ences meeting on nuclear structure in 1971. At an international nuclear physics conference in Munich in August 1973, Academician G. N. Flerov, director of the heavy-ion laboratory in Dubna, said the UNISOR project had inspired his laboratory to secure funds for a new, much improved isotope separator which is now installed on-line to their heavy-ion cyclotron to be used for detailed studies of nuclei far from stability.

The UNISOR model for research has inspired a second such project, the Atomic Physics Consortium at Oak Ridge (APCOR). After an exploratory conference at Oak Ridge, scientists from ten institutions met in November 1973 to form an organizing committee for APCOR. As with UNISOR, the universities and the AEC will each provide a significant portion of the capital and operating costs. Heavy ions have opened up much new research in atomic physics, but such accelerator-based research represents a real "shift from traditional approaches concerning how, where, and on what time scale atomic physics experiments should be done" (*17*).

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18. Deep thanks are due to several people who helped significantly in bringing UNISOR into being. First are the late Governor Buford Ellington of Tennessee and S. H. Roberts, his administrative assistant. The support and encouragement of university administrators and department chairmen and of those at every level at Oak Ridge National Laboratory, Oak Ridge Associated Universities, and the Atomic Energy Commission have been important. In particular, I thank H. W. Davis, W. G. Pollard, E. E. Gross, P. H. Stelson, J. L. Fowler, A. Zucker, and Alvin Weinberg. The many efforts of the ORIC staff are gratefully acknowledged.

Behavioral Regulation of the Milieu Interne in Man and Rat

Food preferences set by delayed visceral effects facilitate memory research and predator control.

John Garcia, Walter G. Hankins, Kenneth W. Rusiniak

The Dichotomous Environment

In 1968, it was proposed that there is, in animals, a theoretical distinction between behavioral adaptation in the milieu externe and behavioral regulation of the milieu interne (*1*). It was pointed out that mammals, in particular, face two vastly different survival problems. First, in coping with the external world, an animal's survival depends upon its accurate utilization of information received by its telereceptors. For example, it uses vision, audition, and olfaction to discover predators at a distance so that it may avoid painful attacks upon its body surface. The animal uses the same telereceptors to locate food and mates at a distance, and to guide its motor responses toward these attractive goals. Thus, time and space discriminations measured in milliseconds and millimeters provide the animal with crucial vector information for avoiding naturally punishing features and for approaching naturally rewarding features of the milieu externe. Second, in coping with the internal homeostatic environment, the animal's survival depends primarily upon its accurate responses to demands from internal receptors. For example, it uses gustation to select the nutrients demanded by the monitors of the internal fluid environment and to avoid the malaise caused by ingested toxins. Because the rewarding effect of a nutrient and the punishing effect of a toxin may occur hours after ingestion, time discriminations measured in milliseconds are of little value. Similarly, because motor movements after a particular nutrient has been consumed cannot help the animal to escape toxicosis or achieve well-being, space discriminations measured in millimeters are not of much value either. On the basis of previous experience, the animal must be able to accept or reject food in the mouth before ingestion if it is to avoid distress in the milieu interne. The simplest way to accomplish this is to acquire a taste for nutrients and an aversion for toxins.

Dr. Garcia is professor of psychology and psychiatry, Dr. Hankins is an assistant research psychologist, and Mr. Rusiniak is a graduate teaching assistant at the University of California, Los Angeles 90024.

Dual external-internal specialization is beautifully illustrated by the puzzling behavior of the rat in a radiation field. This animal, like many others, can detect the presence of x-rays because the radiant energy penetrates the nasal cavity and stimulates the olfactory receptors by producing chemical changes in the olfactory mucosa. A "blip" of 1 roentgen is more than sufficient to arouse a sleeping rat, and just a few milliroentgens will signal it to avoid a shock to the paws (*2*). If the rat remains in the radiation field exposing its entire body to 100 r it will sicken. If it is exposed to 1000 r it will die. These illness effects are apparently due to an accumulation of toxin-like products produced in its tissues and fluids by absorption of the radiant energy (*3*).

What is puzzling, however, is that when the animal is given a spatial choice between two clearly marked areas, one exposed to radiation and the other shielded from radiation, even though it can detect x-rays it is apt to accumulate a fatal dose of radiation by repeatedly entering the exposed area. Only with special training will the rat demonstrate a mild tendency to avoid the compartment in which it has been repeatedly exposed to, say, 50 r. This tendency is not strong enough to protect it when a free choice is available (*4*).

On the other hand, after a single dose of the same magnitude (50 r) a rat will demonstrate strong tendencies to cope with radiation effects by altering its diet. It will avoid foods consumed prior to, and during, exposure. Apparently, evolution has designed this species, and many others, to cope with foods that produce illness, but has left them relatively helpless to deal with places that produce illness, even when the agent producing the illness can be detected. To use Lorenz's analogy, the "internal schoolmarm" instructs the rat to respond to illness with dietary strategies within its food domain, not with spatial maneuvers in its territorial domain (*5*).

