13

Stimulus Control of Behavior

Did you know that

- even simple stimuli have many features or elements? Which stimulus feature controls behavior is identified by how responding varies with changes in that stimulus feature.
- control of behavior by a conditioned stimulus often generalizes to other, similar stimuli?
- stimulus generalization and stimulus discrimination are complementary concepts?
- generalization of behavior from one stimulus to another depends on the individual's training history with those stimuli?
- discrimination training produces differential responding and increases the precision of stimulus control?
- equivalence training leads to responding in a similar manner to physically different stimuli?
- stimulus equivalence training is highly relevant to the learning of vocabulary words, and, more generally, to concept learning tasks?

Throughout this book, we have seen various aspects of behavior that are controlled by antecedent stimuli and other environmental events. Elicited behavior and responding that result from Pavlovian conditioning are obvious examples.

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Instrumental behavior can also be regarded as responding that occurs because of the presence of an antecedent stimulus. As we saw in Chapter 7, an antecedent stimulus may activate the instrumental response directly, or it may do so indirectly by activating a representation of the reinforcing outcome or the response–reinforcer relation.

Strong stimulus control is a critical feature of appropriate or normal behavior. Hugging someone is an appropriate instrumental response, under some circumstances, and is reinforced by social approval if the individual is a close personal friend or family member. Hugging strangers is not appropriate and may get you slapped in the face. For a teacher to hug a student may also be inappropriate and may result in disciplinary action. These examples illustrate that whether an instrumental response is reinforced depends on the stimulus situation in which the response occurs. Taking a candy bar off the shelf and putting it in your pocket is fine if you are at home, but you are bound to get in trouble if you do the same thing at the corner store.

Clearly, much of learned behavior occurs because of the presence of particular stimuli or environmental events. Up to this point, however, our discussion of learning has left two critical issues about the stimulus control of behavior unanswered. The first concerns the measurement of stimulus control: How can we determine whether a specific stimulus or feature of the environment is responsible for a particular response and how closely is the behavior tied to that stimulus feature? Once we know how to measure differences in stimulus control, we can tackle the second issue, which concerns the determinants of stimulus control. What factors determine which stimuli will gain control over a particular response and the degree or precision of the stimulus control that is achieved?

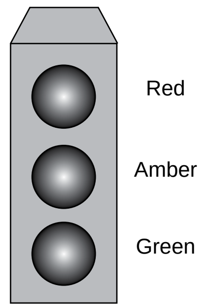
MEASUREMENT OF STIMULUS CONTROL

Questions about stimulus control arise in part because of the complexity of environmental events. Even something as simple as a traffic light is a complex stimulus with multiple features. The red light in a traffic light has a specific color, brightness, shape, and position. How do we figure out which of these stimulus features is critical in controlling the behavior of a driver? Once a stimulus feature has been identified, how do we figure out the degree of precision involved in the control of behavior by that stimulus feature?

The fundamental strategy for determining whether a response is controlled by a particular stimulus is to see if variations in that stimulus produce corresponding changes in the response. A response is said to be under the control of a particular stimulus if the response is altered by changes in that stimulus. A change in responding related to changes in a stimulus is called **differential responding**. We can identify which stimulus feature is responsible for the target behavior by seeing if changes in that stimulus feature cause changes in responding.

Traffic lights are often arranged in a vertical array, with the red light on top and the green light on the bottom (see Figure 13.1). Which feature is important,

FIGURE 13.1. Stimulus Features of Traffic Lights



Note. The lights differ in both color and position.

the color of the light or its position? Do drivers stop when they see a red light, or do they stop when the light on top is illuminated? To determine whether the color is critical, we have to test red and green lights presented in the same position. To determine whether the position is important, we have to test lights of the same color in different positions.

When we vary one feature of a stimulus while keeping all others constant, we are testing the importance of a particular **stimulus dimension** for the behavior in question. Different stimulus dimensions may be important for different drivers. Drivers who are color-blind and cannot easily identify the color red have to focus on the position of the illuminated light. Other drivers may respond primarily to the color of traffic lights. Still others may respond to both the color and the position of the light. Thus, substantial individual differences in stimulus control may occur in the same situation.

Determining whether a particular stimulus feature is important is the first step in the analysis of stimulus control. The next question is how precisely is the behavior tuned to a particular stimulus feature? Continuing with the traffic light example, let us assume that a driver stops whenever he sees a red traffic light. What shade of red does the light have to be? To answer this question, we would have to test the driver with a range of colors, including several shades of red.

