

Dynamic Changes in Reinforcer Effectiveness: Satiation and Habituation Have Different Implications for Theory and Practice

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Reinforcers lose their effectiveness when they are presented repeatedly. Early researchers labeled this loss of effectiveness as *satiation* without conducting an experimental analysis. When such an analysis is conducted, *habituation* provides a more precise and empirically accurate label for the changes in reinforcer effectiveness. This paper reviews some of the data that suggest that habituation occurs to repeatedly presented reinforcers. It also argues that habituation has surprisingly different implications than satiation for theory and practice in behavior analysis. For example, postulating that habituation occurs to repeatedly presented reinforcers suggests ways for maintaining the strength of an existing reinforcer and for weakening the strength of a problematic reinforcer that differ from those implied by an account in terms of satiation. An habituation account may also lead to different ways of conceptualizing the regulation of behavior. For example, habituation may be a single-process contributor to the termination of behaviors that are usually attributed to satiation (e.g., ingestive behaviors such as eating and drinking), fatigue (e.g., energetic behaviors such as running), the waning of attention (e.g., cognitive behaviors such as studying), and pharmacodynamic factors (e.g., drug taking).

Key words: within-session patterns of responding, reinforcer effectiveness, habituation, satiation

This paper is based on an invited tutorial given at the 2004 meeting of the Association for Behavior Analysis. It does not contain new information. Rather, it summarizes past work in a shorter, more accessible, form. The paper will be useful for those who want only a basic understanding of dynamic changes in reinforcer effectiveness. It will also provide needed references for those who want a more thorough understanding. The tutorial reviews the evidence that reinforcers lose their effectiveness when they are presented repeatedly. It argues that habituation provides a more accurate and useful description than satiation for the loss of effectiveness. Finally, it argues that ha-

bituation has surprisingly different practical and theoretical implications than satiation for behavior analysis.

OPERANT RESPONDING CHANGES SYSTEMATICALLY WITHIN EXPERIMENTAL SESSIONS

Approximately 15 years ago, my students and I reported that rates of operant responding may not be constant within experimental sessions even when the conditions of reinforcement are held constant across the session. Rate of responding often increases to a peak and then decreases, but it sometimes only increases or only decreases within a session (e.g., McSweeney, 1992; McSweeney, Hatfield, & Allen, 1990). These changes occur in steady-state behavior. They are not transitional effects (e.g., acquisition curves).

Examples of within-session changes in operant responding appear in Figure 1. The decreasing pattern of responding (bottom) is usually observed when reinforcers are provided at a high rate (e.g., 4 reinforcers per minute); the increasing pattern (or no within-session

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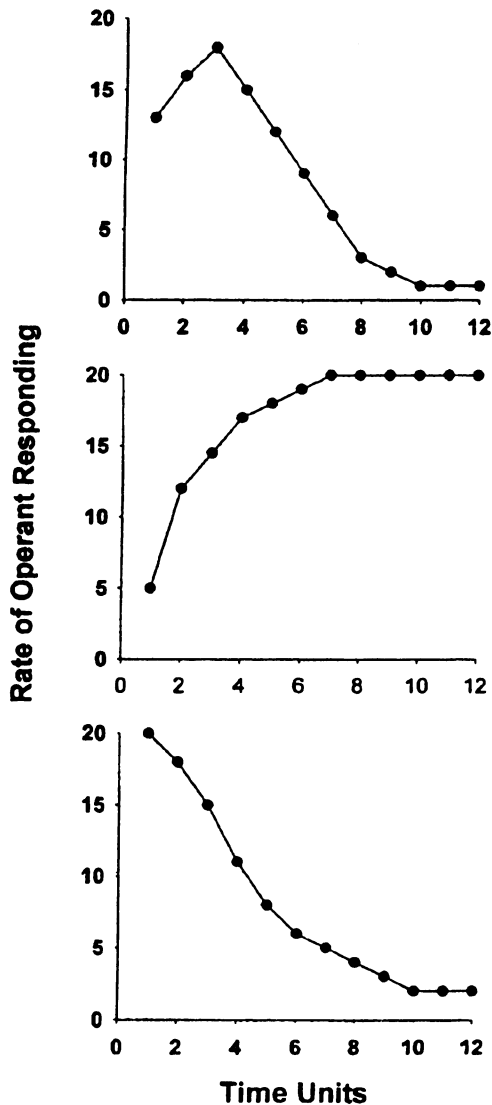


Figure 1. Three common within-session patterns of responding. Rate of responding during successive time units in an experimental session is shown. The results are hypothetical curves taken from Murphy, McSweeney, Smith, and McComas (2003, p. 422; copyright 2003 by the Society for the Experimental Analysis of Behavior Inc., reprinted with permission).

pattern) (middle) is usually observed when reinforcers are provided at a low rate (e.g., 1 reinforcer per 4 minutes); the bitonic pattern (top) is usually observed when reinforcers are presented at intermediate rates (e.g., 1 reinforcer per minute).

We were not the first to notice that

rate of operant responding changes within sessions (see McSweeney & Roll, 1993, for a review). Earlier authors, such as Skinner (e.g., 1932) and Reese and Hogenson (1962), labeled within-session decreases in responding *satiation*. To reflect their usage, many textbook writers defined satiation as a decrease in the effectiveness of a reinforcer with its repeated consumption (Catania, 1998, p. 408; see Malott, Malott, & Trojan, 2000, and Miller, 1997, for similar statements). By this definition, within-session decreases in responding are produced by satiation, but we believe this is a misleading use of the term.

Within-session decreases in responding were attributed to satiation without conducting an experimental analysis. An experimental analysis is needed to answer two questions. First, are the changes in operant responding produced by systematic changes in the effectiveness of the reinforcer rather than by other factors? Second, does satiation produce the changes in reinforcer effectiveness? When we conducted an experimental analysis, we found that within-session changes in operant responding are produced by systematic changes in the effectiveness of the reinforcer, but that satiation does not provide a good description of these changes.

