CONTRAST, INDUCTION, FACILITATION, SUPPRESSION, AND CONSERVATION¹

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Ten rats received all of their water in daily 1-hr sessions. Following a baseline phase in which lever and water spout were freely available throughout each session, subjects were trained to press the lever for water on mixed schedules composed of two alternating components. Each component gave access to water for a fixed cumulation of drinking time every time the rat cumulated a fixed amount of lever-pressing time. Changes in one component produced contrast and induction effects, both positive and negative, with respect to both lever pressing and drinking in the unchanged component. All schedules facilitated lever pressing relative to baseline. All schedules suppressed drinking relative to baseline, even though contingency sessions allowed ample time to perform the baseline amount of drinking. The entire pattern of results was predicted in quantitative detail by assuming that the total amount of a dimension apportioned to lever pressing and drinking is conserved between baseline and contingency sessions. Conservation theory was shown to predict several effects produced by simple fixed-ratio schedules, and was compared favorably with probability-differential (Premack, 1971) and response-deprivation (Timberlake and Allison, 1974) theory.

Key words: conservation, contrast, induction, facilitation, suppression, mixed schedule, lever press, drinking, rats

Contrast and induction in operant conditioning (Skinner, 1938) are typically studied by means of multiple schedules composed of variable-interval components (Freeman, 1971; Rachlin, 1973). The present paper investigated contrast and induction effects in mixed schedules composed of cumulative time components arranged in regular alternation. An important reason for studying this unusual paradigm is that it yields readily to a powerful theoretical analysis that can be generalized successfully to simple fixed-ratio schedules.

The present paradigm, though highly structured, can reveal positive and negative contrast and induction effects that truly reflect the subject's behavior, and not merely the structure of the experiment. All contingency training sessions have the same duration, and employ a mixed schedule composed of two

alternating components. Each component remains in force until its two response requirements are completed by the subject, and only then gives way to the other component. The requirements are defined in terms of two responses, symbolized as Response *i* and Response *c*. Each component requires a fixed amount of each response, symbolized *I* in the case of Response *i*, and *C* in the case of Response *c*. The two components are distinguished by the subscripts 1 and 2.

In the present example, Response *i* is pressing and holding a lever, Response *c* is drinking from a water spout, and the requirements refer to the time spent performing each response. Component 1 requires that the rat press and hold the lever for a fixed amount of time, a cumulative total of *I*₁ sec, for access to the water spout. After *I*₁ sec of pressing and holding, the lever retracts and the spout appears. The rat must then drink for a fixed amount of time, a cumulative total of *C*₁ sec, for the spout to retract and the lever to reappear. Component 2 is then in force, requiring *I*₂ sec of pressing and holding for *C*₂ sec of drinking, after which the spout retracts, the lever reappears, and Component 1 is in force once again.

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The full sequence of response requirements is thus I_1 sec of lever pressing, followed by C_1 sec of drinking, followed by I_2 sec of lever pressing, followed by C_2 sec of drinking. The number of times the subject completes this sequence before the session expires is the dependent variable, N . The total time spent lever pressing in Component 1 is therefore NI_1 sec, plus any additional pressing the subject might do in Component 1 without completing the full sequence. Similarly, the total times spent drinking in Component 1, pressing in Component 2, and drinking in Component 2 are approximately NC_1 , NI_2 , and NC_2 sec, respectively.

A hypothetical example is shown in the first row of Table 1. Schedule A in Table 1 specifies four schedule requirements of 10 sec each. If the subject were to complete the sequence 30 times ($N = 30$), with no partial completions, the total amount of each response would be 300 sec in each component.

The rest of Table 1 shows how the subject might respond in subsequent sessions if the experimenter were to change Schedule A by modifying Component 2 alone. Rows 2 through 6 refer to Schedule B1, which is the same as Schedule A except that I_2 and C_2 have been changed from 10 sec each to 5 sec each. Row 2 shows what would happen if the subject were to complete the B1 sequence 40 times. Relative to Schedule A, the total time spent lever pressing, and thus the session rate of

lever pressing, would increase in the unchanged Component 1, and decrease in the changed Component 2 (positive contrast).