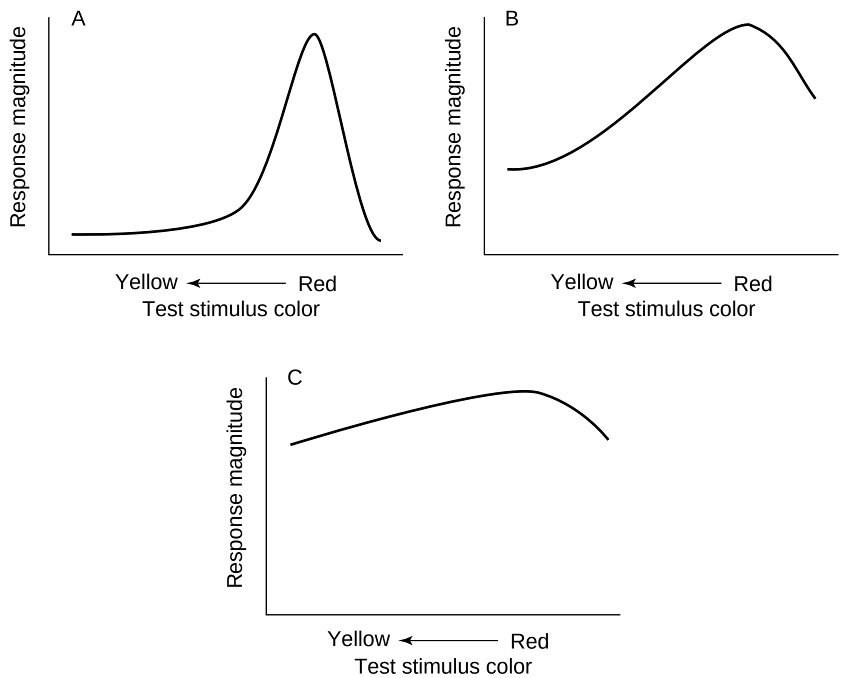
The wavelength of red light is at the long end of the visual spectrum. Shorter wavelengths of light appear less red and more orange. As the wavelength of light becomes even shorter, the light appears more and more yellow (and then green, blue, indigo, and violet, following the colors of the rainbow). A detailed test of stimulus control by different colors requires systematically presenting lights of different wavelengths.

Stimulus Generalization Gradients

Several outcomes may occur if a variety of test colors, ranging from deep red to deep yellow, are presented. If the driver was paying close attention to color, they would stop only if the light had a perfect red color. Lights with a tinge of orange would not cause the driver to stop. This possibility is illustrated by Curve A in Figure 13.2. At the other extreme, the driver may stop when he sees any color that has even a vague resemblance to red. This possibility is illustrated by Curve C in Figure 13.2. An intermediate outcome is shown by Curve B. In this case, the driver's behavior exhibits considerable sensitivity to differences in color but responding is not as closely limited to a specific shade of red as in Curve A.

In **stimulus generalization**, the responding that occurs with one stimulus is also observed when a different stimulus is presented. Each of the curves in Figure 13.2 is called a **stimulus generalization gradient**. We previously encountered the concept of stimulus generalization in connection with habituation, where habituation to one stimulus could generalize to other similar stimuli. Generalization gradients can be obtained for any stimulus feature—stimulus position, size, brightness, shape, height, and so forth. As Figure 13.2 illustrates, the gradients may be very steep (Curve A) or rather shallow (Curve C). The steepness or slope of the generalization gradient indicates how closely the behavior is controlled by the stimulus dimension being tested. A steep generalization gradient indicates strong control by the stimulus feature that is varied in the generalization test. A shallow or flat generalization gradient indicates weak stimulus control by that stimulus dimension.

FIGURE 13.2. Hypothetical Stimulus Generalization Gradients Indicating Different Degrees of Control of Responding by the Color of a Stimulus



Note. Curve A illustrates strongest stimulus control by color; Curve C illustrates weakest stimulus control by color.

Stimulus Generalization and Stimulus Discrimination

Stimulus generalization gradients involve two important phenomena: generalization and discrimination. Points 1 and 2 in Figure 13.3 illustrate the phenomenon of stimulus generalization. Behavior that occurred at Point 1 also occurred at Point 2, or generalized to Point 2. Generalization of responding signifies similar responding to different stimuli.

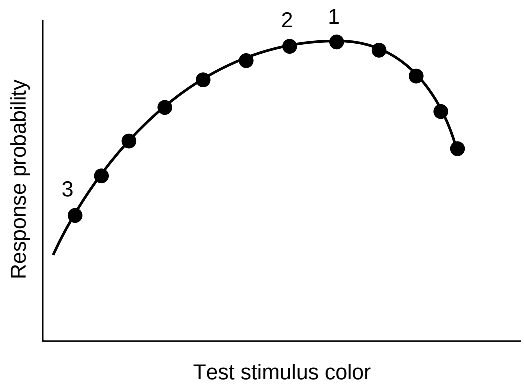
Stimulus discrimination is the opposite of stimulus generalization. Here changes in a stimulus result in different levels of responding. Points 1 and 3 in Figure 13.3 illustrate the phenomenon of stimulus discrimination. More responding occurred to the stimulus at Point 1 than to the stimulus at Point 3. Thus, the participant discriminated or distinguished between Points 1 and 3. Responding at Point 1 did not generalize to Point 3.

