Level 1

Learning, Psychology of

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CONTENTS

In its psychological usage, 'learning' refers to the process by which an animal (human or non-human) interacts with its environment and becomes changed by this experience so that its subsequent behavior is modified.

INTRODUCTION

Procedures for Demonstrating Learning

0562.001 In order to demonstrate that learning has occurred, two observations of behavior must be made. There are two general procedures for doing this. In the first, a given individual is observed twice in the same situation, and if it behaves differently on the second occasion, we make the inference that that there has been some change in the organism. In order to make this inference it is necessary that the test situation be identical to the initial training situation – otherwise any change in behavior could just as well derive from a change in the external conditions as from a change in the organism itself.

0562.002 The change in the organism could occur as a consequence either of its initial experience of the training situation itself or of some experience that has occurred between the first observation of behavior and the second. An example of the former case is provided by the phenomenon of habituation in which, for example, the startle response evoked by a sudden loud noise is reduced in magnitude on the second presentation of the stimulus. We infer that the first presentation of the noise produced some change in the animal that caused it to respond differently to this stimulus on the second presentation. For an example of the latter case, consider the behavior of a student confronted with the question 'How is learning defined?' before and after reading this article. We may hope that the response to the question will be different on the two occasions and infer that the intervening activity (reading the article) has produced learning.

The second procedure is to compare the behavior of two individuals in a given test situation. Provided that they are matched in other respects, differences in their behavior may be attributed to differences between them produced by their differing individual experiences. Many of the individual differences exhibited by members of our own species are likely to be produced in this way, although the possible role played by genetic differences must also be taken into account. However, if two laboratory rats of the same genetic stock differ in (for example) their ability to perform a maze-running task when one has been raised in an enriched environment and the other has lived all its life in a standard cage, we may confidently attribute the difference in their behavior to learning. 0562.003

An advantage of this procedure is that evidence for learning can be obtained even when the test situation is quite different from that used in training. A disadvantage is that it is not possible to know in which of the animals being compared the learning has occurred – does enrichment enhance the performance of the rat, or does an impoverished environment produce a change that retards performance? (Although learning will often make an organism better able to deal with the demands of its environment, there is nothing in our definition that requires that this be so.) 0562.004

Qualifications

These basic definitions and procedures are subject to certain qualifications, of which the three most important are the following. 0562.005

Firstly, although the demonstration of learning requires a change in behavior, it is possible that a given experience might produce a change in the animal (i.e., produce learning) that is behaviorally silent under the conditions of the test. (A young child may learn from experience that the volume of a fluid is not changed when it is poured from one container to another, but may fail to show this 0562.006

when tested in the particular circumstances employed by the developmental psychologist.) The absence of a behavioral change cannot prove that no learning has occurred.

0562.007 Secondly, some changes in behavior, although undoubtedly a consequence of interaction with the environment, are not usually regarded as instances of learning. For example, a rat will press a lever for the reward of a food pellet less readily on the second occasion than on the first if, in the meantime, it has been given free access to food. Such a change in behavior is attributed to a change in motivation rather than to learning. It is difficult to specify a set of rules for distinguishing between these two sources of behavioral change, but it is widely accepted that the changes that constitute learning are more permanent (or, at least, less easily reversed) than those classified as motivational. Similar considerations apply to the short-term behavioral changes produced by muscular fatigue or adaptation of the sensory system.

0562.008 Thirdly, some of the changes in behavior shown by an individual over the course of its lifespan, although they satisfy the definition of learning offered above, are not usually regarded as such, but are attributed to a process of maturation. An example is the difference in behavior shown by a one-year-old when confronted with a flight of stairs and that shown by a two-year-old in the same situation. The input supplied by the environment over the intervening 12 months (even if it consists only of providing a good diet and the opportunity for exercise) is undoubtedly important in producing the change in the child that allows it to display enhanced stair-climbing ability. But whether this justifies our concluding that the ability has been 'learned' (in the sense in which we may say of an older child that he has learned to ride a bicycle) is a matter of debate.

