JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1993, 60, 129–140 NUMBER 1 (JULY)

RESPONSE DEPRIVATION, REINFORCEMENT, AND ECONOMICS

JAMES ALLISON

INDIANA UNIVERSITY

Reinforcement of an instrumental response results not from a special kind of response consequence known as a reinforcer, but from a special kind of schedule known as a response-deprivation schedule. Under the requirements of a response-deprivation schedule, the baseline rate of the instrumental response permits less than the baseline rate of the contingent response. Because reinforcement occurs only if the schedule deprives the organism of the contingent response, reinforcement cannot result from any intrinsic property of the contingent response or any property relative to the instrumental response. Two typical effects of response-deprivation schedules—facilitation of the instrumental response and suppression of the contingent response—are discussed in terms of economic concepts and models of instrumental performance. It is suggested that response deprivation makes the contingent response function as an economic good, the instrumental response as currency.

Key words: reinforcement, response deprivation, behavioral economics, facilitation, suppression, performance models

---

Textbook accounts of reinforcement suggest that many psychologists have yet to absorb the still-valid lesson of an article published nearly 20 years ago. This lesson is that reinforcement of an instrumental response, contrary to the law of effect and its many relatives, may not result from a special kind of response consequence called a *reinforcer* but from a special kind of schedule called a *response-deprivation* schedule (Timberlake & Allison, 1974).

Response deprivation is defined partly in terms of a paired-baseline condition in which two different responses are freely available without constraint. The total amount of the response, measured in any convenient unit, is referred to as the paired-baseline amount of the response. In a subsequent contingency session of the same duration as the baseline session, one of the two responses will function as the instrumental response and the other as the contingent response. The schedule used in the contingency session is said to deprive the individual of the contingent response if, and only if, the baseline amount of the instrumental response permits less than the baseline amount of the contingent response.

A graphic example of a fixed-ratio (FR) schedule that deprives the individual of the contingent response appears as Schedule 1 in Figure 1. The schedule constraints that apply throughout the 1-hr contingency session appear as a step function in which each horizontal run signifies the instrumental running requirement and each vertical rise signifies the amount of contingent drinking allowed immediately each time the rat satisfies the instrumental requirement. The units of measurement are the number of turns of the activity wheel and the number of licks at the water spout. The large circle located at 200 wheel turns and 3,000 water licks, the paired base point, shows the total amount of each response performed in the paired-baseline condition.

The response requirements under Schedule 1 are 10 instrumental wheel turns and 40 contingent licks. Under those terms the baseline amount of the instrumental response, 200 wheel turns, would permit only 800 licks—2,200 fewer than the baseline number, 3,000. The closed circle on Schedule 1 portrays the typical behavioral response to deprivation schedules—facilitation of the instrumental response (performance above the baseline rate) and suppression of the contingent response (performance below the baseline rate). These two terms, *facilitation* and *suppression,* may seem to be unnecessary jargon (others might be better), but they are used here as more neutral substitutes for such words as *reinforcement* and *punishment,* which are perhaps too laden with interpretive connotations. The literature contains numerous examples of the facilitation and suppression effects that are illustrated in Figure 1 (Allison, 1976; Allison & Boulter, 1982; Allison, Buxton, & Moore, 1987; Allison, Miller, & Wozny, 1979; Allison & Moore, 1985; Allison & Timberlake, 1974; Bernstein

---

I thank Justin English and Alison Buxton for comments.
Correspondence should be addressed to James Allison, Department of Psychology, Indiana University, Bloomington, Indiana 47405.

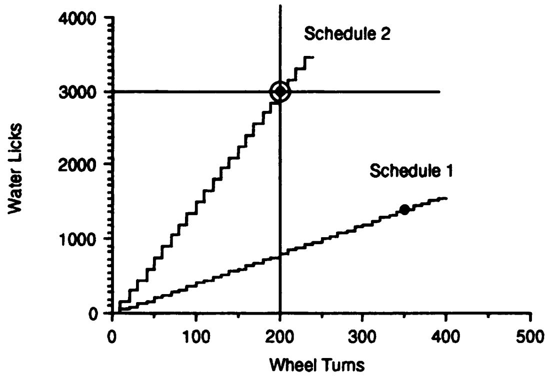

Fig. 1. Water licks as a function of wheel turns. The data are hypothetical. The open circle at 200 wheel turns and 3,000 licks represents paired-baseline amounts. The step functions represent fixed-ratio schedules that require a specified number of instrumental wheel turns for a specified number of contingent water licks. The closed circles represent typical responses to the schedule constraints.

& Ebbesen, 1978; Klajner, 1975; Podsakoff, 1982; Timberlake & Allison, 1974). Sometimes, but much less commonly, the facilitation of the instrumental response is accompanied by performance of the contingent response at its baseline rate (Harrison & Schaeffer, 1975; Wasik, 1969).

Schedule 2 (Figure 1) is a graphic example of a nondeprivation schedule. Its terms are 10 instrumental wheel turns for 150 contingent water licks. Under those terms the baseline amount of the instrumental response, 200 turns, permits the baseline amount of the contingent response, 3,000 licks. Accordingly, Schedule 2 does not deprive the rat of the contingent response. The closed circle on Schedule 2, inside the paired base point, represents a common behavioral response to nondeprivation schedules: performance of each response at its baseline level, revealing no effect on either response relative to the baseline rates (Gawley, Timberlake, & Lucas, 1986; Konarski, Crowell, Johnson, & Whitman, 1982; Konarski, Johnson, Crowell, & Whitman, 1980; Podsakoff, 1982; Wozny, 1979).

Nondeprivation schedules sometimes suppress both responses (Tierney, Smith, & Gannon, 1987; see Timberlake, 1980, for a review of the effects of nondeprivation schedules). This may occur in cases in which the dimensions of the behavior under study do not covary as closely as presumed. For example, if the contingent requirement is defined in terms of the number of licks at a water spout, the rat may achieve its baseline water intake before reaching its baseline number of water licks (Buxton & Allison, 1990). Symmetrically, if the contingent requirement is defined in terms of volumetric intake, the rat may achieve its baseline number of water licks before reaching its baseline intake (Allison & Buxton, 1992; see also Allison, Moore, Gawley, Mondloch, & Mondloch, 1986). In any event, the suppression of both responses under a nondeprivation schedule suggests that response deprivation may not be sufficient for reinforcement. If a nondeprivation schedule suppresses the instrumental response, then a second schedule that imposes a small amount of response deprivation may result in more instrumental responding than the first schedule, but not enough to reveal a facilitation effect. Thus, response deprivation appears to be necessary for instrumental reinforcement, but may not be sufficient.

