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Hull

Clark L. Hull (1884–1952) was able to synthesize into a unified system many of the achievements of earlier theorists. He did, in fact, stand on the shoulders of his predecessors, building on their strengths and avoiding some of their pitfalls. Hull's system of behavior was in the S-R tradition, but it was deductive and mathematical in form, and it was almost purely behavioristic, with hardly a taint of mentalism or mechanism. Hull's theory was explicit and highly testable, and it was tested. For years it was subjected to systematic experimentation both by those who sought to attack it and those who rushed to its defense. During Hull's lifetime and for some years after his death his ideas dominated the animal-learning literature; he founded an empire with Yale University as its capital. More than anything else, Hull stimulated research.

Although Hull was nearly the same age as Tolman, his commitment to the study of learning came approximately a decade later. During the intervening years Hull had distinguished himself by his research in such diverse areas as concept formation (Hull, 1920) and aptitude testing (Hull, 1928). In 1929 he went to Yale to head a group at the Institute of Human Relations, whose mission was to study the place of learning in the conduct of human affairs. Hull's original orientation was strongly

Pavlovian. He was evidently impressed with the systematic nature and scientific aura of Pavlov's work, and he depended almost exclusively upon the principles of Pavlovian conditioning to account for learning. Of course, he was not alone in this commitment; most theoretical statements in the early 1930s were made within a conditioning framework.

Hull's first papers on learning theory in 1929 and 1930 were attempts to show that purposiveness in behavior could be explained with Pavlovian S-R associations. In other words, Hull sought to extend the Pavlovian framework from the original conditioning situation to the kind of situation in which behavior appears highly flexible, adaptive, and intelligent. Hull did not deny these descriptive attributes of behavior. He sought rather to derive them from simple conditioning principles. The argument was like that made a few years later by Guthrie (see Chapter 4). Hull argued that there is a tendency for the consummatory response to be elicited not only by goal-box stimuli but also by stimuli similar to those in the goal box that arise in other parts of the apparatus.

Then there was an important new development. Thorndike had returned to the study of learning and was vigorously defending the idea that learning occurs as a result of reinforcement. By the mid-1930s a confrontation between Thorndike's reinforcement position and the better-established conditioning position seemed inevitable. The crisis for Hull apparently came when he wrote a long analytical review of a new book by Thorndike (Hull, 1935). In this review Hull noted a major inadequacy of conditioning theory: its failure to deal convincingly with the phenomena of motivation. Hull saw that motivation may be viewed as either a learned aspect of behavior (as Guthrie regarded it) or a behavioral determinant quite independent of learning (as Tolman regarded it), but one way or the other, it had to be given more status than it was afforded at that time.

A final factor that gave form to Hull's theory came not from the intellectual environment but from the man himself. He was greatly impressed by the elegance and power of quantitative and deductive methods in science. In his early theoretical papers Hull proclaimed that the proper strategy for science would be to start with certain specific, testable postulates even if they would have to be based upon minimal evidence. Concrete, empirically verifiable deductions could then be derived from these postulates. When these deductions were tested, the system of postulates would then be either confirmed or shown to require modification. The task of the theorist would therefore be to formulate postulates in such a way that they would lead to unequivocal deductions. If there were no question about what inferences the theory led to, the deductions from the theory could be tested by anyone who cared to test them. The worth of a theory must then ultimately reside in how much research it generates and how consistent with its theoretical deductions the resulting findings are. We may note that applying this strategy to predictions about behavior necessarily requires us to be behaviorists. We cannot be concerned about the mental or physiological events giving rise to behavior if the postulates themselves are framed in behavioral form, as they were in Hull's work.

To summarize the several factors that formed the conceptual background for Hull's theoretical synthesis, the first was the challenge presented by Tolman, both by his view of the purposiveness and goal-directedness of behavior and by his emphasis upon motivation and the important part that it plays in behavior. Second was Thorndike's concept of reinforcement, which came to the fore to challenge classical conditioning as the universal learning process. The third factor was Hull's desire to create a quantitative and deductive system to put behavior theory on a strong scientific footing. Hull struggled for years to establish a postulate system that he thought would account for what was then known about learning and motivation. When the final system was presented in his major book, *Principles of Behavior* (Hull, 1943), it embodied all the characteristics that we have described. It was a system of intervening variables, most of which were put in mathematical form. It incorporated distinct motivational and learning mechanisms, and learning was said to be based on reinforcement, rather than just on contiguity. Let us look at this 1943 theory.

Hull's Theory

The ultimate function of behavior in an animal, according to Hull, is to enable it to solve its biological problems. Consider an animal that has a need. Perhaps it has a need for food. A useful reaction to such a problem would be for the animal to become active. It does not matter too much what kind of behavior the animal engages in; as long as it does something it is likely to improve its chance of survival. Let us suppose further that while the animal is engaged in this increased activity it accidentally makes a response that leads to food; the food eliminates the original need and solves the animal's immediate biological problem. What an elegant system we would have if this event, the reduction in need, were to serve as reinforcement and produce learning of the lucky response! The animal would then be, in effect, an automatic problem-solving system. Need would produce behavior, and the particular behavior that reduced the need would be gradually learned. Animals would thus come to adapt to the special requirements of their environments in solving their particular problems. This is precisely the kind of system that Hull postulated.

First, there is drive. The animal's need state, whether it be hunger, thirst, sexual arousal, pain, or some other type of biological problem, produces a state of motivation that Hull called *drive.* Drive activates and generates behavior—no particular behavior, just behavior. Second, there is reinforcement, which occurs whenever drive is reduced so that there will be learning of whatever response solves the animal's problem. Over a number of trials, the animal's behavior will become increasingly efficient and more highly adapted to its environment. The animal will become increasingly adept at solving its problems in a given environment.

The same mechanism works in the laboratory. An animal in a box is suddenly in pain because of an electric shock applied to the grid floor. The animal displays a lot of behavior; it scrambles around and jumps and cries. In the course of this disorganized behavior it happens to press the bar in the box and terminate the shock. How elegant it would be if the bar-press response were automatically strengthened; then the next time the rat was in such a difficulty (on the next trial) it would be somewhat more likely to press the bar again. Hull's scheme predicts that animals will learn to solve their problems both in the laboratory and in nature. Hull's system provides a basic concept of need-related motivation, drive, and S-R learning produced by reinforcement. The S-R connection was called "habit." Let us see how these basic concepts were developed in more detail.