EXAMPLES OF LEARNING

0562.009 In spite of these qualifications, the psychologist's use of the notion of learning is much wider than that of the layperson. The latter is likely to restrict usage to cases in which new information is acquired (as in learning the properties of the elements in the periodic table) or in which a new skill is acquired (as in learning to drive a car). Both of these are certainly examples of learning under our definition, but so are the examples listed below. The list is not intended to be exhaustive; rather, its purpose is to give an indication of the variety of learning phenomena that have been studied by psychologists. Most of the cases cited below are from controlled laboratory studies (often from studies conducted on animal subjects rather than people), but their relevance to everyday instances of learning will be obvious. (See A00476; A00496)

Habituation

The magnitude of the response initially elicited by 0562.010
the presentation of a given stimulus will decline with repeated presentations of that stimulus. We have already cited the waning of the startle response to a loud noise, but the effect is found in many other response systems (e.g., a rat given a novel food will initially decline to eat it, but this neophobic response will decline with repeated presentations of the food). Habituation effects are not to be attributed to muscular fatigue or sensory adaptation: other tests reveal that an animal that has undergone habituation can still detect the stimulus and is still capable of performing the motor response, so that this behavior change should be categorized as learning.

Pavlovian Conditioning

A dog (the experimental subject used by the Rus- 0562.011
sian physiologist Ivan Petrovich Pavlov in his early work on this phenomenon) given presentations of a neutral stimulus (such as the flashing of a light) immediately before the presentation of food will develop a tendency to salivate in response to the light. The light is then referred to as a conditioned stimulus (CS) and the response it evokes as a conditioned response. Food itself is an unconditioned stimulus (US), which, even without special training, is capable of evoking the unconditioned response (UR) of salivation. (See A00502; A00656)

The essential feature of this training procedure 0562.012
appears to be that the animal experiences paired presentations of two environmental events. Such pairings are effective in producing learning even when the detailed procedures used are very different from those used by Pavlov in his original studies. For example, a rat that experiences (experimentally induced) nausea after eating a novel food will develop a tendency to shun that food in the future (flavor aversion learning); a rat that experiences an electric shock while a tone is being sounded will develop a conditioned emotional response (showing freezing and other signs of fear) when the tone is sounded again.

These effects are not confined to laboratory 0562.013
animals – the phobias (strong, seemingly irrational

fears) exhibited by some people are plausibly interpreted as being the consequences of emotional conditioning that occurred early in life.

Instrumental (or Operant) Conditioning

0562.014 If a hungry rat happens to perform some action, such as pressing a lever, that results in the delivery of a pellet of food, its behavior will change so that the rate at which it performs this action will increase. This form of learning is referred to as conditioning, but it differs from Pavlovian conditioning in that the paired events are an action performed by the animal and an environmental event, rather than two environmental events. It is called ‘operant’ because the animal operates upon its environmentto produce an effect, or ‘instrumental’ because the animal’s behavior is instrumental in producing that effect.

0562.015 Other combinations of action and consequence will also produce learning. A response that removes the animal from a set of circumstances in which aversive events have previously occurred will tend to increase in frequency (a phenomenon known as avoidance learning); a response that is followed by an aversive consequence (as when a lever press produces an electric shock) will tend to decrease in frequency (a phenomenon known as punishment). The general principle underlying these forms of learning is that the likelihood of occurrence of a given form of behavior will be determined by the consequences that have followed that behavior in the past. Although the events that serve as rewards and punishments may be more subtle, it seems likely that much of our everyday behavior is governed by this principle – indeed, according to the American psychologist B. F. Skinner, operant conditioning is solely responsible for shaping all of the behavior that we conventionally refer to as ‘voluntary’. (See A00039)

Discrimination Learning

0562.016 In discrimination learning, the subject learns to respond in different ways to different stimuli. A pigeon that receives food after pecking at a green disk but not after pecking at a red disk shows this form of learning as it comes to choose the green exclusively. Human subjects show the same sort of ability when they are required to sort a pack of cards, putting all those that bear a triangle (say) into one pile and all those that bear a circle into another.

0562.017 The stimuli used in discrimination learning experiments may be much more complex than in these examples. In one study, pigeons were rewarded for pecking at each of 40 different pictures of oak leaves but not for pecking at pictures of other leaves. They not only solved the discrimination problem but also showed positive transfer when a new set of pictures of oak leaves replaced those used in initial training.

