Licking one saccharin solution for access to another in rats: Contingent and noncontingent effects in instrumental performance

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Separation of the contingent and noncontingent effects of a schedule on amount of instrumental responding is desirable but difficult in schedules that involve instrumental and contingent responses that are either highly probable or very similar. Three studies in which rats were required to lick a solution of .1% saccharin for access to a preferred solution of .4% saccharin showed that neither single nor paired operant baselines of the instrumental response allowed accurate separation of the contingent and noncontingent effects of a fixed-ratio schedule. Two within-subject yoking procedures provided the best baselines of noncontingent effects: the massed baseline measured amount of .1% licking when each subject received free access to the total amount of .4% licking it obtained at asymptote under the schedule; the matched baseline measured .1% licking when each subject received the same access to the .4% solution, but presented in the intermittent pattern obtained during the schedule. Of the three algebraic models used to predict noncontingent effects, the substitution model was most promising, but still not adequate. The procedure of a between-subjects yoked control was also not effective.

There has been much recent interest in using measures of responding in baseline sessions to predict performance under an instrumental contingency (Allison, 1976; Dunham, 1977; Mazur, 1975; Rachlin & Burkhard, 1978; Staddon, 1979; Timberlake & Allison, 1974). In a typical study, the paired baseline of two responses is measured during sessions of fixed length when both responses are freely and simultaneously available. Then, using the same session length, relative access to the contingent response (the reward) is reduced by a ratio schedule that requires a relatively large, fixed amount of instrumental responding for each access to the contingent response. Much attention has been directed to models that predict the total increase in instrumental responding that occurs under these conditions. A relatively neglected aspect of this research is the separation of increased instrumental responding into portions due to the contingent and noncontingent effects of the schedule (cf. Bernstein & Ebbesen, 1978; Staddon, 1979), that is, separating the increase due to the contingent relation between the reward and the instrumental response from that increase due to reduction of the contingent

response and to the instigating effects of its temporal pattern of access.

The purpose of this paper was to develop a reliable and readily usable baseline to separate the contingent and noncontingent effects of a schedule on amount of instrumental responding. The results of using this baseline should be clear, and consistent with other measures of contingent effects (e.g., changes in latency, pattern, efficiency, and stability of responding). Separation of the contingent and noncontingent effects of reward has been traditionally an important problem in the study of learning (Kimble, 1961; Mackintosh, 1974; Rescorla & Holland, 1976). To identify contingent effects in operant conditioning, researchers have employed yoked groups (e.g., Berlyne, 1969) and have analyzed patterns of responding (e.g., Ferster & Skinner, 1957). But the primary method of measuring the contingent effects of a schedule is to compare amount or rate of instrumental responding under a schedule with the operant baseline of that response.

Traditionally, operant baselines of responding have been obtained in two ways. In the paired baseline, both the instrumental and contingent responses are simultaneously available; in the single baseline, only the instrumental response is available. Unfortunately, neither baseline provides an adequate estimate of the noncontingent effect of schedules that involve highly probable or related instrumental and contingent responses. In a paired baseline, there may

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be considerable competition for expression, either because the responses are highly probable and independent (Dunham, 1972) or because the responses are so similar that one substitutes for the other (Jacobson & Premack, 1970; Young & Greene, 1953). Under a typical schedule, there is less competition than in the paired baseline because the amount of contingent responding is reduced (Allison, 1976). Thus, the apparent contingent increase in instrumental responding may be inflated because of the effect of decreased competition with the contingent response. In contrast, the single baseline measure of instrumental responding is obtained in the complete absence of competition with the contingent response. When a schedule is imposed, programmed access to the contingent response will compete with the instrumental response, thereby potentially decreasing the contingent effect. In short, in the case of highly probable or substitutable responses, use of the paired baseline will overestimate the contingent increase in instrumental responding and use of the single baseline will underestimate the contingent increase.

A further disadvantage of single and paired baselines is that neither considers possible noncontingent instigating effects that are produced by intermittent access to the contingent response under the schedule (Falk, 1971; Staddon, 1977). Such adjunctive responses may supplement the instrumental response (Powell & Curley, 1978), compete with the instrumental response (Iverson, 1976), or substitute for the contingent response.

The present experiments have two goals. The first is to document the problems of using single and paired baselines to assess the contingent increase in instrumental responding under schedules that involve two highly substitutable responses, licking a .1% saccharin solution for access to a .4% saccharin solution. The second is to describe procedures that yield adequate and readily usable baselines to separate the contingent and noncontingent effects of a schedule. Two highly related licking responses were used as a severe test of the ability of the proposed baselines to evaluate increases in instrumental responding. Not only should a schedule relating two saccharin-licking responses produce a considerable substitution effect, but the contingent increase, if any, should be relatively small (Allison & Timberlake, 1974). Baselines that are able to assess the nature of instrumental responding in this situation should do well in less difficult circumstances.

The present experiments investigated several alternative noncontingent baselines. The first experiment demonstrated the anticipated difficulties of using the single and paired baselines, and attempted to estimate a noncontingent baseline of competition and substitution effects using algebraic models. The second experiment used a yoked group (Berlyne,

1969) to directly measure a noncontingent baseline that combined substitution and adjunctive effects. The third experiment directly measured noncontingent baselines of substitution and adjunctive effects using within-subject yoking procedures.

EXPERIMENT 1

The first experiment documented the problems of using single or paired baselines to determine the nature of increased instrumental responding. It also assessed the possibility that an algebraic model could be used to estimate the noncontingent substitution effect produced by reduction of the contingent response below its paired baseline level. The principal advantage of using a model is that it can be applied after the results of the contingency are known; it requires no special experimental procedures. Use of a model also allows contact with the models of total responding referred to in the introduction. A potential drawback of the models tested was that they did not consider the possibility of adjunctive effects of the schedule.