Experimental Bait-Shyness

As those who poison animals for commercial purposes know, if an animal consumes a poisoned bait and survives it develops a "shyness" for that particular bait, as if it selectively associated the taste of the bait with the resulting malaise (*6*). Experimental analysis of bait-shyness requires that the taste cues be separated from the agent causing the malaise. In such a study reported in 1955 (*6*), rats were arbitrarily given saccharin-flavored water and exposed to 30 r or more. Subsequently, the animals displayed an aversion for saccharin that persisted through many weeks of continuous preference testing (*6, 7*).

Since 1955, taste aversions have been produced under a wide variety of experimental conditions. Rats, mice, cats, monkeys, ferrets, coyotes, birds, fish, and reptiles have served as subjects. Sweet, sour, bitter, salty, fruit juice, coffee, milk, as well as natural prey and foods, have been employed as tastes. Ingested toxins, injected drugs, x-rays, gamma rays, neutron bombardment, transfusion of blood and serum from irradiated donors, and motion sickness have been used as noxious agents (*8*). Human subjects report aversion to a variety of foods consumed coincidently before a bout of illness (*9*).

Several principles have been unequivocally established. First, all other conditions being equal, the stronger the taste of the food or drink the greater the aversion induced by illness. Second, given a constant taste, the more severe the illness the stronger the aversion for that taste. Third, given a constant taste and an equivalent illness severity, the strength of the aversion is inversely related to the span of time between consumption and illness. Figure 1 illustrates these primary relationships in the rat. Although they probably have a reasonable degree of generality, differences in slope can be obtained with different taste, illness agents, and species (*10, 11*). These relationships are generally what one would expect in traditional conditioning studies except that (i) the time scale is expanded from seconds to hours, and (ii) food taste is the only cue that rats will associate with delayed illness. Thus, behavioral regulation of the milieu interne violates two cardinal rules considered to be vital for associative learning in the milieu externe.

The first rule violated is the contiguity rule which specifies that punishing stimuli, or rewarding ones, must immediately follow signals, or re-

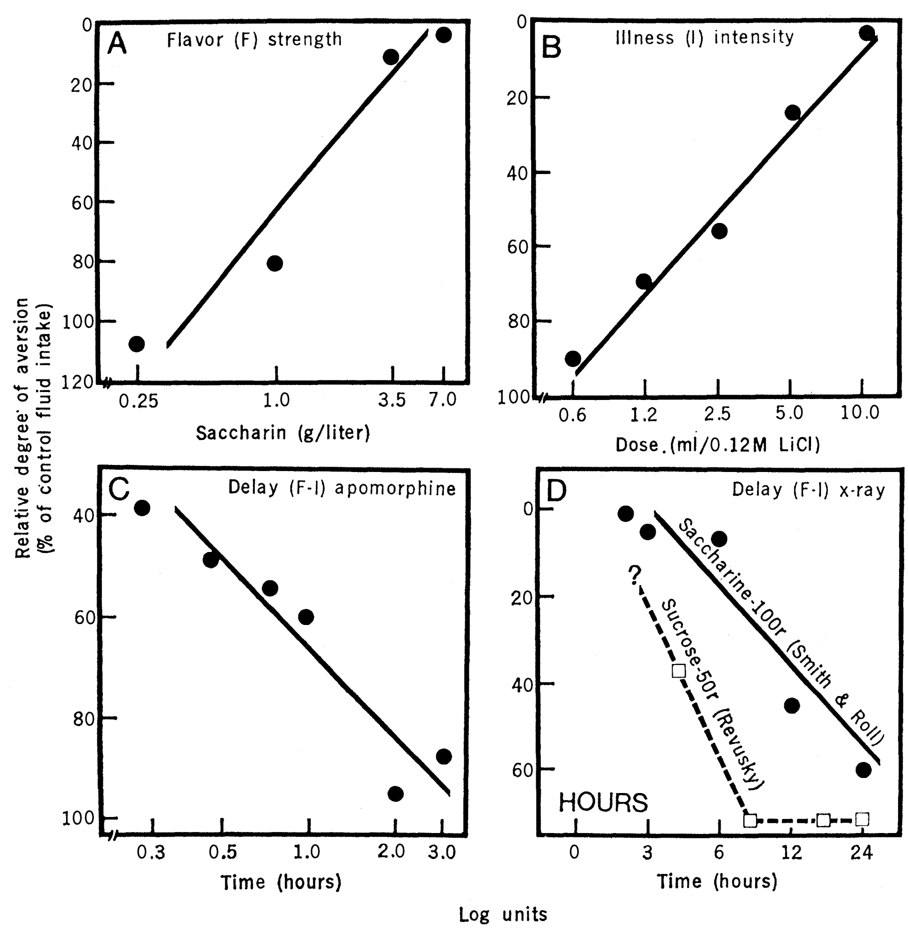


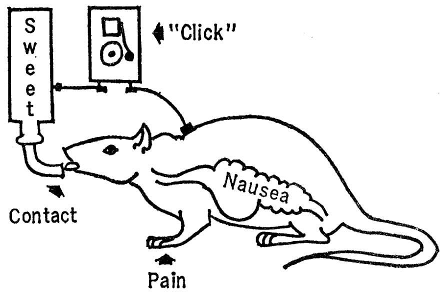
Fig. 1. The effect of varying intensity and time parameters upon aversions induced by agents producing illness (*10, 11*). [Replotted from Hankins (*10*)]

sponses, or both, if learning is to occur. The validity of this rule is supported by numerous studies in which external stimuli, such as lights or bells paired with shocks or with food rewards, have been used in conjunction with the locomotor activities of rats in the external world. But the acquisition of a food aversion is another matter: the rat will avoid the food even if illness occurs hours later. Moreover, it will not necessarily avoid the last food consumed; when the last food is bland and familiar, the rat is more apt to avoid a food eaten earlier, if that food had a novel salient flavor (*12*).