Rows 3 through 6 show that this positive contrast effect with respect to lever pressing is not a necessary consequence of the restrictions imposed by Schedule B1. The effect depends on N , and is therefore a consequence of the subject's behavior. Row 3 demonstrates more lever pressing than Schedule A in both components (positive induction), and Row 4 demonstrates less (negative induction). Finally, Rows 5 and 6 show that Schedule B1 need not produce either effect. If switched from Schedule A to Schedule B1, the subject might do more or less lever pressing in one component without changing the amount done in the other component (no contrast, and no induction).

The preceding analysis shows that this type of schedule could reveal several different outcomes with respect to lever pressing. It is also clear that any particular schedule will *exclude* positive contrast, negative contrast, or both. Schedule B1 happens to exclude negative contrast, for any value of N large enough to produce an increase in the time spent lever pressing in Component 2 would necessarily also produce an increase in the time spent lever pressing in the unchanged Component 1, and this would be positive induction. With this type of schedule, a negative contrast effect cannot occur unless the lever-pressing param-

Table 1
Hypothetical responding to schedules requiring I_1 sec of lever pressing for C_1 sec of drinking in Component 1, and I_2 sec of lever pressing for C_2 sec of drinking in Component 2.

							Total Responding in Session					
							Lever		Drink			
							Component		Component			
Row	Sched- ule	I_1	C_1	I_2	C_2	N	1	2	Effect Relative to Schedule A	1	2	Effective Relative to Schedule A
1	A	10	10	10	10	30	300	300		300	300	
2	B1	10	10	5	5	40	400	200	Positive contrast	400	200	Positive contrast
3						70	700	350	Positive induction	700	350	Positive induction
4						20	200	100	Negative induction	200	100	Negative induction
5						30	300	150	—	300	150	—
6						60	600	300	—	600	300	—
7	B2	10	10	15	15	25	250	375	Negative contrast	250	375	Negative contrast
8						10	100	150	Negative induction	100	150	Negative induction
9						40	400	600	Positive induction	400	600	Positive induction
10						30	300	450	—	300	450	—
11						20	200	300	—	200	300	—
12	B3	10	10	15	10	25	250	375	Negative contrast	250	250	Negative induction
13						20	200	300	—	200	200	Negative induction

eter I_2 is increased relative to Schedule A, and positive contrast cannot occur unless I_2 is decreased.

Schedule B2 (Rows 7 through 11) is the same as Schedule A, except that I_2 and C_2 have been changed from 10 sec each to 15 sec each. Unlike Schedule B1, Schedule B2 excludes positive contrast, but not negative contrast. Row 7 shows what would happen if the subject were to complete the sequence 25 times. Relative to Schedule A, lever pressing would decrease in the unchanged Component 1, and increase in the changed Component 2 (negative contrast). Rows 8 through 11 show that this negative contrast effect is not a necessary consequence of the restrictions imposed by Schedule B2, as the possible outcomes include negative induction, positive induction, and no contrast or induction.

The conclusions also apply to the other response, drinking. Table 1 shows that such schedules may reveal positive or negative contrast or induction effects with respect to drinking, and that none of these outcomes is a necessary consequence of the restrictions imposed by the schedule. Positive contrast cannot occur unless the drinking requirement C_2 is decreased relative to Schedule A, and negative contrast cannot occur unless C_2 is increased.

It follows that the two responses need not show the same effect, as demonstrated with Schedule B3 in Rows 12 and 13. Row 12 indicates negative contrast with respect to lever pressing, but negative induction with respect to drinking. Row 13 indicates no contrast or induction with respect to lever pressing, but negative induction with respect to drinking.

