Chapter Title: Stimulus Relations in Pavlovian Conditioning

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Stimulus Relations in Pavlovian Conditioning

Did you know that

- delaying the unconditioned stimulus (US) a bit after the start of the conditioned stimulus (CS) produces stronger evidence of conditioning than presenting the CS and US simultaneously?
- a gap of just half a second between the CS and US can seriously disrupt excitatory fear conditioning?
- taste aversions can be learned with a delay of several hours between the conditioned and unconditioned stimuli?
- CS–US contiguity is neither necessary nor sufficient for Pavlovian conditioning?
- different CS–US contingencies produce different levels of conditioned responding because of differences in the conditioning of contextual cues?
- organisms learn both positive and negative signal relations between CS and US? Positive signal relations result in conditioned excitation and negative signal relations result in conditioned inhibition.
- in addition to binary excitatory and inhibitory CS–US associations, organisms can also learn hierarchical relations in which one stimulus signals that a second CS will be paired (or unpaired) with the US? Such hierarchical relations are revealed in positive and negative occasion-setting tasks.

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In Chapter 4, we discussed Pavlovian conditioning as a type of learning that involves establishing an association between two stimuli, the conditioned and the unconditioned stimulus (CS and US, respectively). For two stimuli or events to become associated with one another, they have to be related to each other in some way. In the present chapter, we consider various relations that can exist between a CS and US. We also explore how different stimulus relations determine what is learned in Pavlovian conditioning.

TEMPORAL RELATION BETWEEN CS AND US

Historically, the most prominent relation in Pavlovian conditioning is the temporal relation between the CS and US—when in time the stimuli occur relative to each other. In thinking about various temporal arrangements that are possible between a CS and a US, consider a railroad crossing on a roadway. Railroad crossings have flashing lights that indicate that a train is about to arrive. In this example, the flashing lights are the CS, and the train crossing the road is the US.

Common Conditioning Procedures

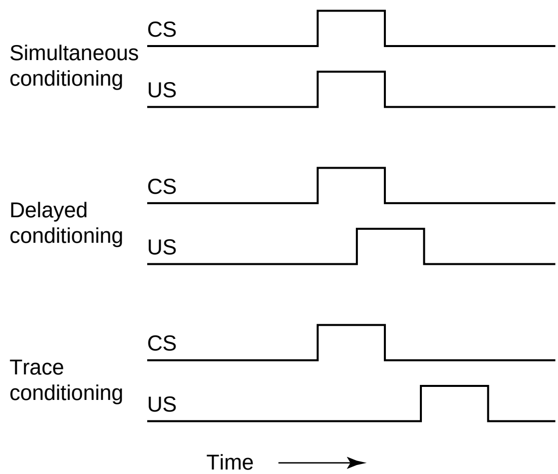
The influence of the temporal relation between a CS and a US on the development of conditioned responses has been studied using a variety of conditioning procedures. Some of the more common ones involve presenting the CS and US simultaneously, presenting the CS just before but overlapping with the US, and presenting the CS before the US but with a period of time elapsing between CS offset and US onset. As we will see in this section, these subtle procedural differences can have drastic effects on the emergence of new conditioned responses to the CS, and this fact is one of the basic ones that theories of Pavlovian learning ultimately need to address.

Simultaneous Conditioning

Perhaps the simplest temporal arrangement is the presentation of a CS with a US at the same time. Such a procedure is called **simultaneous conditioning** and involves perfect **temporal contiguity**, or coincidence, between CS and US (see the top panel of Figure 5.1). Because simultaneous conditioning brings the CS as close as possible to the US, one might presume that it would be the most effective temporal relation to produce conditioned responding. Surprisingly, there is little evidence that conditioned responding develops to a simultaneously trained CS. For example, simultaneous conditioning does not produce an eyeblink response to the CS (M. C. Smith et al., 1969).

Using the railroad crossing analogy, with simultaneous conditioning, the flashing lights would start when the train was already going through the road crossing. In this case, the flashing lights would not provide any new or predictive information about the arrival of the train. You could not avoid getting hit by the train by responding to the flashing lights. Thus, simultaneous conditioning does not lead to an anticipatory conditioned response. However, some

FIGURE 5.1. Procedures for Simultaneous, Delayed, and Trace Conditioning



Note. One conditioning trial (involving a presentation of the conditioned stimulus and unconditioned stimulus) is shown for each procedure. In a typical experiment, the conditioning trial is repeated until evidence of learning develops.

investigators have managed to obtain evidence of simultaneous conditioning using more complex test strategies (e.g., Matzel et al., 1988; Rescorla, 1980).

Delayed Conditioning

Most of the evidence for associative learning comes from a type of procedure in which the CS starts shortly before the US on each trial (Schneiderman & Gormezano, 1964). Such a procedure is called **delayed conditioning** because the US is delayed after the start of the CS (see middle panel of Figure 5.1). Notice that in the delayed conditioning procedure, the CS remains until the US occurs, without a gap between the stimuli. Common measures of conditioning (conditioned eyeblink, sign tracking and goal tracking, and conditioned freezing) reflect the anticipation of the US and are readily observed with a delayed conditioning procedure.

Warning signals at railroad crossings typically employ a delayed conditioning procedure. The flashing lights begin before the train arrives at the crossing, enabling you to anticipate that the train will be there soon. The most effective delayed conditioning procedure is one in which the CS begins shortly before the US. Unfortunately, this is often not the case with railroad crossings. The lights begin to flash a while before the arrival of the train, not immediately before the train arrives. This encourages people to cross the tracks quickly before the train shows up. The use of a shorter interval between the signal and the arrival of the train would discourage such risky behavior.