The first model, the response competition model, estimated the substitution baseline by applying Luce's (1959) choice axiom to the schedule situation (see also Greeno, 1968, Chapter 3). According to Luce, the relative value of each member of a set of responses can be measured by its probability of choice when all responses are freely and simultaneously available. Remove one alternative, and the remaining responses will increase in probability in such a way as to maintain the ratio of their baseline probabilities. Dunham (1972) used a variant of this constant ratio rule to predict responding when the opportunity for a rat to lick or wheel-run was removed in baseline. He phrased the rule as "given two incompatible behaviors, each will occupy a constant proportion of the time available" (Dunham, 1972, p. 449).

Luce's model can predict the effect of a reduction in the contingent response if it is assumed that the relative values of three exhaustive response classes, instrumental, contingent, and background, can be measured by duration of responding in paired baseline. When the schedule reduces the contingent response, the instrumental response should increase to fill in the time while maintaining a constant ratio of expression with the background responses present. According to this model, the noncontingent baseline of instrumental responding should be: the paired baseline level of the instrumental response plus the proportion of the decrease in the contingent response that is "filled in" by the instrumental response,

$$S_i = O_i + \frac{O_i}{O_i + O_b} (O_c - S_c), \quad (1)$$

where S_i is the total instrumental responding predicted on the basis of noncontingent effects, O_i is the paired baseline of the instrumental response, $O_i/(O_i + O_b)$ is the ratio of the baseline of the instrumental response to its baseline plus the baseline of background responses, and $O_c - S_c$ is the decrease in contingent responding under the schedule. All responses are measured in seconds.

Though I will evaluate the baseline predicted by the response competition model, it is unlikely to be appropriate because of the relatedness of the two licking responses. The model was presented because it is often cited and will serve as a reference point. In his original formulation, Luce (1959) assumed that all responses were independent, and that only response competition determined the outcome of removing an alternative. Restle (1961), Staddon and Ayres (1975), and Tversky (1972) pointed out that lack of independence among alternatives should produce differential increases in related responses. A second potential problem is that the background responses may produce less competition than expected from their relative duration; on this basis, too, a differential increase in instrumental responding might be expected.

To deal with the problem of related responses, Luce's model can be modified by assuming that the subject, in filling in for the decrease in contingent responding under the schedule, preserves the ratio of instrumental responding to background responses shown in the single baseline, rather than the ratio shown in the paired baseline. The ratio in the single baseline should include any differential increase in the instrumental response due to its relatedness to the contingent response. If the responses are independent, the ratio of the instrumental response to background responses should be the same in single and paired baselines. Thus, for either independent or related responses, the duration of instrumental responding expected on the basis of a reduction in the contingent response can be written by replacing the multiplier in Equation 1 with $O_{i,s}/T$, the ratio of the instrumental response in the single baseline to the total of instrumental and background responses, T , the session time:

$$S_i = O_i + \frac{O_{i,s}}{T} (O_c - S_c). \quad (2)$$

Again, all responses are measured in seconds. I will call this expression the mixed model, because it potentially assesses a form of unique substitution between the instrumental and contingent responses while still assuming that competition for expression exists between the instrumental and background responses. A problem remaining with this model is that

the actual competition from background responses may be much less than indicated by their relative duration; thus, the maximum level of instrumental responding may be expressed well before the end of a session, and the subject may be left with low value responses for the remaining time. If this occurs, use of the session time (T) as a divisor will produce too low an estimate of the rate at which the instrumental response substitutes for the contingent response and Equation 2 will predict too low a noncontingent baseline.

A possible solution to the problems of related responses and low competition is to assume that only substitution of the instrumental response for the contingent response determines the noncontingent effect of the schedule on amount of instrumental responding; the effects of response competition are unimportant. In other words, a unit of increment in the instrumental response substitutes at a certain unlearned (noncontingent) rate for a unit of decrement in the contingent response. For this model, the multiplicative constant in Equation 1 can be replaced with a noncontingent substitution rate estimated by dividing the increase in the instrumental response from paired to single baseline, $(O_{i,s} - O_i)$, by the decrement in the contingent response from paired to single baseline $(O_{i,c} - 0)$. Thus, Equation 1 can be rewritten as:

$$S_i = O_i + \frac{O_{i,s} - O_i}{O_c} (O_c - S_c). \quad (3)$$

Measures other than duration can be used if they are applied consistently. The accuracy of this model should depend on the constancy of the unlearned rate of substitution across all levels of reduction in the contingent response and on the absence of significant competition from background responses.

In summary, I described three models that predict the noncontingent baseline of instrumental responding resulting from reduction in the contingent response under a schedule: the response competition model, based on Luce's (1959) choice axiom, which assumes that all responses are independent; the mixed model, which assumes that the instrumental response substitutes for the contingent response, and the resultant tendency to respond competes for expression with the background responses; and the substitution model, which assumes that only unlearned substitution determines the noncontingent effect of the schedule on amount of instrumental responding. All are formally identical, linear models, relating the decrement in the contingent response to the increment in the instrumental response by different multiplicative constants.¹ It is important to remember that these models are intended to predict only a noncontingent baseline of instrumental responding. Any contingent

or adjunctive effects of the schedule on amount of instrumental responding should be shown by an increase that exceeds the appropriate noncontingent baseline. Of the three models, either the substitution or the mixed model appears most likely to estimate an appropriate baseline. If the responses were independent, the response competition or mixed models would be most appropriate.

