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Characteristics, Theories, and Implications of Dynamic Changes in Reinforcer Effectiveness

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The formulation of the Matching Law (Herrnstein, 1970) changed the dependent variable in many studies of operant conditioning from the moment-by-moment changes in responding studied by Skinner (e.g., Skinner, 1938) and others to response rate averaged over the experimental session. The use of averaged responding rests on the assumption that responding does not change systematically within sessions. If it does, then average measures will obscure significant changes in behavior at a more molecular level.

Recent evidence shows that operant response rates are not constant within experimental sessions, but may increase, decrease, or increase and then decrease within the session (e.g., McSweeney, 1992; see Figure 14.1). These within-session changes in responding may appear during the first session of training and persist after many sessions (e.g., 60) of exposure to schedules that provide a flat distribution of reinforcers within the session (e.g., variable-interval (VI) schedules; McSweeney & Hinson, 1992). The changes are not transitional effects (e.g., acquisition curves).

Within-session changes in responding deserve study because they are not anticipated by existing theories. The changes are also at least as large as those usually studied by operant psychologists. For example, McSweeney, Roll, and Weatherly (1994) reported that rate of responding changed by a factor of 92 from the beginning to the end of the session. Admittedly, the reported size of the change would be different if the changes had been measured over different time intervals, but within-session changes in responding are clearly large.

Within-session changes in responding are also highly general. McSweeney and Roll (1993) found such changes in approximately 200 studies that used procedures such as positive reinforcement, avoidance, punishment, extinction, discrimination, delayed matching to sample (DMTS), concept formation, maze and alley running, and laboratory analogues of foraging. The studies employed a wide variety of schedules
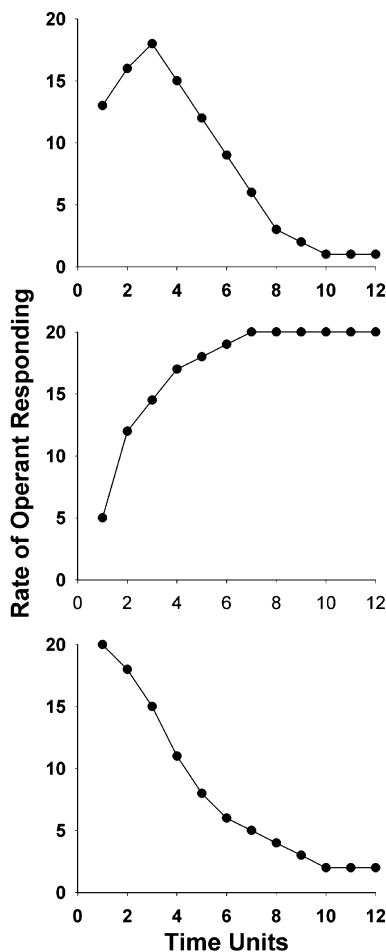
Figure 14.1 Three common within-session patterns of operant responding as a function of time. The units of time and behavior are arbitrary. The results show that operant response rate may increase (middle graph), decrease (bottom graph), or increase and then decrease (top graph) within the experimental session even when the conditions of reinforcement are held constant across the session. From "Dynamic changes in reinforcer effectiveness: Theoretical, methodological, and practical implications for applied research," by E. S. Murphy, F. K. McSweeney, R. G. Smith, and J. J. McComas (2003), *Journal of Applied Behavior Analysis, 36*, p. 422. Copyright 2003 by the Society for the Experimental Analysis of Behavior, Inc. Reprinted with permission.

including continuous reinforcement, fixed interval (FI), fixed ratio (FR), VI, differ-
ential reinforcement of low rates of responding (DRL), differential reinforcement of
other behavior, multiple, concurrent, and second-order. The changes occurred for a
wide variety of species, including mice, rats, pigeons, goldfish, raccoons, rhesus and
cebus monkeys, greater galagos, and slow loris.

In this chapter, we will review the empirical characteristics of within-session
changes in operant responding and then consider potential theoretical explanations

for them. We conclude that sensitization (increases in responding) and habituation (decreases in responding) to the sensory properties of the reinforcer alter the ability of the reinforcer to support behavior with its repeated delivery. We discuss some methodological, applied, and theoretical implications of this idea for the basic and applied conditioning literatures and beyond. The predictions of the habituation hypothesis are interesting because they differ markedly from those of more traditional concepts, such as satiation.

Empirical Characteristics

Reinforcer Rate (Stimulus Rate)

Changing the rate of reinforcement changes the form of the within-session pattern of responding. Within-session changes usually peak earlier in the session and are larger when reinforcers are presented at higher, than at lower, rates. Figure 14.1 illustrates this finding. Delivering reinforcers at the intermediate rate used in many studies (e.g., 60 reinforcers/hour) usually produces the bitonic response pattern (top graph). Delivering no reinforcers (see "Extinction") or delivering reinforcers at high rates (e.g., 120 reinforcers/hour or more) usually produces the decreasing response pattern (bottom graph). Responding usually does not change within sessions when reinforcers are delivered at low rates (e.g., fewer than 15 reinforcers per hour). Although primarily increasing patterns are sometimes found (middle graph), the factors that produce these patterns are not known (see McSweeney, 1992; McSweeney, Roll, & Cannon, 1994; McSweeney, Roll, & Weatherly, 1994; McSweeney, Swindell, & Weatherly, 1996b; 1998; Murphy, McSweeney, & Kowal, 2007).

Presentation, Not Amount

Weatherly, McSweeney, and Swindell (1995, Experiment 1) reported that changing the rate of reinforcement exerted its effect because of changes in the number of reinforcers presented, not because of changes in the amount of food delivered. Pigeons responded on five different multiple schedules that provided scheduled rates of reinforcement from 15 to 240 reinforcers per hour. The size of the food reinforcers changed with the schedule so that subjects obtained at most 300 seconds of reinforcement per session during all schedules. The within-session pattern of responding changed with the change in schedule even though the total amount of food presented per session was constant (see also "Reinforcer Size," "Prefeedings").

Reinforcer Effectiveness

The ability of the reinforcer to control behavior (its effectiveness or value) changes systematically within sessions when measured by a probe preference test (e.g., Williams, 1991). In McSweeney, Weatherly, and Swindell (1996a), pigeons' left-key pecking was reinforced by mixed grain delivered by VI 15-second, VI 30-second, VI 60-second, VI 120-second or VI 240-second schedules in different conditions. Every

30 seconds, the right key was also illuminated for 30 seconds with a probability of 0.1. When the right key was illuminated, pecking that key yielded wheat according to a VI 60-second schedule. The ratio of the response rates for mixed grain and wheat changed systematically within the session during schedules that provided high rates of mixed grain reinforcement (e.g., 60–240 reinforcers/hour). Because the rate of responding for wheat remained relatively constant across the session, the changes in these ratios were attributed to changes in the effectiveness of the mixed grain reinforcers within the session.

Absolute, Not Relative, Time or Number

Within-session patterns of responding depend on absolute, not relative, time in the session. For example, McSweeney, Weatherly, and Swindell (1995a) varied session duration from 20 to 100 minutes in 5 steps. Within-session patterns were identical for sessions of different lengths when the patterns were plotted in terms of successive 5-minute intervals in the session (absolute time), not in terms of proportion of total-session time (relative time; see also McSweeney, 1992; McSweeney, Roll, & Cannon, 1994). However, these experiments confounded time with number of reinforcers because they delivered reinforcers at the same rate at all times in the session. Therefore, the within-session pattern may depend on absolute number of reinforcer deliveries and/or absolute time.

