mouse when it *can* see (see Plate I). When I tossed a mouse into the leaves, the owl turned quickly to face it, leaned forward slightly, and held perfectly still. Then it pushed off from the perch, made one stroke with its wings, and glided straight to the mouse. During most of the flight the owl's feet were tucked beneath its tail; but, about three feet from the mouse, it suddenly swung its feet forward until they almost touched its bill. Next, it pulled its head back as if it had started to dive into the leaves but decided at the last moment to land feet first. Then, with its head held high, its eyes closed, its legs stretched out, and its claws spread, it struck.

Plate I.

The pictures in Plate I are separate frames from a movie of a barn owl catching a mouse in the light, when the owl can see the mouse. In Picture 1, the owl leaves its perch and takes one stroke with its wings (completed by Picture 4). It then glides, without flapping its wings, all the way to the floor. In Picture 7, it is very close to the mouse, and it starts to raise its wings and bring its feet forward. In Picture 10, the owl's feet are beneath its bill, and, in Picture 11, they are extended very quickly while the owl withdraws its head. Unfortunately, it is very difficult to see the mouse in Picture 12, but it is under the owl's left foot. Notice that the owl's eyes are closed as it hits the ground.



Strikes in Darkness

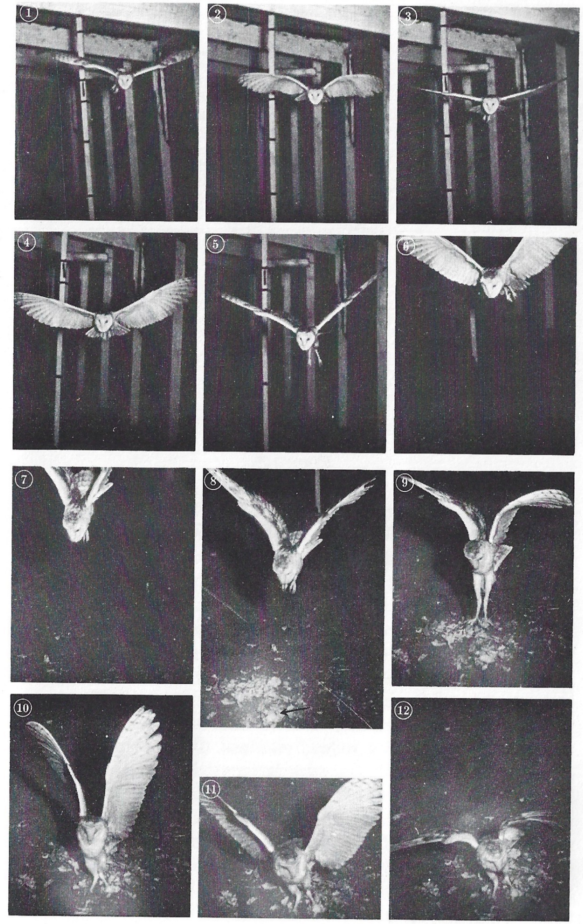
The next motion pictures I made show strikes by an owl hunting in total darkness (see Plate II). As it had done in light, the owl turned to face the sound and leaned forward. When the mouse became still, the owl took off and flapped its wings several times, its feet swinging beneath it like pendulums. It moved only about half as fast as it had done when there was light. Again, in the last moment of flight it swung its feet forward, drew its head back, spread its claws, and struck.

Correcting for Distance

Why does the owl use the particular style of attack just described? I think it is a very neat way to avoid another problem concerned with angles. You may recall that although an owl locates a mouse with its ears, it must strike the mouse with its feet.

Plate II.

This is a series of frames from a motion picture of a barn owl striking in darkness when it cannot see. Notice that in the dark, a barn owl flaps its wings all the way to the ground. Notice also that its feet are not tucked beneath its tail, as they are in flights when the owl can see (it looks here as though the owl is prepared to land at any moment). By Picture 7, the owl has started to bring its feet forward beneath its bill. Picture 8 shows the mouse beneath the owl (just beyond the tip of the arrow). Picture 9 shows the owl's feet fully extended, while the head is withdrawn. In Picture 10, the owl strikes the mouse (which can be seen clutched in the owl's left foot). Notice that even in the dark, the owl's eyes are closed at the moment of contact with the ground.



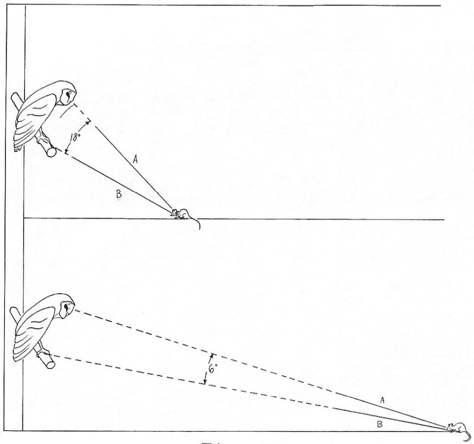


Figure 7.