In this form of discrimination learning, the 0562.018
animal shows an ability to respond differentially according to the category to which the stimulus belongs. Category learning has been much investigated in our own species, for instance in studies of the way in which medical students become able to assign a particular disease name to the varying clusters of symptoms shown by individual patients. (See A00047)

Perceptual Learning

Expert wine tasters are said to be able to make fine 0562.019
discriminations (e.g., distinguishing, by taste, between the top and bottom halves of a bottle) that are impossible for the rest of us. This ability is learned, depending on long experience of the relevant stimuli. The facilitation of discrimination by prior exposure to the stimuli has also been shown in laboratory studies. In one experiment, rats were exposed for many days in their home cages to cut-out geometrical shapes (triangles and circles). No explicit training was given at this stage; but when subsequently the animals were required to learn a discrimination in which one shape was associated with food and the other not, they were able to learn the task very readily. Thus, mere exposure to stimuli can modify the way in which they are perceived, making similar events more discriminable. This phenomenon is known as perceptual learning. (See A00591)

Observational Learning

In one study, children were allowed to watch an 0562.020
adult behaving in an aggressive way towards a toy doll. Just watching was enough to produce learning, as was evidenced by the fact that the children subsequently repeated some of the actions of the adult and also behaved in a violent way to a range of other toys.

Learning by watching others may be a general 0562.021
phenomenon. An adult rhesus monkey confronted by a snake (or a model of one) will show a characteristic set of fear responses; these responses are not normally shown by a laboratory-raised infant. But if the infant is allowed to watch its mother show the

fear response, the infant will come to acquire the reaction.

0562.022 Imitation constitutes a special case of observational learning in which an observer acquires some new skill from watching it being exhibited by a more competent demonstrator. Young primates who learn how to tackle some novel food may do so by imitating their elders. To some extent their performance may simply reflect the fact that the behavior of the demonstrator has drawn the attention of the observer to the relevant food object; but when the observer is seen to make use of the specific pattern of movement used by the observer, true imitation may justifiably be inferred.

Verbal Learning

0562.023 For the experimental investigation of learning in people, words (written or spoken) provide a convenient stimulus material. Verbal learning has been extensively studied. (See A00635)

0562.024 A variety of procedures have been used. In the paired-associate procedure, the subject is exposed to a series of pairs of (usually unrelated) words. Learning is evidenced as the subject develops the ability to respond with the second word of the pair when presented just with the first.

0562.025 In serial list learning, the subject is presented with a string of, say, 12 words, each being exposed for a few seconds before the next takes its place. With sufficient training the subject will acquire the ability not only to recall the items in the list but to put them in the correct serial order.

0562.026 In one version of the procedure known as priming, subjects are presented in the training phase with a set of names of common objects. Later they are tested with questions for which the names of objects from the first list might be appropriate answers. Although the subjects may profess no memory of the original list, they are more likely to respond with an item from that list than are subjects not given the initial training (e.g., if 'ostrich' was in the first list they are likely to respond with this, rather than the more usual responses of 'canary' or 'sparrow', when asked to name a bird).

TYPES OF LEARNING

0562.027 We have distinguished the examples of learning listed above largely in terms of their procedural or descriptive characteristics. Although these distinctions may be pragmatically useful, we may ask whether the various examples can be understood in terms of a smaller number of basic 'types' of learning that differ at a more fundamental level (in the mechanisms that produce them). This question has been vigorously debated since the early twentieth century, and has yet to be fully resolved.

Associative Learning

An extreme view, espoused by Pavlov himself, is that there is only one type of learning: that the process revealed by the Pavlovian conditioning procedure lies at the heart of all other examples of learning. This process was regarded by Pavlov as involving association formation, i.e., the formation of a newly functional link between the brain center that responded to the conditioned stimulus (CS) and the center sensitive to the unconditioned stimulus (US). This link was assumed to allow presentation of the CS to evoke activity in the US center – and thus to evoke behavior appropriate to the US (e.g., salivation to a light that had previously been paired with food) – even in the absence of the US itself. 0562.028

Pavlor did not explain how such a process might result in, for example, the acquisition of a motor skill or the formation of a new concept; but in the absence of any well-specified alternative, it is difficult to rule out the possibility that the apparent complexity of these examples of learning might derive from the operation of a fundamentally simple associative mechanism. 0562.029