Response-Independent Reinforcers (Classical Conditioning)

Within-session patterns of responding are observed when reinforcers are delivered independently of responding (classical conditioning). For example, McSweeney, Swindell, and Weatherly (1996b) exposed pigeons to an autoshaping procedure in which an 8-second key light was followed by response-independent food. The average intertrial interval varied from 7 to 232 seconds in different conditions. Rates of responding usually changed within sessions during the autoshaping procedures in a manner similar to that observed during operant conditioning (e.g., McSweeney, 1992; McSweeney, Roll, & Cannon, 1994. See also McSweeney, Swindell, & Weatherly, 1999).

Response Rate, Not Accuracy

Response accuracy usually does not change within sessions. McSweeney, Weatherly, and Swindell (1996c, Experiment 1) studied responding by pigeons on a DMTS procedure. A trial started when a sample stimulus (red or green light) was presented for at least 5 seconds. A choice period in which two keys were illuminated with white light followed the sample after a delay of 1, 5, 12, 8 or 3 seconds in different conditions. During the choice period, a peck on one key was correct if one sample stimulus was presented; a peck on the other key was correct if another sample was presented. A 20-second intertrial interval followed each trial and sessions ended after 60 minutes. Rate of responding on the sample stimulus changed systematically within sessions when the delay between the stimulus and the choice period was short (1–5 seconds; i.e., high reinforcer rate), but not when it was long (8–12 seconds; i.e., low reinforcer rate). The

percentage of responses that were correct (response accuracy) did not change within sessions (see also Edhouse & White, 1988; Wilkie, 1986; but see also McSweeney, Weatherly, & Swindell, 1996c, Experiment 2; Olton & Samuelson, 1976).

Unconsumable and Unconsumed Reinforcers

Within-session changes in responding occur for reinforcers that are not consumed. Early studies showed that punishers (e.g., Azrin, 1960) and negative reinforcers (e.g., Jerome, Moody, Connor, & Ryan, 1958) may lose their effectiveness late in the session. Running in wheels by rats decreases within sessions (Aoyama & McSweeney, 2001a). Large within-session decreases in responding are reported during extinction when no reinforcers are delivered (see "Extinction"). Temple, Giacomelli, Roemmich, and Eptstein (2008) also reported systematic within-session changes in operant responding when human subjects played a computer game for potato chip reinforcers. Within-session changes in responding were observed regardless of whether subjects consumed the reinforcers during the session or only after the session ended (see Figure 14.2B).

Reinforcer Intensity (Stimulus Intensity)

Within-session patterns of responding may be steeper for less intense, than for more intense, reinforcers. Melville, Rue, Rybiski, and Weatherly (1997) reported that rats'
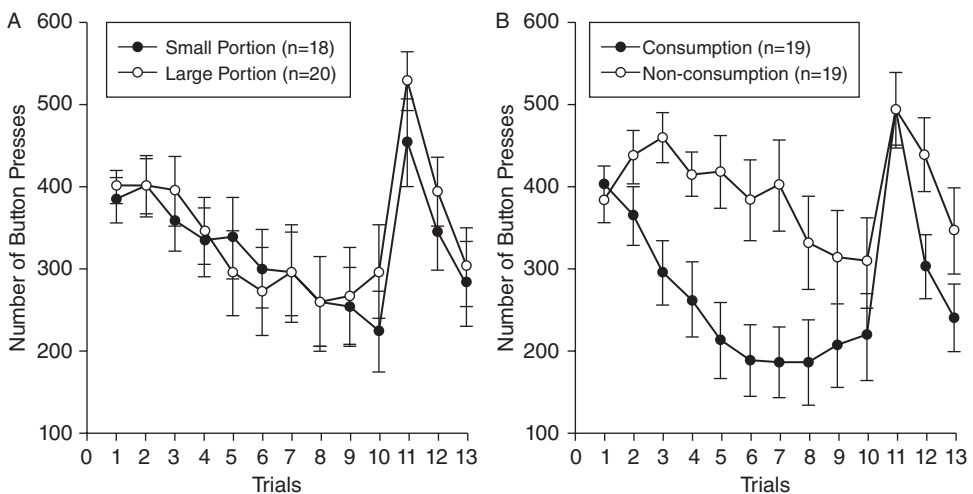
Figure 14.2 Stimulus specificity of operant responding in humans. Results are presented as mean number of responses for potato chips (trials 1–10) and M&M's (trials 11 –13) for individual subjects assigned to (A) small (75 kcal; black circles) and large (225 kcal; white circles) portions of food and (B) who consumed the food throughout the duration of the experiment (black circles) and those who had to delay consumption until the end (white circles). Error bars represent the standard error of the mean. From "Habituation and within-session changes in motivated responding for food in children," by J. L. Temple, A. M. Giacomelli, J. N. Roemmich, and L. H. Epstein (2008), *Appetite, 50,* p. 394. Copyright 2007 by Elsevier Ltd. Reprinted with permission.

responding sometimes decreased more steeply late in the session when less concentrated, rather than more concentrated, sucrose solutions served as reinforcers.

Experimental Context

Brief exposure to the experimental context may alter the within-session response pattern during a following session. McSweeney, Swindell, and Weatherly (1998) placed rats and pigeons in the experimental enclosure 0, 5, 10, 15 or 30 minutes before the start of an experimental session. Exposure to the experimental context for 5 minutes altered the within-session response pattern relative to the pattern shown when the session started immediately after the subject was placed in the enclosure. Increasing exposure from 5 to 30 minutes did not increase the effect beyond that seen with a 5-minute preexposure (see also Weatherly & McSweeney, 1995; but see also McSweeney & Johnson, 1994). Large within-session changes in responding also occur during sessions of extinction. Exposure to the experimental context may contribute to these changes (see "Extinction").

Recovery (Spontaneous Recovery)

Within-session patterns of responding recover if enough time elapses between sessions. The amount of recovery may increase with increases in time between sessions. For example, Murphy, McSweeney, Kowal, McDonald, and Wiediger (2006) reported that within-session patterns of responding were identical during two consecutive sessions that were separated by 24 hours, but not by 5 minutes or 2 hours when alcohol-preferring rats' lever pressing was reinforced by ethanol (see also Aoyama & McSweeney, 2001a; but see McSweeney & Johnson, 1994).

After Stimulus Change (Dishabituation)

Introducing an arbitrary stimulus, such as a light or noise, increases responding once the baseline is restored. For example, in Aoyama and McSweeney's (2001a) baseline condition, rats ran in a wheel for 30 minutes. In experimental conditions, a new stimulus was applied for 5 seconds at 20 min and 55 seconds into the session. The new stimulus was either an intermittently-applied brake or a flashing houselight. Rate of running was faster immediately after the new stimulus than it had been at a comparable time in the baseline condition (see Figure 14.3; McSweeney, Kowal, Murphy, & Varao, 2005; Murphy et al., 2006).