The paramount conclusion to be drawn from Figure 1 is that reinforcement of instrumental running does not result from the consequence of drinking but from a contingency schedule that deprives the rat of drinking. If we explain the facilitation of running seen under Schedule 1 in terms of some intrinsic property that makes drinking a reinforcer, we cannot explain why the same consequence, with the same intrinsic properties, fails to facilitate instrumental running under Schedule 2. Thus, it seems inappropriate to insist that reinforcement of an instrumental response results from a special kind of response consequence called a reinforcer, of which a thirsty rat's drink would serve as a universally accepted example. It seems instead that reinforcement results from a special kind of schedule—a response-deprivation schedule. If the schedule deprives the rat of the contingent drinking response, the schedule will probably reinforce instrumental running. If the schedule does not deprive the rat of drinking, the schedule will probably not reinforce instrumental running (Premack, 1965).

Additional conclusions flow from the relations shown in Figure 2, in which the unit of measurement is time on both abscissa and ordinate. Under Schedule 1, Response A is instrumental and Response B is contingent. Given the baseline amounts shown as the open circle at 50 units of Response A and 100 units of Response B, Schedule 1 plainly deprives the

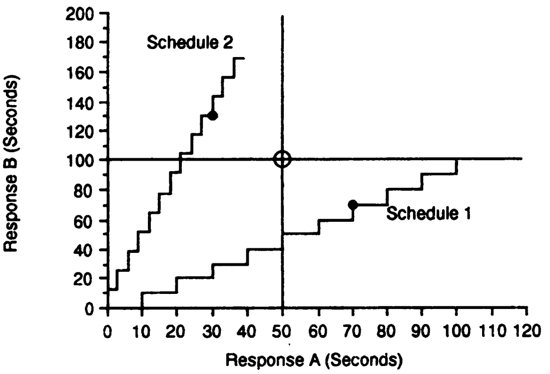

Fig. 2. Response B as a function of Response A. The data are hypothetical. The open circle at 50 units of Response A and 100 units of Response B represents paired-baseline amounts. Under Schedule 1, Response A is instrumental and Response B is contingent. Under Schedule 2, Response B is instrumental and Response A is contingent. The closed circles represent typical responses to the schedule constraints.

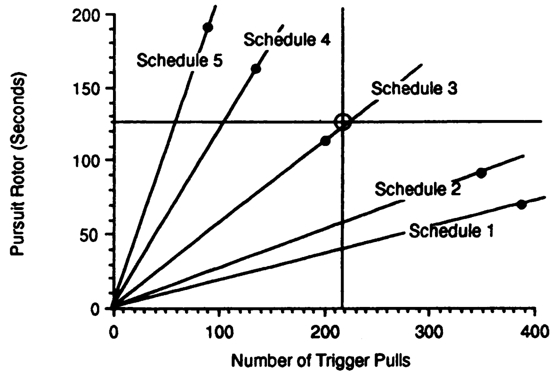

Fig. 3. Pursuit-rotor activity as a function of trigger pulls, based on data reported by Podsakoff (1980, 1982). The open circle represents paired-baseline amounts. The closed circles represent responses to schedule constraints.

individual of contingent Response B. The typical response to Schedule 1, shown by the closed circle, is that instrumental Response A rises above its baseline level (facilitation) and contingent Response B falls below its baseline level (suppression). Under Schedule 2, Response B is instrumental and Response A is contingent. Schedule 2 plainly deprives the individual of contingent Response A: Under the terms of Schedule 2, the baseline amount of Response B permits less than the baseline amount of Response A. The typical response to Schedule 2, shown by the closed circle, is facilitation of instrumental Response B and suppression of contingent Response A.

The paramount conclusion to be drawn from Figure 2 is that it is possible to devise a schedule that deprives the individual of any response emitted in the paired-baseline condition, regardless of its amount or probability relative to the other response. Thus, if we measure response probability in terms of time allocation under the baseline condition, we see that Schedule 1 deprives the individual of the high-probability contingent Response B. But we see too that Schedule 2 deprives the individual of the low-probability contingent Response A. Thus, a schedule that deprives the individual of the contingent response facilitates or reinforces the instrumental response, whether the contingent response is more (Schedule 1) or less (Schedule 2) probable than the instrumental response. Accordingly, it is inappropriate to suppose that reinforcement results only if the contingent response is more probable than the instrumental response (Premack, 1965). The literature contains numerous examples of the effects that are illustrated in Figure 2 (Heth & Warren, 1978; Konarski, Crowell, & Duggan, 1985; Konarski et al., 1982; Podsakoff, 1982; Timberlake & Allison, 1974; Timberlake & Wozny, 1979; Wozny, 1979). Also pertinent are many additional experiments that have demonstrated facilitation of a high-probability instrumental response under deprivation schedules that employ a low-probability contingent response (Allison et al., 1979, Experiment 2; Allison & Timberlake, 1974; Eisenberger, Karpman, & Trattner, 1967; Klajner, 1975; Konarski et al., 1980; Mazur, 1975).

All of the relations shown schematically in Figures 1 and 2 are realized in Figure 3, which summarizes the results of an experiment reported by Podsakoff (1980, 1982). In the paired-baseline session, male college students had free access to a trigger and a pursuit-rotor device. Figure 3 plots time engaged in the pursuit-rotor task as a function of the number of trigger pulls; the open circle is the paired base point, showing the group mean of each behavior. The figure represents each schedule as a continuous line rather than a step function. Schedules 1 and 2 deprived the subjects of the contingent pursuit-rotor response; performance under those schedules, shown as closed circles, indicated that each schedule facilitated the instrumental trigger-pull response and suppressed the contingent pursuit-rotor response. Schedule 3, a nondeprivation schedule, had no significant effect on either response relative to the paired base point. Schedules 4 and 5 deprived the subjects of the contingent trigger-pull response; they facilitated the instrumental pursuit-rotor response and suppressed the contingent trigger-pull response.