Generalization and discrimination are complementary phenomena. A great deal of generalization among stimuli means that the participant responds similarly to these stimuli, and hence there is little discrimination between them. In contrast, a great deal of discrimination among stimuli means that the participant is responding differently to the stimuli, and hence there is little generalization among them (see also Figure 3.2 in Chapter 3).

Contrasting Conceptions of Stimulus Generalization

Why do individuals respond similarly to different stimuli, or, in other words, why do they generalize from one stimulus to another? Pavlov favored a spread-of-effect interpretation. He assumed that the presentation of a stimulus causes activation of a particular location in the cortex of the brain, and this activation automatically spreads to other nearby locations. Because of that spread-of-effect, responses conditioned to one stimulus automatically generalize to other similar stimuli. When a child first learns the word for cow, she is likely to use

FIGURE 13.3. A Hypothetical Generalization Gradient for Responding to Different-Colored Stimuli



Note. Points 1 and 2 illustrate the phenomenon of stimulus generalization. Points 1 and 3 illustrate the phenomenon of stimulus discrimination.

the word *cow* not only when she sees a cow but also when she sees a bull, and perhaps even a horse. According to the spread-of-effect interpretation, such generalization occurs because bulls and horses are similar in their appearance to cows.

Lashley and Wade (1946) presented an alternative to Pavlov's explanation. Instead of viewing stimulus generalization as due to the automatic spread of cortical activation based on stimulus similarity, Lashley and Wade emphasized the role of learning. According to Lashley and Wade, individuals respond similarly to different stimuli because they have not learned to distinguish between them. This suggests that one can limit generalization between stimuli with appropriate training. That is indeed what happens as a child learns to limit using the word *cow* with pictures of cows and use a different word when presented with a picture of a bull or a horse.

DETERMINANTS OF STIMULUS CONTROL: SENSORY AND MOTIVATIONAL VARIABLES

As our discussion of stimulus control unfolds, we will consider how various types of learning determine the steepness of generalization gradients. Before we get to that, however, let us consider how stimulus control depends on features of a stimulus and features of the organism.

Sensory Capacity

Perhaps the most obvious factor determining whether a particular stimulus feature will influence behavior is the **sensory capacity** of the organism. An organism cannot respond to a stimulus if it lacks the sense organs needed to detect the stimulus. People are unable to respond to radio waves, ultraviolet light, and sounds above about 20,000 cycles per second (cps) because they lack the sense organs to detect such stimuli. Dogs are able to hear sounds of much higher frequency than human beings and are therefore capable of responding to ultrasounds that are inaudible to people.

Sensory capacity sets a limit on the kinds of stimuli that can come to control an organism's behavior. However, sensory capacity is merely a precondition for stimulus control. It does not ensure that behavior will be influenced by a particular stimulus feature. People with a normal sense of smell have the capacity to distinguish the aroma of different red wines. However, for someone who rarely drinks wine, all red wines may smell pretty much alike.

Sensory Orientation

Another prerequisite for stimulus control is **sensory orientation**, or orientation of the relevant sense organ in relation to the source of the stimulus. This is particularly important with a localized visual stimulus, which is visible to the organism only if it is facing towards the visual cue. For example, if you are watching for traffic signs on the right side of a road, you may miss a sign placed on the left side. For a stimulus to gain control over some aspect of an individual's behavior, the stimulus must be accessible to the relevant sense organ. Sounds and overall levels of illumination spread throughout an environment. Therefore, such stimuli are likely to be encountered whether or not the individual is oriented toward the source of the stimulus. For this reason, tones and overhead lights are popular stimuli in learning experiments.

Stimulus Intensity or Salience

Other things being equal, behavior is more likely to come under the control of intense or salient stimuli than weak ones (e.g., Kamin, 1965). **Stimulus intensity** is very important for most biological functions, and this includes learning and behavior. More intense stimuli tend to elicit more vigorous behavior and more rapid learning. In addition, the presence of an intense stimulus can interfere with the control of behavior by a weaker cue. This phenomenon, first identified by Pavlov (1927), is referred to as **overshadowing**. A weak stimulus "b" may be effectively conditioned when it is presented by itself on conditioning trials. However, less learning about "b" will be evident if stimulus "b" is presented simultaneously with a more intense stimulus "A" in a compound stimulus "Ab." In this case, stimulus "A" may overshadow the conditioning of stimulus "b." This phenomenon, among others, has played an important role in theoretical models of Pavlovian conditioning such as those discussed in Chapter 6. (For detailed analyses of learning in terms of components or elements of a stimulus, see Harris, 2006; McLaren & Mackintosh, 2000, 2002; Wagner, 2008.)

Motivational Factors

The extent to which behavior comes under the control of a particular stimulus is also determined by the motivational state of the organism. Motivational factors in the stimulus control of behavior have not been investigated extensively. However, the available evidence indicates that attention can be shifted away from one stimulus modality to another by a change in motivation or emotional state. In these experiments, a compound stimulus is typically used consisting of a tone and a light. With such a tone–light compound, rats and pigeons conditioned with food as the reinforcer come to respond to the light more than to the tone. In contrast, animals conditioned to avoid pain learn to respond to the tone more than to the light (Foree & LoLordo, 1973; LoLordo, 1979).