In the present experiment, obtained instrumental licking was compared with predicted noncontingent baselines under schedules in which subjects were required to complete different durations of licking a .1% saccharin solution for 10-sec access to a .4% saccharin solution; the required licking durations ranged from 5 to 30 sec. All schedules satisfied the response deprivation condition (Timberlake & Allison, 1974) and so were expected to produce an increase in instrumental responding over the paired baseline level. Further, since amount of response deprivation increased with increased required duration of licking, instrumental performance was expected to be directly related to the size of the licking requirement (Timberlake & Allison, 1974).

Method

Subjects. The subjects were six male Wistar albino rats, 160 days old at the beginning of the experiment. The rats were housed two per cage under ad-lib feeding conditions and a 12:12-h light-dark cycle.

Apparatus. The apparatus was a 39.5 × 23 × 20.5 cm plywood box, painted gray. The roof of the box was a hinged piece of Plexiglas; the floor was a grid of stainless steel bars, 1 cm in diameter and spaced 2 cm on center. Two 1.6 × 2 cm holes were located in one end wall 7 cm from each side wall and 5 cm above the floor. The holes allowed access to two glass drinking tubes with an inner diameter of 7 mm and a tip aperture of 2.5 mm. Access to the tubes was controlled by motor-driven retractable mounts. When available, the tubes projected 7 mm into the box. The tubes were connected by flexible tubing to bottles containing .1% and .4% saccharin solutions (1 or 4 g of sodium saccharin in 1,000 ml of tap water). The position of each solution was counterbalanced across subjects. Licking was monitored by two BRS drinkometers.

The duration of licking in seconds was obtained by defining a bout of licking as including all licks with onsets separated by less than 250 msec (cf. Allison & Castellan, 1970). The experimental apparatus was enclosed in a ventilated, sound-attenuating chamber containing a 7½-W light mounted directly above the box. The control equipment (BRS) was located in an adjacent room.

Procedure. Each subject received one 10-min session per day for a total of 80 sessions. Experimental sessions on alternate days occurred within 45 min prior to and after the change from light to dark. The animals were trained under each experimental condition for at least 6 days and until the mean instrumental licking for the group did not differ significantly between the last two successive two-session blocks. The last four sessions (two blocks) defined asymptotic licking.

Subjects received 16 sessions of paired baseline during which the drinking tubes containing .1% and .4% saccharin solutions were freely and simultaneously available. Following determination of the baseline, each subject entered a contingency phase of 42 sessions during which the subjects were required to complete a fixed amount of .1% licking in order to gain a 10-sec, time-limited, access to the .4% solution. When the instrumental re-

Figure 1. Average seconds of licking the .1% saccharin solution during different schedule requirements and paired and single baselines. Noncontingent baselines calculated from response competition, mixed, and substitution models are also shown.

quirement was satisfied, the .1% solution was withdrawn and the contingent .4% solution was inserted for 10 sec, after which the .1% solution was reinserted. During the first 12 sessions of the contingency phase, the instrumental requirement was 5 sec of .1% licking to gain 10 sec access to the .4% solution. During successive six-session blocks, the instrumental requirement was increased to 10, 15, 20, 25, and 30 sec of .1% licking. Following the contingency phase, each subject received 18 further sessions of paired baseline and four sessions of single baseline. The second paired baseline was used in all computations for the different models since it was assessed closest in time to the single baseline. All *t* tests are two-tailed unless otherwise indicated.

Results

In Figure 1, average duration of licking the .1% saccharin solution is shown in paired and single baselines and as a function of two-session blocks under each scheduled duration of licking. Asymptotic licking of the .1% solution over the last two-session blocks exceeded the paired baseline level under all schedule requirements [all *ts*(5), *p* < .05], and the increase in .1% licking was a direct function of the duration of licking required for access to the .4% solution [*F*(5,25) = 12.1, *p* < .01]. However, even at its highest level under a schedule, the average duration of licking the .1% solution did not significantly exceed its single baseline level. At each of the last three schedule requirements (20, 25, and 30 sec), average duration of licking the .1% solution was less than, though it did not differ significantly from, the single baseline level [*ts*(5) = 1.80, 1.34, 2.15, all *ps* > .05].

Figure 1 also shows the noncontingent baseline of licking the .1% solution predicted by the response competition, mixed, and substitution models. As expected, the response competition model predicted only a very small increase in licking the .1% solution as a function of reduction in the contingent response by the schedule. The baseline predicted by the mixed model was considerably higher; it exceeded asymptotic .1% licking in the first schedule requirement and fell significantly below asymptotic licking over the last four schedule requirements [all *ts*(5), *p* < .05].

Table 1
Obtained and Predicted Seconds of .1% Licking at Asymptote
(Two Session Blocks) for Each Schedule Requirement

Subject	Source	Instrumental Requirement in Seconds					
		5	10	15	20	25	30
1	Obtained	68	121	188	206	217	191
	Predicted	138	144	132	138	144	159
2	Obtained	47	43	48	49	69	75
	Predicted	68	60	65	69	68	69
3	Obtained	21	44	90	131	135	156
	Predicted	210	195	184	174	186	185
4	Obtained	85	157	173	192	188	169
	Predicted	103	102	125	137	150	164
5	Obtained	43	73	152	178	206	174
	Predicted	146	157	142	144	145	153
6	Obtained	49	86	119	130	133	142
	Predicted	160	182	190	195	211	212

Note—Predicted licking is based on the substitution model.

The baseline predicted by the substitution model was highest of all; it significantly exceeded the obtained licking values during the first schedule requirement [$t(5) = 3.25, p < .05$], and did not differ significantly from asymptotic .1% licking over the last four requirements [all $t(5), p > .10$]. However, the lack of difference between duration of instrumental licking and the substitution baseline failed to indicate consistent differences between obtained and baseline levels of licking for individual subjects. Table 1 shows that three of the six animals (1, 4, 5) consistently licked more than the substitution baseline over the last four requirements, and one animal (2) licked more than its predicted baseline over the last two requirements. The remaining two animals (3, 6) consistently licked considerably less than their predicted baselines. The relation between instrumental licking and the predicted baseline resembled a learning effect in that once a subject exceeded the predicted substitution baseline for a particular schedule, it continued above the baseline for the remainder of the schedules.