In the experiment reported here, schedules of the type shown in Table 1 produced positive and negative contrast and induction effects with respect to both lever pressing and drinking. The entire pattern of results was predicted in quantitative detail by assuming that the subject conserves the total amount of a dimension apportioned to lever pressing and drinking between two kinds of session having the same duration. One kind is the contingency session in which the subject must perform a fixed amount of each response for access to the other response. The other kind is the paired operant baseline session (Timberlake and Allison, 1974), in which both responses are freely and simultaneously available

throughout the entire session, and the subject performs a total amount of Response i , which is symbolized O_i , and a total amount of Response c , which is symbolized O_c .

The dimension conserved is not specified, and need not be specified in order to derive the predictions that are the concern of this paper. However, it may be helpful to consider for a moment that energy expenditure is a specific example of a dimension shared by lever pressing and drinking. This example is cited to make it clear that whatever the dimension might be for any particular pair of responses, it is not to be viewed as some mysterious entity that can never be identified directly or indirectly. It would clearly be possible in principle to test the speculation that it is the total amount of energy expended in lever pressing and drinking that is conserved between baseline and contingency sessions.

Contrast and induction effects are relations between contingency sessions. In addition to these, the experiment revealed two relations between contingency and baseline sessions. First, there was considerably more lever pressing in the contingency than in the baseline session. Second, this large increase in lever pressing fell short of the increase required if the subject were to perform the baseline amount of drinking. The resulting deficit in drinking was not the artifact of an impossibly high lever-pressing requirement, and occurred despite the fact that the subject had no chance to drink outside the experimental sessions. Both of these effects—the facilitation of lever pressing relative to the baseline amount O_i , and the suppression of drinking relative to the baseline amount O_c —were predicted by the conservation model for this kind of schedule.

Conservation Model

The parameter k is the amount of the dimension entailed in performing one unit of Response i , relative to the amount entailed in performing one unit of Response c , and is therefore a unit-free ratio. On the understanding that I and O_i refer to the same unit of measurement, and that C and O_c refer to the same unit of measurement, the conservation model for the kind of schedule shown in Table 1 is then

$$N(kI_i + C_i + kI_c + C_c) = kO_i + O_c. \quad (1)$$

Given the definition of k , Equation 1 specifies

the total amount of the dimension apportioned to Responses *i* and *c*, as measured in the unit used for Response *c*. The right side specifies this total for the baseline session, and the left side specifies this total for the contingency session. The equal sign asserts that the subject conserves this total between baseline and contingency sessions.

An important advantage of this model is that the presence of *k* makes the two responses commensurate in terms of the dimension conserved. In testing the implications of Equation 1, the two responses can therefore be measured in the same unit, such as seconds for Response *i* and seconds for Response *c*, or in entirely different units, such as seconds for Response *i* and milliliters for Response *c*. There are no theoretical restrictions on units of measurement, except for the trivial restriction that the units must not be changed between baseline and contingency sessions.

In theory, this tendency toward conservation is fundamental. That is, if it is found that one particular schedule of this kind facilitates or suppresses a response relative to baseline, or that two different schedules of this kind produce different amounts of responding, these behavioral modifications are a necessary, predictable, and incidental result of the behavioral conservation defined by Equation 1. These implications will be derived from Equation 1 in the course of describing the present results. Apart from Equation 1 itself, the only other assumption needed to account for the present results is that lever pressing and drinking both entail a positive amount of the dimension, so that the ratio *k* is greater than zero.

METHOD

Subjects

Ten male albino rats, approximately 90 days old, were purchased from Harlan Industries (Cumberland, Ind.).

Apparatus

The apparatus was an aluminum operant conditioning box (Waltke Scientific Instruments, Bloomington, Ind.) 25 cm square and 19 cm high, equipped with a retractable lever. A metal drinking spout connected to a water bottle was centered in the rear wall about 5.5 cm above the stainless-steel floor. The lever

was centered about 8 cm to the left of the spout, and 9 cm above the floor.