The motivational state or behavior system that is activated is thought to include a **stimulus filter** that biases stimulus control in favor of visual or auditory cues. For example, when pigeons are hungry and operating in the feeding system, they are especially sensitive to visual cues. The dominance of visual cues in the feeding system extends to learning when food may be found as well as learning when food is not available (Reed-Elder & LoLordo, 1985). In contrast, when pigeons are fearful and motivated to avoid danger, they are especially sensitive to auditory cues. For other species, these motivational influences may take different forms. A species that hunts for live prey at night, for example, may be especially attentive to auditory cues when it is seeking food.

DETERMINANTS OF STIMULUS CONTROL: LEARNING FACTORS

Learning processes cannot teach you to respond to microwaves that are beyond the capacity of your sense organs. However, learning processes have a lot to do with how you come to respond to stimuli that are within the range of your senses. We turn to these learning mechanisms next. In general, behavior comes under the control of a stimulus if that stimulus becomes significant for some reason.

Pavlovian and Instrumental Conditioning

As we discussed in Chapter 4, simple Pavlovian conditioning procedures make an initially ineffective and unimportant stimulus (the conditioned stimulus [CS]) significant by establishing an association between that event and an unconditioned stimulus (US). Stimulus significance can also be established through instrumental conditioning. In the case of positive reinforcement, the reinforcer, or outcome (O), is presented contingent on a response (R) in the presence of an initially neutral stimulus (S). The three-term S–R–O instrumental contingency increases control of R by stimulus S by establishing an association between S and the reinforcing outcome O, or the R itself, or by having stimulus S signal when the response will be reinforced (see Chapter 7). A similar result occurs in the case of negative reinforcement (see Chapter 12). In the discriminated avoidance procedure, for example, the instrumental response results in avoidance of aversive stimulation only if the response occurs in the presence of a warning signal. Because of this, the warning stimulus gains control over the avoidance response.

Although simple Pavlovian and instrumental conditioning procedures serve to bring behavior under the control of the stimulus that signals the US or reinforcer, they do not determine which feature(s) of that stimulus will be most important. Consider, for example, a compound stimulus that consists of a tone and a light. Whether the visual or the auditory component will gain predominant control over the conditioned response will depend on the sensory and motivational factors that we described in the preceding section. If the participant has a keen sense of sight but poor hearing, the visual component will predominate. If both senses are adequate and the participant is motivated by fear, the auditory component may be more important. However, if the visual component is much more intense or salient than the auditory feature, the visual component may overshadow the auditory cue. Finally, the participant could learn about both features under some conditions, especially if they are equally salient (e.g., Mackintosh, 1976).

How about stimulus features that cannot be distinguished based on sensory and motivational variables? How can they come to control differential responding? Consider, for example, a car that has plenty of gas and one that is about to run out of gas. There is little difference between these two types of cars in terms of the modality and intensity of the stimuli a driver encounters. The only difference is the position of the fuel gauge indicator, and that difference may be less than an inch. Nevertheless, the difference in the position of the fuel indicator between having plenty of gas and being nearly empty is highly significant to drivers. People also respond very differently to seeing the word "fire" compared with the word "hire," even though the visual features of these two words are nearly identical. How do such highly similar stimuli come to control dramatically different responses? The answer rests with conditioning procedures that involve stimulus discrimination training.

Stimulus Discrimination Training

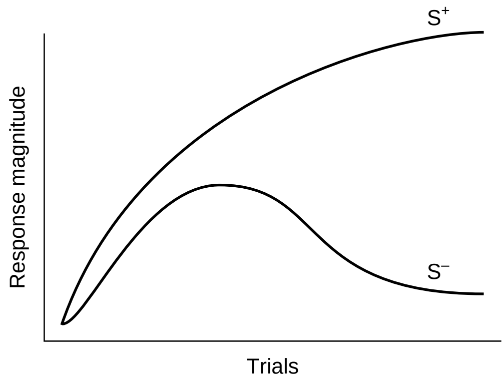
The key feature of **stimulus discrimination training** is to provide different outcomes or experiences in the presence of different stimuli. That is, stimulus discrimination training involves differential reinforcement in the presence of different stimuli. This can be accomplished with either Pavlovian or instrumental methods. Simple cases of Pavlovian and instrumental conditioning involve only one CS or stimulus condition. In contrast, stimulus discrimination training requires at least two stimuli. Differential reinforcement is arranged by presenting the US or the reinforcer in association with one of the cues but not the other.

Any pair of stimuli may serve as stimuli in a discrimination procedure. One of the cues is called the **S^+**, and the other is called the **S^-**. For example, S^+ and S^- may be the letters f and h, a tone and a buzzer, or a light and a noise. The S^+ and the S^- are called discriminative stimuli. Each trial involves presenting one of the discriminative stimuli, and trials with the S^+ and the S^- are presented in a random sequence.