Hull (1943) postulated that drive and habit multiply together to determine the strength of behavior. This proposal was based upon a pair of experiments conducted by two students, Williams (1938) and Perin (1942). Williams trained groups of rats to press a bar for food, each group being given some fixed number of reinforcements ranging from five to ninety. Immediately after acquisition the response was extinguished in all animals. The resistance to extinction that Williams found in each group is shown in Figure 6.1. Perin's experiment was conducted in exactly the same way. Different groups of animals were given a fixed number of reinforcements for pressing the bar and then the response was extinguished. Perin's results are also shown in Figure 6.1. The major difference between the two experiments, and presumably the reason the results came out differently, is that Williams' animals had been food-deprived for twenty-two hours at the time of testing, whereas Perin's animals had been deprived for only three hours. Hull noted that the strength of behavior depends upon both the animal's motivating conditions at the time of testing and the amount of prior learning. He analyzed the data further and found that it was possible to fit a mathematical learning curve to the results of each experiment. In each case the equation came out in this form:

$$\text{Behavior strength} = A(1 - 10^{-BN})$$

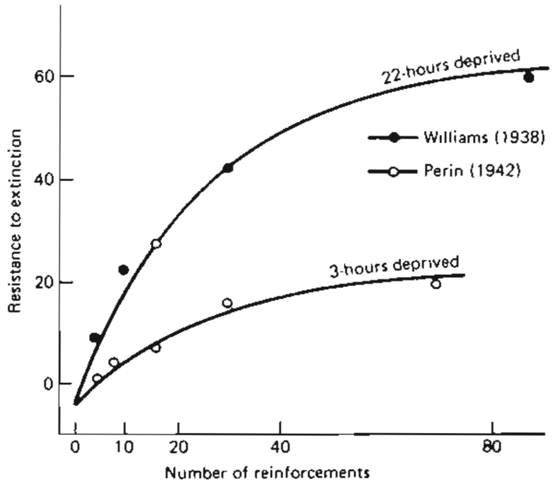

Fig. 6.1 The famous Perin-Williams data showing how the strength of behavior, as measured by resistance to extinction, depends on both current motivation conditions (drive) and prior learning (habit). (From Perin, Behavioral potentiality as a joint function of the amount of training and the degree of hunger at the time of extinction. *Journal of Experimental Psychology*, 1942, *30*, 93—113. Copyright 1942 by the American Psychological Association. Reprinted by permission.)

When A indicates the level of performance ultimately reached with a given deprivation condition, B is the "growth constant" that indicates how fast the habit is formed, or how fast the animal approaches the ultimate level of performance, and N is the number of prior reinforcements.[1] Once these equations were obtained for Perin's and for Williams' data, Hull discovered that the term B was almost identical in the two experiments; the only real difference in the two sets of results was in the constant A. Hull therefore tentatively identified the factor $(1 - 10^{-BN})$ with habit and emphasized that it was not dependent upon deprivation; it seemed to depend only upon the number of prior reinforcements. Similarly, Hull identified the constant A with the animal's motivational state, or level of drive, which seemed to depend only upon deprivation conditions. The strength of behavior then becomes motivation times learning, or drive times habit, or $D \times H$.

Here we have a mathematical equation, an approach toward quantification, that describes behavior as a function of the two factors that it is supposed to depend upon, motivation and learning. We note, too, that, according to this equation (and in accordance with common sense) neither motivation nor prior learning by itself will tell us how much behavior we will obtain from an animal. Thus, if we have an animal running rather slowly in an alley, we cannot tell whether it is not motivated but has a well-learned habit or is highly motivated and is just beginning to learn. The same response strength can be produced in either way. Consequently it is impossible to assess either drive or habit from a single observation. It takes a series of observations, together with some assumption, such as the $D \times H$ equation, to establish what is determining the behavior in a particular instance.

The principles of quantification that appear in Hull's theory were rather elaborate and, as it turned out, rather prematurely formulated. Hence we do not have to be concerned with his mathematical formulations. But it is important to understand the kind of deductive system that Hull attempted to create. According to Hull, science depends upon systematic observation and measurement, but in addition science requires that sooner or later there be basic laws, preferably in mathematical form, from which it is possible to deduce theoretically what the results of experimental observations should be. Let us digress briefly to see how this deductive process works in the well-established science of classical mechanics.

In the seventeenth century Isaac Newton observed that if a pendulum was swung back and forth, it moved with a fixed period; it was therefore possible to determine how fast a particular pendulum swung. Newton did a number of experiments to see what determines this fixed period, and some of these experiments were rather interesting. If a heavy weight was put on the pendulum, it swung at precisely the same speed; weight was not a determining factor (which is rather interesting because the results are counter to intuition, or at least to some people's intuition). The amplitude of the motion—how far the pendulum swung—did not affect the period either, which is also a rather interesting negative result. But Newton discovered that the period of the pendulum did vary with its length. In fact, length turns out to be the only variable that affects how fast the pendulum swings. Having established some facts about the simple pendulum, Newton proceeded to derive an equation to describe his results. He assumed that the force of gravity always operates downward, and with a little mathematical manipulation he was able to conclude that the acceleration of the pendulum is

[1] This equation describes the growth over time of a great variety of biological systems. It is likely to be applicable to any system on which there is some limit to how much growth can occur. It is based on the assumption that the rate of growth is proportional to the amount of growth still possible. For Hull, the amount of habit acquired on a given trial was proportional to the amount still possible to acquire.

$a = \frac{F}{m}$, when F is the force of gravity and m the mass of the pendulum. Then, happily, when this equation is solved to determine the period, the m term drops out, so that this deduction is consistent with the observation that the mass of the pendulum is not a factor in determining its period. Indeed, all of Newton's observations were consistent with the equation. He rewrote the equation as $F = m \times a$, and in this form it was the basic postulate that summarized pendular motion. But, as with many mathematical models, there were some additional benefits. The $F = m \times a$ equation turned out to describe not only the behavior of pendulums but also the behavior of cannon balls, falling stones, celestial bodies, and the motion of the earth about the sun. Observation of an immense variety of phenomena revealed that Newton's equation was almost universally valid. Now we know of situations in which Newton's equation fails to describe scientific observations, but for more than two centuries it met all experimental challenges.