Trace Conditioning

Introducing a gap between the CS and the US changes a delayed conditioning procedure into **trace conditioning**. A trace conditioning trial is illustrated in the bottom panel of Figure 5.1 for contrast with the delayed conditioning trial shown in the middle panel. The gap between the CS and the US is called the **trace interval**.

Using our railroad crossing example, a trace conditioning procedure would be one in which the flashing lights ended 5 or 10 seconds before the train arrives. If you knew that the flashing lights would end before the train arrived, you would be less likely to stay off the tracks when the lights started flashing. Rather, you would avoid the tracks when the flashing lights ended.

Introducing a gap or trace interval between the CS and the US can drastically reduce the degree of conditioned responding that develops. In an early experiment on fear conditioning, Kamin (1965) found that introducing a trace interval of as little as a half a second significantly reduced the level of conditioned responding that occurred. Since the work of Kamin (1965), investigators have found stronger evidence of trace conditioning in a variety of learning situations. Trace conditioning is of considerable interest because it requires a process that bridges the gap in time between the CS and the US. Such a time-bridging process in not required for delayed conditioning.

Investigations of the neural bases of learning have been particularly interested in trace conditioning because trace conditioning is usually mediated by different neural mechanisms than delayed conditioning. In a pioneering study using functional magnetic resonance imaging in human participants, Knight et al. (2004) found that trace conditioning activates many of the same brain areas as delayed conditioning but trace conditioning also recruits several additional brain regions, including the hippocampus. Investigators are continuing to examine the neural circuitry and neurobiology of trace conditioning in a range of species including the fruit fly (Grover et al., 2022; Raybuck & Lattal, 2014; J. J. Siegel et al., 2012).

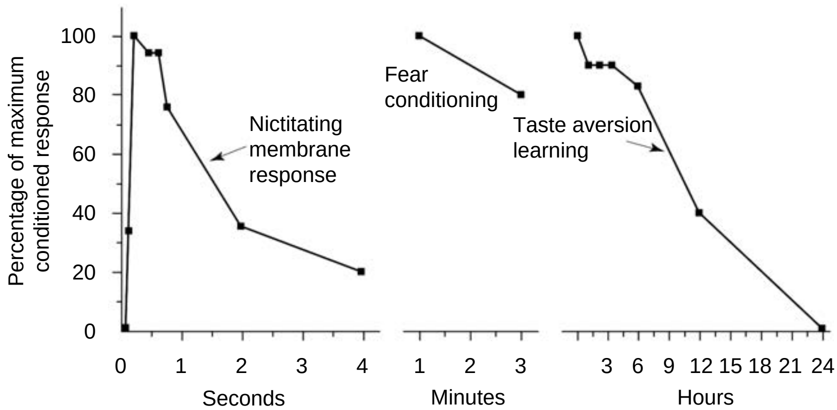
Effects of the CS–US Interval

Another temporal relation that is critical for associative learning is how much time passes between the start of the CS and the presentation of the US on each conditioning trial. The interval between when the CS begins and when the US is presented is called the **CS–US interval** or the **interstimulus interval**.

As we noted earlier, in many conditioning situations, there is little evidence of learning with simultaneous conditioning, where the CS–US interval is zero. Conditioned responding is more likely with delayed conditioning procedures, where the CS–US interval is greater than zero. However, the benefits of delaying the US after the start of the CS are limited. As the CS–US interval becomes longer and longer, evidence of learning declines. How rapidly responding declines as the CS–US interval is increased depends on the response system that is being conditioned.

Figure 5.2 illustrates the effects of the CS–US interval in three conditioning preparations. The left panel represents data from conditioning of the nictitating membrane response of rabbits. The nictitating membrane is a secondary

FIGURE 5.2. Strength of Conditioned Responding as a Function of the Conditioned Stimulus–Unconditioned Stimulus Interval



Note. Strength of conditioned responding as a function of the conditioned stimulus–unconditioned stimulus interval in conditioning the nictitating membrane response of rabbits (data from Schneiderman & Gormezano, 1964; M. C. Smith et al., 1969), fear conditioning (i.e., **conditioned suppression**; data from Kamin, 1965), and taste aversion learning (data from J. C. Smith & Roll, 1967).

eyelid present in many species. Like closure of the primary eyelid, closure of the nictitating membrane can be elicited unconditionally by a puff of air to the eye. The best results in conditioning the nictitating membrane response are obtained with CS–US intervals of 0.2 to 0.5 second. If the CS–US interval is shorter, less conditioned responding develops. Moreover, conditioned responding drops off quickly as the CS–US interval is extended past half a second. Little if any learning is evident if the CS–US interval is more than 2 seconds (Schneiderman & Gormezano, 1964).

Fear conditioning represents an intermediate case. The strongest fear is learned with a CS–US interval that is less than a minute, but learning can also occur with CS–US intervals in the range of 2 to 3 minutes (Kamin, 1965).

Learning over the longest CS–US intervals is seen in taste aversion learning. In the conditioned taste aversion procedure, the ingestion of a novel flavored food (or drink) results in some form of illness or interoceptive distress (Lin et al., 2017; Reilly & Schachtman, 2009). The novel flavor is the CS, and the illness experience serves as the US.

A taste aversion can be learned even if the illness experience is delayed several hours after ingestion of the novel flavor. This phenomenon was first documented by John Garcia and his associates (e.g., Garcia et al., 1966) and is called **long-delay learning** because it represents learning with CS–US intervals that are a great deal longer than the intervals that will support eye-blink or fear conditioning. However, as Figure 5.2 illustrates, even with taste aversion learning, less conditioned responding is observed with longer CS–US intervals.