The second rule violated is the Pavlovian rule of the equipotentiality of conditioned stimuli, which specifies that any perceptible stimulus can signal an animal that reward or punishment is eminent. But the rat acquires an aversion only for the taste of the food, not for the size or the shape of the food, or for the dish, although all of these stimuli are as perceptible as the taste and bear the same associative relationship to the delayed illness (*13*).

Figure 2 illustrates the design and the results of a number of experiments that disprove the equipotentiality rule. The rat is electronically connected to a circuit that produces a "click" when the rat's tongue touches the bottle containing "sweet" water; thus, the animal has two cues, click and taste, that lead to punishment. The rat can also receive punishment in either of two ways: with experimentally induced nausea or with electric shock administered to the paws. If punished by nausea, the rat will quickly acquire an aversion for the sweet taste and refuse to drink. However, it will not acquire an aversion for the click, even if the click is repeatedly followed by delayed illness. On the other hand, if punished by electric shock, the rat will quickly learn to defend against shock by backing away from the clicking spout, yet it will find the sweet taste much more difficult to use for the same defensive strategy (*14–16*).

This basic experiment has been repeated in several laboratories where various stimulus parameters and experimental arrangements have been used. Shock has been delivered directly to the mouth, or delivered with a gradually increasing and then decreasing intensity designed to resemble a bout of illness. Tasted substances have been consumed or merely washed through the mouth without ingestion. Illness has been induced long after ephemeral tastes have been completely altered by the digestive process, or while the animal is under anesthesia, indicating that the effect does not depend upon discrimination of remnants of the meal lingering in the gastrointestinal tract. The only requirement for an enduring aversion is stimulation of the gustatory receptors followed by a visceral illness (*17*).



		Consequences	
		Nausea	Pain
Cues	Sweet	Aquires aversion	Does not
	"Click"	Does not	Learns defense

Fig. 2. The effects of pairing a gustatory cue or an auditory cue with external pain or internal illness. [Based on Garcia and Koelling (*14*), and reprinted from Garcia *et al.* (*15*), courtesy of Plenum Press, New York]

Such an aversion is a negative preference shift from the hedonic value of the gustatory stimulus set by evolutionary pressures. Sweet stimuli have a high hedonic set point because they usually signify carbohydrate nutrients; bitter stimuli have a low hedonic set point because they often signify alkaloid toxins. In the natural setting, animals selecting sweet foods and avoiding bitter ones have a higher probability of surviving and passing their preferences on to their offspring. Experiments with bait-shyness reveal that these set points or preferences can be altered, and that these changes are critical in the behavioral regulation of the milieu interne.

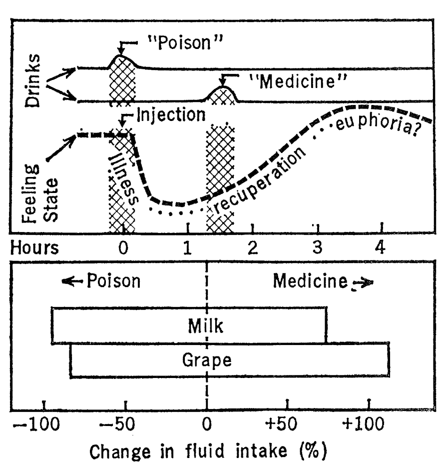


Fig. 3. The effects of arbitrarily presenting one taste before illness (poison) and another taste before recuperation (medicine) resulting from the emetic injections. These data indicate that the reputed efficacy of both medicines and placebos may be due to gustatory-visceral conditioning. [Based on Green and Garcia (*20*)]

Self-Regulatory Functions in Rats and Men

Behavioral control of the milieu interne has a long history in physiological psychology. In 1942, Richter presented his Harvey lecture on the "Total self-regulatory functions in animals and human beings." This lecture reviewed the monumental research led by Richter which extended Claude Bernard's "milieu interne" and Walter Cannon's "wisdom of the body" by adding the coping behavior of the organism to the repertoire of physiological and chemical regulators by which the organism maintained homeostasis in its internal fluid environment. In discussing the problem of mammalian body temperature regulation, for example, Cannon explained that when an animal is placed in a cold environment, internal temperature drops and a variety of "involuntary" physiological and biochemical mechanisms ensue. Heat production is maximized by metabolization of stored fat and by shivering, while heat loss is minimized by constriction of peripheral blood vessels and cessation of sweating. Richter demonstrated that the animal's "voluntary" motor behavior also served as a homeostatic mechanism. In one study he provided rats with the tab end of a roll of soft paper one-half inch (1.25 centimeters) wide and 500 feet (166 meters) long and measured the amount of paper pulled out and used each day. When room temperature was reduced from 80° to 45°F (27° to 7°C) the animals increased their use of paper from 500 to 6000 cm in order to build huge nests to conserve body heat. When internal physiochemical heat production was damaged by hypophysectomy or thyroidectomy, nest building behavior was increased,

". . . another instance in which after removal of the physiological regulators homeostasis was maintained by a total organism response" (*18*).

