Animal Behavior: The Puzzle of Flavor Aversion

The ability of rats to avoid poisoned diets has been well known by exterminators for years, and has also been demonstrated in the laboratory by a number of scientists since the 1930's. But some of the properties of flavor aversion learning have not been easily reconciled with traditional learning principles; a lively controversy has developed over the phenomenon's implications for learning theory. Recent studies have attempted to clarify the characteristics of flavor aversions in different species, their physiological bases, and how research on them might help solve practical problems such as predation on domestic livestock.

Traditional learning theory has always maintained that it makes no difference what stimulus is paired with what consequence. The animal will still learn to associate the two so long as they are presented close together in time. But John Garcia, now of the University of California at Los Angeles, and his colleagues found that a rat can easily associate a novel flavor with a subsequent illness resulting from radiation, but associating a light or a buzzer with an illness or a flavor with a shock is difficult.

These results, and results of later studies, seem to challenge the assumption that an animal can learn to pair any stimulus with any consequence as well as another, perhaps more important, assumption. Although learning theory has also maintained that learning could not occur unless the consequence followed the stimulus immediately, many investigators have recently found that the illness can be delayed for several hours. A rat will still show the aversion, albeit a weaker one; the strength of the aversion will depend on such factors as the intensity of the illness and the concentration of the flavor stimulus. Furthermore, flavor aversions are usually acquired after only one poisoning, a result which is unlikely according to traditional learning theory. Rats also seem to retain an aversion to the flavor for a long time even if they sample the substance many times without being poisoned.

Flavor aversions have been demonstrated in many genera and phyla, including monkeys, rodents, reptiles, fish, snails, and slugs. There is some evidence that humans form flavor aversions easily, particularly in conjunction with radiation treatment for cancer. Most of these animals quickly form an aversion to the taste of a novel food if it is followed by illness, but they will not necessarily learn to avoid the food by its appearance. Hardy Wilcoxon and his coworkers at the George Peabody College for Teachers, however, point out that not all animals choose their food on the basis of taste. Some birds, such as the bobwhite quail, have deficient taste and odor receptors and probably choose their food primarily on the basis of appearance. The investigators found that quail could associate illness with either colored or flavored water, but they show a stronger avoidance of the color.

Apparently some rodents are also able to use cues other than taste to avoid certain foods which are followed by illness. Norman Braveman, of the Memorial University of Newfoundland, observed that guinea pigs can learn to avoid colored water, although, if given a choice, they associate a taste cue rather than a visual cue with illness. In addition, rats in other laboratories have learned to avoid odors, which has led many scientists to agree that illness can be paired with any one of a variety of food-related stimuli besides taste, such as the kind of food container and the location of the food. However, visual aversions have not been demonstrated when the interval between eating and sickness is longer than 30 minutes, and they extinguish relatively easily. Indeed, the vast majority of species tested form aversions most readily to taste cues followed by illness and tend to ignore visual or auditory cues.

Garcia's group tested some species under seminatural conditions, and has found that they usually form flavor aversions easily. For example, they found that hawks develop an aversion to dead mice prey "flavored" with quinine if they are subsequently made ill with an injection of lithium chloride. The hawks learned the aversion more slowly if the mice were distinguished only by appearance (black coat).

Aversion to a flavor seems to develop most readily if the flavor is novel. Sam Revusky and his colleagues at the Memorial University of Newfoundland fed rats a new food for several days and then gave them both this food and a second unfamiliar food before inducing illness with radiation. This procedure produced an aversion to the second new food, but not to the first with which they had become familiar. Some scientists have emphasized the importance of novelty and familiarity in the rats' categorization of foods. For example, the reluctance of wild rats to taste novel substances may help them to avoid poisons.

Nevertheless, it seems to be possible to produce aversions to almost any taste, even water, provided the animal does not sample any novel foods. Donna Zahorik and her colleagues at Cornell were surprised to find that hamsters could even form an aversion to the taste of female vaginal secretions, a substance very important in the animal's communication system.