Encoding When the US Occurs

The differences in learning that occur between simultaneous, delayed, and trace conditioning and the CS–US interval effects we just described illustrate that Pavlovian conditioning is highly sensitive to time factors. A growing and impressive line of evidence indicates that participants learn a great deal about the precise time when the US is presented in relation to the CS. This type of learning is called **temporal coding** (Molet & Miller, 2014). Evidence of temporal coding indicates that Pavlovian conditioning involves more than a simple linkage or "association" between the CS and the US representations in the brain. Rather, Pavlovian conditioning involves learning precise information about when USs occur relative to other events in the environment. In fact, some have suggested that this type of temporal learning is more central to what occurs in Pavlovian conditioning than the familiar concept of a CS–US association (Balsam et al., 2010). Whether or not this view is correct, the more general question of precisely how temporal coding is best conceptualized continues to be an exciting area of contemporary research.

Drivers who cross a railroad track when the lights at the crossing begin to flash are demonstrating temporal coding. They have learned not only that the flashing lights are associated with the train's arrival, but also how long the lights are on before the train actually arrives. As noted earlier, knowledge of the timing of the train's arrival encourages drivers to sneak across the tracks if the lights have not been on very long. Unfortunately, the learning of precise temporal information takes a bit of practice. At a railroad crossing, inadequate temporal learning can have fatal consequences.

SIGNAL RELATION BETWEEN CS AND US

In the previous section, we described some of the ways in which the temporal relation between the CS and US is important in Pavlovian conditioning. In the late 1960s, three investigators (Kamin, Rescorla, and Wagner) independently identified several learning phenomena that all questioned the centrality of temporal contiguity between CS and US as the main driver of Pavlovian learning—blocking (Kamin, 1969), contingency (Rescorla, 1967, 1968), and relative cue validity (Wagner et al., 1968). Collectively, these three phenomena, and their subsequent theoretical analyses, dramatically changed how we view associative learning. In short, the new approach emphasized that conditioned responding develops with procedures in which the CS provides reliable "information" about the occurrence of the US, cases in which the CS serves as a reliable "signal" for the US. Here we describe two of these important phenomena in more detail.

In the typical delayed conditioning procedure, each conditioning trial consists of the CS, followed shortly by the presentation of the US. Furthermore, the US does not occur unless it is preceded by the CS. Thus, occurrences of the US can be predicted perfectly from occurrences of the CS. The CS signals occurrences of the US perfectly, resulting in rapid acquisition of a conditioned response to the CS.

The Blocking Effect

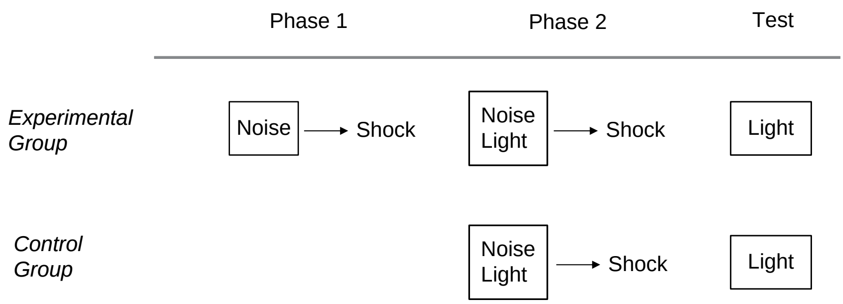
How might the signal relation between the CS and US be disrupted? One way is to present the target CS with another cue that already predicts the US. If there is another cue that already predicts the US, the target CS will be redundant, and you may not learn much about it. If one of your passengers has already pointed out to you that your car is about to run out of gas, a similar warning from a second passenger is redundant and is less likely to command much of your attention. This idea, first developed experimentally by Leo Kamin, has come to be known as the **blocking effect** (Kamin, 1969).

Kamin studied the blocking effect using a fear conditioning procedure with laboratory rats, but the phenomenon may be illustrated more effectively with a hypothetical example of human taste aversion learning. Let us assume that you are allergic to shrimp and get slightly ill every time you eat it. Because of these experiences, you acquire an aversion to the flavor of shrimp. On a special occasion, you are invited to a private dinner by your pastor, and the main course is shrimp served with a steamed vegetable you don't remember eating before. Because you don't want to offend your host, you eat some of both the vegetable and the shrimp. The vegetable tastes pretty good, but you develop a stomachache after the meal.

Will you attribute your stomachache to the shrimp or to the new vegetable you ate? This is basically a credit-assignment problem. Which food (the vegetable or the shrimp) should be credited as the cause of your stomachache? Given your history of bad reactions to shrimp, you are likely to attribute your malaise to the shrimp and may not acquire an aversion to the vegetable. In this situation, the presence of the previously conditioned shrimp blocks the conditioning of the novel vegetable even though the novel vegetable was just as closely paired with the illness US.

The blocking effect shows that what individuals learn about one CS is influenced by the presence of other cues that were previously conditioned with the same US. The conditioned stimuli Kamin used in his seminal experiments were a light and a broadband noise (see Figure 5.3). For the blocking group, the noise CS was first conditioned by pairing it with foot shock enough times to produce strong conditioned fear to this auditory cue. In the next phase of the experiment, the noise and light CSs were presented simultaneously, ending in the shock US. A control group also received the noise–light compound paired with shock, but for this group, the noise had not been previously conditioned. For the control group, the noise and light were both novel stimuli in Phase 2. The focus of the experiment was on how much fear became conditioned to the novel light CS. Because of the prior conditioning of the noise in the blocking group, less conditioned fear developed to the light in the blocking group than in the control group.