CHANGES IN REINFORCER EFFECTIVENESS PRODUCE WITHIN-SESSION CHANGES IN RESPONDING

Many operant psychologists assume that within-session changes in responding must be produced by changes in the effectiveness of the repeatedly delivered reinforcer. On the contrary, many other factors might contribute. To date, our research has questioned several alternative explanations, including recovery from handling (McSweeney & Johnson, 1994), anticipation of events that follow the session (e.g., feeding or handling; McSweeney, Weatherly, & Swindell,

1995), changes in a general motivational state (e.g., arousal; McSweeney, Swindell, & Weatherly, 1996a, 1996b), changes in interference from adjunctive behaviors (McSweeney, Swindell, & Weatherly, 1996a) or exploration (Roll & McSweeney, 1997), changes in factors produced by the act of responding (e.g., muscular warm-up, fatigue; McSweeney, Weatherly, & Roll, 1995; McSweeney, Weatherly, Roll, & Swindell, 1995; Melville, Rybiski, & Kamrani, 1996; Weatherly, McSweeney, & Swindell, 1995), and changes in "attention" to the task, defined in several ways (McSweeney, Roll, & Weatherly, 1994; McSweeney, Weatherly, & Swindell, 1996c; Melville & Weatherly, 1996). An opponent-process explanation (e.g., Solomon & Corbit, 1974) also seems unlikely because early-session increases in responding sometimes occur without late-session decreases and vice versa. Most of these conclusions are supported by converging evidence from several parametric studies, conducted with both rats and pigeons. Therefore, we have some confidence in them.

Instead, within-session changes in responding are produced primarily by changes in the effectiveness of the reinforcer with its repeated delivery. For example, altering characteristics of the reinforcers such as their rate of delivery (McSweeney, 1992; McSweeney, Roll, & Cannon, 1994; McSweeney, Roll, & Weatherly, 1994; McSweeney & Swindell, 1999a; McSweeney, Weatherly, & Swindell, 1996b) or their nature (e.g., McSweeney, Swindell, & Weatherly, 1996b) alters the within-session response pattern. Independent measures of reinforcer effectiveness also change systematically within sessions when probe preference tests are used to measure effectiveness (McSweeney, Weatherly, & Swindell, 1996a). At this time, changes in the effectiveness of the reinforcer appear to be the major, but not the sole, determinant of within-session changes in responding. Exposure to the experimental context also contributes, but the ef-

fect is small (McSweeney, Swindell, & Weatherly, 1998).

Because we attribute within-session changes in responding to changes in the effectiveness of the reinforcer, we also argue that repeated presentation of the reinforcer is an establishing operation that momentarily alters the ability of that stimulus to serve as a reinforcer (e.g., Michael, 1982, 1993). What remains uncertain is the best label for this establishing operation. Debate has been heated on this issue. Although some authors believe that the establishing operation is arousal-satiation (Bizo, Bogdanov, & Killeen, 1998; DeMarse, Killeen, & Baker, 1999; Hinson & Tension, 1999; Palya & Walter, 1997), we believe that sensitization-habitation provides a more accurate and useful description (e.g., McSweeney, Hinson, & Cannon, 1996; McSweeney & Murphy, 2000; McSweeney & Roll, 1998). Satiation, not habituation, was among our own initial explanations for the within-session changes in responding. We abandoned this description after repeated experiments questioned it. To clarify, we must define satiation and habituation.

DEFINING SATIATION AND HABITUATION

Any technical term that is adopted for use by behavior analysts should be defined as it is in its literature of origin. *Satiation* and *habituation* are both technical terms with large literatures devoted to their study. These literatures are older, and more generally accepted among other scientists, than the literature on behavior analysis. For example, those who study satiation often belong to the Society for the Study of Ingestive Behavior and publish their results in journals such as *Appetite*.

If we do not use technical terms as others use them, our field will risk epistemological isolation (e.g., Staddon, 2001). Productive collaborations will decrease as communicating with others becomes difficult. We also risk ridicule. Just as we would dismiss

someone who argued that the term reinforcer should be defined as "anything that I like," so researchers in other fields will question us if we use their terms inappropriately. Finally, as we will see, terms such as *satiation* and *habituation* lose their content, and therefore their predictiveness, if they are not tied to an empirical literature.

Those who study ingestive behavior talk about satiation as the cessation of an ingestive behavior. The factors that contribute to cessation are called satiety factors. Much research has been devoted to the identification and specification of these factors. For example, Mook (1996) identified factors in the mouth, stomach (e.g., distention), intestine (e.g., cholecystokinin), and liver (e.g., blood sugar level as measured at the liver) as satiety factors for eating. Mook also identified oral stimulation, stomach filling, and cellular hydration as satiety factors for drinking. One should note that habituation to the sensory properties of food is one of the mouth factors that contribute to satiation for food for at least some animals (e.g., Epstein, Rodefer, Wisniewski, & Caggiula, 1992; Ernst & Epstein, 2002; Swithers & Hall, 1994). One should also note that satiety factors differ for eating and drinking. As a result, it cannot be assumed that a factor that has been identified as contributing to satiety for food also contributes to satiety for other stimuli. This will become important later.

Habituation refers to a decrease in responsiveness to a stimulus that is presented repeatedly or for a prolonged time (e.g., Thompson & Spencer, 1966). Habituation is often regarded as the simplest learning process (e.g., Thorpe, 1966). It is ubiquitous, occurring for most if not all species and stimuli (e.g., Thorpe). In the past, researchers have resisted attributing a role in operant conditioning to this simple and powerful process (e.g., Boakes, 1984). Part of their resistance may come from a sort of reverse law of parsimony. In my experience, researchers prefer more complicated to

simpler explanations for their results. For example, in recent years, conditioning phenomena have been routinely attributed to complex processes such as memory (e.g., Bouton, 1993) or attention (e.g., Hinson & Tennison, 1999), rather than to simpler explanations (see, e.g., McSweeney, Murphy, & Kowal, in press, for an alternative explanation for some findings attributed to memory; McSweeney & Murphy, 2000, for an alternative explanation for some findings attributed to attention).

Resistance may also come from several misunderstandings about the nature of habituation. For example, it is sometimes argued that habituation occurs for reflexive, but not for the emitted, responses studied by operant conditioners. On the contrary, habituation occurs for many emitted behaviors (e.g., exploration; Poucet, Durup, & Thinus-Blanc, 1988). It is sometimes assumed that habituation is irrelevant to conditioning because it is unlearned. However, habituation comes in both a short-term (unlearned) and a long-term (learned) form (e.g., Wagner, 1976). It is sometimes argued that habituation does not occur for the biologically important stimuli that often serve as reinforcers in operant experiments (e.g., Williams, Hamilton, & Carlton, 1974). This assumption seems to be based on intuition. On the surface, an animal that habituated to, say, the presence of a lion would not live to pass on its genes. When this issue is studied empirically, however, habituation occurs to biologically important stimuli (e.g., food; Epstein et al., 1992; Swithers & Hall, 1994). Finally, it is sometimes argued that habituation is irrelevant because the term is unpredictable. In contrast, habituation is one of the best understood of psychological processes, and its characteristics are relatively similar for different species and stimuli (e.g., Baker & Tiffany, 1985; but see also Hinde, 1970). Thompson and Spencer (1966) argued that habituation has nine empirical properties. McSweeney and Murphy (2000) expanded this list to 14 on the basis of more re-