   Changing some aspect of the experimental conditions for a brief time in the session has a similar effect. For example, in Aoyama and McSweeney's (2001b) baseline condition, rats' lever pressing was reinforced by food on an FR 4 schedule. During experimental conditions, the situation was changed for 3 minutes in the middle of the session in four ways: the lever was withdrawn; lever pressing was reinforced on an FR 6 schedule and two Noyes pellets were delivered per reinforcer; the schedule was changed to an FR 8; and two FR schedules (2 and 6) alternated. In all four cases, response rate increased relative to baseline after the changed condition was removed and subjects once again responded on the FR 4 schedule. This increase in responding was observed regardless of whether rate of responding decreased (e.g., no lever) or
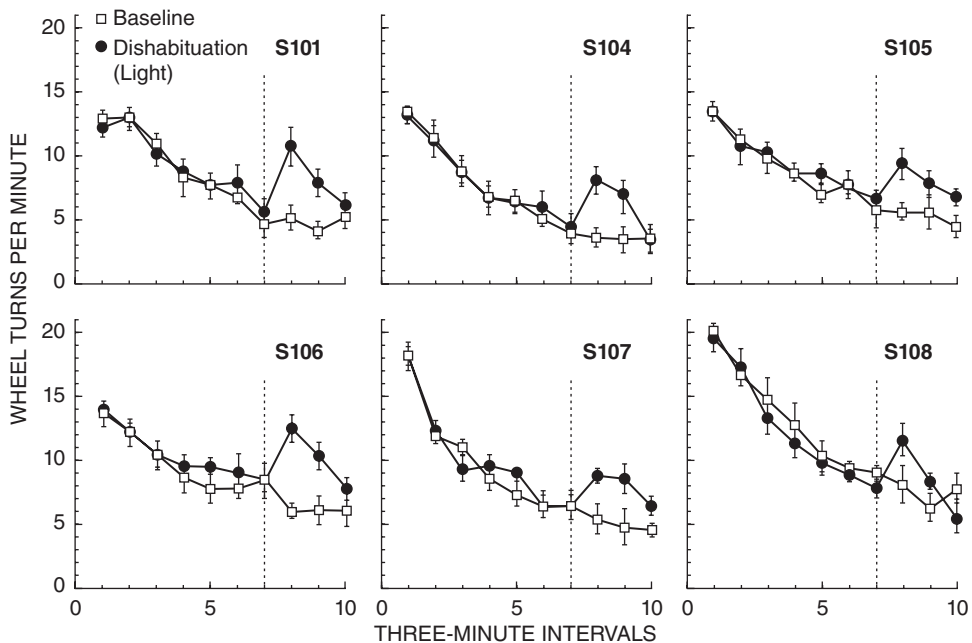
Figure 14.3 Dishabituation of wheel running in rats. Results are presented as rate of responding (responses/minute) during successive 3-minute intervals in the session. Each set of axes presents the results for an individual subject responding during baseline (open circles) and experimental (filled squares) conditions. The dotted vertical line indicates the time at which the stimulus was briefly changed in the experimental conditions. During the stimulus change, the houselight went off for 1 second, on for 1 second. Error bars represent the standard error of the mean. When error bars are not apparent, the bars were smaller than the diameter of the data symbol. From "Habituation contributes to within-session changes in free wheel running," by K. Aoyama and F. K. McSweeney (2001), *Journal of the Experimental Analysis of Behavior, 76*, p. 294. Copyright 2001 by the Society for the Experimental Analysis of Behavior, Inc. Reprinted with permission.

increased (e.g., FR 8) relative to baseline while the stimulus was changed. The increase also occurred regardless of whether subjects obtained more (e.g., FR 6-2 pellets) or less (e.g., no lever) food relative to baseline while the stimulus was changed (see also McSweeney & Roll, 1998; McSweeney, Kowal, Murphy, & Varao, 2005; but see also Ernst & Epstein, 2002).

During Stimulus Change (Stimulus Specificity)

Changing stimulus conditions also increases responding while that change is in effect, not just after baseline is restored (previous section). For example, Aoyama and McSweeney (2001a) examined wheel running in rats. Rats ran faster in the second half of the session when the wheel was changed in the middle of the session than when it was not (see also Figure 14.2; Epstein et al., 2003; Ernst & Epstein, 2002; McSweeney, Swindell, & Weatherly, 1996c; McSweeney, Weatherly, & Swindell,

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1996a; Murphy et al., 2006; Temple, Giacomelli, Kent, Roemmich, & Epstein, 2007; Temple et al., 2006.)

Variety (Variety Effects)

Within-session decreases in responding occur more slowly to stimuli that are presented in a variable, than in a fixed, manner. For example, Ernst and Epstein (2002) allowed human participants to play a computer game for food delivered on a VR 32 schedule. In one condition, the food was always pieces of turkey sandwiches. In another condition, the food varied among three different foods that provided the same number of calories and macronutrient content as the constant food (pieces of turkey or roast beef sandwiches, potato chips). Within-session decreases in responding were steeper for those given the same food each time a reinforcer was delivered than for those given a variety of foods (see Figure 14.4; see also Aoyama & McSweeney, 2001b; Lupfer-Johnson, Murphy, Blackwell, LaCasse, & Drummond, 2010; Melville, Rue, Rybiski, & Weatherly, 1997; Murphy et al., 2007).

Reinforcer Size

Altering reinforcer size alters within-session response patterns, but only when the size change is large. Temple et al. (2008) reported no effect on within-session patterns when they changed reinforcer size by a factor of 3 for human participants (see Figure 14.2A). Cannon and McSweeney (1995) and Roll, McSweeney, Johnson, and
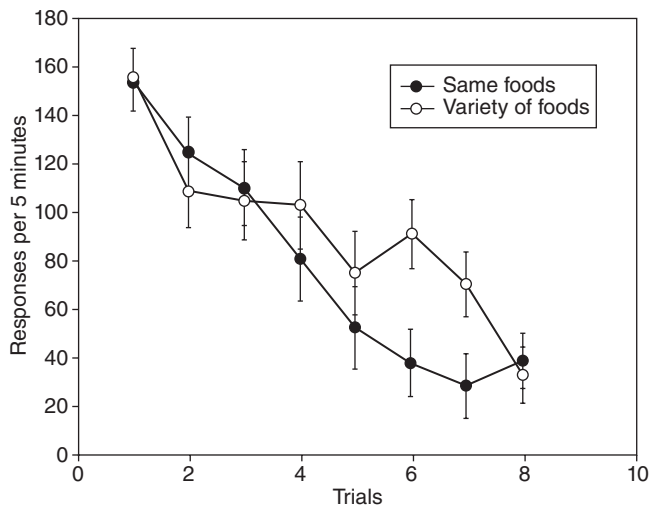
Figure 14.4 Variety effects in humans. Results are presented as the number of responses per 5-minute trial as a function of successive trials for the mean of all human subjects responding for turkey sandwiches (filled circles) or for three different isolcaloric foods (open circles). Error bars represent the standard error of the mean. From "Habituation of responding for food in humans" by M. M. Ernst and L. H. Epstein (2002), *Appetite,* 38, p. 229. Copyright 2002 by Elsevier Ltd. Reprinted with permission.

Weatherly (1995, Experiment 3) found that changing reinforcer size by a factor of 5, but not by a factor of 3, altered within-session patterns. For example, in Roll et al. (1995, Experiment 3), each reinforcer was 0.20 ml of condensed milk plus 0, 0.40 or 0.80 ml of condensed milk infused directly into the stomach in different conditions. The within-session response pattern changed when reinforcer size increased from 0.20 to 1.0 ml, but not from 0.20 to 0.60 ml (see also, Bizo, Bogdanov, & Killeen, 1998, Experiment 1; DeMarse, Killeen, & Baker, 1999, Experiment 2; Palya & Walter, 1997, Experiment 2).

Prefeedings

Feedings delivered before the session may alter within-session response patterns, but only when the pre-session food is eaten, not infused. DeMarse et al. (1999, Experiment 3; see also Murphy, McSweeney, & Kowal, 2003) fed pigeons 0, 5, 15 or 25 g of milo prior to a session in which pigeons' key pecks were reinforced by milo. The within-session decreases in responding were steeper for larger pre-feedings than for smaller ones. In contrast, Roll et al. (1995, Experiment 2) examined responding by rats when no prefeedings were given. Then the amount of condensed milk reinforcer consumed up to the point in the session at which the peak response rate occurred was calculated for each rat. Subjects were divided into two groups that received either 1.0 or 2.0 times their predetermined amount of milk infused directly into the stomach, immediately before the session. Prefeeding the subjects did not alter the within-session pattern of responding from its baseline form for either group. An explanation for the differences in results between these studies will be offered in "Reinforcer Delivery."