Hull attempted to follow the Newtonian model. He started with a few simple experiments like the studies by Perin and Williams and summarized these results in terms of a simple equation:

$$\text{Behavior strength} = D \times H$$

This equation then serves as a postulate or tentative hypothesis about the determinants of behavior in general. Its generality is tested by means of a variety of experiments the outcomes of which are deduced from the postulate. If the deductions are consistent with observation, well and good; the postulates have gained in generality. If the results are inconsistent with the postulates, then the postulates must be modified. In what follows we will examine some of Hull's postulates.

Motivation

Hull (1943) attributed a number of specific properties to drive. We have already seen that he related drive to the animal's biological needs, considering it an immediate, unlearned physiological reaction to need. According to Hull, drive does not contribute to the direction of behavior. For example, a hungry animal is not motivated to do anything about its hunger *per se;* it is just motivated. The different needs can be regarded as different sources of drive (Brown, 1961), but in each instance the same kind of motivation, i.e., drive, is produced. Different sources of drive simply multiply the existing habit structure without biasing the animal to engage in any particular behavior. One prediction from this postulate is that, after a hungry animal has learned a particular response, such as pressing a bar, the execution of this response should not be dependent upon the animal being hungry. If the rat were suddenly shifted from hunger to thirst, the behavior ought to persist because it would be motivated by the new source of drive. Of course, extinction would occur unless the source of reinforcement were shifted at the same time from food to water, but the point is that there should be no sudden loss of behavior when the animal is first motivated inappropriately. Some early experiments tended to confirm this remarkable prediction (for example, Webb, 1949), but a number of more recent experiments have failed to find such motivation transfer when proper care has been taken to use sources of drive that can really be manipulated independently. Food and water deprivation are inappropriate, it turns out, because when an animal is deprived of water it is both thirsty and hungry (Grice & Davis, 1957). For many years Judson Brown was the chief spokesman for the idea that different sources of drive are interchangeable, but more recently he has reported that in a hunger-fear conflict situation, the behaviors motivated by hunger and by fear appear to be motivated relatively independently (Brown, Anderson & Brown, 1966).

There is another implication of Hull's concept of generalized drive: An irrelevant source of drive should contribute an additional increment of drive, leading to greater strength of behavior. For example, a hungry rat should be more likely to press a bar for food if it is also a little thirsty, a little frightened, or has some other source of irrelevant drive. Again, some early experimental reports suggested that this was the case (for example, Perin, 1942), but more recent and careful experimentation has shown that the summation of different sources of drive is very unpredictable. The effect can be found with some sources of drive and in some situations, but it appears to have little generality (this literature is reviewed by Bolles, 1975). Evidently, the motivation of behavior cannot be attributed to a completely general kind of mechanism, as Hull originally postulated.

Of course, Hull knew that animals make specific responses when satisfying particular needs. As early as 1933 he had shown that the rat can learn to make one response to obtain water when it is thirsty and another response to obtain food when it is hungry. But in formulating his principles of behavior Hull retained the notion of drive as a generalized energizer and added an additional postulate, that specific stimuli (equivalent to what Guthrie called maintaining stimuli) are characteristic of each need state. These stimuli were said to have no motivational function; they were simply stimuli to which adaptive behavior, like behavior to satisfy the need, could be conditioned. This postulate therefore contained virtually the entire substance of Guthrie's motivational principles, but Hull had, in addition, all of the other hypothetical properties of drive.

Learning

The basic construct involved in learning was habit, according to Hull. Whereas he assumed drive to be quite generalized and unable to direct behavior, he proposed that habit was very specific. In fact, all the specificity of behavior was attributed to habit; he emphasized the point by placing subscripts *S* and *R* around the symbol *H*. Thus $_SH_R$ indicates the tendency of a specific stimulus to evoke a specific response. In his 1943 postulate system Hull treated habit as a function of the number of reinforcements (see Figure 6.1) and, in addition, the amount and delay of reinforcement. For example, the rat should learn to press a bar more quickly if it has received a large, immediate food pellet. But in 1952, when Hull revised a number of his postulates, he said that habit depends only upon the number of reinforcements.

Another basic postulate that was altered in detail but remained essentially the same over the years was Hull's famous postulate 4, which asserted that habit is built up as a result of drive reduction. Relief from pain and relief from hunger are obvious instances of reinforcement by drive reduction. In the last experiment reported from Hull's own laboratory, a dog was prepared with a fistula in the esophagus so that it could only "sham eat." That is, food taken into the mouth would pour out through the fistula in the neck without ever reaching the stomach. Hull and his collaborators (Hull *et al.*, 1951) tested the dog in a T maze where going to one side permitted sham eating and going to the other side resulted in no food but did permit the animal to have its stomach filled via a tube. The first choice offered the animal the possibility of consummatory behavior; the second choice gave it the possibility of need reduction. It was reported that the animal showed an initial preference for sham eating but after a few trials switched to the side that reduced drive. Drive reduction appeared to produce learning of the new response. These results therefore provided nice confirmation of Hull's postulate.

There are now, however, a number of lines of evidence to support alternative interpretations of reinforcement. Let us just briefly note some of this evidence. Miller (1957) has summarized a series of experiments similar in concept to the study of Hull and his colleagues (1951). These carefully controlled experiments clearly indicate that placing food directly in the stomach is reinforcing but that food in the mouth is much more reinforcing. Other researchers have developed techniques by which the rat maintains itself without eating. A bar-press response activates a pump, which puts a small amount of food directly into the stomach through a surgically implanted tube. The results of these experiments (for example, Holman, 1969) indicate that it is extremely difficult to elicit new learning with this procedure. The rat typically does not maintain its body weight, and even when the procedure does work it is not certain that there are not sensations in the head that accompany the passage of food on its way to the stomach. Thus it appears that some kind of mouth or head stimulation may be a much more important factor in reinforcement than placement of food in the stomach and the reduction in drive that it produces.