Figure 7 shows two views of an owl sitting on his perch. The only difference between the two views is that the mouse is closer to the owl in the first view than it is in the second. In both cases, Line *A* is the path the owl should fly as indicated by its ears, but line *B* is the path it must fly if it is to hit the mouse with its feet. Notice that when the distance between the mouse and the owl changes, the angle between lines *A* and *B* will be different. The owl must correct the difference between what its ears direct it to do and what its feet must in fact do; but it cannot make the same correction every time the location of a mouse changes. It must make a new correction every time a mouse is located at a new distance. This means the owl must know not only the direction in which to fly to a sound source but also the distance. The barn owl resolves this tricky little problem of angles in a very simple way (see Figure 8). It leans forward while it is listening to the mouse, so its feet can shove it off along a direct path from its ears to the mouse on the floor. Then, at the last moment, it

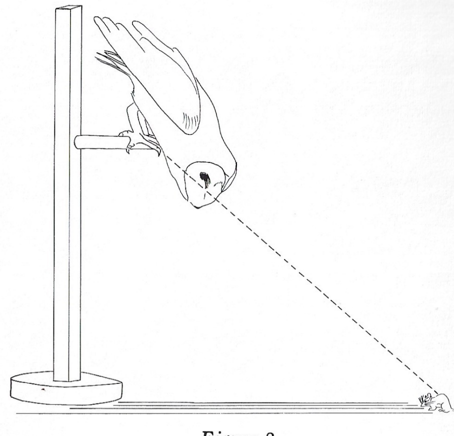


Figure 8.

turns end-for-end in midair. That is to say, it pulls its head back and thrusts its feet forward, so that its claws are brought into the exact path that its ears were following a moment before.

Covering the Greatest Area with a Strike

I have mentioned many things that improve an owl's accuracy in locating a mouse; but even if it knows exactly where the mouse is, the owl will lose the mouse unless it can get several claws into it. Somehow the owl must cover the widest possible area by spreading its claws. I took photographs of a barn owl with its claws stretched out the instant before a strike in total darkness. Then, putting a piece of paper over a hidden loudspeaker that was playing mouse sounds, I got the owl to stab holes in a piece of paper with its claws. The pattern shows that by holding its claws spread out (see Plate III), the owl covers the largest possible strike area.

Hearing the Direction in Which a Mouse Points

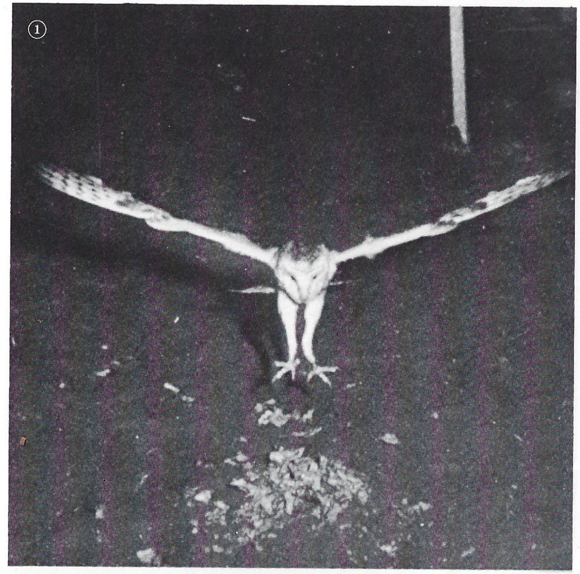
The strike area surrounded by an owl's claws is about the same size as a mouse. Since the length and width of the claws and mouse are about the same, an owl will put most claws into a mouse if it can get the strike pattern lined up with the mouse and directly over it. This means that an owl has to discover, by listening, not only where a mouse is but also the direction in which it faces. Perhaps one of the biggest surprises I had during my research was to find out that an owl can do this!

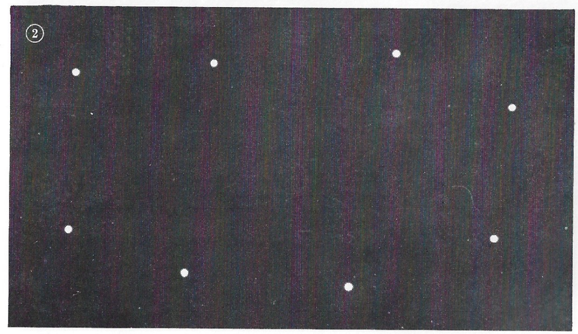
The way I discovered it is as follows. By carefully analyzing the movies I took in darkness, I noticed that though the owl flew at a mouse directly, bringing its feet forward just before impact, in some cases its whole body spun about for a quarter turn or so, just before its claws hit the mouse (see Plate IV).