Factors That Do Not Alter the Within-Session Response Pattern

To date, manipulating several factors has failed to alter within-session patterns of responding. These factors include: handling the subject before the session (McSweeney & Johnson, 1994); deprivation for the reinforcer (Roll et al., 1995, Experiment 2); the caloric density of the reinforcer (McSweeney et al., 1990; Roll et al., 1995; but see Melville et al., 1997, in "Reinforcer Intensity (Stimulus Intensity)"—a potential explanation for the different results of these studies will be offered in "Reinforcer Delivery"); and the nature and rate of responding (Aoyama & McSweeney, 2001a; 2001b; Ernst & Epstein, 2002; McSweeney, 1992; McSweeney, Hatfield, & Allen, 1990; McSweeney & Johnson, 1994; McSweeney, Roll, & Cannon, 1994; McSweeney, Roll, & Weatherly, 1994; McSweeney, Weatherly, & Roll, 1995; McSweeney, Weatherly, Roll, & Swindell, 1995; Melville, Rybiski, & Kamrani, 1996). Of course, negative results are difficult to interpret. Future experiments might show an effect of these variables if, for example, the variables were manipulated over a wider range.

Quantitative Descriptions

Two equations have described within-session patterns of responding well (see also E. G. Bittar, Del-Claro, L. G. Bittar, & da Silva, 2012, for a new model that deserves further evaluation). McSweeney, Hinson, and Cannon (1996) proposed Equation 1.

P is the predicted proportion of total-session responses that should occur during a time interval in the session. *T* is the ordinal number of that time interval in the session; *e* is the base of the natural logarithm and *a, b,* and *c* are free parameters. We will argue later that *a* and *b* govern habituation and *c* applies to sensitization (see "Reinforcer Delivery").

$$P = \frac{b}{e^{aT}} - \frac{c}{c+T} \qquad (1)$$

Aoyama and McSweeney (2001b; see also Aoyama, 1998, 2000) proposed Equation 2 where R_r is rate of operant responding, R_c is cumulative number of reinforcers delivered, and *a* and *b* are free parameters. Parameter *b* is the y-axis intercept of the regression line (i.e., response rate at the beginning of the session) and *a* is the slope of the regression line (i.e., the decrease in response rate produced by an obtained reinforcer).

$$R_r = b - aR_c \qquad (2)$$

Both equations fit the data well. For example, Equation 1 accounted for a median of 92% of the variance in 106 data sets (McSweeney, Hinson, & Cannon, 1996). As will be discussed, this equation also describes data taken from the literatures on extinction (see "Extinction"), habituation (see "Habituation"), and motivation (see "Motivation"). Equation 2 has the advantage of parsimony because it is a simple linear equation. It also fits the data well when within-session decreases in responding are observed (e.g., Aoyama, 1998, 2000; Aoyama & McSweeney, 2001b). However, it must be supplemented by other equations to describe the often-observed early-session increases in responding.

Potential Theoretical Explanations

Responding

Operant responding might increase early in the session as subjects' muscles warm up. Responding might decrease later in the session because of fatigue (e.g., Mosso, 1906). Contradicting this idea, many studies have shown that changing the nature, or rate, of the response over a wide range does not alter the within-session pattern of responding (see "Factors That Do Not Alter the Within-Session Response Pattern").

Interfering Responses

A response (e.g., exploration) might wane early in the session (e.g., Bindra, 1959), allowing operant responding to increase. Another response (e.g., falling asleep; e.g., Pavlov, 1928) might develop as the session progresses, forcing operant responding to decline.

    To date, studies have ruled out two potential candidates for these interfering responses: exploration (Roll & McSweeney, 1997) and adjunctive behaviors (e.g.,

Falk, 1971). For example, McSweeney, Swindell, and Weatherly (1996a) examined rats' lever pressing that was reinforced by food delivered by different FI schedules in different conditions. A drinking spout (Experiment 1) or running wheel (Experiment 2) was also available during some conditions, but not during others. Within-session patterns of lever pressing did not differ when either drinking or running was available than when it was not. The correlation between the amount of lever pressing and the amount of drinking or running at a particular time in the session was also positive for some schedules and subjects, and negative for others. Within-session changes in adjunctive drinking and running were not consistently negatively correlated with within-session changes in operant responding, as predicted by the interfering response theory.

A General Motivational State

Within-session patterns of responding might be attributed to changes in a general motivational state, such as arousal (e.g., Killeen, Hanson, & Osborne, 1978). Arousal has been defined in many ways (e.g., Anderson, 1990; Duffy, 1962; Neiss, 1988), but the most common definition is probably a state of the animal that determines the "energy" level of its behavior (e.g., Duffy, 1962). If a general motivational state changed within the session, then changes in all behaviors would be positively correlated during that session. Instead, as just argued, McSweeney, Swindell, and Weatherly (1996a) reported that the correlation between rate of lever pressing and the rate of drinking or running at a particular time in the session was inconsistently positive or negative (see also McSweeney, Swindell, & Weatherly, 1996c).

Time

Responding might increase early in the session if subjects required time to recover from the handling that brought them to the experimental enclosure. Responding might decrease late in the session in anticipation of the session's end. For example, a conditioned emotional response might interfere with operant responding as subjects anticipate being handled again after the session (e.g., Estes & Skinner, 1941).

McSweeney and Johnson's (1994) results question a contribution from recovery from handling. In their experiment, pigeons' key-pecking was reinforced by food delivered by a VI 1-minute schedule in two successive 50-minute sessions. Subjects were handled during the intersession interval in some conditions, but not in others. Early-session increases in responding occurred in the second of their 50-minute sessions even if subjects were not handled between the first and second sessions.

McSweeney, Weatherly, and Swindell's (1995a) results question a contribution from anticipation of the end of the session. They reported that within-session response patterns were identical regardless of whether the end of the session was predictable (constant-length sessions) or unpredictable (randomly-ended sessions). If anticipatory factors produced the late-session decreases in responding, then these late-session decreases should have been eliminated when the end of the session could not be anticipated (see also the within-session patterns of responding during the first session of conditioning in McSweeney, 1992).

Cognitive Factors

Within-session changes in responding might be caused by within-session changes in several cognitive factors, including memory (Spear, 1973), attention (Blough, 1983), or information overload (e.g., Richardson & Campbell, 1992) or underload (e.g., boredom). Results to date have ruled out two potential definitions of changes in attention as causes of within-session changes in responding.

First, changes in the accuracy of responding during DMTS procedures are often taken as an index of changes in attention to the task (e.g., McCarthy & Voss, 1995). McSweeney, Weatherly, and Swindell (1996c, Experiment 1) reported that the accuracy of responding (percentage correct) during a DMTS procedure did not change within sessions even when the rate of responding on the sample stimulus did change systematically within sessions (see "Response Rate, Not Accuracy").

Second, the operant contingency might exert greater control over behavior when subjects attend to the experimental task than when they do not. During discrimination tasks, increasing control by the operant contingency should produce an increase in responding during S+ (responding is reinforced) and a decrease in responding during S− (responding is not reinforced). Therefore, response rates should change in the opposite directions during S+ and S− if attention to the task changes within the session. Instead, McSweeney, Weatherly, and Swindell (1996c, Experiment 2) reported that rate of responding during the S+ and S− of multiple VI extinction schedules changed in similar, not opposite, ways within the session (see also McSweeney, Roll, & Weatherly, 1994).

Reinforcer Delivery

Factors related to the delivery of reinforcers contribute to the within-session changes in responding. For example, changing the rate of reinforcement changes the within-session pattern (see "Reinforcer Rate (Stimulus Rate)"). In addition, the ability of the reinforcer to control behavior also changes systematically within sessions (see "Reinforcer Effectiveness").

The question then becomes, what variable produces these systematic changes in reinforcer effectiveness? Because food served as the reinforcer in most of our experiments, we initially thought that satiation causes the within-session decreases in reinforcer effectiveness. In fact, a definition of satiation that is often used in the operant literature identifies these changes as satiation. For example, Millenson (1967, p. 367) states, "Satiation is . . . repeatedly presenting the reinforcer until it loses its power to reinforce." Unfortunately, this definition of satiation provides a redundant description, not an explanation for within-session changes in operant responding. To avoid this problem, we turned to the satiety literature for a more substantive definition.