TABLE 1

Some empirical characteristics of habituation (adapted from McSweeney & Murphy, 2000). An asterisk indicates that this characteristic of habituation has been confirmed for within-session changes in operant responding for food

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- *1. Spontaneous recovery (e.g., Thompson & Spencer, 1966): Responsiveness to an habituated stimulus recovers when that stimulus is not presented for a time.
 - *2. Stimulus specificity (e.g., Swithers & Hall, 1994; Whitlow, 1975): Habituation is disrupted by changes in the presented stimulus.
 - *3. Variety effects (e.g., Broster & Rankin, 1994): Habituation occurs more slowly to stimuli that are presented in a variable, rather than a fixed, manner (e.g., after variable, rather than fixed, interstimulus intervals).
 - *4. Dishabituation (e.g., Thompson & Spencer, 1966): Presenting a strong, different, or extra stimulus restores responsiveness to an habituated stimulus.
 - 5. Dishabituation habituates (e.g., Thompson & Spencer, 1966): Repeated presentation of dishabitators reduces their ability to restore habituated responding.
 - *6. Stimulus rate (e.g., Thompson & Spencer, 1966): Faster rates of stimulus presentation yield faster and more pronounced habituation than slower rates.
 - 7. Stimulus rate and recovery (Staddon & Higa, 1996): Spontaneous recovery may be faster after faster than after slower rates of stimulus presentation.
 - *8. Stimulus exposure (e.g., Thompson & Spencer, 1966): Responsiveness to a repeatedly presented stimulus decreases with increases in stimulus exposure.
 - *9. Long-term habituation (e.g., Wagner, 1976): Some habituation is learned and persists over time.
 - *10. Repeated habituations (e.g., Thompson & Spencer, 1966): Habituation may become more rapid with repeated habituations.
 - *11. Stimulus intensity (e.g., Thompson & Spencer, 1966): Habituation is sometimes, but not always (e.g., Groves & Thompson, 1970), faster and more pronounced for less, than for more, intense stimuli.
 - *12. Generality (e.g., Thorpe, 1966): Habituation occurs for most, if not all, stimuli and species of animals. The exact rate of habituation depends on the species, the stimulus, the response, and the individual subject (e.g., Hinde, 1970).

Habituation is often accompanied by "sensitization" (e.g., Groves & Thompson, 1970). Therefore, if habituation occurs, the following phenomena might also be observed:

- *13. Sensitization by early-stimulus presentations (e.g., Groves & Thompson, 1970): An increase (sensitization), rather than a decrease (habituation), in responsiveness may occur during the first few presentations of a repeatedly presented stimulus.
 - 14. Sensitization by stimuli from another modality (e.g., Swithers & Hall, 1994): 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). Both sensitization and dishabituation (Characteristic 4) 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).
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cent research. Their list of properties appears in Table 1. Although any one example of habituation might not show all of these properties, all examples of habituation would show several of them.

Notice Characteristic 13 in Table 1 (sensitization by initial stimulus presentations). Groves and Thompson (1970) argued that a companion process, *sensitization*, often, but not always, accompanies that of habituation.

Sensitization refers to an increase in responsiveness to a stimulus during the first few presentations of that stimulus. So far, we have discussed within-session decreases in responding (Figure 1, bottom) and ignored the increases (Figure 1, middle). With the identification of sensitization, however, the habituation hypothesis can be expanded to explain both the increases (primarily sensitization) and decreases (primarily habituation) in operant responding. Sati-

ation can also explain the increases in responding with the addition of another factor, such as arousal (e.g., Killeen, Hanson, & Osborne, 1978). But, this expansion is post hoc. We know of no satiety researcher who argues that satiation has an opposite companion process. In contrast, research on habituation anticipated the discovery of within-session increases in responding by at least 20 years.

SEPARATING SATIATION AND HABITUATION

Some of the characteristics of behavior undergoing habituation are predicted by other potential explanations for within-session changes in responding. For example, almost all explanations for the decreases in operant responding predict that spontaneous recovery will also occur. If responding decreases because of physical fatigue, responding should recover over time spent pausing as the muscles are restored. If responding decreases because of a nonhabituation satiety factor (e.g., stomach distension), responding should recover over time as the stomach empties of the distending food. Other characteristics are more useful in separating habituation from other explanations including other satiety factors. The most useful characteristics are dishabituation, variety effects, and stimulus specificity. We will illustrate the presence of each of these characteristics in operant responding for food reinforcers.

Dishabituation (Table 1, Characteristic 4) refers to the fact that presenting a strong, different, or extra stimulus restores responsiveness to an habituated stimulus. Figure 2 presents an example of dishabituation taken from Aoyama and McSweeney (2001b; see also McSweeney & Roll, 1998). During baseline, rats pressed a lever for a reinforcer of one food pellet delivered according to a fixed-ratio (FR) 4 schedule in a 45-min session. Dishabituation conditions were similar to baseline except that the conditions of reinforce-

ment were changed for 3 min in the middle of the session. In one dishabituation condition, the lever was withdrawn (top left). In another condition, lever pressing was reinforced under an FR 6 schedule, and two pellets were delivered whenever a reinforcer was obtained (top right). In a third condition, the schedule was changed to an FR 8 (bottom left). In a final condition, two FR schedules (2 and 6) alternated for each reinforcer (bottom right).

Figure 2 presents within-session patterns of responding for the baseline and dishabituation conditions. It shows that responding was always faster after the dishabituating manipulation concluded, and the FR 4 schedule was restored, than it was at a comparable time during baseline. This increase in responding was observed regardless of whether rate of responding decreased (e.g., no lever) or increased (e.g., FR 8) while the manipulation was in effect. It was also observed regardless of whether subjects obtained more (e.g., FR 6, two pellets) or less (e.g., no lever) food while the dishabituating manipulation was presented than during baseline. Finding such dishabituation is compatible with the idea that habituation contributes to the decreases in responding (e.g., Thompson & Spencer, 1966). It is not consistent with the action of other satiety variables (e.g., blood glucose levels, stomach distension). Providing more reinforcers should decrease, not increase, responding by producing more of these satiety factors (e.g., higher blood glucose levels, more stomach distension).