DRIVE, INCENTIVE, AND INDIVIDUAL DIFFERENCES

Analyses of instrumental performance based on response deprivation may appeal to measured differences in the baseline levels of one or both responses to account for individual differences in instrumental performance or performance differences classically attributed to incentive motivation or drive. The basis for this account is that variations in baseline levels may affect the amount of response deprivation imposed by a particular schedule.

The amount of response deprivation is the difference between the baseline amount of the contingent response and the amount that could occur if the individual were to perform the instrumental response at its baseline level. It follows that the same schedule would impose a relatively large amount of deprivation of contingent drinking among individuals with a relatively high baseline level of drinking. Within limits, instrumental performance typically increases with the amount of response deprivation (Timberlake & Allison, 1974). Tested with the same schedule, individuals with a relatively high baseline level of drinking may therefore be expected to show a relatively high rate of instrumental responding for water (cf. Allison, 1964).

In the area of incentive manipulations, rats that have had unlimited access to water will show a higher baseline level of licking if the spout contains saccharin than if it contains water. Accordingly, they may show a higher rate of instrumental responding for saccharin than for water even if the two schedules use the same requirements, because the amount of deprivation imposed by the saccharin schedule is greater than the amount imposed by the water schedule.

In the area of drive manipulations, rats that have gone without water for a relatively long time will have a relatively high baseline level of drinking. Accordingly, the amount of response deprivation with respect to drinking will increase with hours of water privation, so instrumental performance for water may increase with thirst.

ACTIVE AND PASSIVE CONSEQUENCES

Instrumental responses typically have two kinds of contingent consequences with clear operational distinctions. The experimenter defines one kind in terms of an opportunity to perform a response with certain stimulational consequences. This is the kind normally involved in both theoretical and experimental treatments of response deprivation. Examples include the opportunity to perform a specified number of licks at a water spout, to rotate an activity wheel a specified number of times, to eat a specified number of food pellets, or to read a particular book for a specified amount of time. The experimenter defines the second kind of consequence in terms of stimulation that ensues independently of the subject's behavior. Examples include the cessation of electric shock for a specified amount of time, electrical stimulation of the brain for a specified amount of time, or the intubation of a certain amount of food directly into the stomach.

Both kinds of consequences depend crucially on the stimulation that ensues, but in one kind the ensuing stimulation requires no active response on the part of the subject and in the other kind it does (e.g., approach to the spout, extension of the tongue, lapping at the tip of the spout; running movements; approach to the food cup, seizing of the food pellet, chewing and swallowing). Thus, in terms of the participation required of the subject for the occurrence of the crucial stimulational consequence, one kind is relatively passive and the other is active. Uncertainty is sometimes expressed about the applicability of the response-deprivation analysis to the action of such passive consequences as electrical stimulation of the brain (ESB). How can we apply the analysis to this kind of consequence?

The general solution to this problem is to convert the passive kind of consequence into an active one, so as to make it possible to measure the paired-baseline level of the consequence. In the specific case of brain stimulation, a suggested solution is to provide the rat with two retractable levers side by side (Allison, 1983; Timberlake & Allison, 1974).

Pressing one lever has no programmed consequence; each press of the other lever results in the delivery of a specified train of electrical pulses to the rat's brain for a specified duration. Under the paired-baseline condition, both levers are freely available throughout the duration of the session. Given optimal electrode placement, pulse rate, intensity, and duration, the rat would press the ESB lever considerably more frequently than the ineffective lever under the paired-baseline condition. Under the contingency condition, access to the ESB lever would be contingent on pressing the ineffective lever. Deprivation and nondeprivation schedules would be defined as usual, and only under deprivation schedules would contingent ESB be expected to facilitate responding on the ineffective lever. Given the high level of responding on the ESB lever relative to the ineffective lever under the baseline condition, the set of schedule requirements that would deprive the rat of ESB is extremely large. The much smaller nondeprivation set would combine an unusually large contingent reward—many responses on the ESB lever each time it appears—with even the smallest instrumental requirement.

According to the response-deprivation analysis, contingent ESB will facilitate the instrumental response if, and only if, the schedule deprives the organism of ESB. If such an experiment were done, an outcome in line with theoretical expectation might do much to consolidate the central implication of the response-deprivation analysis: Instrumental reinforcement results not from special kinds of response consequences but from special kinds of schedules. Although no such experiment seems to have been reported, a similar approach has proved to be successful in the analysis of escape and avoidance (Timberlake & Allison, 1974). Under the paired-baseline condition, the rat received continuous shock in the presence of two levers. One lever was ineffective; the effective lever turned shock off for the duration of each press. The rats spent almost the entire session pressing the effective lever and only a little time pressing the ineffective lever. In the contingency session, presses on the previously effective lever were not effective unless the rat pressed the formerly ineffective lever. Thus, shock-free time was contingent on pressing the initially ineffective lever instrumentally. Each schedule tested deprived the rat of shock-free time, and each schedule facilitated the instrumental response. Schedules that imposed a relatively large amount of deprivation produced a relatively large amount of instrumental responding. This functional relation between the amount of response deprivation and the size of the facilitation effect suggests by extrapolation that a nondeprivation schedule might produce no facilitation effect. Thus, escape or avoidance of shock may not facilitate the instrumental response unless the schedule deprives the organism of shock-free time.

THE ONE-CONJUNCTION SCHEDULE

Other questions are often raised about the applicability of the response-deprivation analysis to reinforcement that results from a single conjunction of instrumental response and contingent consequence. For example, consider the situation in which the session or trial is over as soon as the rat completes one instrumental press of a lever and 20 contingent licks at a water spout. In this kind of situation, the paired-baseline session does not end after a specified amount of time but after a specified amount of responding—one press and 20 licks. The baseline session begins with the simultaneous presentation of both lever and spout and ends when both one press and 20 licks have occurred.