Ingestion of food and water is perhaps the most important behavioral means by which an animal maintains the integrity of the milieu interne. Richter's rats rejected toxic solutions in concentrations too low to have any detectable physiological effect and displayed a marked preference for nutrient solutions at concentrations too low to be of much actual benefit. When he surgically removed their adrenal glands, disrupting salt metabolism and increasing urinary salt excretion, he found that animals given free access to a salt (NaCl) solution increased their saline intake sixfold and thus prolonged survival.

Richter proposed a hypothetical receptor change to account for compensatory ingestion. Speaking specifically of rats in need of salt, he suggested that the sodium ion would be expected to diffuse more readily across the taste receptor membrane of a sodium-depleted rat than the normal rat with a higher salt content. Such a specific mechanism for salt may indeed exist, but subsequent electrophysiological and behavioral studies have negated the notion of a receptor change in salt sensitivity. It seems more likely that a central process activated by salt depletion drives the rat to seek the sensory stimulation of salt (*19*). Other such specific mechanisms may also exist, but experiments with bait-shyness have now demonstrated that animals possess a general capacity to adjust the palatability of any flavor in accordance with internal states. For example, when an animal is injected with a drug such as apomorphine, it experiences a sudden brief bout of illness from which it rapidly recuperates (see Fig. 3). If the animal is given an arbitrary fluid, say milk or grape juice, before the onset of illness, then it will express a negative hedonic shift in the set point of that taste—that is, it will treat the taste as poisonous (*20*). If an animal injected with apomorphine is given the milk or grape juice prior to recovery from illness, then it will express a positive hedonic shift—that is, it will treat the taste as that of a medicine. Such positive hedonic shifts also occur when an animal suffering from thiamine deficiency is given an arbitrary taste followed by an injection of thiamine. Negative aversions caused by ingesting the deficient diet coupled with positive effects of recuperation can readily account for the selection of balanced diets (*21*).

In a theoretical discussion published in 1962 entitled "The sense of taste, a model S-R system," Pfaffman proposed that ". . . sensory stimulation per se, together with its ensuing central neural events, be considered as a prime determinant in the chain of events culminating in acceptance behavior, reinforcement, and hedonic effect" (*22*). Precisely such a sequence was discussed recently by Cabinac in human beings (*23*). A warm stimulus applied to the skin is described as "pleasant" when the subject's internal temperature is lower than normal. Conversely, when the internal temperature is high, the warm stimulus is perceived as "unpleasant." Richter's rats trying to conserve their core temperature also acted as if the warm insulating nest were pleasant. Similar hedonic shifts occur in gustatory sensations. Cabinac's subjects reported that glucose was a pleasant taste when blood sugar was low and an unpleasant taste when blood sugar was high. When forced to take extra sugar by stomach tube, Richter's rats reduced their free intake of the stock diet by an amount equivalent in calories to the extra intubated sugar; they too acted as if excessive food were unpleasant.

These observations seem to provide a foundation for Thorndike's law of effect (*24*) and support Mayer's more specific glucostatic theory of hunger (*25*). Thorndike's "satisfying state of affairs," defined as a state which the animal strives to maintain, is no longer considered a general law for strengthening habits but it is an apt description of how physiological factors guide the coping behavior of animals (*24*). When internal receptors report an internal deficit, then the needed substance produces a pleasant sensation when it contacts the peripheral receptors, so the animal maintains that contact. When the deficit is corrected, the now unneeded substance is no longer pleasant and the animal breaks off contact. These hedonic shifts are transient, changing as internal constituents fall below and rise above the homeostatic set points, but illness and recuperation can produce more permanent changes in the hedonic tone of gustatory stimuli.

In feeding behavior, when the internal monitoring system goes awry, the organism is at the mercy of external stimuli. Schachter (*26*) has recently compared the literature on the feeding behavior of obese rats suffering from ventromedial hypothalamic lesions and disrupted homeostatic regulation with the literature on obese human beings whose feeding "shut-off" mechanisms are also, presumably, ineffective. Feeding in these obese mammals is dependent upon palatability or high hedonic set point of food because internal signs of hunger have been disrupted. In the absence of caloric need, both the rat with a lesion and the obese man will eat more than normal when stimulated by external feeding cues, when food is palatable, and when little effort is required. In contrast, normal controls of both species, if they have an internal need for calories, search more diligently for food, eat more unpalatable food, and work harder for food than either the rat with a lesion or the obese man (*26, 27*).