Another problem connected with the drive-reduction hypothesis is the discovery by Olds and Milner (1954) that electrical stimulation of certain areas of the brain is reinforcing. Since the initial discovery of this phenomenon there have been many studies that show learning reinforced by brain stimulation in a variety of situations. In some cases this source of reinforcement is enormously effective and preferred by the rat to eating, mating, or any other kind of more natural consummatory response. But, if learning occurs under these conditions, then we have to ask where is the source of drive that is being reduced? Where is the "need" for the stimulation? There are also a number of more natural situations in which learning occurs in the absence of an apparent need and in which there seems to be no possible drive reduction. For example, it was discovered that the rat would learn a maze problem in order to get into a complex situation that it could explore. Exploration thus seems to be a kind of consummatory response the occurrence of which is reinforcing. Again we may ask where is the drive that is reduced? Some writers have gone so far as to invent a new source of drive, claiming that the rat becomes bored in a familiar situation and that exploration reduces this new source of drive. But again we may ask what is the underlying need that produces boredom? How does boredom threaten the biological integrity of the animal? It can be argued that animals have to explore their natural environments if they are to survive, so there is a need in some sense, but this long-term and subtle need is very different from the brutal necessity of having food or water. The same argument could of course be made about mating as a source of drive. It, too, is a need in a biological sense, but it is not the kind of need and does not have the kind of time course that Hull was thinking about when he postulated that need gives rise to motivation.

Perhaps the most straightforward and convincing demonstration of reinforcement in the absence of drive reduction was reported in several early studies by Sheffield and his associates. Sheffield and Roby (1950) found that rats would learn to run in an alley if they could drink saccharin in the goal box. It was found that it was the vigor with which the consummatory response occurred, rather than the nutritional benefit to the animal (saccharin contains no calories and cannot reduce need), that made saccharin reinforcing. Sheffield proposed that it is not reduction in need or drive or any variant of this idea discussed by Hull that constitutes reinforcement; it is simply the occurrence of a consummatory response that produces learning. The rat learns a response when this response permits it to eat, mate, explore, or whatever else it is motivated to do. The occurrence of the consummatory response undoubtedly increases the animal's level of arousal momentarily. Sheffield (1966) therefore suggested that reinforcement may be thought of as more like drive induction than drive reduction.

The evidence against the drive-reduction hypothesis was just beginning to turn up at the time that Hull died. But he had already begun to question the validity of the hypothesis (Hull, 1952a). He was impressed with Sheffield's work and was evidently aware of other mounting problems connected with his theoretical position. As more negative evidence became available, would he have attempted to defend the drive-reduction hypothesis? Would he have accepted some alternative view of reinforcement such as Sheffield's? Would he have abandoned the reinforcement principle altogether and tried to explain learning without it, as Guthrie and Tolman had done? We do not know, but we do know that for several years, when Hull's work was being carried forward and defended by a number of colleagues, former students, and independent parties who had been won over to the Hullian persuasion, the reinforcement question became the all-important issue of the day. All during the 1950s the question of what constitutes reinforcement and whether or not reinforcement is necessary for learning received a great deal of research attention. It is not clear why this particular issue should have become such a battleground, but it did. Ultimately the battle was lost by Hull's followers. The drive-reduction hypothesis has been abandoned by one after another of those who had originally attempted to defend it.

Inhibitory Factors

So far we have been talking about excitatory factors that lead to the production of behavior. Both D and H contribute positively to the expression of a response. But Hull also postulated the existence of factors that inhibit behavior and subtract from its expression. He proposed that there are two kinds of inhibition. One type, which he designated "reactive inhibition," or I_R, is specific to a particular response. It is as if the response mechanism becomes fatigued when the response occurs. This fatiguelike inhibition dissipates in time, however, and, as the inhibition dissipates, response strength returns to the full potential given by the basic formulation $D \times H$. Hull introduced reactive inhibition into his system to explain the Pavlovian phenomenon of spontaneous recovery. The same mechanism also helped explain the fact that performance is poorer under massed than under distributed trials. The argument is that under massed trials I_R does not have the opportunity to dissipate from one trial to the next, so that the expression of behavior is always somewhat less than if it were determined just by the strength of $D \times H$.

Hull's second kind of inhibition also had a strong Pavlovian flavor. It was called "conditioned inhibition" and was symbolized ${}_SI_R$. It was also hypothesized to subtract from the strength of behavioral expression. As the symbol indicates, ${}_SI_R$ was supposed to be specific to a particular stimulus and a particular response. As the basic mechanism was postulated, when a response occurs in a particular situation and reinforcement does not follow, there will be a build up of ${}_SI_R$ in a manner parallel to the buildup of ${}_SH_R$ when a response is reinforced in a given situation. In effect, there are two learning mechanisms, one that makes reinforced responses more probable and one that makes unreinforced responses less probable. As we have noted already, the spontaneous recovery often found after extinction is caused by the dissipation of I_R during the long intertrial interval. But at the same time repeated extinction trials will ultimately lead to the cessation of responding, and this permanent inhibition of behavior is caused by the buildup of ${}_SI_R$. Hull's basic equation was thus modified to read:

$$\text{Behavior strength} = D \times {}_SH_R - I_R - {}_SI_R$$

Hull was one of the few theorists to give explicit recognition to the fact that behavior is essentially probabilistic. He noted that, even when an experimenter has done all that can be done to maximize habit strength and drive level and to minimize inhibitory factors and distracting stimuli, we may still find a disconcerting amount of variability. We find to our consternation that response strength varies widely over a group of animals and varies from trial to trial in an individual animal. To deal with this variability Hull postulated the existence of an oscillation mechanism. He proposed that the overt expression of any behavior requires that the factors, D, H, and I, produce a tendency to respond that is greater than some threshold value. A subthreshold response tendency is simply not overtly expressed. Then Hull assumed that the threshold of response evocation varies randomly in time according to an oscillating function, ${}_SO_R$, which can sometimes lead to the expression of a weak response tendency but at other times may inhibit the overt expression of a strong response tendency. This oscillatory function ${}_SO_R$ is subtracted from the other determinants of response strength. The complete equation is therefore:

$$\text{Behavior strength} = D \times {}_SH_R - I_R - {}_SI_R - {}_SO_R$$

The idea of an oscillating threshold was not entirely new; it had been applied to sensory-detection thresholds for many years, but Hull's system was unique in postulating the existence of such indeterminacy on the behavioral side of the organism. It was an admission that behavior can be predicted only on the average, over a period of time, or over a group of animals.

