Finding Their Way: Orientation and Navigation

Within its local environment, an animal can organize its behavior spatially by orienting to landmarks, as honeybees and digger wasps do. But what if the destination is a considerable distance away? In this section we examine several modes of long-distance navigation.

Piloting animals orient themselves by means of landmarks

In most cases an animal finds its way using simple means: It knows and remembers the structure of the environment through which it moves. Navigating by means of landmarks is called **piloting**. Gray whales, for example, migrate seasonally between the Bering Sea and the coastal lagoons of Mexico. They find their way by following the west coast of North America. Coastlines, mountain chains, rivers, water currents, and wind patterns can all serve as piloting cues. But some remarkable cases of long-distance orientation and movement cannot be explained by piloting.

Homing animals can return repeatedly to a specific location

The ability of an animal to return to a nest site, burrow, or other specific location is called **homing**. In most cases, homing is merely piloting in a known environment, but some animals are capable of much more sophisticated homing. Marine birds provide many dramatic examples of homing over great distances in an environment where landmarks are rare. Many marine birds fly over hundreds of miles of featureless ocean on their daily feeding trips and then return directly to a nest site on a tiny island. Albatrosses display remarkable feats of homing. When a young albatross first leaves its parents' nest on an oceanic island, it flies widely over the southern oceans for 8 or 9 years before it reaches reproductive maturity. At that time, it flies back to the island where it was raised to select a mate and build a nest. After their first mating season, the pair separate, and each bird resumes its solitary wanderings. The next year they return to the same nest site at the same time, reestablish their pair bond, and breed. Thereafter they return to the nest to breed every other year, spending many months in between at sea. Homing pigeons can be transported to remote sites where they have never been, and when they are released, fly home. Data on departure directions, known flying speeds, and distances traveled show that homing pigeons fly fairly directly from the point of release to home. They do not randomly search until they encounter familiar territory.

Scientists have used homing pigeons to investigate the mechanisms of navigation. One series of experiments tested the hypothesis that the pigeons depend on visual cues. Pigeons were fitted with frosted contact lenses so that they could see nothing but the degree of light and dark. These pigeons still homed and fluttered down to the ground in the vicinity of their loft. Thus, they were able to navigate without visual images of the landscape.

Migrating animals travel great distances with remarkable accuracy

For as long as humans have inhabited temperate and subpolar latitudes, they must have been aware that whole populations of animals, especially birds, disappear and reappear seasonally— that is, they migrate. Not until the early nineteenth century, however, were patterns of migration established by marking individual birds with identification bands around their legs. Being able to identify individual birds in a population made it possible to demonstrate that the same birds and their offspring returned to the same breeding grounds year after year, and that these same birds were found during the nonbreeding season at locations hundreds or even thousands of kilometers from their breeding grounds. Because many homing and migrating species are able to take direct routes to their destinations through environments they have never experienced, they must have mechanisms of navigation other than piloting. Humans use two systems of navigation: distance-and-direction navigation and bicoordinate navigation.

Distance-and-direction navigation requires knowing the direction to the destination and how far away that destination is. With a compass to determine direction and a means of measuring distance, humans can navigate.

Bicoordinate navigation, also known as *true navigation*, requires knowing the latitude and longitude (the map coordinates) of both the current position and the destination. The behavior of many animals, such as the albatrosses mentioned above, suggests that animals are capable of bicoordinate navigation. It is possible that these species could use their circadian clock information about time of day and the position of the sun to determine their coordinates—much as sailors did in the days before global positioning satellites. However, there is no strong scientific evidence for such mechanisms to date—though, of course, it is not easy to do experiments on world-traveling animals such as albatrosses. The best evidence for mechanisms of animal navigation comes from studies of distance-and-direction navigation. Researchers conducted an experiment with European starlings to determine their method of navigation. These birds migrate between their breeding grounds in the Netherlands and northern Germany and their wintering grounds to the west and southwest, in southern England and northern France (Figure 18).

The researchers captured birds on their breeding grounds, marked them, transported them to Switzerland— south of their breeding grounds—and released them. The researchers expected that if the starlings were using distance- and-direction navigation, the marked birds would be recovered in southern France and Spain, to the southwest of where they were released. Naive juvenile starlings did use

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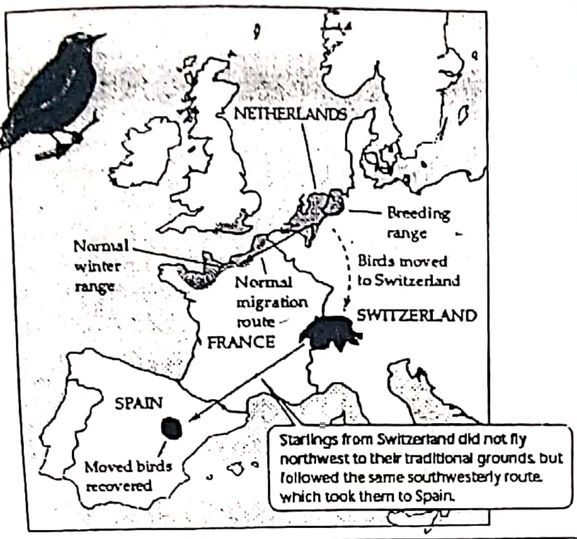
distance-and-direction navigation and ended up in Spain, but experienced adult birds were less disrupted by their geographic displacement.