Variety effects (Table 1, Characteristic 3) refer to the fact that habituation occurs more slowly to stimuli presented in a variable, rather than a fixed, manner. Figure 3 presents an example of a variety effect taken from Aoyama and McSweeney (2001b; see also Ernst & Epstein, 2002). In this experiment, rats responded for food pellets according to FR schedules and matched variable-ratio (VR) schedules that required the same mean number of re-

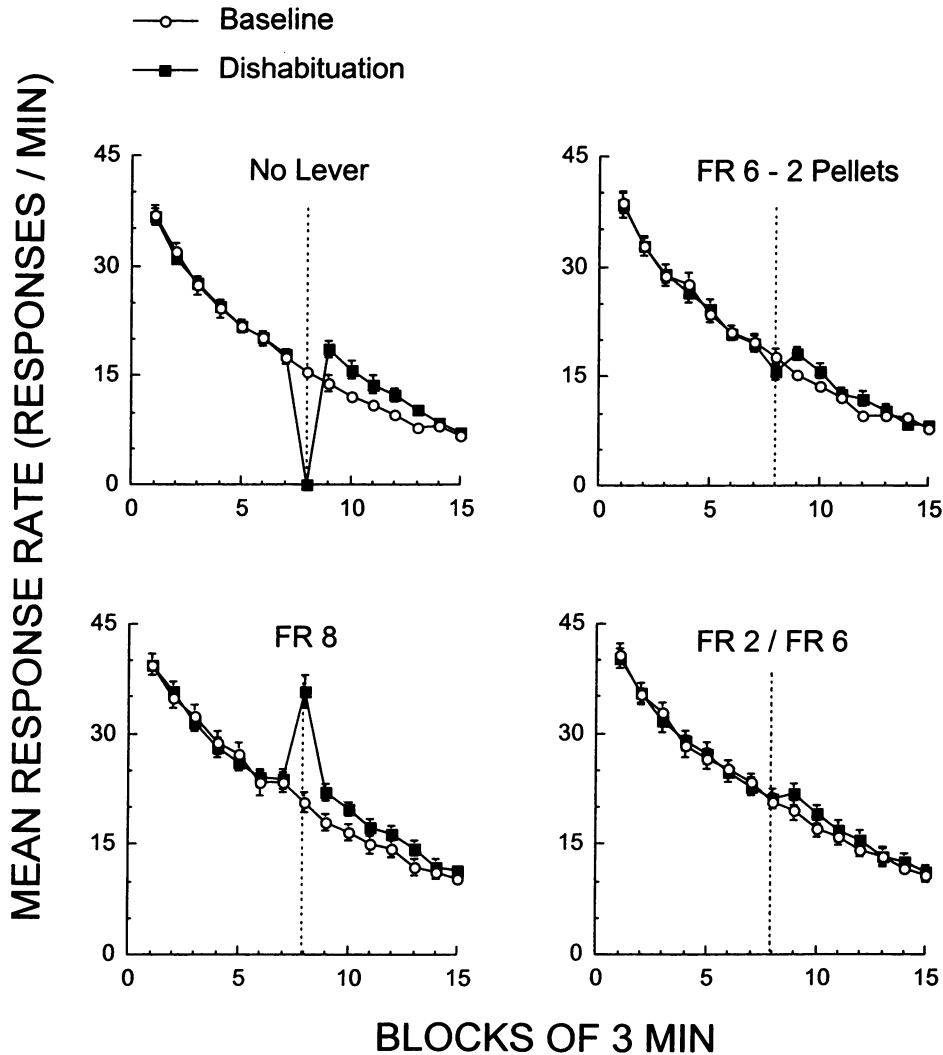


Figure 2. Mean response rate (responses per minute) during successive 3-min blocks in the session for each condition. Each graph compares the results from one of the dishabitation conditions to baseline responding. Error bars indicate standard error of the means. When error bars are not apparent, the bars were smaller than the diameter of the circles used as symbols. Vertical dashed lines indicate the time of presentation of the dishabituating event. Results were taken from Aoyama and McSweeney (2001b, p. 82; copyright 2001 by the Psychonomic Society, reprinted with permission).

sponses per reinforcer as the FR schedule.

Figure 3 presents the within-session patterns of responding for several pairs of FR and VR schedules. Responding declined more quickly within the session when reinforcers were delivered according to an FR schedule than when responding was reinforced according to a matched VR schedule. Such a variety

effect was predicted by habituation. These results are not consistent with the action of nonhabituation satiety factors. Subjects responded faster, and therefore obtained more food, at comparable times in the session from the VR than from its matched FR schedule. Obtained rate of reinforcement is proportional to rate of responding on ratio schedules. As a result, nonhabi-