The tip of the spout was centered in a circular hole in the wall about 1.5 cm in diameter, and recessed 1 cm beyond the inside surface of the wall. Access to the spout was controlled by means of a thin metal flag interposed between the outside surface of the wall and the tip of the spout. An electric motor raised or lowered the flag, thereby giving or preventing access to the spout. The lever projected 1.5 cm through a rectangular hole slightly larger than the cross section of the lever (3.5 by 1.5 cm). Microswitch closure required a force of about 0.1 N. In its retracted position, the lever was flush with the inside surface of the wall.

Experimental events were controlled and recorded automatically by solid-state circuitry and electromechanical counters located in an adjoining room. Illumination was provided by a green 1-W light centered 3 cm above the lever, and an identical light centered 3 cm above the spout. Extraneous sounds were masked by white noise emitted from a source approximately 1 m beside and below the box.

Tongue contacts with the spout were monitored by a solid-state drinkometer circuit (BRS/LVE, DO-201). Time spent drinking was recorded by a 0.1-sec clock that started when the circuit detected a lick, and stopped when 300 msec elapsed with no further licks. Total water intake was measured by reading the graduated bottle to the nearest milliliter before and after each session. Time spent lever pressing was recorded by a 0.1-sec clock that started when the microswitch was closed, and stopped when the microswitch was opened. Other counters recorded the total number of licks, the total number of lever presses, the time spent in Components I_1 , C_1 , I_2 , and C_2 , and the number of times the subject completed C_1 and C_2 .

Procedure

Throughout the experiment, each subject had free access to food in both the home cage and the apparatus, where three to four laboratory chow pellets were scattered about the floor before the daily 1-hr test session. Beginning several days before the first test session, subjects were adapted to a 1-hr watering schedule that was maintained throughout the rest of the experiment, and coincided with the in-

dividual subject's usual time of testing. The adaptation period varied from four to 35 days across subjects. Watering in the home cage was discontinued on the day of the first session; thereafter, the only source of water was the spout in the apparatus.

Baseline sessions were begun by extending the lever and raising the flag simultaneously. Lever and spout remained freely available throughout the session, which was ended by retracting the lever and lowering the flag simultaneously.

Contingency sessions were begun by extending the lever alone. When the lever-pressing requirement was completed, the lever was retracted and the flag raised simultaneously, allowing access to the spout. When the drinking requirement was completed, the flag was lowered and the lever extended simultaneously. The contingency session was ended by retracting the lever or lowering the flag.

The experiment was divided into five phases: precontingency baseline, preliminary contingency training, Phase A contingency training, Phase B contingency training, and postcontingency baseline. The precontingency baseline phase varied from 10 to 25 sessions across subjects. Each subject was tested until its baseline performance seemed reasonably stable (four consecutive sessions with no consistent upward or downward trend in lever pressing or drinking). This was followed by one to four preliminary contingency training sessions in which 1 sec of lever pressing was required for 1 sec of drinking; no shaping procedure was employed. The stability cri-

terion used in precontingency baseline was also used to determine the number of training sessions in Phase A, which varied from seven to 19 across subjects. All subjects received 10 sessions in Phase B, and four postcontingency baseline sessions.

In Phase A, all subjects received the same nominal schedule, $I_1 = C_1 = I_2 = C_2 = 10$ sec. In Phase B, Component 1 remained the same as in Phase A, but the nominal values of I_2 and C_2 were changed. The changes are shown in Table 2, along with the other differential treatments.

Because of the time lag in the mechanical systems that retracted the lever and lowered the flag, it was possible for the subject to overshoot each nominal value by a fraction of a second. Overshooting was negligible in the case of lever pressing, but subjects consistently overshoot the drinking requirement by about 0.6 sec. Theoretical analyses took this into account by adding 0.6 sec to the nominal values of C_1 and C_2 .

RESULTS

With a few noted exceptions, each of the following analyses was based on the subject's mean for the last two precontingency baseline sessions, the last two Phase A contingency sessions, all 10 Phase B contingency sessions, and all four postcontingency baseline sessions.