The strongest arguments against Pavlov's unitary view came from those psychologists who studied another, seemingly simple, example of learning in laboratory animals, namely, instrumental learning. The essential feature of this procedure – that learning depends on the effect produced by the response – appears to have no parallel in Pavlovian conditioning. It was argued, therefore, that the two forms of learning depended on fundamentally different mechanisms: reward-produced strengthening of the response, in the instrumental case, and association formation produced by the contiguous occurrence of two stimuli, in the Pavlovian case. It was further suggested that these two processes might operate selectively on different response systems: that Pavlovian conditioning works for simple reflex responses, whereas the modification of voluntary behavior depends on the instrumental learning process. 0562.030

The distinction has, however, proved difficult to maintain given more recent demonstrations of the instrumental conditioning of involuntary responses and of the fact that supposedly voluntary behavior (e.g., that shown by an animal in moving about its environment) can be modified by classical conditioning. The consensus now is that both are 0562.031

examples of associative learning, differing only in the nature of the events that become associated: two stimuli in the Pavlovian case; a response and its outcome in the instrumental case.

0562.032 The notion that associations form between events that co-occur (be they neutral stimuli, motivationally significant events such as the delivery of food, or patterns of behavior emitted by the animal) provides a powerful explanatory tool which can be applied not only to classical and instrumental conditioning but to several others of the examples of learning given above. In discrimination learning, for instance, when the pigeon chooses one stimulus rather than another, this may simply reflect the fact that one has become associated with food and the other with the absence of food. The observational learning shown by an infant monkey may be interpreted as the formation of an association between the originally neutral stimulus and the aversive state engendered by the sight of its mother in distress.

0562.033 In general, the fact that so many examples of learning involve presenting the animal with conjunctions of events makes the associative principle a plausible candidate for the explanation of all of them. But there remain examples in which learning occurs after exposure to just a single event (the most obvious cases are habituation and priming, but perceptual learning is also relevant here). It is difficult to see how associative mechanisms could be responsible for the behavior change seen in these procedures. We may therefore need to acknowledge the existence of at least two types of learning: associative learning (by which the animal learns what goes with what) and a nonassociative form of learning that allows the animal to learn something about the characteristics of an event to which it is exposed.

Implicit and Explicit Learning

0562.034 Another distinction between different types of learning (which cuts across the distinction between associative and nonassociative learning) has recently been the subject of much attention. This is the distinction between explicit and implicit learning. When normal adult humans learn, they can often report the results of their learning verbally (they can tell you that, as a result of experience, they know that canaries are birds or that fire is hot). Sometimes they can report the details of a particular learning episode (they can tell you what they did on their twenty first birthday). But not all learning is explicit in this way. Some people who have suffered damage to certain parts of the brain seem unable to acquire new facts or recall recent events from their everyday life. But although they may deny all knowledge of the episodes responsible, they are still capable of some forms of learning: they will show improvement when given practice at a new motor skill (e.g., learning to trace a pattern that is viewed only in a mirror); and they are sensitive to standard conditioning procedures (e.g., they will tend to blink to a neutral stimulus that has been paired with a puff of air to the eye). (See A00550)

Implicit learning phenomena are not confined to 0562.035
amnesic patients. The phenomenon of priming, described above, is a laboratory-based example. But anyone who practises a motor skill (as when learning to ride a bicycle) is likely to show an improvement from one session of training to the next while remaining largely unaware of the changed patterns of muscular coordination that produce the improvement (try explaining to a beginner exactly what he needs to do to ensure that the bicycle remains upright). And much of the learning that occurs as we acquire our native language remains implicit. Given a set of word strings we are usually able to distinguish those that are permitted by the rules of the language (those that are grammatical) from those that are not, even when we cannot specify the formal rules that justify the distinction. The learning of so-called artificial grammars may involve the same process. For example, people may be exposed to strings of letters that appear random but are in fact constrained by certain rules (e.g., when a J occurs it must always be followed by a V or an X, W can never be followed by itself). The subjects are not told these rules, and indeed are incapable of stating them, but nonetheless they prove able to make correct categorizations of new instances. (See A00384; A00267)

The importance of the distinction between impli- 0562.036
cit and explicit learning remains a matter of debate. One problem with the distinction is that it rests on the observation that the experimenter is unable to obtain from the subjects a verbal statement of what they have learned. Such a failure might be the fault of the experimenter rather than of the subject. Recent work has shown that in some cases more subtle interrogation will allow subjects to make explicit information that simpler questions (and the subject's own initial introspection) fail to reveal.