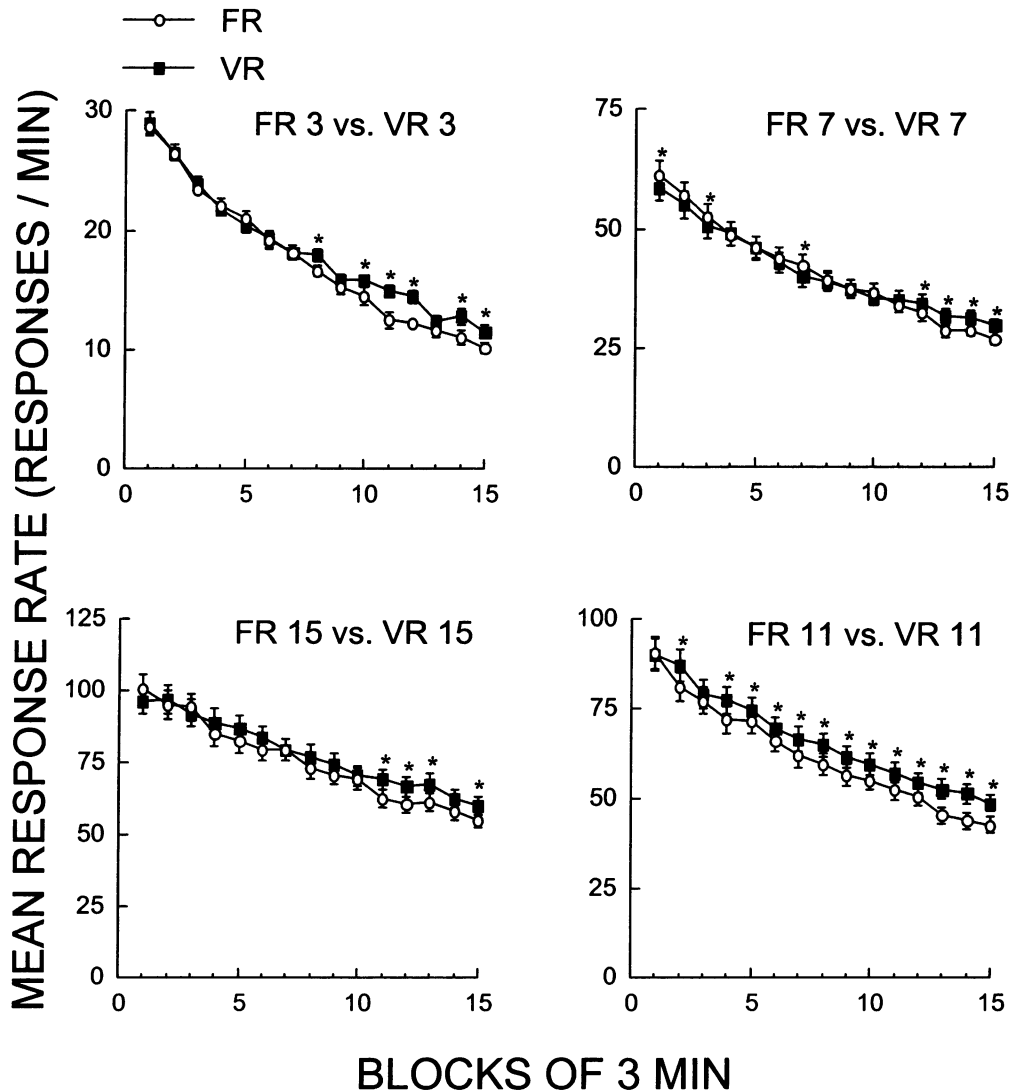


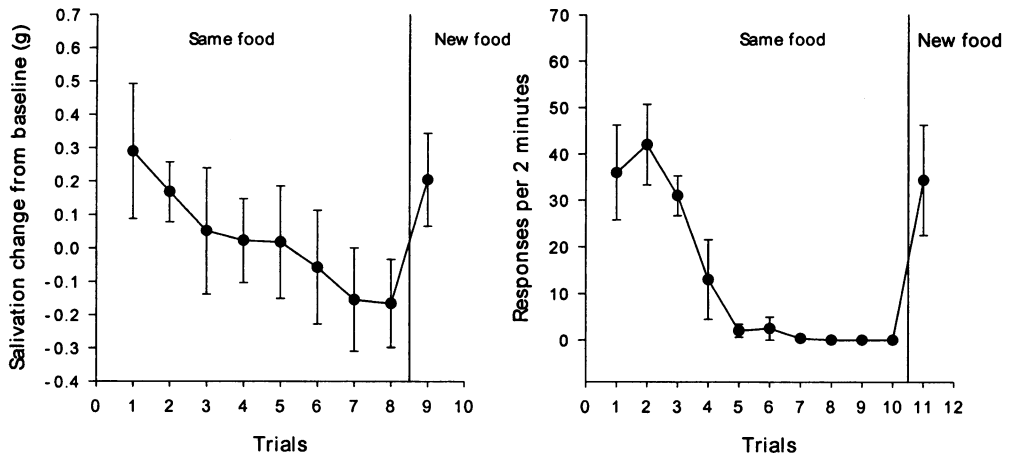
Figure 3. Mean response rates (responses per minute) during successive 3-min blocks in the session for FR and matched VR schedules. Each graph presents the results for a different FR-VR pair. Error bars indicate standard error of the means. When error bars are not apparent, the bars were smaller than the diameter of the circles used as symbols. An asterisk indicates that rates of responding during the FR and VR schedules were significantly different ($p < .05$). Results were taken from Aoyama and McSweeney (2001b, p. 86; copyright 2001 by the Psychonomic Society, reprinted with permission).

tuation satiety factors predict that responding should have declined faster on the VR (more food) than on the matched FR (less food) schedules. The opposite was observed.

Stimulus specificity refers to the fact that habituation is disrupted by unpredictable changes in the presented stimulus (Table 1, Characteristic 2). Figure

4 presents an example of stimulus specificity taken from Epstein et al. (2003). In this experiment, 8- to 12-year-old nonobese children were repeatedly exposed to the smell of one half of a heated cheeseburger. On either the ninth (top left) or tenth (bottom left) exposure (trial), the stimulus was changed to the smell of dutch ap-

Salivation changes across trials - Group 1 Responses for food - Group 1



Salivation changes across trials - Group 2 Responses for food - Group 2

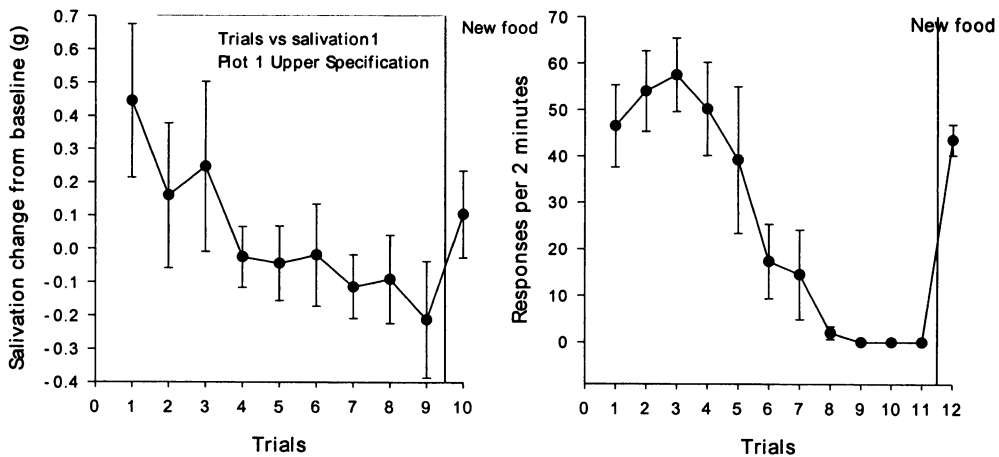


Figure 4. Mean salivation (left) and mean rate of lever pressing (right) across the session. The vertical line indicates a change in the stimulus. Results were taken from Epstein et al. (2003, p. 288; copyright 2003 by Elsevier, reprinted with permission).

ple pie. A 1-min interval separated all trials. The left graphs present the amount of saliva generated on successive trials. Then, the same subjects were allowed to play a computer game. Moving a joystick until objects matched on a screen was reinforced by a point that was exchangeable for half a cheeseburger. During either the 11th (top right) or the 12th (bottom right) 2-min interval of the session, the reinforcer changed to apple pie. The right graphs present the rate of operant responding during successive 2-min in-

tervals in the session. The change in stimulus (indicated by the vertical line) was made on two different trials (top vs. bottom graphs) to ensure that changes in responding were not produced by the passage of time.

The similarity of the decreases in salivation, a generally accepted measure of habituation for food, and operant responding for food is striking. Nevertheless, this similarity establishes a correlation rather than causation. In contrast, the recovery of operant responding with the change of stimulus

strongly suggests that habituation contributed to the decrease in responding. Habituation should be disrupted by a change in stimulus (Table 1, Characteristic 2). In contrast, other satiety variables, such as stomach distension or blood sugar level, should only increase over trials.