Baseline versus Contingency: Responding in Both Components Combined

The total amount of lever pressing in both components combined is approximately

Table 2
Differential Experimental Treatments

Subject	Adaptation Period (days)	Number of Sessions		Phase A	Phase B Parameters			
		Precon- tingency Baseline	Prelim- inary Contin- gency		I_1	C_1	I_2	C_2
R-1	4	15	1	10	10	10	12	8
R-2	4	13	4	8	10	10	12	8
R-3	4	11	1	14	10	10	8	12
R-4	4	11	1	19	10	10	8	12
R-5	35	16	4	7	10	10	10	15
R-6	35	11	1	8	10	10	10	5
R-7	35	10	1	15	10	10	5	10
R-8	35	25	2	7	10	10	15	10
R-9	35	17	1	7	10	10	15	15
R-10	35	16	1	7	10	10	5	5

$N(I_1 + I_2)$, and the amount of drinking in both components combined is approximately $N(C_1 + C_2)$. Solving Equation 1 for the dependent variable N , the conservation model predicts that

$$N = \frac{kO_i + O_c}{kI_1 + C_1 + kI_2 + C_2}. \quad (2)$$

The model therefore predicts that the total amount of lever pressing in both components combined, relative to the baseline amount of lever pressing, will be approximately

$$\begin{aligned} N(I_1 + I_2) - O_i &= \frac{(I_1 + I_2)(kO_i + O_c)}{kI_1 + C_1 + kI_2 + C_2} - O_i \\ &= \frac{O_c(I_1 + I_2) - O_i(C_1 + C_2)}{k(I_1 + I_2) + C_1 + C_2}. \end{aligned} \quad (3)$$

Similarly, the model predicts that the total amount of drinking in both components combined, relative to the baseline amount of drinking, will be approximately

$$\begin{aligned} N(C_1 + C_2) - O_c &= \frac{(C_1 + C_2)(kO_i + O_c)}{kI_1 + C_1 + kI_2 + C_2} - O_c \\ &= \frac{k[O_i(C_1 + C_2) - O_c(I_1 + I_2)]}{k(I_1 + I_2) + C_1 + C_2}. \end{aligned} \quad (4)$$

Equations 3 and 4 imply that the contingency will facilitate lever pressing relative to baseline, and suppress drinking relative to baseline, if, and only if, the baseline and schedule parameters form one particular relation. The essential relation is that the product $O_c(I_1 + I_2)$ is greater than the product $O_i(C_1 + C_2)$. The proof is seen by noting that only then will Equation 3 be positive (facilitation of Response *i*), and Equation 4 negative (suppression of Response *c*).

Each of the 10 subjects met the essential condition for testing these two predictions. That is, in Phase A as well as Phase B of training, and in the pre- as well as the post-contingency baseline phase, it was true of every subject that $O_c(I_1 + I_2)$ was greater than $O_i(C_1 + C_2)$. This condition was not accidental. The schedule parameters were deliberately selected so as to guarantee that the condition would be met, given some prior knowledge of how much lever pressing and how much drinking would be likely to occur in the baseline session. As the model predicts under this condition, every subject spent more time lever pressing and less time drinking per session in both phases of contingency training than in

either baseline phase. Volumetric intake was also lower in both Phase A and Phase B than in either baseline phase, with one exception out of 40 possible comparisons. The exception came from Subject R-9, whose intake was slightly higher in Phase A than in pre-contingency baseline. The data for individual subjects are presented in Table 3.

Inspection of individual records showed that drinking was stable throughout Phase B, with no discernible trend toward recovering previous deficits. This impression was confirmed by Friedman tests applied to water intake, time spent drinking, and time spent lever pressing. None of these measures showed a significant change over the 10 sessions of Phase B (all p 's > 0.05).