Those who study satiation often use that term to describe the collection of factors that contribute to the termination of ingestive behaviors such as feeding and drinking (e.g., Mook, 1996). However, many variables that help to terminate ingestive behaviors play little or no role in producing within-session changes in responding. Manipulating such classic satiety factors as caloric density, deprivation for the reinforcer (see "Factors That Do Not Alter the Within-Session Response Pattern"), intubated stomach loading (see "Prefeedings"), and reinforcer size (see "Reinforcer Size") failed to alter within-session response patterns, altered them only when large

changes were made, or altered them in the wrong direction (see "Reinforcer Intensity (Stimulus Intensity)"). Within-session decreases in operant responding also occurred even when subjects did not eat the food reinforcer or responded for reinforcers that are not consumable (see "Unconsumable and Unconsumed Reinforcers").

One satiety factor remained untested, however. Habituation to the sensory properties of food contributes to satiety for food (e.g., Swithers & Hall, 1994). "Habituation" is a decline in responsiveness to a stimulus when that stimulus is presented repeatedly or for a prolonged time (e.g., Groves & Thompson, 1970). "Sensitization" is an increase in responsiveness to a stimulus early in its presentation or after the presentation of a strong, different, or extra stimulus (e.g., Groves & Thompson, 1970).

We hypothesized that sensitization and habituation occur to the sensory properties of repeatedly presented reinforcers and that those processes alter the ability of that reinforcer to control behavior. According to this idea, sensitization increases the effectiveness of reinforcers during their first few presentations leading to an early-session increase in operant responding. Habituation decreases the effectiveness of later reinforcers leading to a late-session decrease in operant responding.

Many arguments support the idea that sensitization and habituation to the reinforcer primarily cause within-session changes in operant responding. McSweeney, Hinson, and Cannon (1996), McSweeney and Roll (1998), and McSweeney and Murphy (2000) provided reviews. To recap, we believe that the habituation hypothesis is compatible with the evidence that others have offered to support the satiety hypothesis (e.g., Bizo et al., 1998; DeMarse et al., 1999; Hinson & Tennison, 1999). The habituation hypothesis also explains some conflicting data reported earlier. For example, prefeedings alter the form of the within-session patterns when the food is eaten but not when it is infused (see "Prefeedings"). Subjects are exposed to all of the stimulus properties of the food when they eat that food. Subjects are not exposed to many of the stimulus properties of food when that food is infused (e.g., its taste, smell, shape, color). As a result, eaten prefeedings should produce some habituation to the food, but infused prefeedings should produce little habituation to the food. The large habituation produced by eaten, but not by the infused, prefeedings should alter later within-session patterns if those patterns are caused by habituation to the reinforcer.

Melville et al. (1997) reported that within-session changes in responding were steeper for lower, than for higher, calorie reinforcers when calories were manipulated by changing sucrose concentration (see "Reinforcer Intensity (Stimulus Intensity)"). In contrast, Roll et al. (1995) reported that altering caloric density had no effect when calories were manipulated across different types of reinforcers (e.g., sucrose, saccharin). Neither of these results is easy to reconcile with the idea that satiation produces within-session decreases in responding. Higher caloric foods should produce quicker satiety. In contrast, the divergent results are compatible with habituation. Habituation is more rapid for weaker than for stronger stimuli (e.g., Thompson & Spencer, 1966). Therefore, Melville et al.'s results are compatible with habituation if manipulating sucrose concentration produced its effect by altering the perceived intensity of sucrose, rather than by altering its caloric content. If this reasoning is correct, then it should be possible to reproduce Melville et al.'s results by altering the intensity of the reinforcer in ways that do not manipulate calories (e.g., by altering the concentration of a non-nutritive flavoring).

Nevertheless, the strongest argument in favor of habituation is that the empirical characteristics of within-session changes in responding are strikingly similar to the

empirical characteristics of habituation (e.g., McSweeney, Hinson, & Cannon, 1996; McSweeney & Roll, 1998). Since the time of Thompson and Spencer (1966), conformity to a list of empirical properties has been used as a test for the presence of habituation (e.g., Leaton & Tighe, 1976). Table 14.1 provides such a list. The list is adapted from the consensus list proposed by Rankin et al. (2009). Some of Rankin et al.'s definitions have been slightly revised in Table 14.1 to shorten them without changing their meaning. Rankin et al.'s characteristics have also been increased from 10 to 15 as follows. First, two characteristics of sensitization, taken from Groves and Thompson (1970), have been added to Rankin et al.'s list which applies only to habituation. An additional characteristic of habituation, generality (see Characteristic 13), has been added because habituation is so often observed for different stimuli, responses and species (e.g., Thorpe, 1966). Rankin et al.'s Characteristic 4 has been divided into two parts "stimulus rate" and "stimulus rate and recovery" because stimulus rate has been frequently studied in the literatures that we review, but the effect of stimulus rate on spontaneous recovery has not been studied. Listing these two characteristics as one would leave the mistaken impression that both have been confirmed. Finally, variety effects (e.g., Broster & Rankin, 1994) have been added to Rankin et al.'s list (see our Characteristic 9). Rankin et al. may have omitted this characteristic because variety effects are a direct prediction of their Characteristic 7, stimulus specificity, so adding it may be redundant. We have included it because many authors address stimulus specificity by studying variety effects.

To date, within-session changes in operant responding have shown 12 of the 15 characteristics of sensitization and habituation listed in Table 14.1. The other characteristics have not been studied. Several of the confirmed characteristics were tested as true predictions of the habituation hypothesis and are difficult to reconcile with an explanation in terms of satiation. These characteristics include dishabituation, faster habituation for less intense than for more intense stimuli, stimulus specificity, and variety effects. We have used the labels of the characteristics listed in Table 14.1 to head earlier sections of this chapter to make it easy to find the data supporting each of these conclusions. The similarities between habituation and within-session changes in responding are also quantitative as well as qualitative. When McSweeney, Hinson, and Cannon (1996) fit Equation 1 to 145 data sets taken from the habituation literature, it accounted for a median of 89% of the variance in the data.

As a result of these similarities, we believe that the contribution of habituation to within-session changes in responding has been established. In fact, researchers have applied the term habituation to phenomena that share as few as three of the characteristics of habituation (e.g., Eisenstein & Peretz, 1973). Nevertheless, we are not arguing that factors other than sensitization-habituation never contribute to within-session changes in responding. Most of our studies used easy-to-manipulate operanda and intermediate rates of reinforcement. Other variables might contribute under more extreme conditions.