In a Pavlovian discrimination procedure, each presentation of S^+ is paired with the unconditioned stimulus. In contrast, the unconditioned stimulus is omitted on trials when the S^- occurs. Thus, S^+ and S^- are associated with different outcomes or differential reinforcement. For example, S^+ and S^- may be two orange cats that are very similar, except that one is rather friendly and the other is aloof. The friendly cat (S^+) is paired with tactile pleasure because she approaches and rubs up against people. The aloof cat (S^-) does not approach and does not let people pet her and is therefore not paired with the positive tactile US. Because of these contrasting outcomes, we quickly learn to tell the two orange cats apart.

Typical results of a discrimination training procedure are illustrated in Figure 13.4. Early in training, the conditioned response comes to be elicited by the S^+, and this responding generalizes to the S^-. At this stage of learning, the participant responds to both the S^+ and the S^-. With continued discrimination training (and differential reinforcement), responding to S^+ continues to increase, whereas responding to S^- gradually declines. The final outcome is

FIGURE 13.4. Typical Results of a Pavlovian Discrimination Training Procedure in Which S⁺ Is Paired With an Unconditioned Stimulus and S⁻ Is Presented Equally Often Alone



Note. The conditioned responding that develops initially to S^+ generalizes to S^-. However, with continued training, a strong discrimination develops between S^+ and S^-.

that the participant responds much more to S^+ than to S^-. A strong distinction develops between S^+ and S^-. At this point, the two stimuli are said to be discriminated.

Let us consider again the friendly and the aloof cats. As you start to associate one of the cats with tactile pleasure, any affection that you develop for her may generalize when you encounter the other cat. However, as you have additional pleasant encounters with one cat but not with the other, your affection for the friendly cat will increase, and your affection for the aloof cat will decline. You will come to distinguish one cat from the other.

Discrimination training can be conducted in an analogous fashion using instrumental conditioning procedures. Differential reinforcement is provided by reinforcing the instrumental response in the presence of the S^+ but not reinforcing the response in the presence of the S^-. Thus, the discrimination procedure consists of $S^+ \rightarrow R \rightarrow O$ trials and $S^- \rightarrow R \rightarrow$nothing trials. As with Pavlovian discrimination procedures, during initial stages of training, responding on S^+ trials may generalize to S^-. However, eventually the participant will respond vigorously on trials with the S^+ and little, if at all, on trials with the S^-, as shown in Figure 13.4.

In the Skinnerian tradition of behavior analysis, the standard nomenclature for discriminative stimuli is a bit different. S^+ is represented by the symbol S^D and is called the "ess dee" (for "discriminative stimulus"). In contrast, the S^- is represented by the symbol S^Δ and is called the "ess delta" (with the delta symbol indicating lack of reinforcement).

In all stimulus discrimination procedures, different stimuli are associated with different outcomes. In the preceding examples, differential reinforcement was provided by the delivery versus omission of the US or the reinforcer. The presence versus absence of reinforcement represents a common but special case in discrimination training procedures. Any form of differential reinforcement can lead to the learning of a discrimination.

Infants, for example, quickly learn to discriminate Mom from Dad. This does not occur because Mom is a source of reinforcement whereas Dad is not. Both Mom and Dad provide pleasure for the infant, but they are likely to provide different types of pleasure. One parent may provide more tactile comfort and nutritional reinforcement, whereas the other may provide mostly sensory reinforcement in the form of tickling or bouncing. Each type of reinforcer is associated with a different parent, and this allows the infant to learn to discriminate between the parents.

Multiple Schedules of Reinforcement

Differential reinforcement may also be programmed in terms of different schedules of reinforcement in the presence of different stimuli. For example, a variable-interval (VI) schedule may be in effect in the presence of a high-pitch tone (Stimulus A), and a fixed-interval (FI) schedule may be in effect in the presence of a low-pitch tone (Stimulus B). Such a procedure is called **multiple schedules of reinforcement**. As a result of training on a multiple VI FI variable-interval–fixed-interval schedule of reinforcement, participants will come to respond to Stimulus A in a manner typical of variable-interval performance and will respond to Stimulus B in a manner typical of fixed-interval performance (see Chapter 8).

A multiple schedule is in effect as you listen to different instructors in different classes. Listening behavior is reinforced by the new information you hear in each class. Some professors say lots of new things during their classes, thereby reinforcing listening behavior on a dense variable-interval schedule. Other professors predictably make just four or five important points during a lecture and spend about 10 minutes elaborating each point. This reinforces listening behavior on what is akin to a fixed-interval schedule. Each schedule of reinforcement is in effect in the presence of the distinct stimuli of each professor and class. Across both classes, therefore, listening behavior is reinforced on a multiple schedule. Because of that, how you listen changes when you move from one class to the other.