Dual Neural Control System

The duality of neural specialization subserving the external and internal control is classically illustrated by Herrick (*28*) in his description of the organization of the somatic and visceral neuropils in the medulla oblongata of the tiger salamander. The somatic neuropil receives fibers from the auditory system and from the cutaneous receptors and sends fibers to the striated motor system. This somatic system is ideally suited to control the milieu externe. The visceral neuropil receives fibers from the gustatory system and from the visceral receptors and sends fibers to the smooth muscles of the viscera. This visceral system is ideally suited to control the milieu interne. The central nervous system of mammals is much more complex than that of amphibians, particularly as far as the external control system is concerned, but their internal control systems are remarkably similar. Both gustatory and visceral receptors, as well as the internal monitors of the area postrema, send fibers to the nucleus of the fasciculus solitarius (*28, 29*).

It is significant that in mammals the olfactory system does not project into the nucleus solitarius, but is more directly involved with the limbic system. Tests of anosmic animals indicate that, contrary to what common sense would suggest, the olfactory system has little to do with setting the hedonic tone of food. In Fig. 4, the performance of peripherally anosmic rats (unable to use odor cues) is compared with that of normal controls on three tests with a fluid (apple juice) possessing both taste and odor. First, anosmic animals display a weak neophobic or finicky reaction to novel apple juice presented for the first time when they are compared to control rats with an intact olfactory system. Apparently, olfactory input to the limbic system facilitates this emotional response to strange foods. Second, when apple juice is followed by foot shock, anosmic animals again perform poorly in the acquisition of motor avoidance responses compared to normal animals which can smell as well as taste the juice. In contrast, when apple juice is followed by illness, anosmic rats, operating only with taste cues, acquire a slightly stronger aversion than normal animals which have both odor and taste cues. Other tests reveal that normal rats find it difficult to acquire an aversion to an odor that is followed by illness in the absence of taste cues. This indicates that taste, not olfaction, is the sufficient and primary modality for acquisition of food aversions. Functionally, the olfactory system is primarily concerned with the milieu externe: it is useful for sniffing out danger and finding mating partners. Because of its proximity to the mouth, the nose is necessarily involved in feeding, but its role is one of appetitive activation and food identification, not of palatability adjustment through visceral feedback (*30*).

Brain lesions can result in at least a partial separation of internal and external control systems. To test the integrity of external control, brain-damaged rats were conditioned to an auditory buzz followed by very mild electric shock to the skin; the integrity of internal control was tested by conditioning them to food with a particular flavor followed by very mild illness. The shock did not produce emotional urination and defecation, nor did the illness produce diarrhea or listlessness. In both cases the performance was measured by the inhibition of drinking to the signal paired with the mild punishment.

The results of a number of such studies are illustrated in Fig. 5. The specific effects fall into three classes. First, lesions in the ventral hippocampus and lateral septum clearly separate

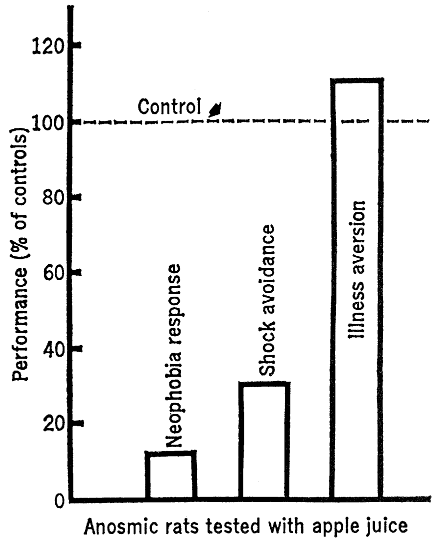


Fig. 4. Performance on three behavioral tests of animals deprived of olfactory input.

the two control systems, disrupting buzz-shock performance and enhancing taste-illness performance. Second, lesions in the amygdala have a devastating effect upon performance in both tests. Anterior cortical lesions and olfactory bulbectomies have a lesser effect upon both tasks, but these performance deficits might easily be overcome by increasing stimulus parameters. The effect of anterior cortical lesions depends more upon size than location, in accordance with Lashley's principle of mass action. Surprisingly, lesions of the taste cortex do not have a greater effect upon taste-illness performance than upon buzz-shock performance. Third, lesions of the posterior cortex, dorsal hippocampus, and the medial septum have little effect on either system, except that posterior cortical lesions tend to disrupt external conditioning and medial septal lesions tend to facilitate internal conditions (*31*).

In general, brain lesions produce a greater deficit in external control than in internal control, suggesting that the latter is a more "basic" function. Because it has not been possible to eliminate internal control by the use of brain lesions, such studies are somewhat disappointing, and exploratory studies with extracellular recordings from the brainstem are now in progress and appear to be promising. Cells that respond to gustatory stimulation seem more likely to respond to visceral stimulation than to cutaneous stimulation. Cells that respond to auditory stimulation seem more likely to respond to cutaneous stimulation than to visceral stimulation (*32*).

Some Theoretical and Methodological Considerations

Coping with the external world has traditionally been viewed as a learning process; for example, a hungry animal learns when and where food is available. Regulation of the internal environment would conventionally be termed a motivational or an incentive process; for example, a hungry animal needs and is attracted to food. Experiments with bait-shyness indicate that the operations by which an animal is trained to cope with externally referred problems are basically similar to the operations by which the motivations of the animal can be altered.