In this kind of situation the amount of responding is not a variable, but time is. Thus, the rat may vary the rate of lever pressing (licking) by varying the time it takes to complete the one lever press (the 20 licks) required. In the paired-baseline condition, the thirsty rat will undoubtedly complete the 20 licks before completing the one lever press, thereby performing the contingent requirement at a higher baseline rate than the instrumental requirement.

Mindful of that likely baseline difference, consider the contingency condition in which pressing the lever is instrumental and licking the spout is contingent. Each contingency session would begin with the presentation of the lever. Upon the occurrence of one lever press, the lever retracts and the spout appears. Upon the occurrence of the 20th lick, the spout retracts and the session or trial ends. Note that this contingency deprives the rat of licking in the usual sense of response deprivation: If the rat were to perform the instrumental lever press at only the baseline rate (time), it will necessarily perform the 20th lick at less than the baseline rate (after the baseline time). The reason is simply that in baseline, the rat licked the spout as often as allowed before it pressed the lever. But if pressing the lever is instrumental, then by definition the rat cannot lick the spout until after it has pressed the lever. The predicted effect would be facilitation of instrumental lever pressing. In other words, the rat should react to this one-conjunction schedule by pressing the lever sooner than it did under the baseline condition, thereby pressing the lever at a rate above the baseline rate.

Under this one-conjunction procedure, the schedule that does not deprive the rat of licking is the one in which the instrumental requirement is 20 licks at the spout and the contingent requirement is one press of the lever. The reason is that in baseline, the rat pressed the lever only after performing the final lick at the spout. Thus, if the rat continues to perform the final lick at only the baseline rate (time), it can also complete the contingent lever press at the baseline rate (time). The predicted effect would be no facilitation of instrumental licking.

Experimental tests of the response-deprivation analysis of this one-conjunction procedure are relatively sparse. However, the predicted pattern of results has been confirmed in one experiment like the one outlined above (Allison, 1982). The response-deprivation analysis has also been successfully applied to a procedure in which rats licked an empty spout instrumentally for contingent access to a saccharin spout, at which they were allowed to make a large or small number of licks (Allison & Timberlake, 1975). For a successful application to the rat's performance in a runway with food in the goal box, see Klajner (1975).

Many readers will have noticed that in the one-conjunction procedure, the response-deprivation analysis may make essentially the same predictions as the probability-differential analysis (Premack, 1965). In the paired-baseline condition, if the contingent response is completed first, it is in a sense more probable than the instrumental response, and the schedule will in addition deprive the organism of the contingent response. In that event, both formulations predict facilitation of the instrumental response. But in the paired-baseline condition, if the instrumental response is completed first, it is in a sense more probable than the contingent response, and the schedule will not deprive the organism of the contingent response. In that event, neither formulation predicts facilitation of the instrumental response. Thus, the two formulations may differ in their predictions of facilitation only when the amount of responding is a variable and the session duration is fixed.

RESPONSE DEPRIVATION AND ECONOMICS

The response-deprivation condition typically engenders two behavioral effects, one describable in terms of reinforcement and both describable in terms of economics. The facilitation of the instrumental response is an effect whose prediction or explanation belongs by tradition to the province of reinforcement theory. Indeed, the theoretical and experimental analysis of the response-deprivation condition began as an attempt to predict and explain instrumental performance or reinforcement, defined operationally in terms identical to the definition of facilitation. The second effect, suppression of the contingent response, was unanticipated. This is not to say that it was irrelevant to theories of instrumental performance under schedule constraint. Indeed, the suppression effect flatly contradicts one widely held regulatory model. According to the model in question, a response-deprivation schedule facilitates the instrumental response because, under schedule constraint, the individual tends to maintain the baseline level of the contingent response. The suppression effect contradicts that particular model. However, both effects have a ready interpretation in terms of economics. It will be seen that these interpretations suggest the following conclusion: The response-deprivation condition may make the contingent consequence function as an economic good or commodity, the instrumental response as currency.

The suppression of the contingent response can be described in terms of the demand law, according to which the quantity consumed (*Q*) declines as the unit price (*P*) of the commodity rises. For example, in the United States a 1% increase in the price of cigarettes is typically accompanied by a 0.35% decrease in cigarette consumption (Houthakker & Taylor, 1966). Response deprivation puts a behavioral price on the contingent response that typically engenders two effects: The individual performs less of the contingent response and more of the instrumental response. The first of these two effects (suppression) can be seen as an instance of the demand law. The second (facilitation) can be seen as a behavioral exchange analogous to revenue on sales of a commodity, the product *PQ*. For example, at $2 per package (*P*), consumption of 64 packages (*Q*) would bring a revenue on sales of $128 (*PQ*).

These relations are illustrated by Figure 4, which plots a rat's total food consumption against total lever presses. The data are hypothetical, but resemble those reported by Teitelbaum (1957) for hyperphagic rats with lesions in the ventromedial hypothalamus. The vertical axis shows total food pellets, the measure of *Q*. The four step functions represent four FR schedules that represent different unit prices of food. Unit behavioral price is defined as *P* = total lever presses divided by total food pellets = presses per pellet. It follows that the slope of the step function is the inverse of price, because slope = total food pellets divided by total lever presses = $1/P$. Thus, the steepest function, with the smallest FR requirement, represents the lowest price. And, from the definitions of *Q* and *P*, it follows that the total number of lever presses, scaled on the abscissa, is the analogue of revenue on sales, *PQ*: As *Q* = total pellets and *P* = total lever presses divided by total pellets, *PQ* = total lever presses.

The schedule represented by the steepest step function deprives the rat of contingent eating and has two effects: facilitation of instrumental lever pressing and suppression of contingent eating. In other words, as the price of food increases, the rat responds by consuming less food and performing more lever presses, in exchange, than it did in the free-baseline condition. We raise the price further in moving to the next schedule, in which the rat consumes still less but emits still more lever presses. That increase in the analogue of *PQ* identifies demand for food as *inelastic* in this range of price (Allison, 1983; Awh, 1976; Samuelson, 1976). We raise the price further in moving to the next schedule, in which the rat again consumes less but emits the same number of lever presses as before. That constant revenue on sales would identify demand as having *unit elasticity* in this range of price. Under the final schedule, the rat responds to the final increase in price by emitting fewer lever presses than it did under the previous schedule. This decrease in the analogue of *PQ* identifies demand for food as *elastic* in this range of price. Thus, response deprivation is a kind of scarcity that makes the contingent response function as an economic good and the instrumental response function as currency. In both the marketplace and the laboratory, demand sometimes grows more elastic as the price of the good rises, in accordance with Figure 4 (Lea, 1978).