Implications for Conditioning

Although the distinction between satiation and habituation may seem trivial, the implications of these two ideas actually differ substantially. We will discuss some of

Table 14.1 Empirical characteristics of sensitization and habituation

#	*Characteristic*	*W*	*D*	*E*	*M*
1	Responding decreases. Repeated or prolonged presentation of a stimulus results in a progressive decrease in some parameter of a response to an asymptotic level.	x	x	x	**x**
2	Spontaneous recovery. Responsiveness to a habituated stimulus recovers at least partially when that stimulus is not presented for a time.	x	x	x	**x**
3	Potentiation of habituation. Habituation may become more rapid and/or pronounced with repeated habituations.	x		x	
4	Stimulus rate. Faster rates of stimulus presentation yield faster and more pronounced habituation than slower rates.	x	x	x	
5	Stimulus rate and recovery. Spontaneous recovery may be faster after faster, than after slower, rates of stimulus presentation.				
6	Stimulus intensity. The weaker the stimulus, the more rapid and pronounced the habituation.	x			
7	Habituation below zero. Repeated stimulus presentations after the response reaches asymptote may alter subsequent behavior.			x	
8	Stimulus specificity. Habituation is disrupted by changes in the presented stimulus.	x	x	x	x
9	Variety effects. Habituation occurs more slowly to stimuli presented in a variable, rather than a fixed, manner.	x	x		x
10	[a]Dishabituation. Presenting a strong, different or extra stimulus restores responsiveness to a habituated stimulus.	x	x	x	x
11	Dishabituation habituates. The amount of dishabituation decreases with repeated applications of the dishabituating stimulus.		x		
12	Long-term habituation. Some habituation is learned and persists over time.	x	x	x	
13	Generality. Habituation occurs for many, if not all, stimuli and species of animals.	x	x	x	x
14	Sensitization by early-stimulus presentations. An increase in responsiveness may occur during the first few presentations of a stimulus.	x	x	x	x
15	[a]Sensitization by stimuli from another modality. An increase in responsiveness to a stimulus may be produced by the introduction of a stimulus from another modality (e.g., a light or noise).	x	x	x	x

Note. The table is based on the characteristics listed in Rankin et al. (2009) with the exceptions noted in the text. An x in the column under the heading of within-session changes (**W**, see "Empirical Characteristics"), drug consumption (**D**, McSweeney, Murphy, & Kowal, 2005), extinction (**E**, McSweeney & Swindell, 2002) and motivated behavior (**M**, McSweeney & Swindel, 1999b) indicates that this characteristic had been shown for that phenomenon at the time of the cited literature review.

[a] Both sensitization (Characteristic 15) and dishabituation (Characteristic 10) may involve the introduction of a stimulus from another modality. Results are conventionally described as "dishabituation" if the added stimulus restores responsiveness to an already habituated stimulus and as "sensitization" if the added stimulus increases responding before substantial habituation occurs to the other stimulus (e.g., Marcus, Nolen, Rankin, & Carew, 1988).

the potential implications of the habituation hypothesis in the following sections. The role of habituation in understanding any one of the following phenomena is far from proven. Nevertheless, the presence of many of the striking characteristics of habituation in most of the following literatures convince us that the contribution of habituation to these phenomena is worth examining.

Methodological Implications

Within-session Designs. Within-session procedures present different values of an independent variable in different parts of a single session rather than in different sessions (e.g., Ettinger & Staddon, 1983; Heyman, 1983). Unfortunately, within-session changes in responding may create problems for using this methodology. Within-session changes in responding may be confounded with the independent variable, thus complicating the interpretation of the data (see also McSweeney, Weatherly, & Swindell, 1995b).

Group or Single-subject Designs. Finding that within-session changes in responding occur and are governed by absolute session time (see "Absolute, Not Relative, Time") suggests that group or single-subject designs should not confound session length with other experimental variables. For example, when studying the effect of rate of reinforcement on rate of responding, the experimenter must confound either session length or number of reinforcers delivered per session with rate of reinforcement. Session length is often confounded because it is assumed not to alter response rates (e.g., Catania & Reynolds, 1968). If, however, responding changes systematically with absolute time in the session, then the rate of responding averaged over the session will differ for sessions of different lengths. As a result, the answer to some theoretical questions may vary with session length. For example, McSweeney (1992) reported that response rate at the beginning of an operant session increased monotonically with increases in the rate of reinforcement, confirming some theories (e.g., Herrnstein, 1970). Responding later in the session increased up to a point and then decreased, confirming other theories (e.g., Baum, 1981; Staddon, 1979). Experimenters should be wary of drawing theoretical conclusions when sessions of different lengths are conducted for different values of their independent variable.

Applied Implications

Murphy, McSweeney, Smith, and McComas (2003) discussed several implications of changes in reinforcer effectiveness for applied behavior analysis. We will give only one example here. If sensitization and habituation alter the strength of reinforcers, then the characteristics listed in Table 14.1 can be used to maintain the effectiveness of needed reinforcers (increase sensitization and decrease habituation) and to weaken the effectiveness of problematic reinforcers (decrease sensitization and increase habituation).

For example, food is often used as a reinforcer for autistic children. To preserve the effectiveness of this reinforcer, a behavior analyst might offer a variety of foods instead of only one (Table 14.1, Characteristic 9). He or she should present the reinforcers according to a variable, rather than a fixed, schedule (Table 14.1, Characteristic 9). He or she should deliver sensitizers by introducing extraneous

stimuli or by working in a noisy, busy, environment (Table 14.1, Characteristic 15). Finally, giving the child a nibble of food might restore the effectiveness of food as a reinforcer once that effectiveness has been lost (Table 14.1, Characteristic 14). Murphy et al. (2003) reviewed evidence that these techniques will work.

Theoretical Implications

Because of space limitations, we will omit a discussion of behavioral economics. The interested reader can find such a discussion in McSweeney and Swindell (1999a) and in McSweeney, Swindell, and Weatherly (1996c). We will also omit a discussion of theories of absolute response rates because we discussed them briefly in "Methodological Implications."

The Matching Law. The generalized matching law (GML) provides a leading description of operant choice behavior (Baum, 1974; Herrnstein, 1970; Equation 3). The rates of responding emitted on, the time spent responding on, and the values of the reinforcers obtained from, one schedule (component) of a concurrent schedule are symbolized by P_1, T_1, and V_1, respectively. The same variables for the other component are symbolized by P_2, T_2, and V_2. Many factors contribute to reinforcer value including the size of the reinforcers, the immediacy of their delivery, and their rate of delivery (e.g., Baum, 1974). The *a* and *b* parameters are "bias" and "sensitivity to reinforcement," respectively. Bias represents preference for an alternative that is not explained by differences in the values of the reinforcers provided by the alternatives (e.g., a position, operandum, or color preference). Sensitivity represents the degree to which preference changes with changes in reinforcer ratios.

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} = a\left(\frac{V_1}{V_2}\right)^b \tag{3}$$

Unfortunately, within-session changes in responding will create problems for assessing the validity of the GML if within-session response patterns differ for the two components of a concurrent schedule. For example, suppose that the peak rate of responding occurs earlier in the session and the within-session changes are larger for components that provide higher, than for those that provide lower, rates of reinforcement (e.g., McSweeney, 1992). In that case, the ratio of the more preferred to the less preferred response rate would not be constant, but would increase to a peak and then decrease, within the session. If the peak rate of responding was reached at a constant time after the beginning of the session regardless of session length, as it is for simple schedules (e.g., McSweeney, 1992; McSweeney, Roll, & Cannon, 1994), then the ratio of response rates would also differ for sessions of different lengths when that ratio was calculated across the entire session (see McSweeney, Swindell, & Weatherly, 1996c for more details).

Within-session changes in responding would not cause problems for the GML if the changes occurred similarly for the two components. Suppose, for example, that within-session changes are related to changes in a multiplier that modulates the absolute rates at which subjects respond. If this multiplier changed in the same way within the session for the two components of a concurrent schedule, then its effect would cancel when the ratios of the response rates were calculated.

To date, within-session patterns of responding have been similar for the two components of a concurrent schedule even when the components differ in the rates of reinforcement they provide, the types of responses they require, or the simple schedules they deliver (McSweeney, Murphy, & Kowal, 2001; McSweeney, Weatherly, & Roll, 1995; McSweeney, Weatherly, & Swindell, 1996b). Neither the parameters, nor goodness of fit, of Equation 3 changed systematically within sessions for these types of concurrent schedules (McSweeney et al., 2001; McSweeney, Weatherly, & Roll, 1995).

In contrast, within-session patterns of responding differ for the components of concurrent schedules when those components provided qualitatively different reinforcers (food and water for rats or wheat and mixed grain for pigeons; McSweeney, Swindell, & Weatherly, 1996c). For most subjects, the bias and sensitivity to reinforcement parameters of the GML, as well as the percentage of variance accounted for, decreased within the session. Negative sensitivity parameters were sometimes found late in the session for concurrent schedules that provided food in one component and water in the other component.