We would seem to have all the conceivable determinants of behavior gathered before us, but there is still one more consideration. The tendency to make a particular response can be measured in different ways. It is possible to measure the vigor or amplitude of a response, that is, the speed or force with which it is executed. It is also possible to measure the rate or probability of responding. The two measures may be correlated, but often they are not. We might have a very frequent response of low amplitude or a rare response of great amplitude. Which are we to say is the "stronger" response? Clearly what is needed is some sort of mathematical formulation that will convert the equation for the strength of behavior directly into feet per second, occurrences per minute, or whatever other response measure we actually record in the laboratory. Hull tentatively postulated different mathematical equations for the different response measures, but none of them proved to be entirely satisfactory. There is, however, one response measure whose treatment within Hull's system has proved to be both widely accepted and highly convenient. Spence (1954) proposed, after reviewing a variety of data, that the probability of a response can be best measured directly in terms of the reciprocal of its latency. For example, if we think of a response as having such strength that it occurs on the average in four seconds, then, according to Spence's analysis, the equation describing the strength of behavior, $D \times H \ldots$, is equal to .25. If the behavioral tendency were twice as strong, so that $D \times H \ldots = .50$, then the response would occur in two seconds on the average. Spence and his students have been quite consistent in analyzing their data in terms of such reciprocal time scores, or speed scores. This consistency is based partly on the conviction that such scores can be directly related to $D \times H \ldots$ and partly on the additional benefit that such scores have desirable statistical properties. Over a series of trials if an animal gives a number of fast starts and a few slow ones, the frequency distribution may be so badly skewed as to be virtually useless for statistical purposes. Taking reciprocals typically makes such distributions much more nearly normal.

Implications of the Theory

Earlier associationists had hypothesized syntactical elements that corresponded precisely in form to their data. Typically, the correlation between the observed response and a particular observable stimulus was assumed to be mirrored by a corresponding S–R connection in the

nervous system. Hull's theory had a much more elaborate syntax. The effective or hypothetical internal stimulus was said to be related to the external stimulus situation by means of additional postulates that we need not discuss here. And then this hypothetical stimulus enters into the structure of the theory at two points. It enters into ${}_SH_R$ on reinforced trials and into ${}_SI_R$ on nonreinforced trials. There will be a tendency to respond when there is an appropriate habit—if there is enough drive and if there is not too much inhibition. And the tendency to respond is finally transformed according to some mathematical function into observable behavior. The value of this type of approach was its extreme flexibility; it enabled the Hullian theorist to apply the system to a tremendous range of behavioral phenomena.

All the theoretical relationships that we have discussed here have been presented mainly in verbal language. Hull also described them all in tentative mathematical equations. Each syntactical link was spelled out formally and precisely in tentative equations. It was thus possible to make rather precise predictions from the theory, and some of the research originating from Hull's own laboratory was extremely mathematical in character.

We could indulge in physiological fantasizing about where various parts of the learning system are located in the central nervous system. We might identify drive as physiological arousal and locate it in the reticular activating system. We might put habit in the cerebral cortex and inhibition in the hippocampus. Hull himself was inclined to such speculations from time to time. But they play no part in his system *per se*. All the constructs are primarily intervening variables (or hypothetical constructs, as Hull preferred to call them). The theory is basically descriptive, each part of it being based upon certain critical experiments. Hull maintained that the proper use of his theory was to predict the outcomes of new experiments and check the outcomes of such experiments against the predictions. Because of the explicitness and relative precision with which Hull's theory was stated, it has been possible to test most of his theoretical assertions. Most of those pertaining to the drive concept, including the famous drive-reduction hypothesis of reinforcement, have now been shown to be either wrong or inadequate. Other parts of Hull's theory, such as his treatment of inhibition, have fared somewhat better, but they have been extensively modified by both Hull and his followers. Between 1943 and 1952 Hull made a great many minor changes in the postulates. For example, reinforcement was no longer attributed to reduction in need or drive, but to the reduction in the stimulus correlated with drive. The amount-of-reinforcement variable was no longer considered to affect the rate of learning but was made a motivational variable (a development that we shall consider in more detail shortly). The oscillation function was altered. All these changes came about as a result of evidence that accumulated in a few years after Hull's theory was first announced in 1943.

It might be inferred from all the changes that Hull made in his theoretical system that its inital form must have been quite inadequate. But this conclusion misses the point of what Hull was trying to do. What mattered to Hull was not whether the details of his postulates were right or wrong but rather the *method* for building a theory. Hull no doubt expected all the specific details to be modified, corrected, or discarded. The details were originally based on very little evidence, but that did not matter. What was important to Hull was that his conjectures could be tested and changed or rejected as the evidence necessitated. Hull's willingness to be wrong was a remarkable, perhaps unique, virtue. It is a virtue that is, unfortunately, not shared by many theorists.

The Secondary Learning System

So far we have considered what may be called the "primary learning system." Hull had, in addition to this $D \times H$ system and superimposed upon it, what we may call the "secondary learning system," which added another whole dimension of flexibility and power to his theory. Hull was aware that many instances of learning found both in everyday life and in the laboratory occur in the absence of any apparent reduction in need. He therefore assumed that learning can be obtained by means of secondary reinforcers. He postulated a class of primary reinforcers, the effectiveness of which is not dependent upon prior experience; food for the hungry animal, relief from pain, and similar events are typical examples of primary, or unlearned, reinforcers. But there is, he assumed, a class of events, such as social approval and money for the human subject, and getting to a box where food has been located for the rat, whose effectiveness as reinforcers depends upon prior experience. These events are secondary, or conditioned, reinforcers. Hull paid relatively little attention to secondary reinforcement, but he included it among the postulates. He also speculated about what is necessary to establish a stimulus as a secondary reinforcer. The necessary condition was said to be pairing of the stimulus with primary reinforcement. It is interesting to note that secondary reinforcers are established through a Pavlovian procedure. Hull accepted Pavlov's claim of higher-order conditioning (using an established CS as if it were a US), and viewed it as equivalent to secondary reinforcement. The CS becomes a US, according to Hull, in the same way that a previously neutral stimulus becomes a reinforcer. It should be noted that what is learned under these circumstances is not a response but rather a new functional property of the stimulus.