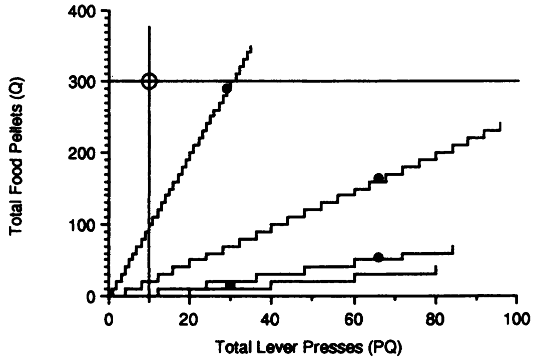

Fig. 4. Total food pellets as a function of total lever presses. The data are hypothetical. The open circle at 10 lever presses and 300 pellets represents paired-baseline amounts. The step functions represent fixed-ratio schedules that require a specified number of instrumental lever presses for a specified number of contingent food pellets. The closed circles represent responses to schedule constraints.

This analysis implies that an item's functional status as an economic good or commodity does not depend on its intrinsic properties. The same is true of an item's functional status as currency or a medium of exchange. Figure 3 provides a convenient empirical example. Under Schedules 1 and 2, pursuit rotor functioned as a good, obeying the demand law; trigger pull functioned as currency, illustrating inelastic demand for the pursuit-rotor activity. Under Schedule 3, neither activity functioned as good or currency. Under Schedules 4 and 5, the functional roles reversed, with trigger pull conforming to the demand law and pursuit rotor functioning as currency, indicating inelastic demand for the trigger-pull good. Thus, an item's functional status as good or currency cannot arise from intrinsic features of the item, but seems to arise instead from external constraints.

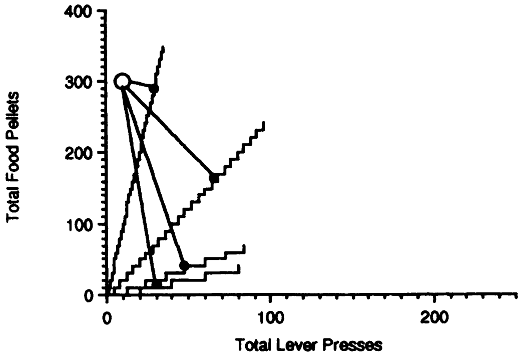

Fig. 5. Total food pellets as a function of total lever presses; predictions based on a bliss-point model. The open circle represents the paired base point. The closed circles represent the minimum possible distance to the paired base point, given the constraints of schedules that require a specified number of instrumental lever presses for a specified number of contingent food pellets.

PERFORMANCE MODELS

Several theorists have attempted to derive the behavioral effects of response deprivation from quantitative models of instrumental performance under schedule constraint. These models are evaluated in terms of their ability to predict performance relative to both the paired base point and the general shape of the schedule function.

A schedule function reflects changes in performance that result from changes in schedule requirements. To visualize the schedule function in Figure 4, imagine a curve fitted to the four closed circles. Viewed from the origin, this curve exhibits a concave shape often seen in experimental measurements of this kind. Linear schedule functions also occur frequently (e.g., Figure 3), but convex functions occur rarely, if ever. Prediction of the exact shape of the function is a problem for quantitative models of performance under schedule constraint. A detailed account of these models is not the purpose of this paper, but a broad summary is appropriate.

Bliss-point models are familiar to both psychologists and economists. In Figure 4 the vertical axis represents one good, food pellets. The horizontal axis represents lever presses, the labor traded directly as currency for food in a kind of barter economy. In addition, the horizontal axis represents a shadow good, leisure. Leisure is called a shadow good because, although it is not measured directly, it is inversely related to a quantity that is measured directly, the total amount of labor (total lever presses). The point of greatest satisfaction or utility—the bliss point—therefore lies in the upper left part of the figure, where there is much food and much leisure. The point of least satisfaction lies in the lower right part of the figure, where there is little food and little leisure. Economic models of labor supply imply that an individual will respond to schedule constraint by making the closest possible approach to the bliss point (Awh, 1976).

In the psychological literature, the minimum deviation model proposed by Staddon (1979) makes similar predictions by assuming that (a) the paired base point functions as a bliss point and (b) performance under schedule constraint represents the closest possible approach to the paired base point. Figure 5 shows the predictions based on this model, assuming that a deviation from one baseline is assigned the same weight as an equivalent deviation from the other baseline. Given this assumption, the closest possible approach to the paired base point is the point at which a line passing through the paired base point intercepts the line of schedule constraint at a right angle. Other weightings are represented by other angles, but the predicted schedule functions would still be concave (viewed from the origin).

The chief strength of these models lies in their ability to predict the concave schedule function known to labor economists as a backward-bending labor supply curve. In contrast, the well-known matching model predicts only the lower limb of a concave schedule function (Herrnstein, 1970; Pear, 1975; Timberlake, 1977). Notable failings of the bliss-point models have emerged in other experimental settings. For example, consider a concurrent FR schedule composed of two different components, each of which deprives the organism of the contingent response. A bliss-point model predicts exclusive responding to the component that represents the lower behavioral price. Contrary to this prediction, numerous experiments have shown that the organism often samples the high-priced component, although it may typically sample the low-priced component more frequently (Allison, 1981b).

Another contrary example comes from experiments in which the organism, tested with a nondeprivation schedule, stops short of the paired base point, demonstrating suppression of both responses (Tierney et al., 1987). A related example involves a special procedure under which the paired-baseline condition is reinstated in the midst of a contingency session. The reinstatement occurs when the rat has already performed more than the baseline amount of the instrumental response but less than the baseline amount of the contingent response. A bliss-point model predicts that the rat will respond to the reinstatement by performing no more of the instrumental response, which is already past baseline, but enough of the contingent response to reach the baseline amount of the contingent response. However, the typical result shows more than the predicted amount of the instrumental response and less than the predicted amount of the contingent response. Thus, the rat typically strays further from the paired base point than necessary and further than predicted by the bliss-point models (Allison et al., 1987).