Plate III.

Picture 1 is a single frame from a movie of an owl striking in darkness. (The owl could not see.) Notice how perfectly spaced all of the talons are.

Picture 2 is a photograph of a piece of black paper with eight holes punched in it. The holes were made by the claws of an owl. This is how it was done. The paper was laid over a loudspeaker which could transmit the sounds of a mouse rustling dry leaves. When the room was dark, I turned on the sound. The owl then flew from its perch and struck the sheet of paper laid over the loudspeaker. The four holes on the left side were made by the claws of the owl's left foot; the four holes on the right side were made by the claws of the right foot. Notice that the spaces between the holes are all about the same size. They show that the owl held its feet in such a way that the space between the inside claws of both feet was the same as the space between the outer claws of each foot, and that both feet were carefully aligned so that the claw pattern was even all the way around. Incidentally, the pattern shown here is the worst example of even spacing that I ever got in a series of such experiments. That may give you some idea of how perfect the claw pattern (strike pattern) can be.





At first I thought this was just because the owl lost its balance on one occasion, or some such thing; but the spinning occurred time after time, and I began to feel that it might be something the owl really intended to do. Though I could scarcely imagine that the owl could actually tell in which direction a mouse was headed just by listening to it, I tried to figure out what sort of technique the owl might use, in case it was possible.

The problem came to this: how would I know which way a mouse was facing just by listening? Since mice do not walk sideways, I could assume that if I heard a mouse move from one place to another and stop, it must be facing along the path I heard it take. By doing the following experiments, I established that the owl must make the same assumption.

I took a dead mouse, glued a very small leaf to its body, and tied a string to its tail. By pulling the string I moved the mouse in total darkness, and the leaf made noises to attract the owl. With a sniperscope, I watched the owl strike the leaf. I did this experiment eighteen times, moving the mouse in many different directions. In six of the trials I moved the mouse directly across the path the owl had to fly in order to reach it, so that the best strike position for the owl to take would involve no spinning. In all six trials the owl did not spin; but in each of the twelve remaining trials when I pulled the mouse over different paths, the owl spun during the last moment of flight until its feet were aligned with the direction in which the mouse had moved.

I experimented further, to make sure that the owl had determined the direction of the mouse's motion through hearing and not through some other means. To do this, I made

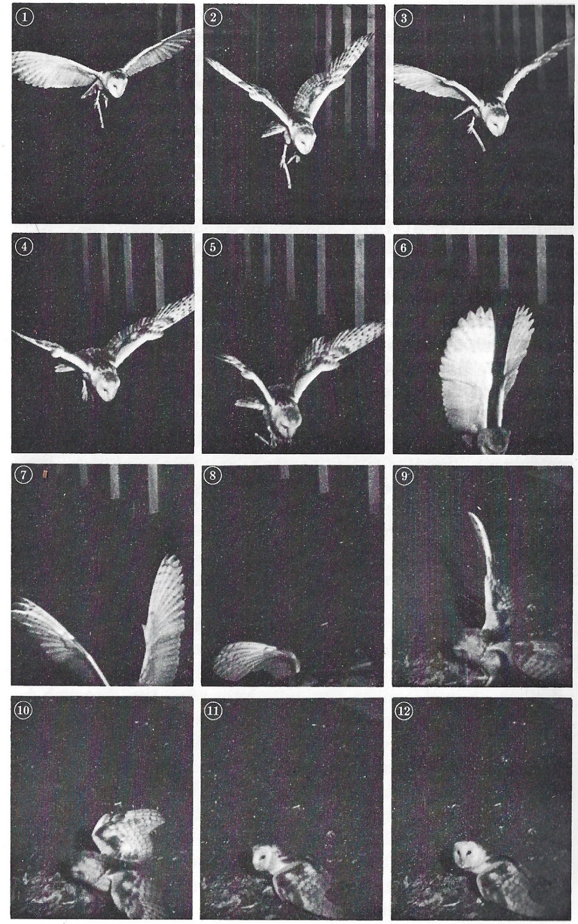


Plate IV.

This is a series of frames from a motion picture, taken in total darkness, of an owl turning to align its strike pattern with the long axis of the mouse's body. Notice that in Picture 1, the line along which the owl is approaching is about at right angles to the final position of the owl in Pictures 11 and 12. The turn occurs during Pictures 7-9.

the mouse "walk" sideways, dragging it by the fur on its side instead of by its tail. The owl still aligned its claws in the direction of the mouse's motion, even though this meant that the owl ended up in the *least* favorable striking position. That is, the owl could not tell that the mouse was headed differently, but was just "assuming" that it was facing in the direction it was moving.