The filled squares in Figure 2 show the duration of licking the .4% solution during the paired baseline and under the different schedule requirements by two-session blocks. The filled triangles show the average proportion of the 10-sec access to the .4% solution that the subjects spent licking. All of the schedules greatly reduced the duration of licking the .4% solution [all $t(5), p < .01$], but the average duration of asymptotic .4% licking at each schedule requirement remained relatively constant [$F(5,25) = 1.50, p > .10$]. In contrast, the asymptotic efficiency of using the access to the .4% solution markedly increased over schedule requirements [$F(5,25) = 23.7, p < .001$]. An arcsin transformation was used to normalize the efficiency proportions prior to applying the analysis of variance.

Discussion

The results clearly illustrate the problems in judging the contingent increase in instrumental responding against either the single or paired baseline levels of the instrumental response. Duration of licking the .1% saccharin solution increased over its paired baseline level, but this result must be weighed against the concurrent drop in duration of licking the .4% solution, and the fact that duration of licking the .1% solution never exceeded its single baseline level. As expected, these comparisons neither established nor contradicted a contingent effect of the schedules on licking the .1% solution.

Interpretation of the relation between the predicted noncontingent baselines and the data is more difficult than anticipated. The average duration of licking the .1% solution clearly exceeded the noncontingent baseline predicted by the response competition model, and, for the last four schedule requirements, also exceeded the baseline predicted by the mixed model. However, the duration of .1% licking never reliably exceeded the baseline predicted by the substitution model.

Two aspects of these data are noteworthy. First, for both the mixed and substitution models, the noncontingent baseline during the initial schedule requirements markedly exceeded the obtained level of .1% licking. This result suggests that the models do not predict appropriate baselines until subjects learn the nature of the contingency, where such learning is indicated by stability in amount and pattern of instrumental responding *and* in amount and efficiency of using access to the reward. On this argument, complete acquisition of the schedules did not occur for most animals until the second or third schedule requirement. However, as in the case of a series of FR schedules of barpressing for food, partial acquisition under the least demanding schedules did not appear to interfere with stable performance at slightly higher schedule values.

Second, the large difference between the noncon-

Figure 2. Average seconds (squares) and efficiency (triangles) of licking the contingent .4% saccharin solution during different schedule requirements and paired baseline. Efficiency was defined as the proportion of access time actually spent licking.

tingent baselines predicted by the mixed and substitution models makes choice between the two necessary, but difficult. As mentioned in the introduction, the mixed model may underestimate the noncontingent effect of a schedule if there is little competition for expression from background responses. On the other hand, the substitution model may overestimate the noncontingent effect of a schedule if the noncontingent rate of substitution is not constant or if there is significant competition for expression. In the present case, it could be argued that use of the single baseline results in too high an estimate of the rate of substitution of the instrumental response for the contingent. In single baseline, the subject is free to lick the .1% solution in uninterrupted fashion. Under the schedule, the subject must initiate and terminate instrumental responding as required by the experimenter.

The status of the substitution baseline is also uncertain because of the large individual differences in responding. Over the later schedule requirements, four subjects consistently performed more than their calculated baselines, while two subjects performed markedly less. This difference might be attributed to failure of the latter two subjects to learn the contingency. However, over sessions, these animals increased efficiency of using access to the .4% solution and, in informal observation, showed the pause and run pattern of responding characteristic of fixed-ratio performance (Ferster & Skinner, 1957). Further, the rate at which the instrumental response substituted for each unit of decrease in the contingent response increased over sessions (though it never reached the single baseline level).²

In the absence of more compelling arguments, or an independent assessment of the contingent effect of the schedule, the baselines provided by the mixed and substitution models were not useful in precisely separating contingent and noncontingent effects of the schedule. Despite the convenience of applying these models, I felt the ambiguity of the results required the anchor of an empirical procedure designed to estimate the noncontingent effects of a schedule. To provide such an estimate, the next experiment used a yoked group of subjects.

EXPERIMENT 2

The second experiment measured directly the combined noncontingent effects of intermittent presentation and reduction of the contingent response by use of a between-subjects yoking procedure (Berlyne, 1969). Subjects in a yoked group were presented access to the .4% saccharin solution whenever their partner in the experimental group earned access to it. In a design similar to that of Experiment 1, the experimental group was required to lick the .1% solution for 5, 15, and 25 sec to obtain a 10-sec access

to the .4% solution. Since the yoked group had no instrumental requirement, their duration of licking the .1% solution should reflect only the effect of reduction in and intermittent presentation of access to the .4% solution. If the yoking procedure is successful, it should provide an empirical technique for evaluating the combined noncontingent effects of a schedule, as well as a basis for evaluation of the baselines predicted by the competition and substitution models.

Method

Subjects. The subjects were 12 male Wistar albino rats, 80-90 days of age at the beginning of the experiment. The subjects were housed two per cage under ad-lib food and water and a 12:12-h light-dark cycle. The experimental sessions occurred during the light part of the cycle.

Apparatus. The animals were run in a pair of adjacent aluminum boxes with grid floors of 2-cm-diam aluminum tubing. Each box was 24 × 35 × 19 cm high, and had a hinged front wall made of Plexiglas. The saccharin solutions were available in two glass drinking tubes of 7 mm i.d. and 2-mm tip aperture. The tubes were recessed 7 mm behind two circular holes, 1.5 cm diameter, centered 3 cm above the floor and 9 cm from the nearest side wall. The tube nearest the Plexiglas wall contained the .1% saccharin solution and the other contained the .4% saccharin solution. Access to the two tubes was controlled by a motor-driven aluminum shutter that simultaneously covered one tube and uncovered the other. White masking noise was presented from a source under the table on which the boxes sat. Seconds of licking were recorded in the manner described in Experiment 1.