These failures suggest that when a bliss-point model correctly predicts the shape of a schedule function, it may do so for the wrong reason. Moreover, the temporal pattern of the two responses suggests that the rat's prior experience under a conventional contingency schedule may leave little effect on the probability of the instrumental response: Upon the reinstatement of the paired-baseline condition, the rat typically performs the contingent response, not the instrumental response, first (Allison, 1976; Allison et al., 1987).

Conservation models are familiar mainly to psychologists, but they share some features of economic alternatives to the bliss-point model (Lancaster, 1966). According to the conservation model, the determining quantity is not the response totals that make up the paired base point but rather is the total amount of some dimension derived from those totals. A convenient didactic example is a paired base point consisting of six apples and eight bananas. According to a bliss-point model, it is the bundle of apples and bananas represented by that bivariate point that drives performance under schedule constraint. According to the conservation model, performance is driven instead by some underlying quantity derived from that bundle, such as the calories derived from the consumption of six apples and eight bananas. If a positive amount of the underlying dimension is derived from each of the two responses, the conservation model implies a linear schedule function, with negative slope,

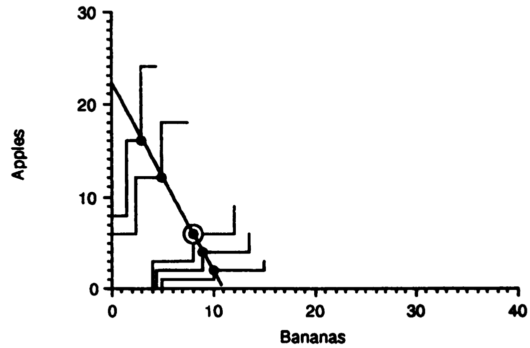

Fig. 6. Apples as a function of bananas; predictions based on a conservation model. The data are hypothetical. The open circle represents the paired base point. The three lower schedules require instrumental consumption of a specified number of bananas for a specified number of contingent apples; the two upper schedules require instrumental consumption of a specified number of apples for a specified number of contingent bananas. The closed circles represent constant caloric intake on the assumption that one banana has twice the caloric content of one apple.

passing through the paired base point (Allison, 1976; Allison et al., 1979).

Figure 6 illustrates the basis for this prediction. The line with negative slope is a constant-calorie line whose slope, -2, reflects the fact that one banana has twice the caloric content of one apple. The step functions sloping upward represent schedule constraints. The model implies that the organism will continue to perform the two responses until the combined response total represents the number of calories on the constant-calorie line, at which time it will stop. The closed circles represent the predicted schedule function. It is apparent why this kind of model has been called a "stop line" model instead of a bliss-point model (Allison et al., 1987).

Of course it is logically impossible to identify with certainty the dimension conserved in any particular instance. Still, the model makes it possible to falsify hypotheses about the dimension. For example, if an actual experiment along the lines of Figure 6 were to reveal a schedule function whose slope differed significantly from -2, we must reject the hypothesis that the organism conserves caloric intake. The reason is that dietetic studies have established independently that one banana has approximately twice the caloric content of one apple.

A related strength in terms of falsifiability is that the model makes it possible to predict the slope of the schedule function for a novel

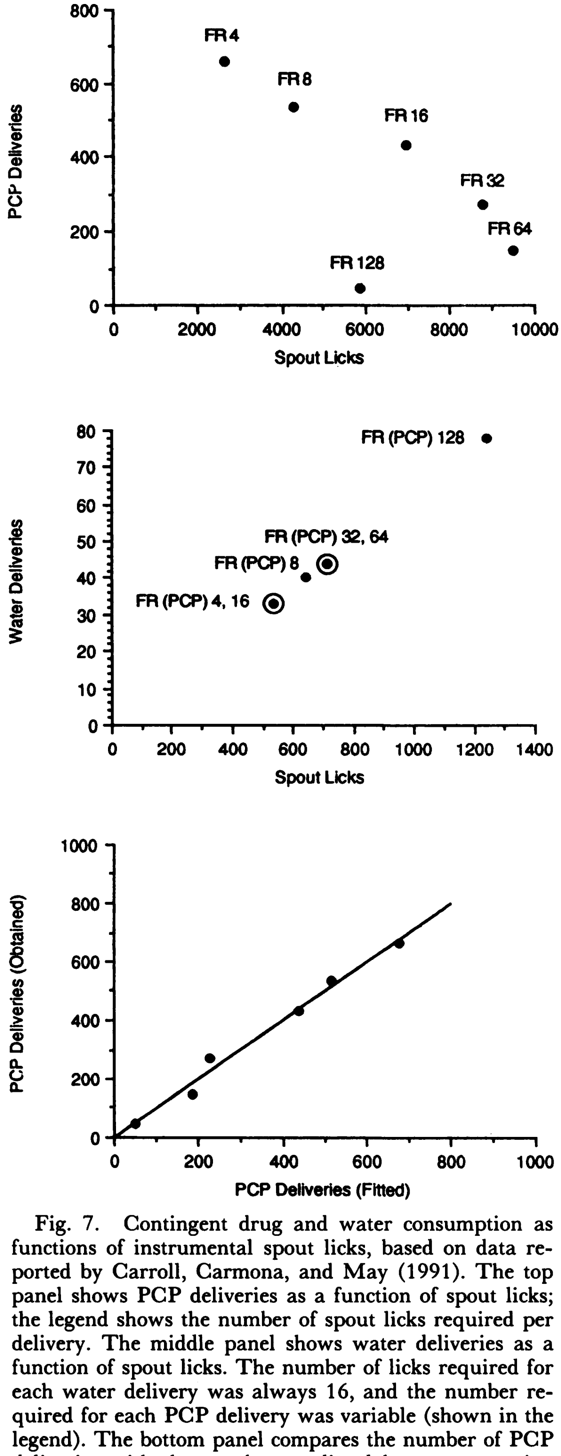

Fig. 7. Contingent drug and water consumption as functions of instrumental spout licks, based on data reported by Carroll, Carmona, and May (1991). The top panel shows PCP deliveries as a function of spout licks; the legend shows the number of spout licks required per delivery. The middle panel shows water deliveries as a function of spout licks. The number of licks required for each water delivery was always 16, and the number required for each PCP delivery was variable (shown in the legend). The bottom panel compares the number of PCP deliveries with the number predicted by a conservation model.

pair of responses. For example, suppose the slope of the schedule function with respect to Response B and Response A is known to be B/A and that the slope with respect to Response C and Response B is known to be C/B. In that event, the slope predicted for the novel pairing of Responses C and A is the product of the two known slopes: (B/A)(C/B) = C/A (Allison et al., 1979, Experiment 4).