In connection with this observation, it is interesting to notice that mice, when surprised by a sound, stop and immediately turn at right angles to the direction they were going. Though such turns may have nothing to do with fooling owls, we might speculate that they represent a way of spoiling the owl's attack and that, in turn, the remarkably silent flight of an owl is a way to combat that trick. How would such a sequence of ploys and counterploys ever come about? Perhaps the silent ancestors of our owls gave no warning to their prey and hence were more successful providers for their young than noisier owls were. If their young inherited this silent behavior, they would also be more successful providers for their offspring, and so on, until all barn owls would be descendants of the best providers — the quietest flyers.

Measuring Distance to a Sound Source

Although the owl's ears can determine the direction in which a mouse is facing, as well as the up-down and left-right flight path to a mouse, this tells us nothing about whether an owl can or can not determine the distance by hearing, since the evidence points both ways.

In support of the distance-telling ability, recall the observation that barn owls bring their feet forward just before they hit the ground. This implies that they must know how far to go before they start to land; that is, that they know how far away a sound is.

However, the difference between an owl's strike in light and its strike in darkness works against the theory that the owl can determine distance. In darkness, the owl flies with its

feet swinging down, as if it were preparing to land at any moment because it does not know the instant when a landing may be necessary. On the other hand, an owl's flapping flight in darkness looks as if it might be a way for the owl to tell how close it is to the ground. On the undersides of its wings, the owl might be feeling changes in pressure caused by backdrafts from the ground as it gets close. It might use these pressure changes as the signal to bring its feet forward into striking position. (Let me emphasize, though, that I do not yet have one scrap of evidence to prove this is true.)

I did an experiment that I hoped would test whether an owl can judge with its ears the distance to a sound source. I let the owl strike at a dead mouse with a leaf attached to it, but I placed this mouse on a fine net several feet above the floor. By pulling a string tied to the mouse, I could rustle the leaf. When the owl heard the rustling noise, it tried to strike. In almost every trial, however, the owl passed over the net and struck on the floor, at a spot directly beyond the leaf. These results seem to indicate that the owl was not able to judge distance by hearing but had to rely on sensations in its wings, or some such means of determining when it was getting close to the ground.

However, owls have memories (you can train them), and my owl may have memorized how far away the floor was in any of several directions. If we give owls credit for this kind of memory, the above results can be explained in this way: the owl was so used to flying from its perch to the floor that it did not believe its ears when they indicated that a leaf was being rustled in midair. (After all, owls must realize that mice do not hover in midair.)

Because of this possibility, my experiment really tells me nothing; and so I have planned the following experiment. I will mount the owl's perch on a machine that can move it up and down. Once the lights are out, I will raise and lower the owl so smoothly and slowly that it will never know how high above the ground it is before a strike. If the owl cannot strike mice on the floor when it has moved in this way, I will conclude that it relies for distance information upon familiarity with its surroundings. If the owl can strike mice on the floor but fails to find them on the net, then it must rely on some means of detecting its approach to the floor as it flies; but if the owl *can* tell distance by hearing, it will be able to strike mice suspended on a net, even if it cannot count on being at a known distance from the floor to begin with.

HOW DO OWLS HUNT IN THE WILD?

Though I am sure that the remarkable hearing of owls was not developed simply to entertain biologists studying them in large, dark rooms, I do not know, unfortunately, how much barn owls use their ears to locate prey in the wild. I have heard that great gray owls can dive into deep, undisturbed snow and bring up mice. This is exciting to me as an example of natural hunting by hearing alone. In this case I imagine that the noise which gives away the presence of mice underneath the snow is *chewing*, a sound which, when you analyze it carefully, contains many of the same tones that leaf rustles do.

In the case of barn owls, they surely can — and often must — hunt chiefly using their eyes; but the experiments which I have described show that they need not go hungry, even on the darkest night or when hunting the best-hidden mice. After having watched wild owls, it seems to me that as they fly through the woods, their excellent eyes must be busy spotting obstacles like twigs and branches which they must avoid in flight. Indeed, if you are lucky enough to see an owl in the wild flying through the woods at night, you will notice that it flies down from a branch, swooping low, and then rises steeply to a perch. Is it perhaps keeping low so that it can see branches as silhouettes against the brighter sky?

In any case, once a barn owl's prey is spotted, by vision or hearing, the fact that both systems are acutely suited to finding prey that scuttles in and out of shadows and secret runways is probably one of the chief reasons that these beautiful birds have been able not only to survive but also to spread over the entire world, in spite of the difficulties of a nighttime existence.