DETERMINANTS OF THE PRECISION OF STIMULUS CONTROL

Differential reinforcement in the presence of S^+ and S^- leads to responding differently to those stimuli. Interestingly, these effects may extend beyond the actual stimuli that were used in the discrimination procedure. The far-reaching effects of discrimination training were first identified in a landmark experiment by Jenkins and Harrison (1960). They compared the stimulus control of pecking behavior in two groups of pigeons (see Table 13.1). Group D was first conditioned to discriminate between the presence and absence of a tone. These pigeons were reinforced for pecking a response key on a variable interval

TABLE 13.1. Outline of Experiment by Jenkins and Harrison

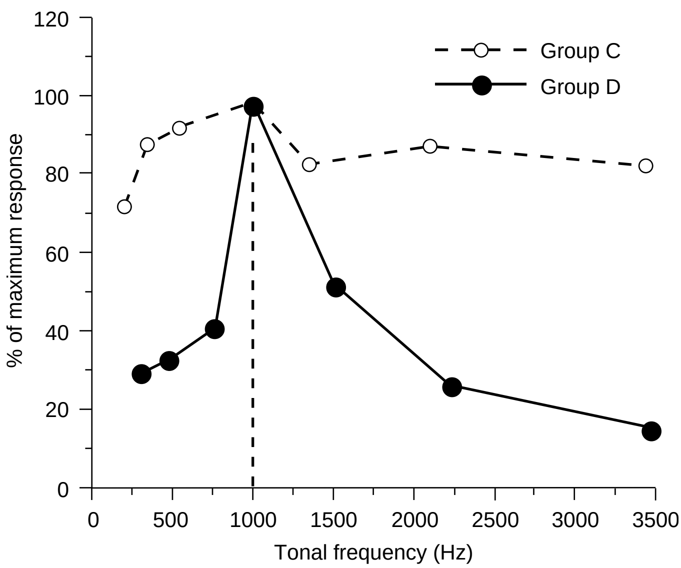
Training	Test
Group D: Discrimination Training	
S^+ (1,000-Hz tone): pecks → food	Tones of various frequencies
S^- (no tone): pecks → no food	
Group C: No Discrimination Training	
1,000-Hz tone: pecks → food	Tones of various frequencies
Tone always present during training	

Note. Hz = Hertz or cycles per second.

schedule whenever a tone with a frequency of 1,000 Hz was turned on (S^+) and were not reinforced when the tone was absent (S^-). The control group (Group C) received similar reinforcement for pecking the response key, but for them the tone was on continuously during the training sessions. Thus, Group C did not receive discrimination training.

After these training procedures, both groups received a test of stimulus generalization. During this test, tones of various frequencies were presented in a mixed order and responses were no longer reinforced. The results are summarized in Figure 13.5. The control group, Group C, which did not receive discrimination training, responded vigorously to the tone that had been present during training (the 1,000-Hz tone). More interestingly, they also responded

FIGURE 13.5. Effects of Discrimination Training on Control of the Pecking Behavior of Pigeons by the Frequency of Different Tones



Note. Before the generalization test, Group D received discrimination training in which the S^+ was a 1,000-Hz tone and the S^- was the absence of the tone. In contrast, Group C received only reinforcement for key-pecking in the presence of the 1000-Hz tone. Based on Jenkins and Harrison (1960).

vigorously to most of the other tones, which they encountered for the first time during the generalization test. Thus, in the absence of discrimination training, a fairly flat generalization gradient was obtained across the frequency dimension. This indicates that the frequency or pitch of the tones did not gain much control over the behavior of these birds.

The results were dramatically different for Group D, which was first trained to discriminate between the presence and absence of the 1,000-Hz tone. These birds showed a steep generalization gradient. They responded a great deal to the 1,000-Hz tone (the S^+), but their behavior quickly dropped off when tones of other frequencies were presented. This is a remarkable outcome because the other tones had not been presented during discrimination training. None of the other tones had served as the S^- in the discrimination procedure. Even though Group D had not encountered nonreinforcement in the presence of tones during training, tones other than the S^+ did not support much pecking behavior.

The results presented in Figure 13.5 show that the shape of a generalization gradient can be dramatically altered by discrimination training. Discrimination training not only produces differential responding to S^+ and S^- but also increases the steepness of generalization gradients. This indicates that discrimination training increases the precision of stimulus control, and this increased precision extends beyond the specific stimuli that are used as S^+ and S^-.

INTERDIMENSIONAL VERSUS INTRADIMENSIONAL DISCRIMINATIONS

So far, we have stressed differential reinforcement in discrimination training procedures as an important factor governing stimulus control. The nature of the S^+ and S^- stimuli also determines the outcome of discrimination training. The similarities and differences between S^+ and S^- are especially important. If S^+ and S^- differ in several respects, the discrimination is called an **interdimensional discrimination**. If S^+ and S^- differ in only one respect, the discrimination is called an **intradimensional discrimination**.