The suppression of drinking evident in Table 3 cannot be explained as an artifactual ceiling effect on the hypothesis that the lever-pressing requirement was too high, and the 1-hr contingency session too short, for the subject to do the amount of drinking done in the 1-hr baseline session. This possibility was evaluated by calculating for each subject in Phase A and Phase B how much total responding, lever pressing plus drinking, the subject would have to do in performing the amount of drinking done in precontingency baseline. This calculated requirement ranged from 1590 sec to 2872 sec (mean = 2263 sec)—far below the ceiling imposed by the 3600-sec contingency session. Other calculations showed that each subject had ample time to perform the amount of drinking done in postcontingency baseline, the calculated requirement ranging from 1516 sec to 2956 sec (mean = 2226 sec). The calculation does not include the minimum time the subject would have to spend in transit between lever and spout, but an extravagant estimate of minimum time in transit would be 400 sec. If this is added to the calculated requirement, the total is still far below the 3600-sec ceiling.

These results make it clear that the lever pressing done in the contingency session cannot be viewed as a means of performing the baseline amount of drinking. However, the results are entirely consonant with the supposition that the subject conserves, between baseline and contingency sessions, the total amount of a dimension apportioned to lever pressing and drinking, each of which entails a positive amount of the dimension.

Table 3
Time Spent Lever Pressing and Drinking (sec), and Volumetric Intake (ml)

Subject	Contingency Phase A									
	Precontingency Baseline			Lever			Drink			
	Lever	Drink	Intake	Component			Component			
				1	2	Total	1	2	Total	Intake
R-1	14.0	1218.0	26	370.1	365.8	735.9	398.7	392.9	791.6	15
R-2	4.1	1067.6	24	456.4	455.1	911.5	491.8	493.8	985.6	20
R-3	0.0	1338.4	24	318.2	312.5	630.7	330.2	327.9	658.1	18
R-4	14.4	988.0	22	237.1	230.2	467.3	252.2	246.1	498.3	19
R-5	1.4	883.1	22	323.8	319.8	643.6	335.2	337.0	672.2	14
R-6	10.4	1077.5	22	340.0	335.2	675.2	356.6	350.4	707.0	18
R-7	2.2	1033.7	22	341.4	334.9	676.3	358.7	354.6	713.3	18
R-8	3.4	1276.5	27	329.8	310.2	640.0	334.2	330.4	664.6	16
R-9	28.4	1273.6	18	300.1	290.2	590.3	321.2	313.0	634.2	20
R-10	4.2	1210.9	28	360.3	355.0	715.3	372.6	372.2	744.8	20
Mean	8.2	1136.7	24	337.7	330.9	686.6	355.1	355.1	707.0	18

Subject	Contingency Phase B									
	Lever			Drink			Postcontingency Baseline			
	Component			Component			Lever	Drink	Intake	
	1	2	Total	1	2	Total				
R-1	353.1	417.5	770.6	379.8	305.6	685.4	19	74.1	1037.8	26
R-2	545.0	650.4	1195.4	586.9	476.4	1063.3	14	7.5	1217.8	30
R-3	315.1	250.4	565.5	329.9	391.2	721.1	20	30.6	1075.0	28
R-4	242.6	188.8	431.4	255.3	295.3	550.6	19	73.9	853.6	24
R-5	312.0	311.0	623.0	327.1	478.4	805.5	17	70.2	963.5	26
R-6	433.6	429.7	863.3	452.7	237.1	689.8	17	67.1	1266.7	28
R-7	359.8	178.9	538.7	375.9	374.8	750.7	20	14.4	1016.6	24
R-8	264.1	389.8	653.9	290.7	277.4	568.1	15	14.5	1371.5	29
R-9	284.4	421.6	706.0	302.1	438.2	740.3	16	45.0	930.0	25
R-10	474.2	234.7	708.9	493.4	258.4	751.8	20	14.7	1419.1	37
Mean	358.4	347.3	705.7	379.4	353.3	732.7	18	41.2	1115.2	28

Responding in Phase B

After deriving an equation for k from the model, an estimate of k was calculated for each subject, using the subject's data from Phase A of contingency training and precontingency baseline. The estimate of k , in conjunction with other equations derived from the model, was then used to predict the subject's performance in Phase B.