Secondly, even if it could be firmly established 0562.037
that some forms of learning produce changes that are truly implicit, this would not necessarily imply that the mechanisms involved are fundamentally different from those involved in explicit learning. We would still want to know why some of our

memories are available to the conscious mind and some are not, but the difference between them might have no bearing on the nature of the physiological or psychological processes by which memories are formed.

MECHANISMS OF LEARNING

Neural Mechanisms

0562.038 The changes that constitute learning almost certainly occur in the animal's nervous system; and one approach to investigating mechanisms of learning is to try to determine the nature of the neural processes involved. The dominant hypothesis (put forward by the eminent neuropsychologist D. O. Hebb in 1949 on the basis of very little evidence) has been that learning consists of a change in the properties of synapses (the structures by which one nerve cell makes contact with another). Hebb's proposal was that experience might render a nonfunctional synapse functional, so that activity in one nerve cell would become capable of inducing activity in another. (See A00455; A00354; A00431)

0562.039 Recent work, principally on the simple forms of learning (e.g., Pavlovian conditioning) exhibited by invertebrates, has confirmed the validity of Hebb's conjecture, at least for the cases studied. In the mollusc *Aplysia*, the sensory neuron (nerve cell) that is sensitive to a touch on a structure known as the siphon makes a synapse with the motor neuron responsible for contraction of the gill. A light touch on the siphon is not usually enough in itself to excite the motor neuron and evoke the response. But pairing the touch with a more effective stimulus (a shock to the tail) produces a change in the synapse (a phenomenon known as presynaptic facilitation) so that a light touch now produces more neurotransmitter and gill contraction occurs. (See A00433)

0562.040 An effect known as long-term potentiation provides evidence of synaptic plasticity in the mammalian brain. This phenomenon concerns the case in which two neurons (*A* and *B*) both have synapses with a third (*C*). Strong activation of one input (say *A*) will produce a near-permanent increase in the sensitivity of *C* to this input; and if *B* is activated (even if only weakly) at the same time as *A* is being strongly activated, the potentiation effect will spread to *B* so that it to will become more able to evoke activity in *C*. Direct links between this neural process and overt behavior have yet to be established; but there is a clear parallel with Pavlovian conditioning, which also depends on pairings of two stimuli, only one of which is initially capable of evoking the target response. (See A00395; A00432)

A Conceptual Nervous System

Although our knowledge of the neural mechanisms 0562.041
responsible for learning is still very incomplete, the psychological analysis of the phenomenon is relatively advanced. Such analysis proceeds by studying, usually in contrived laboratory preparations, how the nature of what an animal learns, and how readily this learning occurs, can vary according to conditions manipulated by the experimenter. It is possible to make deductions about the mechanisms that must be operating in order to produce the behavioral data obtained. The aim is to provide a specification of what has sometimes been called a 'conceptual nervous system'. The properties of this system will, it is hoped, be consistent with what we know about the functioning of the real nervous system; but the specification is usually given in rather general terms, as a high-level design for a machine that could just as readily be made of silicon and copper wire as of nervous tissue.

In fact, there is a widely-accepted picture of the 0562.042
conceptual nervous system that fits very well with what we know of the functioning of the real nervous system. Many psychologists, who have approached the study of learning from a variety of different perspectives, have converged on the view that the mechanism responsible for learning should be viewed as consisting of a large set (a network) of interconnected units. Units may be inactive, or they may be activated to varying degrees, and activity in one unit will engender activity in another unit with which it has a functional connection. Learning is held to consist of changes in the strengths of connections, and thus of changes in the ease with which one unit can modulate activity in its neighbor. Within this scheme, the psychological analysis of learning consists in determining the nature of the units, their pattern of connections, and, most importantly, specifying the factors that determine how connection strengths will change.