Procedure. Each subject received one 10-min session per day for a total of 48 sessions. As in the first experiment, the subjects were trained under a particular condition for at least 6 days and until mean .1% licking for each group did not differ significantly between the last two successive two-session blocks. The subjects were first exposed to 16 sessions of paired baseline during which the drinking tubes containing the .1% and .4% saccharin solutions were freely and simultaneously accessible. The subjects were matched on their duration of licking during the last 6 days of paired baseline and divided into instrumental and yoked groups. The subjects then received 22 sessions of schedule training. To obtain 10 sec of access to the .4% solution, the experimental group was required to lick 5 sec of the .1% solution for the first 6 schedule sessions, 15 sec of the .1% solution for the next 6 sessions, and 25 sec of the .1% solution for the 10 remaining sessions. When an experimental subject licked the required duration, the .1% tube was covered and the .4% tube was uncovered for both the experimental subject and its yoked partner. Following a 10-sec period, the .4% tube was covered and access to the .1% tube was returned. The sound of the synchronous motor and the metal slide against the experimental chamber served as a cue for a change in the available solution. Following the schedule condition, all subjects received 10 additional sessions of paired baseline.

Results

In Figure 3, the filled and open circles show the duration of licking the .1% saccharin solution by the experimental and yoked groups at asymptote during the initial paired baseline, and by two-session blocks during the schedule condition and the following paired baseline. The filled and open squares show the average duration of licking the .4% saccharin solution by the experimental and yoked groups over the same conditions. As in the previous experiment, all schedules increased duration of licking the .1% solution

Figure 3. Average seconds of licking the .1% and .4% saccharin solutions by the experimental and yoked groups during different schedule requirements and paired baselines.

and decreased duration of licking the .4% solution with respect to their paired baseline levels [all $t(5)$, $p < .01$]. Analyses of variance computed on the average duration of licking during the last four sessions at each schedule requirement showed a significant increase in duration of licking the .1% solution [$F(2,20) = 45.4$, $p < .01$] and a significant decrease in duration of licking the .4% solution [$F(2,20) = 20.9$, $p < .01$]. The same analyses showed no difference between the experimental and yoked groups in duration of licking the .1% solution [$F(1,10) < 1$], but the experimental group showed a significantly greater duration of licking the .4% solution [$F(1,10) = 6.6$, $p < .05$]. A last analysis of variance applied to duration of licking the .1% solution in the second paired baseline showed a significant decrease in licking [$F(4,40) = 16.8$, $p < .01$] and no difference between the experimental and yoked groups [$F(1,10) < 1$].

Discussion

The procedure of presenting yoked subjects with the same timed access to the .4% solution earned by their experimental group partners was not successful in establishing a useful noncontingent baseline duration of licking the .1% solution. Though timed access to the .4% solution was identical for the two groups, the yoked group actually licked the .4% solution significantly less. The difference in duration of licking the .4% solution, coupled with a trend toward more .1% licking in the experimental group, suggested the possibility of a significant contingent effect. At the level of substitution found in Experiment 1, the shorter duration of licking the .4% solution shown by the yoked group should have resulted in a compensatory increase in duration of licking the .1% solution. However, this effect cannot be evaluated properly in the absence of an appropriate noncontingent baseline. Also, as in the first experiment, there was an indication that the subjects did not ade-

quately learn the schedule until the second schedule value.

The failure of the yoked group to take advantage of the access time to the .4% solution may be due to several reasons. If a subject in the yoked group was not licking the .1% solution when its partner completed the instrumental requirement, it missed the visual and tactual cues of the metal shutter moving across the opening; however, the sound of the metal shutter sliding against the side of the metal chamber and the activation of the synchronous motor appeared to be very salient stimuli. It may be that the ready substitutability of licking the .1% solution for licking the .4% solution and the use of ad-lib subjects produced less attention to the reward than is typical in, say, food-related schedules. One subject in the yoked group largely ignored the .4% solution, licking the .1% solution almost exclusively.

A last problem with use of the yoking procedure was that the .4% solution often became available to the yoked subjects in close temporal proximity to their licking the .1% solution. Such accidental pairings occurred because of the relatively high probability of licking the .1% solution when the .4% solution was not available. An appropriate baseline of the contingent effects of a schedule should minimize the potential contingent effects of pairing the instrumental and contingent responses as well as reproduce the same amount of contingent responding in the baseline and schedule conditions. The next experiment apparently provided such baselines by using within-subject yoking procedures.

EXPERIMENT 3

As in the previous experiment, the intent of this experiment was to measure directly the noncontingent increase in licking the .1% saccharin solution under a schedule. To separate effects of substitution and intermittent presentation, and to avoid problems created by yoking different subjects (Church, 1964), this experiment used two different within-subject yoked baselines—a massed baseline and a matched baseline.

The massed baseline was a variant of a procedure used by Falk (1971) to determine the adjunctive effects of intermittent presentation of food. In this baseline, subjects received the amount of .4% licking they earned at asymptotic performance under the schedule, but in the absence of any instrumental requirement or eliciting effects of periodic access to the .4% solution. At the beginning of each massed baseline session, the subjects were given simultaneous access to both the .1% and .4% solutions. When the subject completed the amount of .4% licking it was allotted, access to the .4% solution was removed and only the .1% solution was available for the remainder

of the session. To minimize the effect of schedule training on licking in massed baseline, subjects received paired baseline sessions after the schedule and prior to the massed baseline trials.