For example, in avoidance learning, a rat may be trained in a series of trials in which a buzzer signals a subsequent shock to the feet. The animal soon develops a defensive strategy indicating it has acquired an "if buzzer, then shock" association. If the animal is taken off the shock grid for some trials, it quickly learns to heed the buzzer only when it is on the shock grid. The animal acts as if it had acquired information relating the buzzer to the shock in a specific time-space configuration or context. This information is probably represented in memory in the form of a cognitive map, or a hypothesis relating means to an end (*33*).

Except for the expanded time scale, the same operations are used to produce a motivational or incentive change in experimental bait-shyness. For example, a specific taste, say saccharin, is followed by illness in a specific time and place, and the aversion is established. However, the effects are different. The animal's behavior does not indicate that it has acquired an "if taste, then illness association"; rather it now acts as if saccharin were unpleasant. It rubs its chin on the floor in a sign of disgust and grooms itself vigorously. If saccharin is mixed into solid food, the rat is apt to dig the food out of the cup and scatter it on the floor, just as it does when the food is adulterated with bitter quinine. The rat will now refuse saccharin in places where saccharin never made it ill, indicating that the time-space contextual information, so important in the external sphere, is dispensed with as unnecessary for adjusting incentives in the internal sphere.

In some ways, shifts in internal incentive reflect the parametric information obtained during conditioning, just as external coping behavior does. Figure 1 indicates that conditioned bait-shyness is a function of both stimulus intensity and the time between the stimulus and the reward. In addition, bait-shyness, like external conditioning, reflects the probabilistic relationship of cue to consequence. If, in our example of buzzer-shock conditioning, unsignaled shocks or unshocked signals are presented during training, the animal's avoidance response becomes erratic, reflecting the degree of uncertainty in the relationship of signal to punishment. Similarly, if flavors unpaired with illness and illness unpaired with flavor are experienced by an animal during bait-shyness conditioning, the degree of aversion is attenuated, indicating that this hedonic shift is also sensitive to uncertainty in the relationship of flavor to illness.

Experimental bait-shyness violates the temporal contiguity rule of cue to consequence. However, even in external conditioning, temporal contiguity is only necessary when the animal has no other means of making the association between cue and consequence. Consider an animal "behaving" in a problem box, restlessly pacing and manipulating features of this confined space. The experimenter arbitrarily designates one "behavioral bit" from that stream of behavior as the "correct response" and follows it with reward. This bit may be a "stimulus" to which the animal is temporarily oriented, or a motor "response" pattern which he executes, that matters not. If reward is delayed for an hour, how can the animal decide which bit of behavior out of the continuous flow is related to the reward? The animal has no way of "flagging" the appropriate bit for future use, even though it may remember that bit very well. On the other hand, if the behavioral bit is immediately rewarded, the reward itself "flags" the behavioral bit and the animal soon learns to repeat the "correct response." Reinforcement theories generally indicate that this flagging is the reinforcing action unique to rewards and punishments, or their attendant stimulus features.

Recent studies indicate that the correct response can be flagged in other ways. Lett uses two distinct places to help animals sort out the correct response despite a 1-hour delay in reinforcement. Using a two-choice (correct as opposed to incorrect) apparatus, she removes her animal from the apparatus as soon as it makes its choice

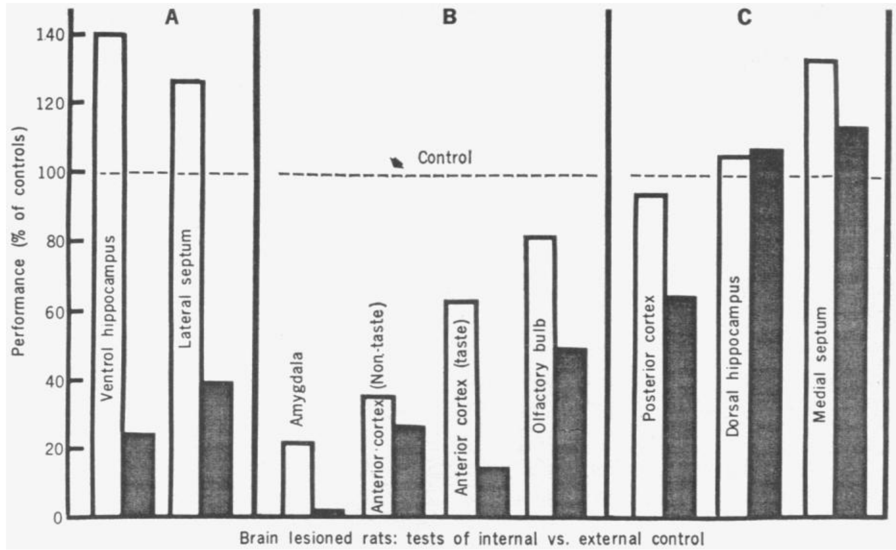


Fig. 5. The effects of a variety of brain lesions upon rats learning a noise-shock or a taste-illness contingency. Open columns show taste-illness tests; solid columns show buzz-shock tests.

and places it in a holding cage without food. An hour later she returns the animal to the starting area of the apparatus, carefully preventing the animal from making a choice. If, an hour before, the rat had made the correct choice, it is fed; if it had made the incorrect choice, it is not fed. The rats learn to increase their correct choices despite the delay in reinforcement; that is, they are apparently able to match the last response in the apparatus with the presence or absence of food in the apparatus an hour later. Removal from the apparatus enables them to flag the last response; subsequent responses during the 1-hour interval are apparently keyed to the holding cage and therefore do not interfere with retrieval of the appropriate, flagged response. This experiment thus further demonstrates that the psychological effect of time depends upon how and where the time is spent (*34*).