Many investigators believe that the evidence from the flavor aversion studies, combined with other, more ethologically oriented studies of learning, requires either a rethinking of the general laws of learning or, alternatively, a serious questioning of whether universal principles of learning actually exist. Paul Rozin of the University of Pennsylvania and James Kalat of Duke University, for instance, believe that taste aversion learning is an example of a learning ability that has evolved special properties to meet environmental demands. They point out that the tendency to associate tastes with the consequences of ingested foods and the ability to learn with a long delay fit perfectly with the special adaptive problems of learning about foods.

Although the investigators recognize the possibility of some more or less universal principles of learning, they emphasize that special abilities necessary for learning a particular task are also likely to exist; they cite imprinting in birds as another example of a specialized learning ability. Garcia also stresses the importance of selection pressures on learning strategies during evolution. Other investigators, including Martin Seligman of the University of Pennsylvania, have formulated theories to explain and describe the biological "prewiring" within an organism that facilitates the learning of certain types of tasks.

Revusky, however, who believes that animals are biologically predisposed to associate a certain cue with a particular consequence, is concerned that the differences between flavor aversion learning and other types of learning may be overemphasized and asserts that their similarities are more important. He points out that flavor aversion learning is in many ways similar to the learning observed in more traditional studies and takes the position that universal laws of learning can be modified to incorporate various biological predispositions.

A few scientists, such as M. E. Bitterman of the University of Hawaii, do not think that the phenomenon has been adequately demonstrated, so that, as of this date, it poses no challenge to traditional learning principles. Richard Krane, now at Acadia University, and Alan Wagner of Yale University criticize in particular the hypothesis that animals may be biologically predisposed to associate two

Latest New Particle Caps the Evidence for Charm

New particle discoveries are occurring faster and faster. In mid-August researchers at the Fermi National Accelerator Laboratory in Batavia, Illinois, announced that they had found 50 examples of a new particle that is substantially different from but related to another particle discovered 2 months earlier at the Stanford Linear Accelerator Center, Palo Alto, California. The latest finding comes close to clinching the idea that the new particles discovered in the last 2 years are composed, in one way or another, of charmed quarks. The theory of charm has done so well at predicting the properties of these new particles that there is little doubt that there is a whole family of charmed particles.

The scientific trail leading to the Fermilab particle began in November 1974, when two different laboratories unexpectedly found a peculiar new particle that was named the J or psi and is now explained as a meson having hidden charm. Mesons are a class of strongly interacting particles that may be created or destroyed in nuclear reactions, and charm is a quantum property postulated 10 years ago by James Bjorken and Sheldon Glashow for both mesons and baryons, the other class of strongly interacting particles. The charm theory is closely linked to the theory that mesons and baryons are made up of hypothetical subunits called quarks—one of which can be a charmed quark.

In mesons of the J/psi type, charm is said to be hidden because the particle is composed of a charmed quark and its antiparticle. At least five different particles related to the J/psi have now been found at Stanford and the Deutsches Elektronen Synchrotron laboratory (DESY) in Hamburg, Germany.

In early summer, a meson with undisguised charm was found at Stanford (*Science*, 18 June, p. 1219). It is composed of a charmed quark and the antiparticle of a normal quark, so no cancellation of the charm quantum number occurs. Two more charmed mesons were subsequently discovered at Stanford, so the number of charmed mesons now stands at three.

The particle discovered at Fermilab apparently extends charm into the baryons, so now an example of charm has been found in each of the major classes of elementary particles. Baryons are composed of three quarks, one of which is charmed in the latest experiments. As with the mesons, many more charmed baryons are presumably waiting to be discovered.

The Fermilab particle has a mass of 2.26 giga-electron volts (Gev) and a relatively long life for such a heavy particle (estimated 10^{-13} second). It is presumably the lightest charmed baryon, and coincides remarkably well with the properties predicted by Sheldon Glashow, Alvaro De Rújula, and Howard Georgi of Harvard University. These authors predicted in the 16 August issue of *Physical Review Letters* that the particle should have a mass of 2.25 ± 0.05 Gev.