A second within-subject baseline, the matched baseline, was employed to measure the eliciting effects of intermittent presentation of access to the .4% solution unrelated to the contingent effect of the schedule. Similar procedures were used previously by Bernstein and Ebbesen (1978), Premack (1965), and Ebbesen, Allen, and Kjos (Note 1). In the present matched baseline, subjects received 10-sec access to the .4% solution at points in the session determined by the time at which each subject earned access to the .4% solution in its last schedule session. Each subject received two versions of the matched baseline, one in which access to the .4% solution was removed after 10 sec, continuously timed, and one in which access to the .4% solution was removed only after the subject licked the average amount it had licked during a 10-sec access under the schedule. To minimize contingent effects from pairings of the instrumental and contingent responses under this baseline, the subjects received paired baseline trials after the schedule and prior to the matched baseline trials.

Several changes in procedure were made to increase the clarity of the results. A large number of acquisition trials was employed to ensure an ample opportunity for all subjects to learn the schedule. Second, frequency was measured rather than duration of licking, to eliminate any possibility that rate differences between the schedule and baseline sessions might affect the results. Third, a greater number of paired baseline sessions was run to insure stable measures of responding prior to the schedule sessions. Finally, instrumental responding under the schedule was compared with the predictions of the substitution model from Experiment 1. The mixed model could not be tested because there was no measure of licking time.

Method

Subjects. The subjects were 12 naive male Wistar albino rats, 150 days of age. Maintenance was the same as in Experiment 2. Four subjects died of respiratory disease during the study, and their data were discarded.

Apparatus. The experimental chamber was a sheet metal cube, 30.5 cm on a side, with a Plexiglas top and a hinged Plexiglas side. The floor of the chamber was a grid of 9-mm-diam galvanized steel rods, separated 2.5 cm on center. Wahman glass cylinders with metal drinking tubes of 2.5-mm tip aperture contained the two saccharin solutions mixed as in Experiment 1. The tubes were recessed 7 mm behind two 16-mm-diam holes, each 6.4 cm above the floor and 6.4 cm from a side wall. The position of the solutions with respect to the chamber door was counterbalanced across subjects. Access to the solutions was controlled by two metal flags which slid across the hole under control of a cam and synchronous motor assembly. When one solution was available, the other was not. The entire apparatus was housed in a sound-attenuating chamber, and sound was masked by white noise and a ventilating fan. BRS programming and data recording equipment were located in the same room.

Procedure. Except in the final single-baseline condition, all animals were trained under each condition for at least 9 days and until the mean instrumental licking of the last 3 days for each group did not differ significantly from the mean of the preceding 3 days. Each subject received 73 daily sessions of 10 min each. In an attempt to stabilize the initial baseline during the first 15 sessions, subjects received, in succession, sessions of paired baseline, single baseline of .1% licking, and single baseline of .4% licking. This sequence was repeated five times and was followed by eight sessions of paired baseline. During the 20 days of acquisition, 15 licks of the .1% solution of saccharin were required for the animal to gain 10 sec access to the .4% saccharin solution. Fifteen licks is equivalent to a 3-5-sec licking requirement.

Following 10 days of paired baseline after the schedule condition, the subjects received 10 days of massed baseline and 10 days of matched baseline in counterbalanced order. In the massed baseline, subjects were presented with both the .1% and .4% solutions at the beginning of the session. As each subject completed the average amount of licking the .4% solution it had performed during the last 6 days of the schedule, access to the .4% solution was terminated, leaving only the .1% solution available for the remainder of the session. In the matched baseline, the subject received a 10-sec access to the .4% solution at points in the session determined by its earned access periods during the last schedule session. Following these procedures, all subjects were run nine sessions on a second matched baseline during which access to the contingent response remained available until the subject had completed the average number of licks it completed per access in the last schedule session. If the subject did not complete its earned amount of .4% saccharin licking prior to the next scheduled access time, the amount of licking available was cumulated. Finally, each animal received four sessions of single baseline of licking the .1% solution.

Results

In Figure 4, average frequency of licking the .1% and .4% solutions is shown by two-session blocks in the schedule condition and subsequent paired baseline, and at asymptotic performance over the first paired baseline and massed, matched, and single baselines. Licking the .1% solution increased significantly over schedule sessions [$F(9,63) = 19.5$, $p < .001$]. At asymptote under the schedule (the last six sessions), .1% licking exceeded both paired baseline

Figure 4. Average number of licks to the .1% and .4% saccharin solutions during the schedule, and paired, massed, matched, and single baselines. In the matched I baseline, access to the .4% solution was always 10 sec in duration. In the matched II baseline, the .4% solution was removed only after the subject licked the average amount it licked during the 10-sec access periods in the asymptotic schedule sessions. A noncontingent baseline calculated from the substitution model is also shown for the schedule trials.

levels [$t(7) = 7.98$ and 2.87 , $p < .01$, one-tailed] but was significantly less than the single baseline level [$t(7) = 8.64$, $p < .01$]. When the schedule was removed and the subjects returned to paired baseline, the amount of .1% licking declined significantly [$F(4,28) = 7.93$, $p < .01$], until over the last four trials it did not differ significantly from the original baseline levels [$t(7) < 1$].

Licking the .4% solution was considerably reduced over the first few schedule sessions, but as licking the .1% solution increased over trials, so did licking the .4% solution [$F(9,63) = 11.2$, $p < .01$]. At asymptote under the contingency, licking the .4% solution did not differ from its original or subsequent paired baseline levels [$t(7) < 1$ and 1.38 , $p > .10$].