These general principles (often referred to as 0562.043
connectionism) have been applied with some success to a wide range of cognitive phenomena that involve complex information processing. But an appreciation of how they work may best be obtained by considering a simple form of learning such as Pavlovian conditioning. Pavlovian conditioning involves pairings of a CS with a US that

evokes a UR. We begin by postulating sensory units, which are activated by presentation of the appropriate stimuli, and an output unit, whose activity generates the response. The US unit must be assumed to be unconditionally connected to the UR unit. The acquired ability of the CS to evoke a response is taken to indicate the formation of a new functional connection. The obvious hypothesis that a connection is formed between the CS unit and the UR unit has not been supported by experiments: conditioning has been demonstrated when the training conditions are such as to preclude the occurrence of the UR. This and other observations have led to the conclusion that Pavlovian conditioning reflects the formation of a connection that allows activity in the CS unit to engender activity in the US unit. (See A00033; A00068)

0562.044 Other cases of conditioning require an associative structure more complex than the 'two units, one link' structure that serves for simple acquisition. For example, animals given training in which the US is paired with a compound stimulus (*A* and *B* presented together) along with separate presentations of *A* and *B* that are not accompanied by the US, will learn to respond just to the compound and not to the individual stimuli. One possible explanation of this accomplishment assumes a structure in which the units sensitive to presentations of *A* and *B* have connections with a third unit, which is activated when it receives inputs from both *A* and *B* (i.e., when the compound is presented). The strengthening of a connection between this third unit and the unit representing the US allows the animal to learn the discrimination and show a response to the compound stimulus. The presence of such hidden units (which are not directly activated by environmental events, but serve a purely computational function) greatly increases the explanatory power of the associative network. Networks employing such units have been applied to complex learning phenomena, such as category learning, with some success. (See A00009)

Laws of Association

0562.045 The proposal that experience can produce changes in the strengths of the connections between units is central to the idea of this conceptual nervous system. Therefore, for a proper account of the mechanisms of learning we need to be able to state the conditions under which such changes will occur. A version of this question has engaged the minds of philosophers for several centuries; and they have proposed a variety of possible laws of association (principles determining the readiness with which one idea is able to 'call up' another). Examples include the law of contiguity (the principle that events that occur together in time and space will become associated) and the law of similarity (the principle that similar events are more likely to become associated than dissimilar events). Experimental study of these proposals has made use of simple learning preparations (particularly of Pavlovian conditioning) in which the nature and timing of the events to be associated can be easily manipulated. The magnitude of the response evoked by the CS is used as an index of the strength of the association that is formed under various conditions.

Conditioning experiments have largely con- 0562.046
firmed the importance of contiguity. The conditioned response develops most readily when the CS and the US are presented close together. This supports the assumption that an excitatory connection will be strengthened when the units representing these stimuli are active concurrently. But contiguity may be neither necessary nor sufficient for learning to occur.

That contiguity may not be necessary for associ- 0562.047
ation formation is illustrated by the fact that in flavor aversion learning, nausea induced several hours after an animal has tasted a novel food will be effective in establishing some measure of aversion to that food. But whether this observation constitutes a fundamental challenge to the contiguity principle is not clear. Conditioning is readily established in more orthodox procedures when there is a short delay (of a second or two) between the CS and the US; and this observation is readily explained by supposing that the activity induced in the CS unit will persist for some time after the CS itself has ended. There is no reason why the same analysis should not be applied to the case of flavor aversion learning. Admittedly, the residual activity in the unit representing the taste of food is likely to be at a rather low level after an hour or so; but if there is any activity at all (and it is difficult to see how an association could be formed if there were not), then the principle of contiguity can be maintained.

It should be noted, however, that such long- 0562.048
delay learning is readily obtained only with certain combinations of events (such as taste and nausea – indeed, it is difficult to establish any association at all with nausea as the US when the CS is an exteroceptive cue such as the sounding of a tone). The special ability of taste and nausea to become associated even over a long delay may indicate that another principle, in addition to the contiguity

principle, is operating in this case. One hypothesis is that events concerned with maintaining the internal state of an animal have special propensity to become associated, thus allowing a taste unit that is only weakly activated to form a strong association with the nausea unit. No mechanism that might be responsible for this propensity has been specified. It may be an example of the more general principle that associations form with particular ease when the events to be associated are similar.

0562.049 That contiguity is not sufficient to produce association formation is well supported by experimental evidence from a variety of procedures. Two examples will be given here. In one experiment, rats were given presentations of a CS that was followed with a certain probability, by the US; pairings occurred often enough that a conditioned response was established, indicating that the association had been formed. Other rats received the same treatment except that, for them, further presentations of the US occurred in the interval between CS presentations. The probability of occurrence of the US was the same in the absence of the CS as in its presence. Rats in the latter condition (who received the same number of CS–US pairings as those in the former condition) did not acquire the conditioned response.