Solving Equation 1 for k ,

$$k = \frac{O_c - N(C_1 + C_2)}{N(I_1 + I_2) - O_i} \quad (5)$$

In the present context, O_c refers to the total time spent drinking, and O_i to the total time spent lever pressing in the paired baseline session. The two remaining terms on the right side of Equation 5 refer to performance during the Phase A contingency session. Specifically, $N(C_1 + C_2)$ refers to the total time spent

drinking in the two components combined, and $N(I_1 + I_2)$ refers to the total time spent lever pressing in the two components combined. For example, Table 3 provides an estimate for Subject R-10 of $k = [(1210.9 - 744.8)/(715.3 - 4.2)] = 0.655$.

Predictive equations for performance in Phase B were obtained by multiplying Equation 2 by I_1 , C_1 , I_2 , or C_2 . For Component 1, the model predicts that the amount of lever pressing will be approximately

$$NI_1 = \frac{I_1(kO_i + O_c)}{kI_1 + C_1 + kI_2 + C_2} = \frac{kO_i + O_c}{k + [(C_1 + kI_2 + C_2)/I_1]} \quad (6)$$

and that the amount of drinking will be approximately

$$NC_1 = \frac{C_1(kO_i + O_c)}{kI_1 + C_1 + kI_2 + C_2} = \frac{kO_i + O_c}{1 + [(kI_1 + kI_2 + C_2)/C_1]} \quad (7)$$

Turning to Component 2, the amount of lever pressing will be approximately

$$NI_s = \frac{I_s(kO_i + O_c)}{kI_i + C_i + kI_s + C_s} \\ = \frac{kO_i + O_c}{k + [(kI_i + C_i + C_s)/I_s]}, \quad (8)$$

and the amount of drinking will be approximately

$$NC_s = \frac{C_s(kO_i + O_c)}{kI_i + C_i + kI_s + C_s} \\ = \frac{kO_i + O_c}{1 + [(kI_i + C_i + kI_s)/C_s]}. \quad (9)$$

Figure 1 shows good agreement between values predicted by Equations 6 through 9, and

values obtained for lever pressing and drinking in each component. The four broken lines are least-squares regression lines, and are close to the theoretical functions shown as continuous lines. The four product moment correlations between predicted and obtained values were high, ranging from 0.95 to 0.97.

For seven of the 10 subjects, the estimate of k was less than 1. The range was 0.090 to 1.138, and the mean was 0.696 ± 0.220 (5% confidence limits). In terms of the model, this means that 1 sec of lever pressing entailed significantly less of the dimension conserved than did 1 sec of drinking. This is the result that might be expected if the dimension hap-

Fig. 1. Time spent lever pressing and drinking in Components 1 and 2, Phase B. Each point represents one subject. Predicted values appear on the abscissa, obtained values on the ordinate. The broken lines are least-squares regression lines, and the continuous lines are theoretical functions. The product moment correlation between predicted and obtained values appears in the upper-left corner of each panel.

pened to be correlated with skeletal activity. In the present experiment, the rat could not score 10 sec of drinking without performing some 50 discrete licks, but could score the same amount of lever pressing by pressing just once, and holding for 10 sec. Frequency data from Phase A showed that every subject did perform more licks per second of drinking than lever presses per second of lever "pressing". The number of discrete licks per second ranged from 5.4 to 6.7 (mean = 6.1), and the number of discrete lever presses per second ranged from 0.6 to 2.9 (mean = 1.3).