Hull formulated another important principle of secondary or learned motivation. Hull's primary motivator was drive, but in addition he recognized a source of learned motivation, which he called "incentive." The phenomenon is best illustrated by the classic experiment of Crespi (1942). Crespi trained three groups of rats to run in an alley for food. Different groups received different amounts of reinforcement. One group received a single pellet of food in the goal box, the second group received 16 pellets, and the third group received 256 pellets, virtually a full day's ration. After twenty trials under these different conditions, the three groups evidenced very different levels of performance in the runway, as shown in the left part of Figure 6.2. At first, Hull (1943) suggested that such differences in behavior reflect differences in habit; more food means more reinforcement, which means a faster buildup of habit. But Hull changed his interpretation because of other results reported by Crespi. After the twentieth trial Crespi equalized the amount of reinforcement for all groups at sixteen pellets. As Figure 6.2 indicates, there were rapid changes in performance following the shift in amount of reinforcement, all groups quickly adopting a running speed that was appropriate to the new conditions. Notice that the shifts in performance of the 1-pellet and 256-pellet groups were much more rapid than the changes in performance in the original learning. Crespi therefore concluded that the amount-of-reinforcement variable does not affect learning (habit) but does affect performance through some kind of motiva-

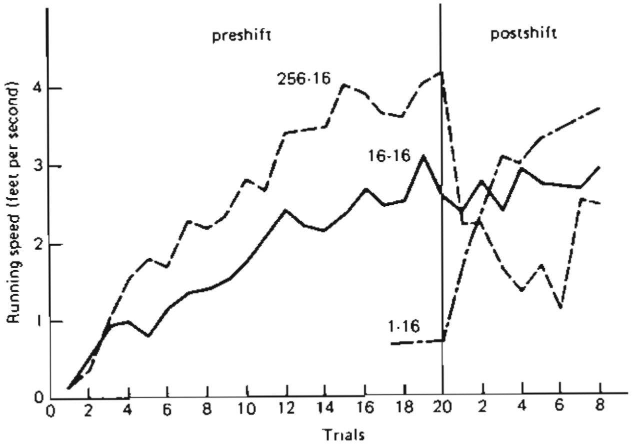

Fig. 6.2 The effect of giving rats different amounts of reward, either 1 or 16 or 256 pellets. Starting with the twentieth trial, all animals were given 16 pellets. (From Crespi, Quantitative variation of incentive and performance in the white rat, *American Journal of Psychology*, 1942, 55.)

tional variable. Hull (1952a) accepted Crespi's argument and designated with the symbol K a new construct, which he called "incentive motivation." Hull simply inserted K in the behavior equation, so that

$$\text{Behavior strength} = K \times D \times {}_SH_R \ldots$$

Hull now had two kinds of motivators, the old primary drive factor and the new secondary incentive factor. He also had, in effect, two kinds of learning: the primary S-R learning embodied in ${}_SH_R$ and the learning involved in establishing secondary reinforcers and incentive motivators. In the first instance it was clearly an S-R connection that was learned, but in the second what appeared to be learned was a new property of a previously neutral stimulus. Hull made everything consistent, however, by assuming that the secondary learning system was based upon the learning of a response—a special kind of response, to be sure, but still a response—which followed the same laws of learning that he had elaborated in the primary system. Hull's argument was that a unique response, such as eating, occurs in the goal box. This goal response, designated R_G, is assumed to become associated with the stimuli present in the goal box. This argument is very much like that noted in our discussion of Guthrie's interpretation of motivation. One difference was that Hull invoked drive reduction for the learning of all responses, including R_G, but the rest of the argument is the same.[2] Then, if other stimuli in the apparatus are similar to those present in the goal box, there will be a tendency for the goal response to generalize forward to other parts of the apparatus. Of course, there is no food anywhere except in the goal box, so the R_G cannot really occur. Certain fractional parts of R_G can occur, however. Specifically, responses such as salivation can occur anywhere in the apparatus. Hull designated this hypothetical response a "fractional anticipatory goal reaction." He expressed it r_G (pronounced "little ar-gee"). Thus r_G is elicited by stimulus generalization by stimuli similar to those present in the goal box where R_G occurs.

There is one more step to the argument. The occurrence of r_G was assumed to provide incentive motivation, which Hull designated with the symbol K. How can the occurrence of a response produce motivation? The answer in Hull's system is that r_G has stimulus consequences. The exact identity of these stimuli was never established, so that we must think of them as hypothetical. These stimuli are designated with a symbol s_G. The occurrence of r_G thus introduces a new stimulus, s_G, into the total stimulus pattern. Then this additional stimulus s_G could, like any stimulus, have the correct response associated with it. The rat thus runs in an alley, partly because running is associated with alley cues but also partly because alley cues produce r_G, which produces s_G, to which running is also associated. Hull's final explanation (1952a) of Crespi's experiment was that animals receiving a larger amount of food have a more vigorous r_G conditioned to the goal box (or perhaps have the same r_G conditioned more strongly). In either case, r_G will be more strongly elicited by alley stimuli, and there will be a more prominent s_G to provide additional stimulus support for running. It was this additional source of stimuli that Hull designated "incentive motivation," or K, and assumed to produce multiplication of D and H. When the amount of reinforcement was suddenly shifted in Crespi's experiment, a different r_G became rapidly conditioned to the goal-box stimuli so that different amounts of r_G and s_G were produced, and a different magnitude of K was generated.

The development of the r_G aspect of the theory, and indeed the whole secondary learning system, may seem unwarranted and unnecessarily complicated in view of the power and flexibility of the primary system. But during the 1950s a variety of facts began to be discovered that simply could not be dealt with in terms of the primary system alone. Much of the research reported earlier by Tolman and his students had also proved extremely embarrassing to S-R theory. The r_G mechanism provided a convenient if not very simple explanation of many of these findings. Consider again the latent-learning experiment in which rats performed poorly on the first few trials when there was no food in the goal box, and then showed a dramatic improvement in performance when food was introduced. Tolman had argued that learning had been occurring all along but that it became manifest in behavior only when the goal box contained an object for which the animal had a demand. Hull's explanation of the same data was that learning had indeed been occurring all along (we may note that there was some decline in errors by both the control animals and the experimental animals before the introduction of reward) but that, although ${}_SH_R$ had built up, performance was very poor because incentive motivation was so low. When the rat encountered food in the goal box, an appreciable amount of K was suddenly established, and it "multiplied" the previously established habit.