In other ways, bait-shyness differs dramatically from external conditioning. For example, the experimental illness, unlike shock, can be imposed when the animal is "unconscious"—that is, when it is under anesthesia or when its cortex is inactivated by potassium chloride, and still have a retroactive effect upon flavor. A number of investigators interested in "memory" have turned to the flavor-illness paradigm because the prolonged interval between stimulus and reward affords them an opportunity to interfere with the "associative" process. These investigators will have to decide whether this involuntary hedonic shift, which can occur without the animal's being aware of the punishing agent, represents the same "memory process" that is displayed by a rat actively coping with externally referred signals and shocks (*35*).

Another source of confusion lies in the duplicity of gustatory function. Taste has a discriminatory function in the milieu externe. In a food-seeking sequence, it provides "reinforcement"—that is, the final informative stimulus denoting success or failure in the animal's efforts. In avoidance training, it may be used to signal the animal that shock is eminent, although it is ill-suited for this task. Taste receptors, after all, are part of the sensory surface of the animal, and, as such, can be used to inform the animal of time-space features of the milieu externe. In this external learning role, taste information is utilized as any other external information is utilized. But taste also has a "timeless" motivational function in the milieu interne, where hedonic functions, distinguished from discriminatory ones, are effected by long-delayed homeostatic processes. Norgren and his associates at Rockefeller University have recently traced out a pontine bifurcation of ascending gustatory projections. These workers have found that one limb projects to the cortex and is thus ideally suited to subserve discriminatory functions, while the other limb is directed toward the feeding areas of the hypothalamus and thus may subserve palatability adjustments (*36*).

The differences between the internal

and external systems affect research strategy, particularly in biofeedback conditioning. The sluggish, vague nature of enduring internal states makes their operant control difficult, because the techniques by which one achieves such control amplify the subject's subtle internal changes and transduce them into external signals more appropriate for aroused reaction to the external world. By analogy, it would be difficult for us to achieve sleep guided by a buzzer signaling drowsiness. A more efficacious technique by which to achieve internal control would be to focus the subject's attention upon the incipient cues accompanying the onset and growth of the internal state, and to associate these cues with the intense feeling state which follows. For example, rats cannot discriminate a toxic solution of 0.12*M* lithium chloride from the harmless 0.12*M* sodium chloride solution, when they are punished with the external pain of shock for drinking the wrong solution. However, if they are allowed to imbibe an illness dose, with practice they will progressively and specifically decrease their consumption of the lithium solution as if they can detect some subtle difference while drinking this toxic solution (*37*).

Behavioral generalization across species from rat to man is hazardous and must be founded upon anatomical structure. Analysis of behavior is not enough because common behavioral patterns do not imply common structural mechanisms, as anyone would know who has observed the feeding patterns of two widely divergent species. For example, both the hummingbird (*Archilochus colubris*) and the sphinx moth (*Protoparce sexta*) fly up to a flower, hover on rapidly beating wings while drawing nectar through a long siphon, and then back up on the wing before moving on to the next flower. Their tactics in exploiting the same niche, their size, and their general appearance are so similar, that at a glance they might easily be confused one for the other. However, even a superficial examination of the feeding siphon reveals that the bird is using its relatively stiff beak while the moth is using its flexible uncoiled tubular tongue (*38*).

Some behavioral differences are subtle and their structural bases are unknown. The quail (*Colinus virginianus*) develops aversions for food consumed before illness but, unlike the rat (*Rattus norvegicus*), it forms a relatively weaker gustatory aversion and a stronger avoidance for visual cues (*39*). Compared to the rat, the bird has a paucity of gustatory sensors and a more complex visual system on which its survival depends (*40*). A blind quail is virtually helpless while the blind rat is quite capable of fending for itself. When feeding on seeds, the rat grinds away the relatively tasteless seed coat with its teeth, thus exposing the seed contents to the gustatory analyzers in its mouth before ingestion. The quail swallows the seed and the grinding of the seed coat occurs after ingestion. Out of necessity, the quail may have developed visual mechanisms that enable it to discriminate seeds containing toxins and thus to reject them as food. Only a comparative experimental analysis of the avian behavior and its neural feeding control system will clarify these species differences.

Some Practical Considerations: Control of Predation

Predation of domestic animals, particularly lambs by feral carnivores such as the coyote and the bald eagle, has led to a sharp controversy between naturalists on the one hand and stockmen on the other. The naturalists view these animals as vital to a balanced ecology in the public lands where they prey upon small mammals. The stockmen view them as "varmits" and have attempted to control predation by scattering poisoned baits and posting bounties on the heads of these carnivores. Poisoned baits kill indiscriminantly and bounty hunters range throughout the public lands and national forests killing coyotes far from the sheep ranges.