Interdimensional Discriminations

Interdimensional discriminations are common. The discrimination learned by an infant between Mom and Dad is an interdimensional discrimination. Mom and Dad differ in many respects, including visual features, differences in how each holds the infant, differences in voice, differences in the time of day each is likely to interact with the infant, and so on. Deciding which app to open on your phone is also an interdimensional discrimination. The icons for different apps differ in graphic design, color scheme, font, position on your home screen, and so on. In fact, app designers try to maximize the various ways in which the icon for their app is different from others you may have downloaded.

Although it may not be obvious, simple Pavlovian and discrete-trial instrumental conditioning procedures also involve interdimensional discriminations. In Pavlovian conditioning, the presentation of a CS ends in the delivery of the US. In contrast, the US is not delivered when the CS is absent. Thus, the discrimination is between times when the CS is present and times when the CS is absent (the intertrial interval). All the features of the CS (its modality, intensity, and location) serve to distinguish the CS from its absence, making this is an interdimensional discrimination.

Discrete-trial instrumental conditioning also involves an interdimensional discrimination between cues present during a trial and cues present during the intertrial interval. The pigeons in Group D of the Jenkins and Harrison experiment (see Figure 13.5) received such a procedure. Pecking was reinforced during the 1,000-Hz tone but not when the tone was absent. Periods of reinforcement differed from the intertrial interval (when the tone was absent) in both the intensity and the pitch of the auditory cues the pigeons heard.

Interdimensional discriminations are easy to learn. Babies quickly learn to distinguish when they are held by their mother or father. When we download a new app on our phone, we quickly learn to distinguish its icon from the others that are already on our home screen. Another noteworthy feature is that interdimensional discrimination training increases stimulus control. We saw this in the Jenkins and Harrison experiment (Figure 13.5), where Group D had a steeper generalization gradient than the control group that did not get discrimination training.

Intradimensional Discriminations

Interdimensional discriminations are effective in establishing stimulus control. However, they do not establish a high degree of control over behavior by any particular stimulus feature. For example, because many things distinguish Mom from Dad, the infant may not respond a great deal to any one distinguishing feature. The most effective way to establish control by a specific stimulus feature is through intradimensional discrimination training (Jenkins & Harrison, 1960, 1962). In intradimensional discrimination training, the stimuli associated with differential reinforcement differ in only one respect.

Many forms of expert performance involve intradimensional discriminations. Reading, for example, requires discriminating between letters that differ in only one respect. The letters E and F differ only in the horizontal bottom line, which is present in E but not in F. The physical difference is small, but the differential consequences in terms of meaning can be substantial. The letters B and P and M and N are other pairs that are similar physically but differ greatly in significance. Learning to read requires learning many intradimensional discriminations of this sort.

One of the interesting things about learning fine intradimensional discriminations is that the participant is not likely to be aware of the physical difference between the stimuli at the outset of training. Initially, the letters E and F may appear the same to a child. The child may recognize E and F as being different from O but may not be able to tell the difference between E and F. The child will come to recognize the difference between the letters only after being taught to say one thing when shown E and something else when shown F. This example illustrates the general principle that differential reinforcement makes us sensitive to physical differences that previously did not matter to us.

Similar effects occur in the acquisition of other forms of expertise. Children learning to sing may not be able to tell at first when they are singing in tune or off-key. However, this skill develops through differential reinforcement from a teacher. Likewise, budding ballerinas learn to make adjustments on the basis of proprioceptive cues indicating the precise position of their arms and legs, and billiard players learn to make precise judgments about angles and trajectories. Intradimensional discrimination training brings behavior under the precise control of small variations in a stimulus, thereby serving to increase sensitivity to these small stimulus variations. The important point here is that sensitivity to variations in environmental stimuli depends not only on sensory capacity but also on one's history of discrimination training.

Perceptual Learning

As we noted earlier, intradimensional discriminations involve stimuli that differ in just one respect. The letters E and F, for example, differ only in the presence or absence of the bottom horizontal stem. All the other sections of those letters are the same. If we think of the letters as consisting of various visual elements, the letters may be represented as AX and BX, where X refers to the visual elements the letters have in common, and A and B represent the unique elements (presence or absence of the bottom horizontal stem). Thus, we may also represent learning to distinguish the letters E and F as learning a discrimination between AX and BX since each of these stimuli have some elements that are distinctive to them and others in common between them.

As we saw, one way to teach a discrimination between AX and BX is by using differential reinforcement. Another way one can learn to distinguish AX from BX is to simply present these cues repeatedly so that you become highly familiar with them. Learning to distinguish stimuli through a process of familiarization is called **perceptual learning** (Hall, 2001). Although the analysis of perceptual learning can become rather complex (McLaren & Mackintosh, 2000, 2002), perceptual learning procedures inevitably involve more exposure to the common element X than to the distinguishing features A and B. Because X is present on every exposure trial, the participant will experience more habituation to X than to A and B. This will move X into the background and help you distinguish better between AX and BX.