FIGURE 5.3. Diagram of the Blocking Procedure in a Conditioned Suppression Experiment



Note. During Phase 1, a noise conditioned stimulus (CS) is conditioned with foot shock in the experimental group until the noise produces maximum conditioned suppression. The control group does not receive a conditioning procedure in Phase 1. In Phase 2, both groups receive conditioning trials in which the noise CS is presented together with a novel light CS, and the noise–light compound is paired with shock. Finally, during the test phase, responding to the light presented alone is measured. Less conditioned suppression occurs to the light in the experimental group than in the control group.

The blocking effect is important because it illustrates that temporal contiguity between a CS and a US is not sufficient for successful Pavlovian conditioning. A strong signal relation is also important. The temporal relation between the novel light CS and the shock US was identical for the blocking and the control groups. Nevertheless, strong conditioned fear developed only if the light was presented with a noise stimulus that was not previously paired with shock. The prior conditioning of the noise reduced the signal relation between the light and shock and that disrupted fear conditioning to the light.

The procedure diagrammed in Figure 5.3 has resulted in disruptions of the conditioning of the added cue (the light in this example) in numerous experiments. However, as with other learning phenomena, the results depend on procedural details. In the blocking design, the critical procedural details concern when and where the added cue (the light) occurs in relation to the previously conditioned stimulus (the noise) when both of those stimuli are presented in Phase 2 of the experiment (Urcelay, 2017). These complications notwithstanding, the Kamin blocking effect has become one of the major learning phenomena that all contemporary theories of learning strive to explain. We consider some of those theories in Chapter 6.

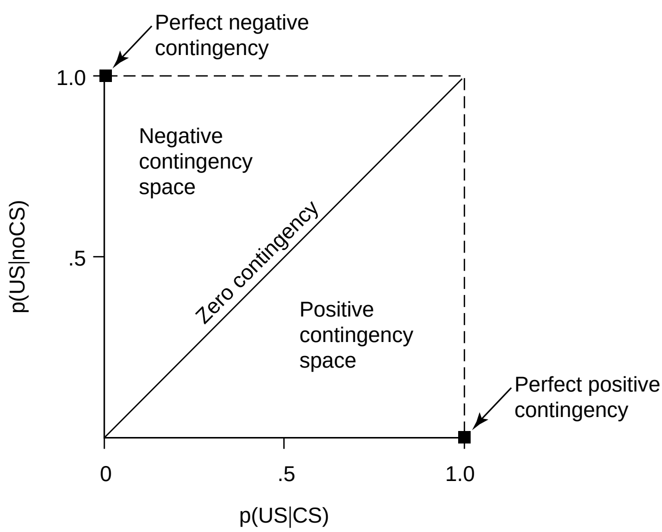
CS–US Contingency

Historically, an important approach to characterizing the signal relation between a CS and US has been in terms of the contingency between the two stimuli (Rescorla, 1967, 1968). The **contingency** between two events is a formal characterization of the extent to which the presence of one stimulus can serve as a basis for predicting the other. It is similar to the concept of a correlation, but the CS–US contingency is defined in terms of two probabilities (see Figure 5.4). One of these is the probability that the US will occur given that the CS has been presented [p(US|CS)]; the other is the probability that the US will occur given that the CS has not happened [p(US|noCS)].

A situation in which the US always occurs with the CS and never by itself illustrates a perfect positive contingency between the CS and US. Smoke, for example, always indicates that something is burning. Therefore, the presence of the US (fire) can be predicted perfectly from the presence of the CS (smoke). In contrast, a situation in which the US occurs when the CS is absent but never occurs on trials with the CS illustrates a perfect negative contingency. In this case, the CS signals the absence of the US. If you use sunblock when you are at the beach, you are likely to avoid the sunburn that you would otherwise get from spending a day at the beach. The sunblock signals the absence of an aversive sunburn. Finally, if the US occurs equally often with and without the CS, the CS–US contingency is said to be zero. When the contingency between the CS and US is zero, the CS provides no useful information about whether the US will occur. This is the case if a dog barks indiscriminately whether or not there is an intruder present. A zero CS–US contingency is also characteristic of the random control procedure we described in Chapter 4.

Originally, the contingency between a CS and US was thought to determine the formation of CS–US associations directly. Since then, it has become more common to consider CS–US contingency as a procedural variable that

FIGURE 5.4. Contingency Between a Conditioned Stimulus (CS) and an Unconditioned Stimulus (US)



Note. Contingency between a CS and US is determined by the probability of the US occurring given that the CS has occurred (represented on the horizontal axis) and the probability of the US occurring given that the CS has not occurred (represented on the vertical axis). When the two probabilities are equal (the 45° line), the CS–US contingency is zero.

predicts how much conditioned responding will develop. Contemporary analyses of contingency effects have focused on conditioning of the background cues that are present in any situation in which an organism encounters repeated presentations of discrete conditioned and unconditioned stimuli. Procedures involving different CS–US contingencies result in different degrees of context conditioning.

Consider, for example, a procedure involving a zero CS–US contingency. Such a procedure will involve presentations of the US by itself, presentations of the CS by itself, and occasional presentations of the CS together with the US. The US-alone trials can result in conditioning of the background or contextual cues in which the experiment is conducted. The presence of these conditioned background contextual cues may then block future conditioning of the explicit CS on those few occasions when the CS is paired with the US (Tomie et al., 1980) or disrupt performance of conditioned responding through a comparator process, which we describe in Chapter 6.