This linear conservation model cannot fit a concave schedule function, except under special conditions discussed elsewhere (Allison, 1979). Other strengths and weaknesses have been revealed by experiments in which the paired-baseline condition is reinstated in the midst of a contingency session. On the favorable side, consider two responses with highly similar consequences—licking either one water spout or another identical water spout next to it. In that case, the rat responds to the reinstatement by moving to a point on the theoretical stop line (Allison et al., 1987, Experiment 1). On the unfavorable side, consider two responses with more disparate consequences—licking an empty spout or a water spout next to it. In that case, the rat may respond to the reinstatement by moving to a point slightly above the theoretical stop line (Allison et al., 1987, Experiment 3).

The latter result suggests the need for a conservation model that is capable of predicting a concave schedule function with respect to the two responses controlled by the schedule. One such model assumes the existence of a third response, available freely or at a fixed price, that also contributes to the dimension conserved (Allison, 1981a, 1983; Allison & Boulter, 1982). If the organism performs more of the third response as the behavioral price of the contingent response increases, the organism will allocate less of the conserved quantity to the instrumental and contingent responses and will therefore generate a concave schedule function, not a linear one.

In a recent realization of this kind of model, monkeys licked a spout instrumentally for contingent oral delivery of a drug, phencyclidine (PCP), at FR prices that ranged from 4 to 128 licks per delivery (Carroll, Carmona, & May, 1991). Concurrently available was another spout the monkeys could lick instrumentally for oral delivery of water at a fixed behavioral price, 16 licks. Despite some raggedness in the measured function, in the fitted function consumption generally increased with the price of the drug. Contingent drug consumption, plotted against instrumental licks at the spout, described a concave schedule function. The data are summarized in the top and middle panels of Figure 7. The bottom panel compares drug consumption with the fitted values I calculated from a quantitative version of the conservation model: PCP deliveries = 1,155.90 − 0.055 (instrumental spout licks) − 9.13 (water deliveries), $R^2 = .985, p < .01$. Related examples of the effects of substitution have been reported by Aeschleman and Williams (1989) and McIntosh (1974). A similar model can account for the suppression of responding by nondeprivation schedules (Allison et al., 1979, Experiment 3; but see Tierney et al., 1987).

SUMMARY

It no longer seems correct to characterize reinforcement as the result of a special kind of response consequence called a reinforcer. Instead, reinforcement appears to result from a special kind of schedule called a response-deprivation schedule. Accordingly, theories that attribute reinforcement to some feature of the response consequence are destined to fail, because they are founded on an erroneous view of the conditions responsible for reinforcement. Response-deprivation schedules typically have two effects: facilitation of the instrumental response (describable in terms of reinforcement) and suppression of the contingent response. In terms of economics, the suppression effect reflects the demand law, and the facilitation effect reflects a behavioral exchange analogous to money traded for a good. Thus, the antecedent condition of response deprivation may make the contingent response function as an economic good, the instrumental response as currency. It follows that the location and shape of any schedule function are likely to depend on the motivational state and the motivational relevance of the contingent response. They are also likely to depend on the place of the contingent response on the luxury–necessity dimension, in that demand for luxuries will be more elastic than demand for necessities. Finally, they are likely to depend on the substitutability of the instrumental response for the contingent response and the availability and substitutability of other responses. Theoretical conceptions of reinforcement and instrumental performance that take such variables into account seem more likely to succeed than those that do not.

REFERENCES

Aeschleman, S. R., & Williams, M. L. (1989). A test of the response deprivation hypothesis in a multiple-response context. *American Journal on Mental Retardation*, **93**, 345–353.

Allison, J. (1964). Strength of preference for food, magnitude of food reward, and performance in instrumental conditioning. *Journal of Comparative and Physiological Psychology*, **57**, 217–223.

Allison, J. (1976). Contrast, induction, facilitation, suppression, and conservation. *Journal of the Experimental Analysis of Behavior*, **25**, 185–198.

Allison, J. (1979). Remarks on Staddon's comment. *Journal of Experimental Psychology: General*, **108**, 41–42.

Allison, J. (1981a). Economics and operant conditioning. In P. Harzem & M. D. Zeiler (Eds.), *Advances in analysis of behaviour: Vol. 2. Predictability, correlation, and contiguity* (pp. 321–353). Chichester, England: Wiley.

Allison, J. (1981b). Paired baseline performance as a behavioral ideal. *Journal of the Experimental Analysis of Behavior*, **35**, 355–366.

Allison, J. (1982). Constraints on performance in two elementary paradigms. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 523–548). Cambridge, MA: Ballinger.

Allison, J. (1983). *Behavioral economics*. New York: Praeger.

Allison, J., & Boulter, P. (1982). Wage rate, nonlabor income, and labor supply in rats. *Learning and Motivation*, **13**, 324–342.

Allison, J., & Buxton, A. (1992). Multidimensional aspects of drinking in the rat. *Physiology and Behavior*, **51**, 267–275.

Allison, J., Buxton, A., & Moore, K. E. (1987). Bliss points, stop lines, and performance under schedule constraint. *Journal of Experimental Psychology: Animal Behavior Processes*, **13**, 331–340.

Allison, J., Miller, M., & Wozny, M. (1979). Conservation in behavior. *Journal of Experimental Psychology: General*, **108**, 4-34.

Allison, J., & Moore, K. E. (1985). Lick-trading by rats: On the substitutability of dry, water, and saccharin tubes. *Journal of the Experimental Analysis of Behavior*, **43**, 195–213.