These results suggest that the mechanism that determines within-session changes in responding integrates (e.g., sums) the reinforcers obtained from the two components of a concurrent schedule as long as the two components provide qualitatively-similar reinforcers. The mechanism does not integrate those reinforcers when the components provide qualitatively different reinforcers. As a result, within-session changes in responding cause problems for assessing the validity of the GML only when the components provide qualitatively different reinforcers (see also Heyman, 1993).

Extinction. Extinction refers to a decrease in operant responding that occurs when a conditioned response is no longer followed by the reinforcer. It also refers to a decrease in a classically conditioned response when the conditioned stimulus (CS) no longer predicts the unconditioned stimulus (US). Extinction is one of the longest known and most fundamental properties of conditioned behavior (e.g., Pavlov, 1927). Nevertheless, there is no generally accepted theory of extinction. Many theories are challenged because behavior undergoing extinction shows some complicated and unexpected characteristics.

McSweeney and Swindell (2002; see also e.g., Humphrey, 1930; Thompson & Spencer, 1966) argued that many of the puzzling characteristics of extinguished behavior could be understood if habituation occurs to some of the stimuli that support conditioned responding. These stimuli help to support conditioned responding either directly (the CS) or by acting as a discriminative stimulus for, or a facilitator of, that responding (the context). Responding should decrease during a session of extinction as habituation occurs to the stimuli that support conditioned responding. Responding should also decrease across sessions of extinction as long-term or learned habituation develops to those stimuli (Table 14.1, Characteristic 12).

Table 14.1 summarizes the characteristics of extinction that are consistent with this idea (McSweeney & Swindell, 2002; see also McSweeney, Murphy, & Kowal, 2004a; McSweeney, Swindell, & Weatherly, 1999). Equation 1 also accounts for more than 90% of the variance in 149 data sets on extinction.

Enough evidence supports the habituation hypothesis to suggest that it is worth testing. Nevertheless the habituation hypothesis cannot explain all of the

characteristics of extinction (McSweeney & Swindell, 2002). Similar to other authors (e.g., Mackintosh, 1974), McSweeney and Swindell (2002) suggested that extinction is multiply determined and that habituation is only one of several factors that may contribute.

Behavioral Contrast. Multiple-schedule behavioral contrast refers to the fact that the rate of responding during a constant component of a multiple schedule may vary inversely with reinforcement in the other component (e.g., McSweeney & Norman, 1979). For example, a multiple VI 1-minute VI 1-minute schedule might be changed to a multiple VI 1-minute extinction schedule. If rate of responding during the VI 1-minute component increased with this worsening of the alternative reinforcement, the increase would be labeled "positive contrast." A multiple VI 1-minute VI 1-minute schedule might be changed to a multiple VI 1-minute VI 15-second schedule. If rate of responding during the VI 1-minute component decreased with this improvement in the alternative reinforcement, the decrease would be labeled "negative contrast."

McSweeney and Weatherly (1998) argued that habituation to the reinforcer may provide a parsimonious explanation for some multiple-schedule contrast. They reasoned that reducing the rate of reinforcement in one component of a multiple schedule (e.g., changing a VI 1-minute schedule to extinction) also reduces the amount of habituation that occurs to the reinforcer across the session. The reinforcers provided in the constant component should be more effective (less habituation) and support a higher rate of responding (positive contrast). Providing more reinforcers in one component (e.g., changing a VI 1-minute, to a VI 15-second, schedule) increases habituation to the reinforcer, reducing the effectiveness of the constant-component reinforcers. Less effective reinforcers should support a lower rate of responding (negative contrast).

McSweeney and Weatherly (1998) reported that many results in the literature on multiple-schedule behavioral contrast are compatible with this idea. Some of these results provide relatively strong support for the theory because they are consistent with the habituation hypothesis but not with most other theories and because they were reported in experiments specifically designed to test the habituation hypothesis (e.g., McSweeney, Kowal, Murphy, & Isava, 2004; McSweeney, Murphy, & Kowal, 2003). For example, as predicted, contrast is largest when habituation is strongest (e.g., later, rather than earlier, in the experimental session; McSweeney, Murphy, & Kowal, 2004b; McSweeney, Swindell, Murphy, & Kowal, 2004; Swindell, McSweeney, & Murphy, 2003). Nevertheless, some results in the literature on behavioral contrast are not predicted by habituation. Because of these incompatible findings, McSweeney and Weatherly argued that habituation is only one of several contributors to behavioral contrast, a common assumption in the contrast literature (e.g., Williams, 1983).

Classical Conditioning Phenomena. Similar stimuli serve as reinforcers in operant conditioning and as USs in classical conditioning. In fact, the term "reinforcer" is often used to refer to the US in Pavlovian procedures (e.g., Davidson & Rescorla, 1986). If habituation occurs to reinforcers, then it should also occur to USs and some phenomena in the classical conditioning literature might be attributed to habituation to the US. For example, the size of the UR may decrease during conditioning (conditioned diminution of the UR; e.g., Kimmel, 1966). Classical conditioning may be weaker when several USs are presented before conditioning begins than when they are not (the US preexposure effect; e.g., Mis & Moore, 1973).

Conditioning may be weaker when a US is presented immediately before a CS-US pairing than when it is not (priming by the US; e.g., Terry, 1976). Conditioning is usually also weaker when a CS is paired with a weak US before it is paired with a strong US than when it is not (the Hall-Pearce Effect; Hall & Pearce, 1979).

Several phenomena might also be attributed, at least partially, to habituation to the CS in classical conditioning. For example, the salience of the CS may change during conditioning (e.g., Pearce & Hall, 1980). Classical conditioning may be weaker when several CSs are presented before conditioning begins than when they are not (latent inhibition; e.g., Lubow, 1989). Conditioning may be weaker when a CS is presented immediately before a CS-US pairing than when it is not (priming by the CS; e.g., Pfautz & Wagner, 1976). In addition, habituation to both the CS and US may contribute to learned irrelevance (e.g., Mackintosh, 1973), the finding that conditioning is retarded following uncorrelated presentations of the CS and US (e.g., Bonardi & Hall, 1996).

Although habituation has been proposed as an explanation for many of these phenomena, the present hypothesis differs from, for example, Wagner's (1976) theory because we take an empirical, not a theoretical, approach to habituation. The predictions of the habituation hypothesis for each of these phenomena has not yet been examined.

Not Preference for Variability. Animals often prefer variable to fixed outcomes (see Kacelnik & Bateson, 1996, for a review.) Slower habituation to variable, than to fixed, outcomes (Table 14.1, Characteristic 9) is one of many potential explanations for this preference (see e.g., McSweeney, Kowal, & Murphy, 2003). McSweeney, Kowal et al. reasoned that if habituation contributes to preferences for variability, then this preference should be strongest when differences in habituation to the fixed and variable outcomes are largest. Differences in habituation should be larger later in the session than earlier because these differences should accumulate with successive reinforcer presentations. Differences in habituation should also be larger when reinforcers are presented at higher than at lower rates (Table 14.1, Characteristic 4). McSweeney et al.'s results failed to confirm these predictions. Instead preference for variability, as measured in the initial link of a concurrent chain schedule, was usually stronger for lower than for higher rates of reinforcement and preference did not change systematically within the session.

McSweeney, Kowal et al.'s (2003) results could be explained by the earlier idea that all qualitatively-similar reinforcers contribute to a single number that represents the total amount of habituation that has occurred to that reinforcer at any one point in the session (see "The Matching Law"). Consistent with this idea, the within-session patterns of responding were similar for the initial links of the concurrent chain-schedule that provided fixed and variable reinforcers.