METHOD Capture young birds before their first winter migration. Mark birds and move them to a distant location and release them. Record where they are recovered.

RESULTS



Conclusion: Juvenile starlings use distance-and-direction navigation.

18 Distance-and-Direction Navigation

How do animals determine distance and direction? In many instances, determining distance is not a problem as long as the animal recognizes its destination. Homing animals recognize landmarks and can pilot once they reach familiar areas. Evidence suggests that circannual rhythms play a role in determining migration distances for some species. Birds kept in captivity display increased and oriented activity at the time of year when they would normally migrate. Such *migratory restlessness* has a definite duration, which corresponds to the usual duration of migration for the species. Because distance is determined by how long an animal moves in a given direction, the duration of migratory restlessness could set the distance for its migration.

Two obvious means of determining direction are the sun and the stars. During the day, the sun can serve as a compass, as long as the time of day is known. In the Northern Hemisphere, the sun rises in the east, sets in the west, and points south at noon. As we have seen, animals can tell the time of day by means of their circadian clocks. Clock-shifting experiments have demonstrated that animals use their circadian clocks to determine direction from the position of the sun. Researchers placed pigeons in a circular cage that enabled them to see the sun and sky, but no other visual cues (Figure 19). Food bins were arranged around the sides of the cage, and the birds were trained to expect food in the bin at one particular direction—south, for example. After training, no matter what time they were fed, and even if the cage was rotated between feedings, the birds always went to the bin at the southern end of the cage for food, even if that bin contained no food.

Next, the birds were placed in a room with a controlled light cycle, and their circadian rhythms were phase-shifted by turning the lights on at midnight and off at noon. After about 2 weeks, the birds' circadian clocks had been phase-advanced by 6 hours. Then the birds were returned to the circular cage under natural light conditions, with sunrise at 6:00 A.M. Because of the shift in their circadian rhythms, their endogenous clocks were indicating noon at the time the sun came up.

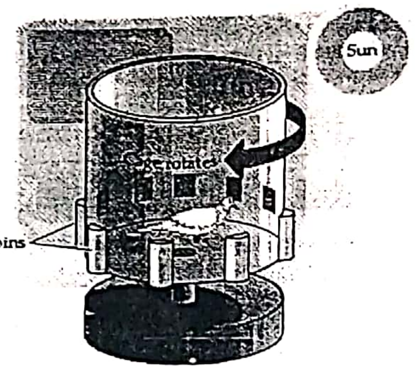
19 The Time-Compensated Solar Compass Pigeons whose circadian rhythms were phase-shifted forward by 6 hours oriented as though the dawn sun was at its noon position. These results show that birds are capable of using their circadian clocks to determine direction from the position of the sun.

EXPERIMENT

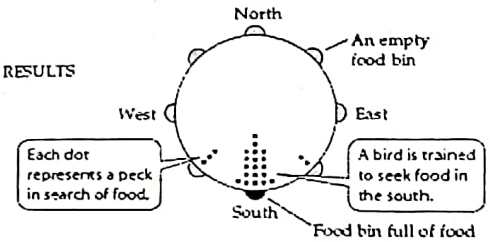
Question: How can pigeons determine compass direction from the sun, whose position changes with the time of day?

Experiment 1

METHOD A pigeon placed in a circular cage from which it can see the sky (but not the horizon) can be trained to seek food in one direction, even when its cage is rotated between trials.



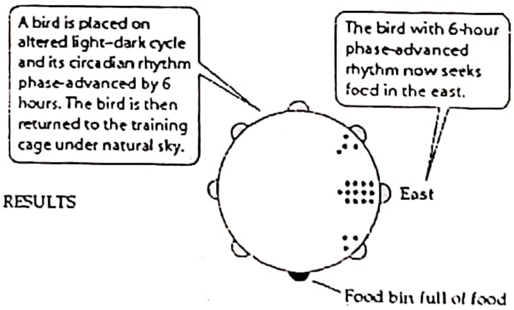
RESULTS



Experiment 2

METHOD

RESULTS



Conclusion: Pigeons have the ability to tell directions by means of a time-compensated solar compass.