Comparison of licking the .1% and .4% solutions under the massed baseline and schedule conditions showed significantly more licking of the .1% solution under the schedule condition [$t(7) = 2.23$, $p < .05$, one-tailed] but, as expected, no difference in licking the .4% solution [$t(7) < 1$]. In the first matched baseline, licking the .1% solution did not differ significantly from the amount under the schedule [$t(7) < 1$], but this lack of difference was difficult to interpret because the subjects licked significantly less of the .4% solution under the matched baseline [$t(7) = 2.52$, $p < .05$]. In the second matched baseline, licking of the .4% solution was the same as the amount under the schedule [$t(7) = 1.21$, $p > .10$] and the subjects licked significantly more of the .1% solution under the schedule [$t(7) = 3.90$, $p < .01$]. Comparison of licking the .1% solution in the massed baseline and the second matched baseline showed no significant difference [$t(7) < 1$], indicating that periodic presentation of access to the .4% solution had no eliciting or contingent effects on frequency of licking the .1% solution.

Figure 4 also shows the baseline predicted by the substitution model from Experiment 1. As in Experiment 1, the predictions of the substitution model for the initial schedule sessions were much higher than the amount of licking obtained, but at asymptote the obtained level of licking the .1% solution significantly exceeded the amount predicted by the model [$t(7) = 2.09$, $p < .05$, one-tailed]. Further, the predicted level of licking the .1% solution was not distinguishable from the amount of .1% licking obtained in the massed baseline [$t(7) < 1$].

Discussion

Experiment 3 established the massed baseline procedure as suitable for determining the noncontingent substitution effect of a schedule on amount of instrumental responding. The matched baseline also provided a serviceable estimate of noncontingent effects when the asymptotic amount of access to the contingent response was guaranteed. Without such a

guarantee, subjects produced less contingent responding than under the schedule, and the instrumental response increased its amount of substitution accordingly.

Though the substitution model from Experiment 1 also appeared to provide a reasonable estimate of the noncontingent baseline, there were several unresolved problems with its use. As in the first experiment, two subjects failed to exceed their predicted baselines. One subject showed increased efficiency in using access to the contingent response and increased rate of substitution over contingency sessions.² Further, this subject exceeded its massed baseline level of licking. Therefore, it could be argued that the substitution model mispredicted the subject's noncontingent baseline. The other subject neither increased efficiency of using access to the contingent response nor exceeded its massed baseline, and showed only a slight initial increase in substitution rate under the contingency. It could be argued that this animal did not learn the contingency, and the substitution model correctly predicted its noncontingent baseline.

A second problem with the substitution model was that it predicted negative levels of performance at asymptote for two animals, and negative session blocks for several others. In the case of each negative value, the subjects exceeded their paired baseline level of the contingent response, thereby resulting in a negative sign for the right side of Equation 3. At a theoretical level, this outcome is difficult to interpret, unless it is assumed that interspersing instrumental and contingent responding under the schedule increased the amount of instigation for both responses. At a practical level, the negative values resulted in misleading averaged estimates of noncontingent baseline. In Figure 4, the last few values of the substitution baseline appear lower than the massed baseline; however, for animals without negative baseline values, the substitution baseline was consistently slightly higher than the massed baseline.

GENERAL DISCUSSION

The Best Noncontingent Baseline

An adequate baseline of the noncontingent increase in instrumental responding under a schedule should be inexpensive to use, easy to measure, clear in its interpretation, and the results of its application consistent with other measures of contingent effects. The single and paired baselines did not fulfill the last two of these criteria in the case of schedules that related highly substitutable licking responses. Initial increases in instrumental licking exceeded the paired baseline, but not a noncontingent baseline, and did not show stability in other measures of contingent effects. Other increases in instrumental licking exceeded noncontingent baselines, showed stable changes in or-

ganization and economy of responding, but did not exceed the single baseline.

In the present conditions, the massed baseline appeared to meet the above criteria best. The massed baseline could be used with a relatively small number of subjects, was easy to apply, and its interpretation was clear and consistent with the presence of other contingent effects, such as temporal patterning and efficiency of using access to reward. The matched baseline with guaranteed amount of access to the contingent response was also a reasonable choice, though it required monitoring of the pattern of responding at asymptote under the schedule. This expense could be reduced by an alternative procedure in which the experimenter presented at random the number of access periods earned at asymptote under the schedule (Bernstein & Ebbesen, 1978; Ebbesen, Allen, & Kjos, Note 1). Another possible problem with the matched baseline is that with high-probability instrumental responses there is the potential for partial reward effects due to intermittent presentation of access to the contingent response in close temporal contiguity to the instrumental response.

Thus, in cases in which adjunctive effects of a schedule are unlikely, the massed procedure is probably the baseline of choice. If adjunctive effects on amount of instrumental responding are expected, then a matched baseline with guaranteed amount of access may be preferable. It might also be possible to use a guaranteed access procedure with a between-subjects yoked group; but this procedure is more costly in terms of animals, and may encounter additional problems of individual differences between experimental and yoked animals (Church, 1964). If it is desirable to separate substitution and adjunctive components of instrumental responding, then the massed procedure must be used in combination with the matched procedure or a yoked group.

The usefulness of the substitution, mixed, and response competition models is unclear from these data. In fairness to the response competition model, it performed as expected given the high degree of similarity between the two responses. The mixed model should be tested further using significant background responses. Though it appeared to be the most satisfactory, the substitution model seemed to overestimate the noncontingent baseline, in some cases by a considerable amount. Further, the negative baselines predicted at the low instrumental requirement in Experiment 3 were difficult to interpret. However, the convenience of the substitution model should lead to further attempts to evaluate it.

An apparent anomaly of both the mixed and substitution models is that some learning of the schedule had to occur before responding came close to the level predicted by the noncontingent (unlearned)

rate of substitution. This result is not as peculiar as it seems, though. Under the contingency, unlearned substitution must take place within the structure imposed by the schedule. Until the subject adjusts to the imposed structure, the levels of behavior predicted by the noncontingent rate of exchange will be too high.