NEGATIVE SIGNAL RELATIONS IN PAVLOVIAN CONDITIONING: CONDITIONED INHIBITION

In the examples of Pavlovian conditioning we have discussed thus far, the focus was on how a CS is directly related to a US (i.e., on learning excitatory CS–US associations). Now let us turn to the opposite stimulus relation, where the CS comes to signal the absence of the US, known as learning inhibitory CS–US associations. This requires us also to consider some of the special procedures used to establish and measure conditioned inhibition.

Inhibitory Conditioning Procedures

The first negative signal relation that was extensively investigated was **conditioned inhibition**, which is when the CS becomes a signal for the absence of the US. Concepts of inhibition are prominent in various areas of physiology. Being a physiologist, Pavlov was interested not only in processes that activate behavior but also in those that are responsible for the inhibition of responding. This led him to investigate conditioned inhibition. He considered conditioned inhibition to be just as important as **conditioned excitation**, which is when the CS becomes a signal for the impending presentation of the US (Pavlov, 1927).

Conditioned inhibition only occurs under special circumstances because ordinarily the absence of something has no particular psychological significance. If a friend tells you out of the clear blue that they have decided not to give you a thousand dollars, you are not likely to be upset because you had no reason to expect that they would give you that much money. If the absence of something is not psychologically meaningful, a CS cannot become a signal for that nonevent. For successful inhibitory conditioning, the absence of the US has to be made salient or important.

We can make you disappointed in not getting a thousand dollars by telling you that you had been entered into a sweepstakes contest and had been selected as the winner of a thousand-dollar prize. The absence of something is psychologically powerful if you have reason to believe that the event will take place. In inhibitory conditioning procedures, the absence of the US is made salient by excitatory conditioning that creates a positive expectation that the US will occur. Later in the chapter, we describe in more detail two of the more popular methods for producing conditioned inhibition, although other procedures have also been explored (e.g., Rescorla, 1969).

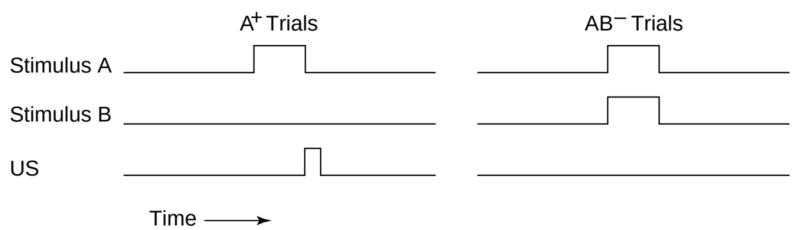
The Standard Conditioned Inhibition Procedure

The standard conditioned inhibition procedure (sometimes called Pavlovian conditioned inhibition) is analogous to a situation in which something is introduced that prevents an outcome that would otherwise occur. A red traffic light at a busy intersection is a signal of potential danger (the US). However, if a police officer in the intersection indicates that you should cross the intersection despite the red light (perhaps because the traffic lights are malfunctioning), you will probably not have an accident. The red light and the gestures of the officer together are not likely to be followed by danger. The gestures inhibit or block your hesitation to cross the intersection because of the red light.

The standard conditioned inhibition procedure involves two conditioned stimuli (A and B) and a US (see Figure 5.5). In the example of a malfunctioning traffic light, stimulus A was the red traffic light and stimulus B was the police officer's gesture for you to cross the intersection. In laboratory experiments, stimulus A might be a light, stimulus B a tone, and the US a brief shock. On some trials, stimulus A is paired with the US. These trials are represented as A^+ (A plus), with the plus sign indicating pairings with US. As a result of the A^+ trials, the participant comes to expect the US when it encounters stimulus A. This sets the stage for inhibitory conditioning.

On inhibitory conditioning trials, stimulus B is presented with stimulus A (forming the compound stimulus AB), but the US does not occur. These trials are represented as AB^- (AB minus), with the minus sign indicating the absence of the US. The presence of stimulus A on the AB^- trials creates the expectation

FIGURE 5.5. The Standard Procedure for Conditioned Inhibition



Note. On A^+ trials, stimulus A is paired with the unconditioned stimulus (US). On AB^- trials, stimulus B is presented with stimulus A, and the US is omitted. The procedure is effective in conditioning inhibition to stimulus B.

that the US will occur. This makes the absence of the US psychologically meaningful and serves to condition inhibitory properties to stimulus B.

Typically, A^+ and AB^- trials are presented in an intermixed order in the standard inhibitory conditioning procedure. As training progresses, stimulus A gradually acquires conditioned excitatory properties, and stimulus B becomes a conditioned inhibitor (Campolattaro et al., 2008). Generally, the excitatory conditioning of A develops faster than the inhibitory conditioning of B because inhibitory conditioning depends on the prior learning of a US expectation.

Negative CS–US Contingency

The standard inhibitory conditioning procedure (A^+, AB^-) is especially effective in making B a conditioned inhibitor, but there are other successful inhibitory conditioning procedures as well. In the **negative CS–US contingency** procedure, for example, only one explicit CS is used (e.g., a tone), together with a US (see Figure 5.6). The tone and the US occur at irregular times, with the stipulation that the US is not presented if the tone has occurred recently. This stipulation establishes a negative contingency between the tone CS and the US. It ensures that p(US|CS) will be less than p(US|noCS) and serves to make the CS a conditioned inhibitor.

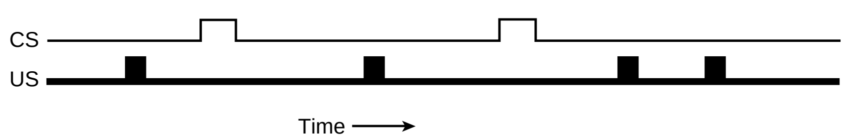
Consider a child who periodically gets picked on by his classmates when the teacher is out of the room. This is similar to periodically getting an aversive stimulus or US. When the teacher returns, the child can be sure that he will not be bothered. The teacher thus serves as a CS^-, signaling a period free from harassment. The presence of the teacher signals the absence of the US.