For another illustration of the incentive-motivation principle, con-

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[2] When Hull first developed the R_G concept in 1930, he believed in Pavlovian conditioning as a universal learning mechanism. But in 1943, when he had switched to drive-reduction reinforcement as the basis for all learning, he invoked this new mechanism for the explanation of R_G learning. At this point Hull had no use for a Pavlovian conditioning mechanism. He argued, for example, that the food used in a Pavlovian experiment was a drive reducer and might be expected to reinforce salivation, and produce learning in that manner. Later theorists, as we shall see in Chapter 8, have tended to follow Spence (1951) in returning to the older view that R_G is a classically conditioned response. It is said to be the pairing of goal-box cues with food that conditions R_G, and produces incentive motivation in the manner about to be described.

sider the place-learning versus response-learning experiment, in which rats trained to run from the south to the east for food continue to run to the east when they are tested from the north. Tolman had maintained that such behavior indicates that the animal has learned where food is and is simply going to the food place. Hull's interpretation was that during training, whenever the animal looks to the right (east), it will encounter stimuli, perhaps extramaze cues, like those present in the goal box, and that these stimuli will elicit r_G and produce s_G. Then, when the animal runs to the right and eats, this drive reduction will strengthen the running response to these s_G stimuli. Later, when the animal is tested starting from the north, it will again run to the choice point and look in both directions; when it looks to the left (east), these s_G stimuli are reinstated and they tend to control the behavior. In short, the r_G–s_G mechanism permitted the Hullian theorist to explain a variety of phenomena that could not be explained by the primary learning system alone.

Hull formulated an additional secondary learning mechanism. He postulated that a stimulus that is paired with drive will itself come to serve as a secondary source of drive. For example, a rat should become hungry if placed in a box where it has been hungry. It should become frightened if placed in a box where it has been frightened. Hull did not pursue the implications of this principle or do any research on it, but others did. During the 1950s an enormous amount of research was addressed to the idea of secondary or learned drive. The only instance in which the mechanism appeared to work as required by the theory was that of fear conditioning. But the results of these experiments were subject to a variety of interpretations and provided little support for the learned-drive concept. We shall consider this complex subject in more detail in Chapter 8.

Applications of the Theory

The 1943 version of Hull's theory was boldly proclaimed as a new scientific program and as a set of postulates to encompass all behavior. Recall that Hull's earlier research had been done with human subjects and that he had brought to his major theory-building efforts a background in human learning. Actually, his first attempt to build a formal mathematical model was related to human verbal learning (Hull *et al.*, 1940). But the research conducted during the 1940s to test Hull's 1943 theory was done almost exclusively with rats, and in 1952 Hull admitted that at that time his behavior system was probably applicable only to hungry rats. But few can resist the temptation to apply a limited system universally. All of our earlier theorists, and particularly their followers, were quite ready to extend their systems to the explanation of social behavior, abnormal behavior, developmental psychology, and the remotest frontiers of psychology. Much of the appeal and popularity of Hull's theory was no doubt due to the programmatic promise of handling problems in these far-flung areas, but its greatest success was in accounting for the data in the area in which its basic postulates had been derived: the study of the rat in the laboratory.

Hull's theory was designed to handle a much wider variety of learning phenomena than any prior theory had been. We have already seen applications of the theory to a number of behavioral phenomena, but two other basic phenomena must be mentioned. One is generalization. Hull treated generalization in terms of stimulus similarity, and he recognized that the question of similarity is basically a perceptual problem. But he also recognized that many perceptual problems can be dealt with quantitatively by using psychophysical techniques. In an early experiment Hovland (1937) had done psychophysical experiments with human subjects and had found that response strength varied in a systematic way (see Figure 6.3) with the distance of the test stimulus

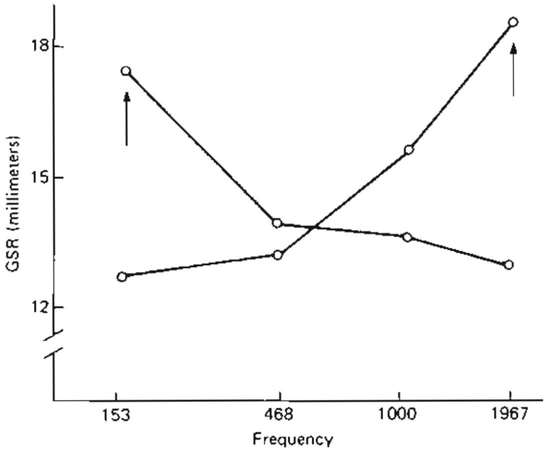

Fig 6.3 Amplitude of conditioned galvanic skin response (GSR) when tested with different frequency tones. The arrow indicates the frequency at which each group was initially conditioned. The frequencies were selected to be equally discriminable, but are plotted here on a logarithmic scale. (From Hovland, *The Journal of General Psychology*, 1937, *17*, 125—148, by permission of The Journal Press.)

from the training stimulus. The distance was measured psychologically in terms of just noticeable differences, that is, the number of detection thresholds, separating the stimuli. Thus, similarity did not have to be judged subjectively; it could be measured along particular physical dimensions, and generalization gradients could be derived from such measurements. In short, it was possible to provide a quantitative analysis of stimulus generalization along any stimulus dimension on which one cared to measure the generalization gradients. These gradients were assumed to be an intrinsic property of the sensory receptors.

Discrimination was easy to deal with in terms of the opposing $_SH_R$ and $_SI_R$ constructs (Spence, 1937). The $_SI_R$ builds up to the negative stimulus and generalizes throughout the stimulus dimension; $_SH_R$ builds up to the positive stimulus, and there will again be generalized habit strength to other stimuli along the stimulus dimension. The resulting strength of behavior is assumed to be the difference between the positive $_SH_R$ and the negative $_SI_R$ components. The scheme is illustrated in Figure 6.4.