Consider, for example, distinguishing between different wines. Inexperienced wine drinkers can easily tell the difference between red wine and white wine. But can they distinguish between "good" and "mediocre" red wine? Probably not. How does one become an expert in making that distinction? A critical factor is gaining a lot of familiarity with different types of red wine. Someone sampling various red wines may be asked which they liked better.

There is no right or wrong answer, so there is no formal differential reinforcement. At first, you may not express a preference, but with repeated exposures, you will become more familiar with red wines and will start to make very fine distinctions between them. (For a more complete discussion of learning to become a wine connoisseur, see Spence, 2019.)

STIMULUS EQUIVALENCE TRAINING

As we have seen, discrimination and perceptual learning procedures foster differential responding and increase the precision of stimulus control—an effect that has sometimes been referred to as **acquired distinctiveness** (e.g., Lawrence, 1950). There are situations, however, in which just the opposite is desired—that is, situations in which physically different stimuli must be treated the same way. This is called **acquired equivalence**. Consider, for example, the same word written in different fonts and sizes. If you are concerned about the meaning of the word, you must treat it as having the same meaning regardless of the font or size in which it is written. This raises the following questions: Are there learning procedures that promote treating different stimuli as being functionally the same? Are there learning procedures that increase stimulus generalization, even for stimuli that are very dissimilar to begin with?

In a discrimination procedure, stimuli are treated differently—they have different consequences. The differential treatment or significance of the stimuli leads organisms to respond to them as distinct from each other. What would happen if two stimuli were treated in the same or equivalent fashion? Would such a procedure lead to responding to those stimuli as similar or equivalent? The answer seems to be yes. Just as discrimination training encourages differential responding, **stimulus equivalence training** encourages generalized responding.

There are several approaches for promoting generalization rather than discrimination among stimuli. One approach is to arrange the same consequence for responding to various physically different stimuli. This is frequently done in **perceptual concept learning** (Wasserman, 2016). For example, pigeons can be trained to respond in a similar fashion to different photographs, all of which include water in some form (ocean, lake, puddle, stream). The basic training strategy is to reinforce the same response (pecking a response key) whenever pictures containing water are presented and not to reinforce that response when photographs without water appear. Herrnstein et al. (1976) trained such a discrimination using 500 to 700 photographs of various scenes in New England. Once the pigeons learned the water/no-water discrimination, their behavior generalized to novel photographs that had not been presented during training.

Arranging a common outcome for different stimuli is one way to establish a stimulus equivalence class, and this can be interpreted in terms of stimulus control developing to those perceptual features that are common to all stimuli within the perceptual category of interest. Another technique is used in concept learning studies that are not perceptually based. In this procedure, the participant is trained to make the same response to a set of perceptually different stimuli. This is essentially what parents do when they train their children to say the same word (*fruit*) in response to a variety of different types of fruit (apples, pears, bananas). The common response serves to create an equivalence class among the various specific examples that are associated with that common response (Urcuioli, 2013), but notice that the exemplars of the category can differ greatly in their perceptual features (e.g., banana vs. apple).

Stimulus equivalence is particularly important in analyses and training of language skills (e.g., Barnes-Holmes et al., 2018). The written word *banana*, for example, derives its meaning from the fact that it is in an equivalence class that includes the spoken word *banana*, a photograph or drawing of a banana, and an actual banana you can eat. All these physically different stimuli are treated as functionally equivalent and interchangeable once the meaning of the word has been learned. For example, you should be able to say the word *banana* when you see a picture of one, and you should be able to pick out the picture if asked to identify what the word *banana* signifies.

Stimulus equivalence training enhances stimulus generalization among stimuli that are physically highly distinct. This supports Lashley and Wade's (1946) early proposition that learning plays a major role in governing how organisms come to respond to different stimuli. Stimulus generalization is not simply predicted by physical similarity. What determines discrimination and generalization among stimuli has turned out to be a complicated question. Important theoretical issues remain, and the mechanisms of discrimination learning continue to be the subject of vigorous scientific inquiry.

SUMMARY

Individuals must learn not only what to do but when and where to do it. When and where a response is made involves the stimulus control of behavior. Stimulus control is identified by differential responding and can be precisely measured by the steepness of generalization gradients. The extent to which a stimulus influences behavior depends on stimulus factors such as sensory capacity, sensory orientation, and stimulus intensity. Stimulus control also depends on the individual's affective or motivational state. However, most forms of stimulus control are a result of training that either facilitates discriminating among stimuli or facilitates generalizing among stimuli.

Discrimination training may involve either *inter*dimensional or *intra*-dimensional stimuli. Intradimensional discrimination training produces more precise stimulus control than interdimensional training and is the basis for various forms of expert performance. However, learning fine discriminations is not always useful. Sometimes you must learn to treat physically different objects in the same fashion. This is accomplished by stimulus equivalence learning. Stimulus equivalence is important in perceptual concept learning, nonperceptual concept learning, language learning, and various aspects of applied behavior analysis.

SUGGESTED READINGS

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