The new charmed baryon was discovered by researchers from Columbia University, the University of Hawaii, the University of Illinois, and Fermilab. Naming of the new particle—so far untitled—is the prerogative of the research group, which was led by Wonyong Lee of Columbia. The group also has some evidence for a second charmed baryon with a mass of about 2.5 Gev.

The new particles were produced when high-energy x-rays interacted with a beryllium target and produced a shower of particles that were collected in a wide-angle magnetic detector. The initiating x-rays were produced at energies of 100 to 200 Gev from the primary proton beam of the Fermilab accelerator. Out of about 15 million events collected over a 3-month period, 50 had the decay properties expected for a charmed baryon. In these events the unseen baryon decayed into four particles: a lambda particle and three pi mesons. The decay sequence is not a unique signature of charm, but it is "very consistent with everything charm theory predicts," according to Lee. It is also the decay mode specifically mentioned by Glashow and his colleagues, who predicted that "lambda-pi spectroscopy can reveal a whole family of singly charmed" baryons.

None of the decay products are charmed, and it is believed that charm vanished because the decay was a weak interaction. In effect, charm was transmuted into strangeness, another quantum number whose introduction dates back 25 years. The lambda is the lightest strange baryon.

The only puzzle in the Fermilab experiment is that two charmed baryons should have been produced in the experiment, but only one has been positively identified. The detected particle has a negative charge (actually the antiparticle of the charmed baryon was detected), and the analogous particle with positive charge should have also been produced. The higher background for positive particles could be obscuring the second particle, however. The 2.5-Gev particle detected in a few instances has a doubly negative charge.

The same sort of evidence for a charmed baryon was reported in April 1975 by Nicholas Samios and co-workers at the Brookhaven National Laboratory, but the datum (a bubble chamber measurement of lambda–three pi decay) was not judged conclusive because only one event was found.

Now that the charm theory has successfully predicted the mass of the lightest charmed meson and the lightest charmed baryon, it appears to be making the transition from the avant-garde to the established. Many more charmed particles are now expected. A few more mesons—including those that are both strange and charmed—should be found, and many more baryons are predicted. According to Lee, there should be about twice as many charmed baryons as strange baryons. Physicists will eagerly search for these, but when they find them the discoveries will probably not be called surprises.—W.D.M.

events. These investigators were able to produce a flavor aversion in rats using shock as the consequence, provided that the shock was delayed for a few minutes. They hypothesize that the only difference between flavor aversion learning and ordinary learning may be that the memory of the taste is more persistent, so that a delayed reinforcement is most effective.

Several other hypotheses have been proposed to account for the ability to learn after a long delay. Some scientists maintain that a taste persists in the form of an aftertaste and is thus present when the metabolic consequences ensue. This hypothesis has been disputed on several grounds. For example, an animal that eats familiar foods after a novel one will still, after becoming ill, avoid only the novel flavor. Furthermore, most scientists dismiss the hypothesis that the rat may regurgitate some of the flavor during the illness and thus retaste it; for example, one study demonstrated that the novel taste has only to be passed over the taste buds and not necessarily ingested.

Revusky hypothesizes that, because of the predisposition to pair tastes with illness, there is little interference from other environmental stimuli, which facilitates long delay learning in this system. Kalat and Rozin have proposed the term "learned safety" to account for this unusual ability, a term which suggests that an animal gradually learns that a food is safe over a period of hours following ingestion. Their hypothesis is based in part on the finding that rats also can learn to prefer a taste that is followed by recuperation from illness, a phenomenon called "specific hunger." Research on the food-seeking behavior of thiamine-deficient rats by Rozin and his colleagues has supported the hypothesis that the same processes underlying flavor aversion are also responsible for this behavior in which rats seek foods with a high thiamine content that will alleviate the vitamin deficiency.