This practical problem afforded Gustavson and his associates (*41*) an opportunity to test experimental bait-shyness under conditions far removed from the laboratory. Coyotes served as subjects. Live lambs and rabbits served as test baits. It was argued that the coyote, a specialized carnivore, was not subjected to the same evolutionary pressures as herbivores. After all, most natural toxins exist in plants, while toxic animals are distinctive and rare. In addition, the coyote is described as a natural killer who kills animals even without a need for food. However, after coyotes had consumed one or two meals consisting of minced lamb flesh, skin, and wool infused with lithium chloride, and had consequently experienced lithium illness, they refused to attack lambs. In fact, these "killers" ran away from the lambs and retched. The same coyotes continued to attack rabbits, indicating that the aversion was specific for lamb flesh—that is, lamb was no longer an incentive for the coyotes. Tests with other coyotes indicated that attacks on rabbits could be averted in the same way without attacks on lambs being inhibited.

Aversion conditioning offers a solution to predation problems that could spare both the prey and the predator. Such a program would require the scattering of bait-packets that tasted like lamb, smelled like lamb, and contained a nonlethal dose of lithium chloride. As a supplemental procedure, carcasses of lambs and sheep could be infused with solutions of lithium chloride and distributed in the same area. After eating one or two meals of lithium-treated sheep flesh, foraging predators would find the taste of sheep unpalatable and would not be attracted by the spoor of lamb. The main advantages of such a program would be its direct approach, in that the sheep-eating animal would be dealt with directly, any eater of sheep flesh, including eagles and wild cats, would be conditioned, and the predator would survive to pass on its selective food habits to its offspring. During the nursing period, the diet of the mammalian mother imparts characteristic tastes to her milk, setting a high hedonic value on these tastes for her offspring. During parental feeding, offspring acquire a taste for specific food brought to the den by the parents (*42*).

Applied ecological programs might also be based upon positive changes occurring in palatability, as when a new food is followed by beneficial nutritional effects. The survival of some species becomes endangered because their favored food source is eliminated by ecological changes. Such species might be saved by conditioning them to new foods and, if need be, by giving them an aversion for the diminishing food source.

Summary

In regulating the internal homeostatic environment mammals, by necessity, employ behavioral strategies that differ from the tactics used in coping with contingencies in the external environment. When an animal consumes a meal, the palatability of that meal

is automatically adjusted in accordance with the ultimate internal effects of that meal. If the meal causes toxicosis, the animal acquires an aversion for the taste of the meal; conversely, if recuperation follows ingestion of the meal, the taste of that meal is enhanced. Unlike the learning that occurs when externally referred visual and auditory signals are followed by punishment in the form of peripheral pain or reward in the form of food in the mouth, conditioning to the homeostatic effects of food can occur in a single trial and rarely requires more than three to five trials, even though the ultimate effects of the meal are delayed for hours. Paradoxically, the animal need not be aware of the ultimate internal effect in the same sense that it is aware of external contingencies. For example, an aversion can be acquired even if the animal is unconscious when the agent of illness is administered. Thus, the way in which food-effects are stored in memory may be fundamentally different from the way in which memories of specific time-space strategies devised for external contingencies are stored. This separation of function is indicated by limbic lesions which disrupt conditioning to a buzzer that is followed by shock and facilitate conditioning to a taste that is followed by illness.

Operationally speaking, one can describe both aversion conditioning and buzzer-shock conditioning in the space-time associationistic terms of classical conditioning. However, psychologically speaking, one must realize that in aversion conditioning the animal does not act as if it were acquiring an "if-then" strategy. It acts as if a hedonic shift, or a change in the incentive value of the flavor were taking place. Such hedonic shifts are critical in regulation of the internal milieu. When an animal is in need of calories, food tends to be more palatable; as the caloric deficit is restored, food becomes less palatable. If the animal's body temperature is below optimum, a warm stimulus applied to the skin is pleasant. When body temperature is too high, the converse is true. In this way, homeostatic states monitored by internal receptors produce changes in the incentive values of external stimuli sensed by the peripheral receptors, and guide feeding behavior.

In mammals at least, the gustatory system, which provides sensory control of feeding, sends fibers to the nucleus solitarius. This brainstem relay station also receives fibers from the viscera and the internal monitors of the area postrema. Ascending fibers bifurcate at the level of the pons and project toward the feeding areas of the hypothalamus and the cortex. The olfactory system which primarily projects to the limbic system does not play a primary role in adjusting food incentives. Rather, it plays a secondary role in the activation of feeding, as do other external sensory systems.

This specialized conditioning mechanism, which specifically adjusts gustatory hedonic values through delayed visceral feedback, is widespread among animals, including man and rat. These two species are remarkably similar in their thresholds and preferences for gustatory stimuli. The behavioral similarities are based on the animals' having similar gustatory systems, similar convergence of gustatory and internal afferents to the nucleus solitarius, and similar midbrain regulatory mechanisms. Thus, it is not surprising that the feeding of obese rats with internal hypothalamic damage resembles the feeding of obese human beings insensitive to the internal signs of this caloric state. Obviously, man has a highly specialized form of symbolic communication and the rat does not, yet man's cognitive specialization does not prevent him from developing aversions to food consumed before illness even when he knows that his illness was not caused by food (*43*).

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