0562.050 The second example comes from a procedure, much studied in recent years, known as blocking. In this, the subject is initially given training in which one CS (*A*) is paired with the US. The subject then receives a further phase of training in which a second CS (*B*) is added, and the compound (*A* and *B*) continues to be paired with the same US. A final test, in which *B* is presented alone, reveals that this stimulus will not evoke the conditioned response: apparently no *B*–US association is formed in these circumstances, in spite of the fact that the subject has been exposed to contiguous presentations of the two events a number of times during the second phase of training.

0562.051 These two examples seem to show that contiguity is not enough: that conditioning will occur only when the CS supplies information about the likelihood of occurrence of the CS. In the first example, learning fails to occur in the condition in which the US is as likely to occur when the CS is absent as when it is present; in the second, the subject fails to learn about a stimulus that supplies no new information about the likelihood that the US will occur (this being fully predicted by the presence of the pretrained stimulus, *A*).

0562.052 One possible specification of the mechanisms responsible for these effects was proposed by the psychologists R. A. Rescorla and A. R. Wagner in the early 1970s. They accepted that an associative link between CS and US units will be formed when contiguous presentation of these events evokes activity of some sort in the relevant units. They went on to point out that the formation of the link means that presentation of the CS will be able to evoke activity in the US unit in advance of the occurrence of the US itself. Further strengthening of the link, they suggested, will be a function of the discrepancy between the level of activity evoked in the US node by the associative connection and that engendered by the application of the US itself.

This simple discrepancy principle (sometimes called the 'delta rule') proves to have wide explanatory powers. Its application to the phenomenon of blocking runs as follows. In the initial phase of training a strong connection is formed between the unit representing CS *A* and the US unit. This connection continues to be effective during the compound (*A* and *B*) trials, and thus fully activates the US unit during these trials. When *B* is presented, therefore, there is no discrepancy between the level of associatively produced activity and the level of activity produced by the US itself, and no connection involving CS *B* is established. 0562.053

The essence of associative learning is that initially the organism does not know what the outcome of a given event will be but that with training it comes to do so. Once the relationship is well established there is no need for further learning. The Rescorla–Wagner principle provides a very simple mechanism by which associative learning may be achieved. It has been very widely accepted. This principle (or some version of it) has been a fundamental feature of all subsequent connectionist theories, and has allowed the successful application of these theories to a wide range of learning phenomena. It remains to be established whether these associative mechanisms can be extended to apply (as some psychologists have argued) to all instances of learning. 0562.054

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Glossary

Association A link between two entities that allows activity in one to generate or modify activity in the other.

Instrumental learning A procedure for generating associative learning in which a motivationally significant event is made contingent on the emission of a response.

Neuron A nerve cell, the unit from which the nervous system is built.

Paired-associate learning A procedure in which the subject is presented with pairs of words during training and is then required to respond with the second when given just the first.

Pavlovian conditioning An associative learning procedure in which two stimuli, a conditioned stimulus (usually neutral) and an unconditioned stimulus (usually of motivational significance), are paired.

Perceptual learning Enhancement of discriminability of a stimulus produced by exposure to that stimulus.

Rescorla– Wagner rule Also called the delta rule, a rule for adjusting the strength of an association which takes into account the discrepancy between the current strength of the association and the strength finally to be attained.

Synapse A junction between nerve cells across which activity can pass on the release of a neurotransmitter substance.

Keywords: (Check)

conditioning; association; connectionism; delta rule

1. ‘Procedures for Demonstrating Learning’, 3rd paragraph, 2nd to 4th sentences, ‘Provided that they are matched … attribute the difference in their behavior to learning.’: The implication (of the word ‘however’) here seems to be that there is a contrast between change due to ‘differing individual experiences’ and change due to ‘learning’. But the definition given of learning seems to identify it precisely with change due to experience. Please clarify.
2. ‘Laws of Association’, 5th paragraph, 1st sentence, ‘…the likelihood of occurrence of the CS’: Should this be ‘…the likelihood of occurrence of the US’?

Publisher Queries ECS Article 562

1. A-headings do not match cover sheet.