Research into the neurological basis of flavor aversion has led some scientists to hypothesize that the brain areas primarily involved are different from those involved in other types of learning. Flavor aversions are still formed in an animal whose forebrain is removed between the presentation of the taste cue and the onset of the illness. Furthermore, several investigators have demonstrated that a rat whose cortex has been depressed chemically can still learn a flavor aversion. James Smith, of Florida State, and his colleagues found that even if the animal were anesthetized during the illness a flavor aversion was formed. Garcia and his associates point out that Pavlovian conditioning requires the animal to remain alert, whereas flavor aversions may result from homeostatic adjustments in the midbrain areas, where many functions are regulated automatically. These adjustments might produce changes in the pleasantness of the taste by a process different from that by which an animal learns to avoid a cue associated with shock.

While the controversy over the peculiar features of flavor aversion learning continue, many scientists who gathered in March at Baylor University are emphasizing the study of flavor aversions for its importance as an adaptive food selection technique in addition to its possible implications for learning theory. One of their goals was to determine the place of flavor aversion in the context of other findings on the way an animal chooses its nourishment. Patrick Capretta of Miami University, for example, presented data that indicated that weanling rats exposed to diverse flavors were more ready to accept novel foods later in life. He further postulated that there appeared to be a critical period during which the rat must experience the diverse flavors. Bennett Galef, Jr., of McMaster University, found that both the flavors present in the rat mother's milk and early social feeding experiences are important in shaping the food selection responses of the offspring.

The development of food selection criteria may also be important in humans. Jane Garb and Albert Stunkard of the University of Pennsylvania conducted a survey which suggested that flavor aversions usually begin to develop between 6 and 12 years of age and then decline steadily during adolescence and adulthood.

The procedures that produce flavor aversion clearly change the animal's behavior. They have thus inspired many researchers to explore their possible practical applications. Carl Gustavson, of Eastern Washington State, along with Garcia and Stuart Ellins of San Bernardino State College have been using flavor aversion in an attempt to alter the sheep-killing habits of coyotes. They found that captive coyotes and wolves refused to attack sheep after experiencing one or two meals of sheep meat followed by an injection of lithium chloride. They have recently had some success in changing the feeding and preying habits of wild coyotes by scattering sheep carcasses salted with lithium chloride across an open sheep range. Although the effectiveness of their procedures has been criticized by scientists concerned, among other things, with the practicality of injections, and by some sheep growers who prefer poisons and rifles, many researchers feel that flavor aversion will prove to be an effective technique for controlling predation on livestock.

Garcia and his colleagues have also attempted to alter the feeding habits of predatory birds and cougars who prey on sheep. Preliminary evidence suggests that flavor aversions are quickly formed in cougars and in hawks.

The food aversions frequently reported by cancer patients treated with radiation therapy may be explained as flavor aversions caused by the nausea many feel after therapy. Garcia's group demonstrated that serum from irradiated rats could cause aversion to food in rats injected with it; they speculated that histamine may have been the cause of this aversion. Furthermore, Smith and his colleagues demonstrated that these aversions can be avoided in rats by injecting the animals with an antihistamine prior to radiation treatment. Although it is not certain that the release of histamine mediates the malaise produced by radiation, Smith suggests that it may be worthwhile to use antihistamines and different meal schedules to reduce the food aversions in humans undergoing radiation.

Pharmacologists, among them Elkan Gamzu of Hoffmann–La Roche, Inc., and other scientists, began to use the flavor aversion procedure to evaluate the "sickness producing" properties of drugs. However, they found in rats that most drugs, such as anesthetic agents, convulsive agents, psychoactive drugs, and depressants, produce no observable signs of sickness, yet do produce flavor aversions. These findings have led many scientists to challenge the assumption that flavor aversions result from sickness and to speculate that sickness may be neither necessary nor in some instances sufficient to produce the aversion.

The controversy over the implications of learned flavor aversion on learning theory may result in a reconsideration of the traditional principles of learning, or foster a comparative study of learning abilities developed by natural selection. Whatever the outcome, it is clear that pairing a flavor with a poison produces a drastic change in the behavior of the animal. Many scientists hypothesize that the phenomenon exists because it has probably helped the species to survive in nature.—PATRICIA WALLACE

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