What provides the excitatory context for inhibitory conditioning of the tone CS in the negative contingency procedure? Because the US occurs when the CS is absent, the background contextual cues of the experimental situation become associated with the US. This then enables the conditioning of inhibitory properties to the CS. The absence of the US when the CS occurs in this excitatory context makes the CS a conditioned inhibitor. In this sense, the negative contingency procedure can be thought of as a special case of the standard A^+, AB^- procedure described earlier, but where A, in this case, is the experimental context.

Behavioral Measurement of Conditioned Inhibition

The behavioral manifestations of excitatory conditioning are fairly obvious. Organisms come to make a new response—the conditioned response—to the

FIGURE 5.6. Negative Contingency Procedure for Producing Conditioned Inhibition



Note. The unconditioned stimulus is presented at random times by itself but not if the conditioned stimulus has occurred recently.

CS. What happens in the case of conditioned inhibition? A conditioned inhibitory stimulus has behavioral effects that are the opposite of the behavioral effects of a conditioned excitatory cue. A conditioned inhibitor suppresses or inhibits excitatory conditioned responding. Unfortunately, special procedures are often required to see this response suppression.

Consider, for example, the eyeblink response of rabbits. Rabbits blink very infrequently, perhaps once or twice an hour. A conditioned inhibitory stimulus (CS^-) actively suppresses blinking. But because rabbits rarely blink under ordinary circumstances, the suppression of blinking during a CS^- is difficult to detect.

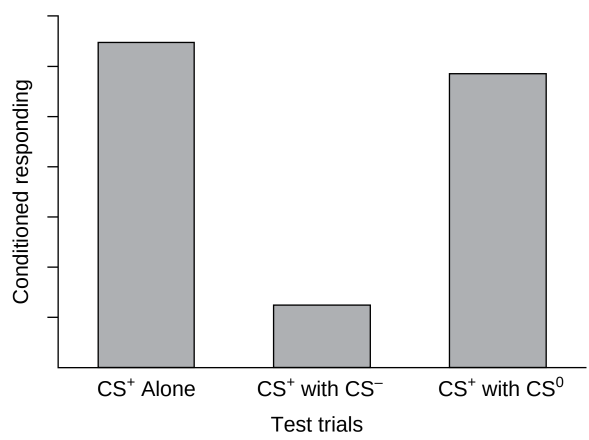
Summation Test of Inhibition

Inhibition of blinking would be easy to determine if the baseline rate of blinking were elevated. If rabbits blinked 60 times an hour and we presented a conditioned inhibitory stimulus (CS^-), blinking should decline substantially below the 60 per hour rate. Thus, the problem of measuring conditioned inhibition can be solved by elevating the comparison baseline rate of responding.

How can the baseline rate of responding be elevated? Perhaps the simplest way is to condition another stimulus as a conditioned excitatory cue (CS^+). Substantial responding should be evident when this new excitatory cue (CS^+) is presented by itself. Using this as a baseline, we can test the effects of a conditioned inhibitory stimulus (CS^-) by presenting the CS^- at the same time as the CS^+. Such a test strategy is called the **summation test** for conditioned inhibition.

Figure 5.7 presents hypothetical results of a summation test. Notice that considerable responding is observed when the CS^+ is presented by itself. Adding a conditioned inhibitory stimulus (CS^-) to the CS^+ results in a great deal less

FIGURE 5.7. Procedure and Hypothetical Results for the Summation Test of Conditioned Inhibition



Note. On some trials, a conditioned excitatory stimulus (CS^+) is presented alone, and a high level of conditioned responding is observed. On other trials, the CS^+ is presented with a conditioned inhibitory stimulus (CS^-) or a neutral stimulus ($CS°$). The fact that CS^- disrupts responding to the CS^+ much more than $CS°$ is evidence of the conditioned inhibitory properties of the CS^-.

responding than when the CS^+ is presented alone. This is the expected outcome if the CS^- has acquired inhibitory properties. However, presentation of the CS^- might disrupt responding simply by creating a distraction. This possibility is evaluated in the summation test by determining how responding to the CS^+ is changed when a neutral stimulus with no history of either excitatory or inhibitory training is presented. Such a neutral stimulus is represented by $CS°$ in Figure 5.7.

In the results depicted in Figure 5.7, $CS°$ reduces responding to the CS^+ a little. This reflects the distracting effects of adding any stimulus to the CS^+. The reduction in responding is much greater, however, when the CS^- is presented with the CS^+. This outcome shows that the CS^- has acquired conditioned inhibitory properties (Cole et al., 1997; Tobler et al., 2003).

Retardation-of-Acquisition Test of Inhibition

The summation test is a performance-based test of inhibition. The basic assumption is that the performance of excitatory conditioned behavior will be suppressed by a conditioned inhibitory stimulus. A second popular approach to the measurement of conditioned inhibition is an acquisition or learning test. This test assumes that once a stimulus has become a conditioned inhibitor, it will be more difficult to turn that stimulus into a conditioned excitatory cue. Conditioned inhibitory properties should slow down the subsequent acquisition of excitatory properties to that same stimulus. Hence this is called the **retardation-of-acquisition test**.