Hull's Impact and Contribution

During the critical years of the 1930s and 1940s, when Hull was putting together and modifying his behavior system, he had the immense advantage of being the center of an extremely active and capable group of students and colleagues. He had the further advantage that many of these coworkers were more than willing to contribute generously to the broad enterprise that became known as Hullian theory. Even as these individuals matured and went their own ways and even as some of them came to develop their own strong theoretical convictions, their efforts continued to contribute to the enterprise. When Hull died there was a new generation of exceptionally able followers to carry forth the program he had started. These individuals tested his ideas, as well as their own, and continued to modify the basic postulates and refine the whole theoretical structure. Many of them had able students of their own who provided a third generation of Hullian or neo-Hullian theorists. Thus the enterprise that Hull began at Yale spread around the country in just a few years. Even psychologists who were not dedicated to Hullian theory itself found themselves caught up in such issues as the nature of reinforcement and the nature of incentive motivation.

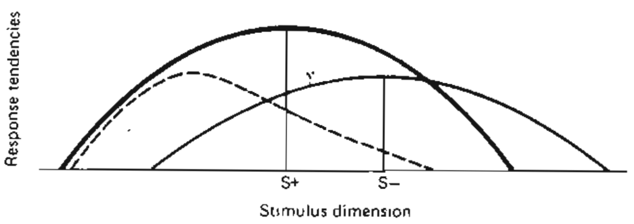

Fig. 6.4 Illustration of Spence's (1937) theory of generalization and discrimination. The higher, heavy line represents the tendency for the excitatory effects of training with S+ to generalize to other points on the stimulus dimension. The lower, lighter line represents the generalization of inhibition resulting from training with S−. The broken line, which is the difference between the two, represents the resulting tendency of the response to occur to different stimuli.

Space does not permit an analysis of all the work or all the issues involved, but we may survey some of the highlights. Some of the basic assumptions of Hull's 1943 theory had been anticipated by his colleagues. The importance of motivation as a codeterminant of behavior (along with habit) had been stressed by O. Hobart Mowrer. In two important theoretical papers Mowrer (1938, 1939) showed the inadequacy of a purely Pavlovian approach to learning, and he began to build a specialized theory of avoidance learning, an extremely challenging phenomenon that no one but the Hullians, and particularly Mowrer, was able to deal with at all adequately. In these same papers Mowrer had also urged that learning by reinforcement be substituted for learning by contiguity, which was still in vogue at that time. Mowrer began to part company with Hull in 1947 and continued to go his own way. He soon began to emphasize the importance of the secondary learning system, and in his 1960 book there was almost no vestige of Hull's original primary learning system.

In 1941 Neal Miller and John Dollard presented a systematic and comprehensive behavior theory that anticipated many features of Hull's 1943 system. The presentation was not as formal or as detailed and complex. The habit construct was essentially the same. The drive-reduction hypothesis of reinforcement was there, but drive was treated considerably differently, not as a separate kind of construct. According to Miller and Dollard, any strong stimulus can have motivating or drive properties without being tied to the needs of the organism. Complications such as inhibition and oscillation were missing from their theory. Extinction, for example, was explained by means of competing responses rather than by inhibition. This simplified version of, or preview of, Hull's theory was shown to have great potential applicability to human social learning (Dollard & Miller, 1950). In subsequent years Miller came to dominate both theory and research in the area of conflict (e.g., Miller, 1959). He, together with Mowrer, clarified and attempted to codify the difficult areas of learned drives and learned rewards (Miller, 1951). These developments are so important for understanding the subsequent history of learning theory that we will devote more space to them in Chapter 8. In the 1950s Miller turned his attention to the relationship between drive and need and the relationship between drive reduction and reinforcement. Much of his work on these problems is summarized in an important paper (Miller, 1957), in which he concludes that the drive-reduction hypothesis can be defended, provided that drive is not tied as closely as Hull tied it to biological needs. In more recent years Miller has focused his attention on the physiological bases of learning and motivation (Miller, 1969).

A few theorists have attempted to follow the principles that defined Hull's primary learning system. For example, Judson Brown (1961) defended the concept of drive, and with considerable success, but his definition of drive was somewhat different from Hull's original definition in that it was expanded to include learned sources of motivation, such as incentive. In recent years, however, most Hullian theorists have followed Mowrer in abandoning the primary learning system in favor of the secondary learning system.

The person who was mainly responsible for the early development of the secondary system was Kenneth Spence. In some important early papers Spence had contributed to the Hullian enterprise in such ways as analyzing discrimination learning (Spence, 1936, 1937) and clarifying the logic of the mathematical deductive approach (Spence, 1944). It was Spence who explicated the r_G theory of incentive motivation (Spence, 1951) and stressed the importance of secondary reinforcement (Spence, 1947). His last major theoretical statement (Spence, 1956) retains so much of the programmatic spirit and scientific philosophy that had characterized the Hullian enterprise that it constitutes, in effect, a final status report on Hull's theory. But at the same time Spence shifted the emphasis so much and broke so much new ground that his book stands apart from Hullian theory and perhaps marks the end of the era. For example, Spence gave a great deal of attention to such phenomena as amount of reinforcement and delay of reinforcement. Much of the relevant research had been done by his own students, and its explanation seemed to require the secondary learning system. The old $D \times H$ equation was of no use in describing these phenomena.

Hull's impact was immense. He was a hero in the heroic age of learning theorists. During the 1950s his ideas completely dominated the research literature. Thus he accomplished what he wanted to do, which was to generate research that would test his theoretical conjectures. Most of Hull's specific conjectures have now been shown to be wrong. But that is not important; what is important is that, because of Hull, we now know a great deal more than we used to.

References for Further Reading

Hull's major works, *Principles of Behavior* (1943) and *A Behavior System* (1952a) are tough going and require extraordinary commitment from the reader. His shorter works are more rewarding but typically present only part of the total theoretical system. Spence (1956) is the best spokesman for both his own and Hull's position on many theoretical issues, there is also an excellent analysis by Logan (1959). Their common philosophy of science is further described in several of Spence's collected papers (Spence, 1960). Hull's motivation principles are discussed in some detail by Brown (1961). For biographical material we are fortunate to have, first, an autobiographical chapter (Hull, 1952b) and, second, the "idea books," a sort of personal intellectual diary (Hull, 1962).

LEARNING THEORY

Second Edition

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