Implications Beyond Conditioning

Habituation

The present argument expands the domain of habituation. To begin with, most studies of habituation examine the waning of a reflexive response (e.g., leg flexion,

Thompson & Spencer, 1966). Arguing that habituation occurs to reinforcers means that habituation may also be observed in "voluntary" or "goal-directed" operant behavior, not just in reflexive behavior. But also, most studies of habituation present a neutral stimulus, such as a light or tone (e.g., Thompson & Spencer, 1966). Arguing that habituation occurs to reinforcers means that habituation also occurs to many biologically significant stimuli that are needed for survival (e.g., food, water).

Motivation

McSweeney and Swindell (1999b) argued that sensitization-habituation may help to explain the initiation and termination of many motivated behaviors. The term "motivation" usually applies to behaviors such as feeding, drinking, aggression, exploration, escape, curiosity and drug taking that are energetic and goal-directed. Early theories of motivation explained these behaviors in terms of a single general process such as homeostasis, instincts, or drives. However, this general-process approach was abandoned as each of these theories encountered problems. For example, motivated behaviors appear to be a heterogeneous class. The class includes some basic biological behaviors (e.g., feeding, drinking, sexual, and maternal behavior), as well as behaviors that are directed at more arbitrary stimuli (e.g., exploration, curiosity). Theories that dealt well with biologically important behaviors (e.g., instincts) tended to fail for more arbitrary behaviors and vice versa.

With the rejection of general-process theories, research on motivation turned to determining the specific factors that govern specific behaviors. For example, termination of ingestion (e.g., eating, drinking) is usually attributed to satiation (e.g., Bizo et al., 1998); termination of energetic responding (e.g., running), to fatigue (e.g., Belke, 1997); termination of cognitive behaviors (e.g., studying), to the waning of attention (e.g., Hinson & Tennison, 1999); termination of drug taking, to pharmacodynamic factors (e.g., Ahmed & Koob, 1999). Unfortunately, the use of different terms to explain different behaviors is unparimonious and is contradicted by the many common characteristics possessed by different motivated behaviors (McSweeney & Swindell, 1999b).

McSweeney and Swindell (1999b) argued that two simple assumptions may contribute to understanding motivated behaviors. First, assume that the goal objects of motivated behaviors (e.g., food) are reinforcers (e.g., Teitelbaum, 1966). Second, assume that sensitization and habituation alter the ability of these goal objects to control behavior with repeated contact. As animals habituate to a goal, the goal loses its ability to control behavior, and behavior directed toward that goal stops. Because spontaneous recovery occurs when the animal is not in contact with the goal (Table 14.1, Characteristic 2), the effectiveness of the goal increases with deprivation and the animal becomes more likely to pursue that goal. McSweeney and Swindell did not argue that habituation is the sole regulator of all motivated behavior. Instead, they argue that habituation is one of serveral variables that contribute to the regulation of many motivated behaviors, just as habituation is one of several variables that help to regulate eating (e.g., Swithers & Hall, 1994).

McSweeney and Swindell (1999b) showed that the characteristics of habituation are found for many motivated behaviors (see Table 14.1). Several predictions of this hypothesis were also confirmed (see Aoyama & McSweeney, 2001a for wheel running;

Murphy et al., 2006; 2007, for alcohol consumption). Finally, Equation 1 accounted for more than 90% of the variance in the data when it was fit to 95 examples of temporal changes in feeding, 16 cases of drinking, 44 cases of exploration, 17 cases of escape, and 27 cases of aggression.

Some of the characteristics of motivated behaviors are surprising. For example, Rolls and her colleagues showed that people eat more when served a variety of foods than when fed constant foods (e.g., B. J. Rolls, van Duijvenvoorde, & E. T. Rolls, 1984) even if the foods differ only in sensory properties such as color or shape (B. J. Rolls, Rowe, & E. T. Rolls, 1982) and even when the foods have no nutritive value (B. J. Rolls, Wood, & E. T. Rolls, 1980). Similar variety effects (Table 14.1, Characteristic 9) have also been reported for drinking (B. J. Rolls et al., 1980) and for sexual behavior (e.g., the Coolidge effect; e.g., Fisher, 1962). In addition, introducing an arbitrary stimulus from another modality strengthens motivated behaviors (Table 14.1, Characteristics 10 and 15). For example, pinching the tail of rats facilitates eating, gnawing, licking, drinking, grooming, locomotion, sniffing, rearing, sexual behavior, maternal behavior and pup retrieval, exploration, vocalization, eating feces or gnawing the cage (e.g., Antelman, Rowland, & Fisher, 1976; Antelman & Szechtman, 1975; Guder & Kornblith, 1979; Robbins & Fray, 1980; Rowland & Antelman, 1976). Bolles (1980) was so perplexed by this phenomenon that he wrote, "Consider the tail-pinch as a source of eating. It is an interesting phenomenon precisely because it does not make much sense; it is the exception to the rule that motivational systems are well-adjusted and independent" (p. 229). This phenomenon is expected, not perplexing, if habituation contributes to the regulation of motivated behavior.

This analysis of motivated behaviors has many interesting applications. We will use obesity as an example here (see McSweeney, Murphy, & Kowal, 2005, for an application to drug taking). Many data support the idea that habituation to the reinforcer contributes to the dysregulation of food consumption that leads to obesity. To give just a few examples, a constant food is more reinforcing for obese subjects than for normal weight subjects (Saelens & Epstein, 1996). Obese subjects also habituate more slowly to food cues than nonobese subjects (Epstein, Paluch, & Coleman, 1996). Obese participants, unlike those of normal weight, fail to slow food intake late in a meal (i.e., show no or slow habituation; Bellisle & Le Magnen, 1981). Raynor and Epstein (2001) also argued that obesity develops and is maintained by the increasing variety of the food supply.

The traditional approach to the control of obesity suggests that a person who wants to lose weight should eat fewer and lower calorie foods and should exercise more to burn excess calories. The habituation model does not deny the importance of these variables, but it emphasizes other variables such as the sensory properties of the food and the environment in which the person eats. The model predicts that a person should eat relatively constant foods to avoid over-consumption. As noted, variety in food reduces the rate of habituation and therefore, can lead to over-consumption (e.g., Ernst & Epstein, 2002). People should avoid eating in places with many environmental distractors (e.g., in front of the television, in a noisy restaurant; e.g., Temple et al., 2007). These unpredictable stimuli will slow habituation by acting as dishabituators or sensitizers. A person should put away food once (s)he has stopped eating. A nibble of an easily available food may produce sensitization,

which will briefly increase the reinforcing effectiveness of food and lead to a resumption of eating.

Recently, Morewedge, Huh, and Vosgerau (2010) confirmed another surprising prediction of this idea. They showed that people who repeatedly imagined eating a food (e.g., cheese) many times subsequently consumed less of the imagined food than did people who repeatedly imagined eating that food fewer times, imagined eating a different food (e.g., candy), or did not imagine eating a food. These results were predicted by the habituation hypothesis. If imagining food generates any of the stimuli associated with eating food, then some habituation to the sensory properties of food should be generated by imagining that food. Of course, this exposure to the sight and/or taste of food should be long enough to ensure that habituation, rather than sensitization, occurs.

Summary

Response rates may increase, decrease, or increase and then decrease within conditioning sessions even when the distribution of reinforcers or USs does not vary across the session. Sensitization and habituation to the sensory properties of the reinforcers mainly produce these within-session changes in responding. Because of sensitization-habituation, the ability of the reinforcer or US to control behavior changes with its successive presentation. This idea has a wide variety of implications for methods, applications, and theory in conditioning and beyond. Dinsmoor (2001) argued that " . . . the goal of scientific theory is to discover and describe the common characteristics that link together seemingly unrelated observations" (p. 324). We believe that the habituation hypothesis has enormous potential for tying together seemingly unrelated phenomena in the conditioning literature and beyond. Because the properties of sensitization and habituation are relatively well known, the model makes many predictions that differ strongly from the predictions made by traditional concepts such as satiation.

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