The retardation-of-acquisition test involves comparing the rates of excitatory conditioning for two groups of participants. The same CS (e.g., a tone) is used in both groups. For the experimental group, the tone is first trained as a conditioned inhibitor. For the comparison group, a control procedure is used during this stage that leaves the tone "neutral." In the second phase of the experiment, the tone is paired with the US for both groups of participants, and the development of excitatory responding is measured. If inhibitory conditioning was successful in the first stage of the experiment, excitatory conditioned responding should develop more slowly in the experimental group than in the control group during the second stage. Traditionally, the summation and the retardation-of-acquisition tests were used in combination to develop evidence of conditioned inhibition (Rescorla, 1969). In contemporary research, the use of both tests has given way to relying primarily on an appropriately controlled summation test in studies of conditioned inhibition (e.g., Austen et al., 2022; Harris et al., 2014).

HIERARCHICAL STIMULUS RELATIONS IN PAVLOVIAN CONDITIONING: POSITIVE AND NEGATIVE OCCASION SETTING

Not all signal relations in Pavlovian learning are between two events. In hierarchical stimulus relations, the focus of interest is on how one CS provides information about the relation between a second CS and the US. Thus, the term **hierarchical stimulus relation** refers to the signaling or modulation of a simple CS–US pairing by another CS. The adjective *hierarchical* is used because one of the elements of this relation is a CS–US associative unit.

One hierarchical stimulus relation that has been the focus of much research is the **conditioned facilitation**, or **positive occasion setting**, procedure. This procedure is illustrated in Figure 5.8. In this example, a light (L) is paired with food but only when the L–Food trial is itself preceded by the presentation of a tone (T). T is said to "set the occasion" for the pairing of the light with food. With this procedure, whether the light elicits a conditioned response will depend on whether L is preceded by T. More conditioned responding will occur to L if it is preceded by T than if it occurs alone. Thus, T comes to facilitate responding to the light (Fraser & Holland, 2019; Schmajuk & Holland, 1998).

The hierarchical stimulus relation captured by the facilitation procedure is not limited to experimental research. When you enter your favorite restaurant, the smell of the food does not guarantee that you are about to eat something delicious. The odor CS is not invariably paired with food. The odor–food pairing only occurs after you order the food. Thus, ordering the food sets the occasion for the odor CS to be paired with the food and thereby facilitates conditioned responding to the odor.

Occasion setting also occurs in aversive conditioning situations. Consider the road sign "Slippery When Wet." The sign indicates that ordinarily the road is safe but that it can be dangerous when it is wet. These circumstances exemplify the basic occasion–setting relation. In this example, the road is ordinarily safe to drive, and cues of the road are not paired with anything dangerous. However, if it is raining, the same road cues can result in an accident or injury. The rain sets the occasion for the pairing of roadway cues with possible injury.

Associations Learned in a Positive Occasion Setting or Facilitation Procedure

Procedures used to produce hierarchical associations are complex and can result in a number of associations. Each of the conditioned stimuli (L and T) can become associated directly with the food US. In addition, a hierarchical relation can be established between T and the L–Food association, signified as T–(L–Food). The major challenge in studying facilitation is to sort out what

FIGURE 5.8. Outline of a Positive Occasion Setting or Facilitation Procedure

Trials with a US	Trials without a US
T → L → Food	L → No Food

Note. A light conditioned stimulus (L) is paired with food if it is preceded by a tone (T) but not if the light occurs without the tone. T facilitates responding to L or sets the occasion for L being paired with food.

aspect of conditioned behavior reflects L–Food and T–Food associations and what aspect reflects the hierarchical T–(L–Food) association.

Types of Conditioned Responses Elicited by Stimuli L and T

One way to sort out which type of association is responsible for the conditioned behavior that occurs in a facilitation experiment is to use conditioned stimuli that generate different conditioned responses. This approach was used extensively in many of the early studies of facilitation in appetitive conditioning (Holland, 1992).

Rats, for example, rear in response to a light that has been paired with food but they show a head-jerk response to a tone paired with food (Holland, 1977). Consider, then, what might occur with a facilitation procedure that consists of a mixture of trials with T→L→Food and L→no–Food. An L–Food association will result in rearing when L is presented on a test trial. If T has come to signal the L–Food association, the rats should show increased rearing to the light if L is announced by presentation of the tone. Notice that this facilitated rearing cannot be attributed to an association of the T with food because a T–Food association produces a head-jerk conditioned response, not a rearing response.

Another strategy for isolating the hierarchical T–(L–Food) association as the source of facilitated responding to L involves using background or contextual cues as the occasion-setting stimulus in place of a tone. Organisms typically do not respond to background or contextual cues with any easily measured responses. However, participants can learn to approach a localized visual CS in the context of one set of background stimuli but not another (Leising et al., 2015).

A particularly interesting category of contextual or background cues is provided by drugs that change how you feel. Research has shown that subjective sensations created by various drugs can serve as occasion-setting stimuli that indicate whether a target CS will (or will not) be paired with food (Bevins & Murray, 2011). In these studies, some experimental sessions are conducted after the rats have been injected with a drug, and other sessions are conducted in the absence of the drug. During drug sessions, a light may be paired with food. During nondrug sessions, the light CS is presented periodically but not paired with food (see Figure 5.9). The typical outcome is that the drug state facilitates the food-conditioned responding to the CS light.

Effects of Extinction of Stimulus B

An alternative strategy for distinguishing between simple associative and hierarchical relations in a facilitation (or positive occasion-setting) procedure

FIGURE 5.9. Outline of a Facilitation Procedure in Which a Drug State Serves as the Higher Order Stimulus Indicating When a Light Is Paired With Food

Drug State	Neutral State
Light ⟶ Food	Light ⟶ No Food

Note. The drug state acts as a positive occasion setter for the Light–Food relation such that more conditioned responding occurs to Light in the drug state relative to the neutral state.

involves testing the effects of extinguishing the facilitating cue. Extinction of T, in our example in Figure 5.8, involves repeatedly presenting stimulus T by itself (T–no-US) after facilitation training has concluded. Presenting stimulus T without the US is contrary to a T–US relation and reduces responding that depends on that relation. (We have more to say about extinction in Chapter 10.) However, the repeated presentation of stimulus T by itself is not contrary to its hierarchical T–(L–US) relation. The opposite of T–(L–US) is T–(L–no-US), not T–no-US. Therefore, extinction of stimulus T should not disrupt responding mediated by the hierarchical T–(L–US) relation.