New stimuli were introduced during tests for both dishabituation (Figure 2) and stimulus specificity (Figure 4). The tests differ, however. Tests for dishabituation measure the effect of the new stimulus on responding for the old stimulus. That is, to qualify as dishabituation, responding for the old stimulus must increase after the introduction and then withdrawal of the new stimulus. Tests for stimulus specificity measure the effect of the new stimulus on responding for that stimulus. To qualify as a test for stimulus specificity, responding must increase after the new stimulus is introduced.

We would not expect anyone to be convinced of our hypothesis on the basis of these results alone. The case for habituation is actually much stronger. Additional arguments may be found in McSweeney and Roll (1998) and McSweeney and Murphy (2000). In addition, McSweeney, Hinson, and Cannon (1996) argued that within-session changes in responding for food share at least 11 of the 14 characteristics of behavior undergoing habituation (see asterisks in Table 1). Although the results of any one study might be dismissed, attributing within-session changes in responding to satiation becomes less tenable as the data and formal arguments in favor of habituation accumulate.

We would not be surprised if future results showed that satiety variables other than habituation contribute to the regulation of within-session changes in operant responding. We argue that habituation contributes to these changes, not that it is the sole contributor. Nevertheless, to date, we have found only evidence for a contribution of habituation and, as can be seen in the preceding figures, the predictions of ha-

bituation prevail when those predictions are pitted against the predictions of other satiety factors.

THEORETICAL AND PRACTICAL IMPLICATIONS OF HABITUATION TO THE REINFORCER

Postulating that habituation occurs to repeatedly presented reinforcers has a large number of practical and theoretical implications for behavior analysis. These implications are surprisingly different from the implications of arguing that satiation occurs. The implications of our arguments for the practice of behavior analysis can be found in detail in Murphy, McSweeney, Smith, and McComas (2003). The theoretical implications of our ideas can be found in many other papers. For example, we have argued that dynamic changes in reinforcer effectiveness have implications for understanding extinction (McSweeney, Murphy, & Kowal, 2004a; McSweeney & Swindell, 2002; McSweeney, Swindell, & Weatherly, 1999), the behavioral interactions observed during multiple schedules (McSweeney, Kowal, Murphy, & Isava, in press; McSweeney, Murphy, & Kowal, 2003, 2004b; McSweeney, Swindell, Murphy, & Kowal, 2004; McSweeney & Weatherly, 1998; Swindell, McSweeney, & Murphy, 2003), some results that are usually attributed to behavioral economics (McSweeney & Swindell, 1999a; McSweeney, Swindell, & Weatherly, 1996b), and the biconic relation between rate of responding and rate of reinforcement (e.g., McSweeney, 1992). I present examples of one practical implication and one theoretical implication here.

A Practical Implication: Regulating the Effectiveness of Reinforcers

Reducing the effectiveness of a problematic reinforcer. Many behavioral problems occur because a reinforcer is too strong and maintains too much be-

havior (e.g., obesity, smoking, drug consumption). To deal with this problem, we recommend consulting Table 1 to find ways of increasing habituation and reducing sensitization to that reinforcer.

To give one example, Ayllon (1963) described the behavior of a schizophrenic patient who was hoarding towels. To reduce the behavior, he delivered towels to the patient noncontingently. Eventually, the hoarding decreased and Ayllon argued that towel delivery produced satiation. Today we know that noncontingent reinforcer delivery has a complex effect on behavior. Some of this effect may be attributed to the accumulating effect of more of the stimulus, but some of the effect is also the result of noncontingency itself. Nevertheless, to simplify, assume that the only effect of noncontingent delivery was to increase the number of towels delivered. How useful is it to attribute the effect of increasing towels to satiation? Because satiety factors differ for different stimuli (Mook, 1996, cf. pp. 70 and 80) and because there is no empirical literature on satiation for towels, such an explanation leaves us with no guidance about how to maximize satiation. Should Ayllon deliver larger or smaller towels? Colored or white towels? Heavier or lighter towels? Pure cotton towels or polyester mixtures?

In contrast, attributing the decrease in behavior to habituation yields many explicit predictions. The characteristics of habituation are relatively similar for all types of stimuli (e.g., Table 1). Habituation could be speeded by presenting relatively uniform towels regardless of their size, color, or material (Table 1, Characteristic 2). The towels should be provided at a faster, rather than a slower, rate (Table 1, Characteristic 6) and at fixed, rather than at variable, intervals (Table 1, Characteristic 3). To reduce sensitization, the towels should be provided in a relatively quiet, uniform environment (Table 1, Characteristic 14). That is, the habituation hypothesis makes very explicit

predictions about how to reduce the effectiveness of this troublesome reinforcer.

Maintaining the effectiveness of a needed reinforcer. Other problems occur because a reinforcer loses effectiveness too quickly. To maintain the effectiveness of that reinforcer, Table 1 should be consulted for ways of decreasing habituation and increasing sensitization to the reinforcer.

For example, suppose that a behavior analyst uses candy to modify the behavior of an autistic child. The behavior analyst will be frustrated if the effectiveness of the candy declines quickly. If he or she believes that the decrease occurs because of satiation, the behavior analyst should switch to a food that is lower in calories or that produces less stomach distension. If, however, the behavior analyst believes that food loses effectiveness primarily because of habituation, a wide variety of other manipulations become available. The effectiveness of the reinforcer could be maintained by offering a variety of foods, regardless of the size or caloric content of those foods (Table 1, Characteristic 3). Effectiveness could be maintained by delivering the food on a variable rather than a fixed schedule (Table 1, Characteristic 3). Once the food loses its effectiveness, giving a nibble should restore its ability to control behavior (Table 1, Characteristic 13). Finally and counterintuitively, sensitization might be increased by working with the child in a noisy, rather than a quiet, environment (Table 1, Characteristic 14).

Occasionally, a diet promises weight reduction if the person eats only, say, grapefruit. It is often assumed that such a diet is effective because grapefruit is low in calories. We argue instead that people would lose weight if they ate only cheesecake or any other food. According to our argument, any food will quickly lose the ability to reinforce its own ingestion, and consumption of that food will decrease, if habituation occurs quickly to that food. Habituation will occur quickly if the sensory

properties of the food are relatively constant (Table 1, Characteristic 2). Notice that, although this is a theoretical prediction, in practice I caution against adopting such a restricted diet (see Raynor & Epstein, 2001, for a discussion of how dietary variety contributes to obesity).