Allison, J., Moore, K. E., Gawley, D. J., Mondloch, C. J., & Mondloch, M. V. (1986). The temporal pattern of unconstrained drinking: Rats' responses to inversion and identity constraints. *Journal of the Experimental Analysis of Behavior*, **45**, 5–13.

Allison, J., & Timberlake, W. (1974). Instrumental and contingent saccharin-licking in rats: Response deprivation and reinforcement. *Learning and Motivation*, **5**, 231–247.

Allison, J., & Timberlake, W. (1975). Response deprivation and instrumental performance in the controlled-amount paradigm. *Learning and Motivation*, **6**, 122–142.

Awh, R. Y. (1976). *Microeconomics: Theory and applications.* Santa Barbara, CA: Wiley/Hamilton.

Bernstein, D. J., & Ebbesen, E. B. (1978). Reinforcement and substitution in humans: A multiple-response analysis. *Journal of the Experimental Analysis of Behavior,* **30,** 243-253.

Buxton, A., & Allison, J. (1990). Efficiency and persistence of licking in rats. *Physiology and Behavior,* **47,** 239-247.

Carroll, M. E., Carmona, G. G., & May, S. A. (1991). Modifying drug-reinforced behavior by altering the economic conditions of the drug and a nondrug reinforcer. *Journal of the Experimental Analysis of Behavior,* **56,** 361-376.

Eisenberger, R., Karpman, M., & Trattner, J. (1967). What is the necessary and sufficient condition for reinforcement in the contingency situation? *Journal of Experimental Psychology,* **74,** 342-350.

Gawley, D. J., Timberlake, W., & Lucas, G. A. (1986). Schedule constraint of the average drink burst and the regulation of wheel running and drinking in rats. *Journal of Experimental Psychology: Animal Behavior Processes,* **12,** 78-94.

Harrison, R. G., & Schaeffer, R. W. (1975). Another test of the Premack principle. *Bulletin of the Psychonomic Society,* **6,** 565-568.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior,* **13,** 243-266.

Heth, C. D., & Warren, A. G. (1978). Response deprivation and response satiation as determinants of instrumental performance: Some data and theory. *Animal Learning & Behavior,* **6,** 294-300.

Houthakker, H. S., & Taylor, L. D. (1966). *Consumer demand in the United States 1929–1970.* Cambridge, MA: Harvard University Press.

Klajner, F. (1975). *The relations among instrumental performance, reinforcement, and contingent-response deprivation in the instrumental conditioning paradigm.* Unpublished doctoral dissertation, University of Toronto.

Konarski, E. A., Jr., Crowell, C. R., & Duggan, L. M. (1985). The use of response deprivation to increase the academic performance of EMR students. *Applied Research in Mental Retardation,* **6,** 15-31.

Konarski, E. A., Jr., Crowell, C. R., Johnson, M. R., & Whitman, T. L. (1982). Response deprivation, reinforcement, and instrumental academic performance in an EMR classroom. *Behavior Therapy,* **13,** 94-102.

Konarski, E. A., Jr., Johnson, M. R., Crowell, C. R., & Whitman, T. L. (1980). Response deprivation and reinforcement in applied settings: A preliminary analysis. *Journal of Applied Behavior Analysis,* **13,** 595-609.

Lancaster, K. J. (1966). Change and innovation in the technology of consumption. *American Economic Review,* **56,** 14-23.

Lea, S. E. G. (1978). The psychology and economics of demand. *Psychological Bulletin,* **85,** 441-466.

Mazur, J. E. (1975). The matching law and qualifications related to Premack's principle. *Journal of Experimental Psychology: Animal Behavior Processes,* **1,** 374-386.

McIntosh, J. W. (1974). *Response deprivation theory of instrumental performance tested with a freely available response: A motivational interpretation.* Unpublished doctoral dissertation, Indiana University, Bloomington.

Pear, J. J. (1975). Implications of the matching law for ratio responding. *Journal of the Experimental Analysis of Behavior,* **23,** 139-140.

Podsakoff, P. M. (1980). *Performance models, microeconomics and schedule responding in humans.* Unpublished doctoral dissertation, Indiana University, Bloomington.

Podsakoff, P. M. (1982). Effects of schedule changes on human performance: An empirical test of the contrasting predictions of the law of effect, the probability-differential model, and the response-deprivation approach. *Organizational Behavior and Human Performance,* **29,** 322-351.

Premack, D. (1965). Reinforcement theory. In D. Levine (Ed.), *Nebraska symposium on motivation* (pp. 123-180). Lincoln: University of Nebraska Press.

Samuelson, P. A. (1976). *Economics* (10th ed.). New York: McGraw-Hill.

Staddon, J. E. R. (1979). Operant behavior as adaptation to constraint. *Journal of Experimental Psychology: General,* **108,** 48-67.

Teitelbaum, P. (1957). Random and food-directed activity in hyperphagic and normal rats. *Journal of Comparative and Physiological Psychology,* **50,** 486-490.

Tierney, K. J., Smith, H. V., & Gannon, K. N. (1987). Some tests of molar models of instrumental performance. *Journal of Experimental Psychology: Animal Behavior Processes,* **13,** 341-353.

Timberlake, W. (1977). The application of the matching law to simple ratio schedules. *Journal of the Experimental Analysis of Behavior,* **27,** 215-217.

Timberlake, W. (1980). A molar equilibrium theory of learned performance. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 14, pp. 1-58). New York: Academic Press.

Timberlake, W., & Allison, J. (1974). Response deprivation: An empirical approach to instrumental performance. *Psychological Review,* **81,** 146-164.

Timberlake, W., & Wozny, M. (1979). Reversibility of reinforcement between eating and running by schedule changes: A comparison of hypotheses and models. *Animal Learning & Behavior,* **7,** 461-469.

Wasik, B. H. (1969). The effects of fixed ratio and contingent time on human lever-pressing behavior. *Psychological Record,* **19,** 95-104.

Wozny, M. (1979). *Models and microeconomics of performance under fixed ratio schedules.* Unpublished doctoral dissertation, Indiana University, Bloomington.

Received June 22, 1992
Final acceptance September 18, 1992