Numerous studies have shown that extinction of an occasion setter or hierarchical stimulus (T) does not reduce the effectiveness of T in modulating responding to a target stimulus L (e.g., Holland, 1989; Leising et al., 2015; Rescorla, 1985). In fact, the lack of sensitivity of facilitation and occasion setting to extinction of the hierarchical stimulus is considered one of the signature characteristics of occasion setting.

We should point out that organisms do not invariably learn a hierarchical T–(L–US) relation with positive occasion-setting (facilitation) procedures. A critical factor is whether T and L are presented sequentially (as illustrated in Figure 5.8) or simultaneously on food trials. With simultaneous presentation of T and L, participants may learn to associate T with food directly and not respond to T as a signal for occasions when L is paired with food (Baeyens et al., 2001; Fraser & Holland, 2019). In other words, the rat displays a head jerk CR on TL–food trials and no CR on L-alone trials, indicating that it had simply learned a T–Food association.

Associations Learned in a Negative Occasion Setting Procedure

Another hierarchical learning procedure is **negative occasion setting**. In this task, one stimulus indicates when another stimulus will not be paired with the US. For example, in Figure 5.10 L–US trials are intermixed with T–L–no-US trials. In this case, T is thought to act in a hierarchical way on the L–US association. Notice that this procedure is very similar to the standard conditioned inhibition procedure that we discussed earlier. The difference is that in the standard conditioned inhibition procedure, the inhibitory cue is presented simultaneously with another CS that is otherwise paired with the US when presented alone (e.g., L^+, TL^-). Conditioned inhibition is thought to result in learning a direct inhibitory CS–US association (e.g., T signals no US).

FIGURE 5.10. Outline of a Negative Occasion Setting or Inhibition Procedure

Trials with a US	Trials without a US
L → Food	T → L → No Food

Note. A light conditioned stimulus (L) is paired with food if it is presented by itself but not if it is preceded by a tone (T). T signals when L will not be paired with food and therefore serves as a negative occasion setter and inhibits responding to L.

However, in a negative occasion-setting procedure, T precedes L on T–L–no US trials. As was true of positive occasion setting, this small procedural change results in a large change in what the organism learns. In this case, T acts hierarchically on the L–US relation by suppressing it.

Notice that in a negative occasion-setting procedure, the occasion setter (T in Figure 5.10) is never paired with the US. What would happen if after negative occasion-setting training, the negative occasion setter (T) was directly paired with the US? Interestingly, such separate pairings of the negative occasion setter with the US do not undermine its ability to suppress responding to its target stimulus (Fraser & Holland, 2019). Had the negative occasion setter become a simple conditioned inhibitor, it should have lost that ability once it was converted into an excitatory stimulus after negative occasion-setting training. This line of evidence indicates that negative occasion setting is distinct from a simpler CS–no-US inhibitory association.

SUMMARY

Pavlovian conditioning involves the formation of an association or connection between two events. Typically, the events are individual stimuli, the CS and the US. However, in more complex cases, one of the events may be an occasion-setting stimulus, and the other is a CS–US associative unit. These cases represent hierarchical relations.

The development of conditioned responding is highly sensitive to the temporal relation between the CS and the US. Delayed conditioning procedures produce the most vigorous responding. Introducing a trace interval of as little as half a second between the CS and US can severely disrupt the development of conditioned behavior. Conditioned responding is also a function of the CS–US interval, but the precise quantitative relationship depends on the response system that is being conditioned.

Pavlovian conditioning also depends on the signal relation between the CS and the US—the extent to which the CS provides information about the US. This is illustrated by the blocking phenomenon and by CS–US contingency effects. Originally, variations in the contingency between CS and US were considered to influence associative processes directly. More recent evidence suggests that different degrees of context conditioning are responsible for CS–US contingency effects.

Simple signal relations in Pavlovian conditioning can be positive or negative. Excitatory CS–US associations are thought to characterize learning of positive signal relations, whereas inhibitory CS–US associations are thought to characterize negative signal learning. In conditioned inhibition procedures, the conditioned inhibitor (CS^-) signals the absence of the US and inhibits conditioned responding that normally occurs to a CS^+. It is also often slow to be converted into an excitatory CS in a retardation-of-acquisition test.

Hierarchical signal relations also occur in Pavlovian conditioning and have been investigated within the context of positive and negative occasion-setting tasks. In positive occasion setting (or conditioned facilitation), the hierarchical stimulus (T) is presented before and indicates when another cue (L) is paired with the US. The outcome is that conditioned responding to L is facilitated by first presenting T. Evidence that the results reflect learning a hierarchical relation [T–(L–US)] often involves information about the topography of the conditioned response to T and L and/or the effects of extinguishing stimulus T. In negative occasion setting, the hierarchical stimulus (T) is presented before and indicates that another cue (L) is not paired with the US. Whether learning reflects binary or hierarchical associations often depends on subtle differences in the procedures employed.

SUGGESTED READINGS

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TECHNICAL TERMS

hierarchical stimulus relation, page 77
conditioned facilitation, page 77
positive occasion setting, page 77
negative occasion setting, page 79

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