*A Theoretical Implication:
Understanding the Factors That
Maintain Behavior*

Habituation may help to explain the termination of a behavior that is usually attributed to a different variable. For example, if I asked you why you stopped eating (an ingestive behavior), you would probably say that you were full (satiated; e.g., Bizo et al., 1998). If I asked you why you stopped running (an energetic response), you would probably say that you were tired (fatigued; e.g., Belke, 1997). If I asked you why you stopped studying (a cognitive behavior), you might say that you were bored (your attention waned; e.g., Hinson & Tennison, 1999). If I asked you why you stopped consuming a drug, you might say that you had obtained the desired high (e.g., Ahmed & Koob, 1999).

We argue, instead, that habituation may be a simple common contributor to the termination of all of these behaviors (McSweeney & Swindell, 1999b). Assume that each behavior occurs because a reinforcer maintains that behavior (e.g., food for eating, the drug for drug taking). This reinforcer increases the frequency of any behavior that it follows including its own consumption. In that case, the behavior might terminate if habituation reduced one's responsiveness to the reinforcer to the extent that the reinforcer no longer supported behavior. The behavior might begin again because habituated responding spontaneously recovers when the stimulus is absent (Table 1, Characteristic 1).

This simple idea accounts for the data that are usually attributed to homeostasis, probably the most popular

and enduring model for the regulation of behavior. According to homeostasis, a behavior (e.g., eating) is triggered when a physiological deficit occurs (e.g., blood sugar levels drop). The pursuit of the behavior (e.g., eating) restores the deficit (e.g., blood sugar levels rise) and stops the behavior. According to the present model, spontaneous recovery, not the accumulation of a physiological deficit, accounts for the increase in a behavior with time since its last pursuit. Habituation, not the correction of a deficit, explains why performing a behavior contributes to its termination. No homeostatic mechanism is needed.

The present model avoids many problems associated with homeostasis. For example, homeostatic models are irrelevant for behaviors that do not have a strong biological basis (e.g., money seeking). In addition, even highly biologically based processes are not homeostatic when they are examined carefully. Feeding and drinking occur before a physiological deficit occurs and terminate before the deficit is corrected (e.g., Ramsay & Woods, 1997). It is also hard to imagine how a homeostatic mechanism could evolve to regulate drugs, many of which do not occur naturally (Ramsay & Woods).

We have already presented evidence that habituation contributes to the loss of reinforcer effectiveness when food, an ingestive stimulus, serves as the reinforcer (for summaries, see McSweeney, Hinson, & Cannon, 1996; McSweeney & Murphy, 2000; McSweeney & Roll, 1998). For example, Figures 2 to 4 show that operant responding for food can be dishabituated, shows variety effects, and shows stimulus specificity.

Aoyama and McSweeney (2001a) provided evidence that habituation may contribute to the termination of an energetic behavior, wheel running in rats. As would be expected if habituation occurred, rate of wheel running decreased over time. Wheel running also showed three of the characteristics

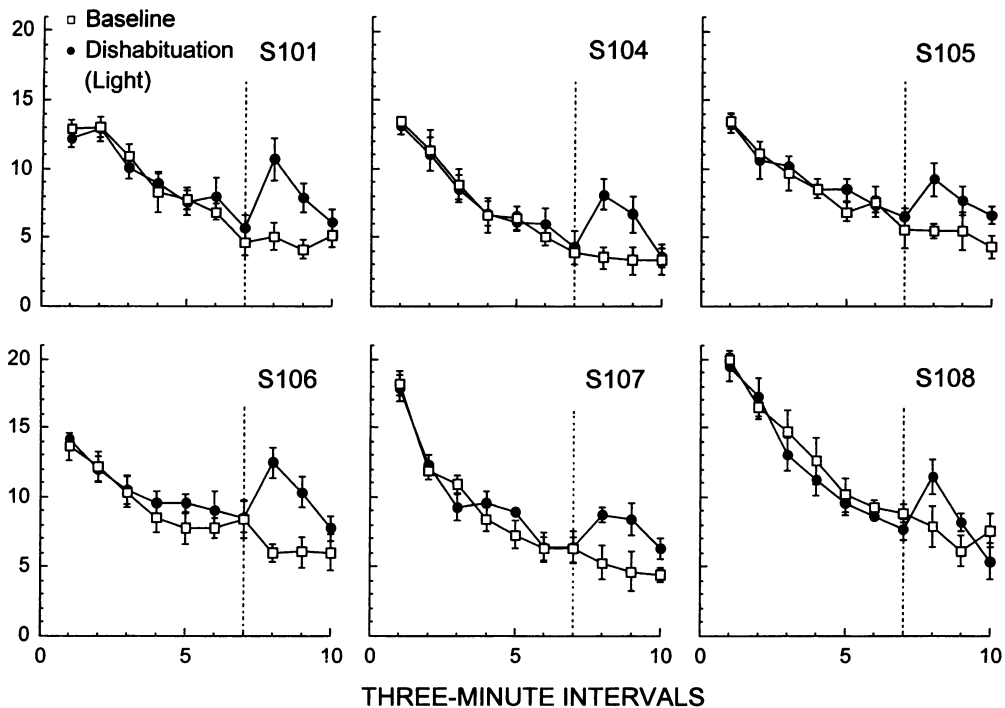


Figure 5. Rate of wheel turning (turns per minute) during successive 3-min intervals in the session. Each graph presents the results for an individual subject. Error bars represent the standard error of the mean. The vertical dashed line indicates the time at which the dishabituating event was presented. Results were taken from Aoyama and McSweeney (2001, p. 294; copyright 2001 by the Society for the Experimental Analysis of Behavior Inc., reprinted with permission).

of behavior undergoing habituation: spontaneous recovery (Table 1, Characteristic 1), dishabituation (Table 1, Characteristic 4), and stimulus specificity (Table 1, Characteristic 2).

To illustrate, Figure 5 presents evidence of dishabituation. During baseline, rats ran in a wheel for 30 min. The dishabituation condition was similar to baseline except that the house-light flashed (off for 1 s, on for 1 s, etc.) for 5 s at 20 min and 55 s in the session (vertical dashed line). Consistent with dishabituation, running was faster after presentation of the light than at a comparable time during baseline for each subject. Notice that these results are not obviously predicted by the idea that running terminates because of physical fatigue. Flashing a light should not reduce many factors that contribute to physical fatigue (e.g., the buildup of lactic acid in the muscles).

Murphy (2003) showed that habituation may contribute to the termination of drug consumption. In his experiment, rats that were bred to consume ethanol (P rats) pressed a lever for a 10% ethanol solution (water substrate). As would be expected if habituation occurred, rate of lever pressing decreased across the session. Lever pressing for ethanol reinforcers also showed spontaneous recovery (Table 1, Characteristic 1) and dishabituation (Table 1, Characteristic 4).