If food was always in the south bin, and it was sunrise, the birds should have looked for food 90 degrees to the right of the direction of the sun. But because their circadian clocks were telling them it was noon, they looked for food in the direction of the sun—in the east bin. The 6-hour phase shift in their circadian clocks resulted in a 90-degree error in their orientation. These kinds of experiments on many species have shown that animals can orient by means of a *time compensated solar compass*.

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Many animals are normally active at night; in addition, many day-active bird species migrate at night and thus cannot use the sun to determine direction. The stars offer two sources of information about direction: moving constellations and a fixed point. The positions of constellations change because Earth is rotating. With a star map and a clock, direction can be determined from any constellation. But one point that does not change position during the night is the point directly over the axis on which Earth turns. In the Northern Hemisphere, a star called Polaris, or the North Star, lies in that position and always indicates north. Stephen Emlen at Cornell University investigated whether birds use these sources of directional information from the stars. He raised young birds in a planetarium, in which star patterns are projected on the ceiling of a large, domed room. The star patterns in the planetarium could be slowly rotated to simulate the rotation of Earth. If the star patterns were rotated each night as the young birds matured, they were able to orient in the planetarium but birds raised in the planetarium under a nonmoving sky could not. These experiments showed that birds can learn to use star patterns for orientation if the sky rotates.

Animals cannot use sun and star compasses when the sky is overcast, yet they still home and migrate under such conditions. There appears to be considerable redundancy in animals' abilities to sense direction. Pigeons are able to home as well on overcast days as on clear days, but this ability is severely impaired if small magnets are attached to their heads—evidence that the birds use a magnetic sense, although the neurophysiology of this sense is largely unknown. Another possible cue is the plane of polarization of light, which can give directional information even under heavy cloud cover. Very low frequencies of sound can provide information about coastlines and mountain chains. Weather patterns can also provide considerable directional information.

Human Behavior

As we saw early in this chapter, the behavior of an animal is a mixture of components that are inherited and components that can be molded by learning. However, even some aspects of learned behavior patterns—such as what can be learned and when it can be learned—have genetic determinants. Thus natural selection shapes not only the physiology and morphology of a species, but also its behavior. In some situations natural selection favors inherited behavior; in others, learned behavior. In many cases, the optimal adaptation is a mixture of inherited and learned behavioral components. Given these considerations, how would we characterize human behavior?

An important characteristic of human behavior is the extent to which it can be modified by experience. The transmission of learned behavior from generation to generation— **culture**—is the hallmark of humans. Nevertheless, the structures and many of the functions of our brains are inherited, including drives, limits to and propensities for learning, and even some motor patterns. Biological drives such as hunger, thirst, sexual desire, and sleepiness are inherent in our nervous systems. Is it reasonable, therefore, to expect that emotions such as anger, aggression, fear, love, hate, and jealousy are solely the consequences of learning?

Our sensory systems enable us to use certain subsets of information from the environment; similarly, the structure of our nervous system makes it more or less possible to process certain types of information. Consider, for example, how basic and simple it is for an infant to learn spoken language, yet how many years that same child must struggle to master reading and writing. Verbal communication is deeply rooted in our evolutionary past, whereas reading and writing are relatively recent products of human culture. Some motor patterns seem to be programmed into our nervous system. Studies of diverse human cultures from around the world reveal basic similarities in facial expressions and body language among human populations that have had little or no contact with one another. Infants born blind still smile, frown, and show other facial expressions at appropriate times, even though they have never observed such expressions in others.

Acknowledging that aspects of our behavior have been shaped by evolution in no way detracts from the value we place on our ability to learn and the importance of cultural transmission of information to our species. Even so, we are recognizing that culture, in its simplest form, is not uniquely human. In the introduction to this chapter we saw what has been characterized as culture in Japanese macaques. Individuals invented new behaviors, and those new behaviors were transmitted by imitative learning through the population. In a recent study, scientists who had spent years studying chimpanzee behavior in seven widely separated areas of Africa compared their findings on chimpanzee behavior. They were able to identify 39 behaviors, ranging from tool use to courtship behavior, that were common in some populations but absent in others. Moreover, the variation in these behaviors was much greater between populations than within populations, and each population had a distinct repertoire of these behaviors. Just as human societies are characterized by different assemblages of culturally transmitted customs or customary behaviors, so are these chimpanzee populations.

It is increasingly difficult to draw a line between human behavior and animal behavior, especially that of our closest primate relatives. But why should we expect such a line to exist? We do not expect such a lack of continuity in molecular, biochemical, physiological, or anatomical characteristics. Similarly, human and animal behavior is points on a continuum. Our challenge is to understand their common mechanisms and the reasons for their quantitative differences.

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