A possible problem with these models is that they fail to consider restrictions on instrumental responding imposed by the contingency, such as changed burst lengths and interburst intervals (Dunham, 1977), or increased "trips" between the instrumental and contingent responses (Allison, Miller, & Wozny, 1979). However, in the present data, the importance of such changes in response organization is not clear. In Experiment 3, the massed baseline, a procedure that eliminates much of the response structure imposed by the contingency, did not produce responding that differed significantly from that in the matched baseline, a procedure that maintains most of the structure of the contingency. It is evident that not all changes in the molecular organization of behavior have effects reflected in overall response levels.

Highly Substitutable Responses

As anticipated, the contingent increase in responding obtained in these experiments was small and difficult to isolate from the large noncontingent substitution effect. The results indicated that care is required in such cases to ensure that increased responding represents a contingent effect and not unlearned substitution. In all three experiments, there was a small, but rapid, increase in instrumental licking in the first session block of the first schedule. In the third experiment, apparently because of the increased number of acquisition sessions, this initial increase was followed by a slower, larger increase. In retrospect, it seems that the rapid initial increase was largely an incomplete noncontingent substitution effect, while the later effect was primarily a contingent one. Such a pattern of results suggests the necessity of fairly stringent criteria of asymptotic responding in determining when to terminate schedules involving highly substitutable responses.

The size and relative slowness of the development of contingent effects in the present experiments, coupled with the failure of the yoked control group in Experiment 2 to make efficient use of their access to the contingent response, suggests that there may be some basic differences between contingencies employing highly substitutable responses and more typical food-reward contingencies (Shettleworth, 1972). However, these differences may be a function of any number of variables, such as deprivation level, or particular combinations of instrumental and contingent responses. The nature of this difference remains to be demonstrated.

Response Substitution, Contingent Effects, and Economics

In the present experiments, the term "substitution" was used primarily to refer to the noncontingent (unlearned) ability of one response to fill in disproportionately for a reduction in another response. A reasonable basis for noncontingent substitution is that the two responses are instigated and controlled by overlapping sets of external and/or internal cues. When the opportunity to engage in a preferred response is reduced, the overlapping cues instigate the related response. The basis for this unlearned overlap in instigating cues was presumed to be independent of the current contingency.

Reasoning in a related vein, it could be argued that imposing a schedule between two responses increases their substitutability by increasing the shared cues that instigate and control them. Through temporal contiguity and the instrumental nature of the schedule, cues that previously instigated and controlled the contingent response may come to control the instrumental response. Thus, increased instrumental responding under a schedule can be viewed as a composite of the effects of learned (contingent) substitution and unlearned (noncontingent) substitution.

Rachlin and Burkhard (1978) recently proposed that changes in responding under a schedule were due to substitution of the instrumental response for the contingent response, but they argued that to predict responding it was unnecessary to consider any unique contingent effects of the schedule. Though I find their equilibrium approach fundamentally sound, I don't think the ability to predict responding under a schedule should preclude consideration of obvious differences between the contingent and noncontingent effects of a schedule (see also Staddon, 1979). The present data suggest that temporal contiguity and instrumentality imposed by the schedule alter the relative substitutability of the instrumental and contingent responses, even in the case of two highly similar licking responses. Certainly, such a change would be much larger in the case of responses such as barpressing and eating. Further, expanding the equilibrium approach to deal with complex contingent effects such as changes in latency, patterning, speed of acquisition, and resistance to extinction of instrumental responding should provide a more general account of learned performance (see Allison & Timberlake, 1975; Ellis & Timberlake, Note 2).

Part of the reason that Rachlin and Burkhard (1978) did not distinguish the contingent and noncontingent effects of a schedule is due to the roots of their approach in microeconomics, the concepts of which have recently been applied to the analysis of responding on operant schedules (Kagel, Battalio, Rachlin, Green, Basmann, & Klemm, 1975; Lea, 1978; Lea & Roper, 1977; Rachlin, Green, Kagel,

& Battalio, 1976). The association of psychology and economics seems promising. However, at least in the case of simple ratio schedules, the economic approach ignores several special characteristics of the operant paradigm. First, different instrumental responses may vary in both contingent and noncontingent substitutability for the same contingent response, a source of variability not usually treated in economic analyses in which money or time is viewed as the invariant yardstick of value. Second, periodic presentation of access to the contingent response may result in adjunctive behavior, another phenomenon not typically treated in economic analyses. For a more technical discussion of other differences, see Lea (1978). Whether these differences can be resolved in some comprehensive model of operant and economic behavior remains to be seen.

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NOTES

1. Another formally identical model was used by Allison (1976) to account for the total change in instrumental responding from paired baseline to schedule condition. In Allison's model, the multiplicative constant is estimated from the schedule data rather than from single or paired baselines. Thus, Allison's model does not distinguish between the contingent and noncontingent effects of a schedule.

In a reciprocal schedule (Timberlake & Allison, 1974), the response competition, mixed, and substitution models all can predict noncontingent baseline levels before the schedule is imposed. In Equations 1, 2, or 3, replace S_i with NI , and S_c with NC , where N stands for the number of repetitions of the instrumental-contingent sequence; compute the value of the multiplier; solve for N and evaluate the expression NI . In the present schedules, which fix time of access rather than amount of the contingent response, the exact relation between instrumental and contingent responding is not specified by the schedule. Thus, the actual decrease in the contingent response must be known before noncontingent baselines can be computed.

2. In a variant of the procedure used to calculate the noncontingent rate of substitution in Equation 3, rate of substitution or exchange under the schedule can be calculated by dividing the increase in the instrumental response (S_i-O_i) by the decrease in the contingent response (O_c-S_c).

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