Figure 6 presents Murphy's (2003) results for dishabituation. During baseline, rats pressed a lever for ethanol reinforcers delivered by a variable-interval 15-s schedule. The tone condition was the same as baseline except that a 60-dB 2-kHz tone sounded for 5 s (1 s on, 1 s off, etc.) at 24 min and 55 s into the session. The light condition was also the same as baseline except that the light over the lever and the

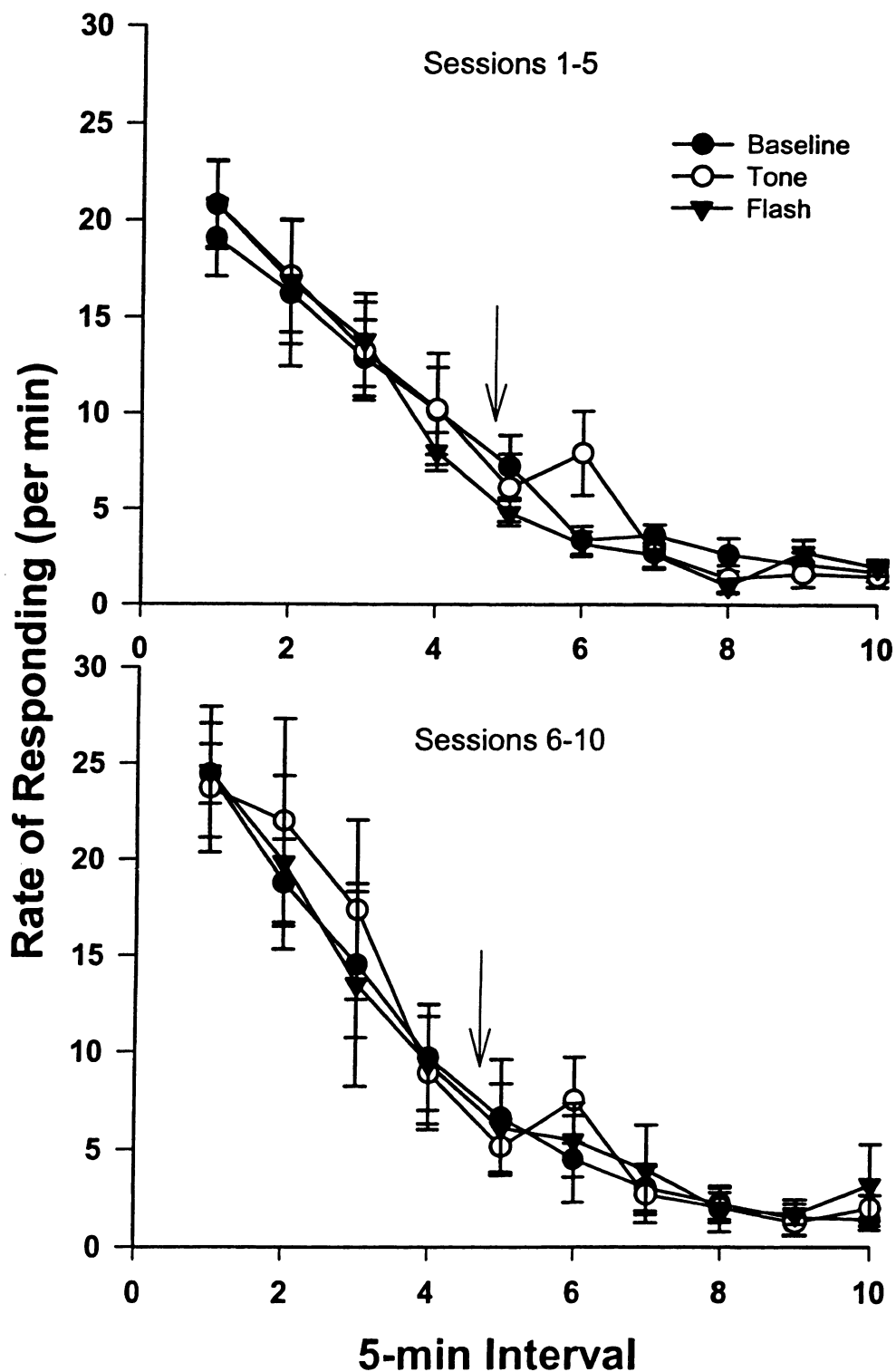


Figure 6. Rate of responding (responses per minute) during successive 5-min intervals in the session when ethanol served as the reinforcer. Results are those for the mean of all subjects averaged over Sessions 1 to 5 (top) and 6 to 10 (bottom). The error bars represent the standard error of the mean. Results were taken from Murphy (2003, reprinted with permission).

housetlight flashed for 5 s (1 s off, 1 s on, etc.) at 24 min and 55 s into the session.

Figure 6 presents within-session response patterns for each condition averaged over all rats and over the first five sessions in which the dishabitua-tors were introduced (top). It also pre-sents these patterns averaged over the next five sessions in which the dishabitua-tors were introduced (bottom). The tone, but not the light, served as a dishabituator. That is, responding was faster after presentation of the tone, but not after presentation of the light, than at a comparable time during baseline. The effect of the tone was also larger during the first five sessions of its in-troduction than during the later five sessions. This is also consistent with habituation. The effect of a dishabitua-tor should habituate (become smaller) with its repeated presentation (Table 1, Characteristic 5). The failure of the light to act as a dishabituator must be explained eventually, and its explana-tion might question our hypothesis. For now, however, we do not give this fail-ure great weight because it has so many potential artifactual explanations (e.g., P rats do not see well).

Notice that the results presented in Figure 6 are not obviously predicted by the idea that ethanol consumption ter-minates because of pharmacodynamic factors (e.g., achieving a certain con-centration of ethanol). There is no rea-son to expect that sounding a tone would alter these factors. McSweeney, Murphy, and Kowal (in press) sum-marize many other implications of ha-bituation to the reinforcer for the reg-ulation of drug taking.

SUMMARY

The message of this paper can be easily summarized. The ability of a re-inforcer to control behavior changes with repeated or prolonged delivery of that reinforcer. The changes in rein-forcer effectiveness are produced largely by sensitization and habituation to the sensory properties of the rein-

forcer. These dynamic changes in re-inforcer effectiveness have practical and theoretical implications for behav-ior analysis. They can help an applied behavior analyst to increase the effec-tiveness of a needed reinforcer (de-crease habituation and increase sensi-tization) or reduce the effectiveness of a troublesome reinforcer (increase ha-bituation and decrease sensitization). Dynamic changes in reinforcer effec-tiveness also have many potential the-oretical implications. For example, ha-bituation to the reinforcer may contrib-ute to the termination of a variety of behaviors that are usually attributed to other mechanisms, such as satiation, fatigue, fluctuations in attention, or ob-taining a particular high.

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