Phase B versus Phase A

Contrast and induction effects were analyzed by means of the ratio $B/(A + B)$, where B signifies the amount of responding in Phase B, and A signifies the amount of responding in Phase A. A ratio greater than 0.5 indicates more responding in Phase B, and a ratio less than 0.5 indicates less responding in Phase B than in Phase A. Positive contrast would be indicated if the ratio were greater than 0.5 in the unchanged Component 1, and less than 0.5 in the changed Component 2. Negative contrast would be indicated if the ratio were less than 0.5 in Component 1, and greater than 0.5 in Component 2. Positive induction would be indicated if both were greater than 0.5, and negative induction if both were less than 0.5.

Two sets of four ratios were calculated for each subject. One set consisted of the ratios obtained for lever pressing in Components 1 and 2, and for drinking in Components 1 and 2. The other set consisted of the corresponding ratios predicted by the model. It was based on the predicted values for Phase B shown in Figure 1, and the values obtained in Phase A.

The ratios of individual subjects are shown in Figure 2. Predicted and obtained ratios were generally close, with a mean absolute difference of only 0.016.

The 10 cross hairs in Figure 2 demarcate the qualitative categories known as contrast and induction effects. Subjects R-1 and R-4 were the only ones that showed any appreciable deviation from their predicted categories. Even they conformed closely to the quantitative model, as their mean absolute difference from the ratios predicted was only 0.011.

Figure 2 shows that Equation 1 provides an economical, accurate account of the quantitative details of results obtained for individual subjects. Nevertheless, it would not be wholly idle to discuss the individual patterns in terms of qualitative contrast and induction effects. A few selected cases will illustrate the

Fig. 2. Time spent lever pressing and drinking in Phase B, relative to Phase A plus Phase B, by individual subjects. Predicted ratios appear on the abscissa, obtained ratios on the ordinate. Diagonal lines are theoretical functions. Circles signify lever pressing, triangles drinking. Closed points signify Component 1, open points Component 2. The values of I_1 , C_2 used in Phase B are shown directly below each subject's identification number.

otherwise bewildering variety of ways in which these effects can occur.

Because the dependent variable N will increase, Equation 1 predicts that lever pressing and drinking in the unchanged Component 1 will increase if the quantity $(kI_2 + C_2)$ is decreased. This can be done by decreasing I_2 or C_2 alone, by decreasing both, or even by changing them in opposite directions. To classify the predicted effect on Component 1 responding as contrast or induction, it is necessary to determine what the model predicts for responding in Component 2. The predictive equation for lever pressing in Component 2 is Equation 8, and the corresponding equation for drinking is Equation 9. Equations 8 and 9 predict that if I_2 alone is decreased, then lever pressing in Component 2 will decrease (positive contrast), and drinking in Component 2 will increase (positive induction). These expected effects—positive contrast with respect to lever pressing, and positive induction with respect to drinking—are illustrated by Subject R-7 (see Figure 2). What should happen if I_2 and C_2 are decreased proportionally, so that the ratio C_2/I_2 is held constant between Phase A and Phase B? Equation 8 implies again that lever pressing in Component 2 will decrease (positive contrast), but Equation 9 implies that drinking in Component 2 will also decrease (positive contrast). The expected effects, positive contrast with respect to both responses, are illustrated by Subject R-10.

Because the dependent variable N will decrease, Equation 1 predicts that responding in the unchanged Component 1 will decrease if $(kI_2 + C_2)$ is increased. Equations 8 and 9 show that if I_2 alone is increased, lever pressing in Component 2 should increase (negative contrast), but drinking in Component 2 should decrease (negative induction). The expected effects are illustrated by Subject R-8.

In several other cases, one particular qualitative effect was produced by a variety of changes in Component 2. With respect to lever pressing, these included the positive induction effects obtained by decreasing C_2 alone (Subject R-6) and by changing I_2 and C_2 in opposite directions (Subject R-2), the negative induction effects obtained by increasing C_2 alone (Subject R-5) and by changing I_2 and C_2 in opposite directions (Subject R-3), and the negative contrast effect obtained by increasing I_2 and C_2 proportionally (Subject R-9). With re-

spect to drinking, positive contrast was obtained by decreasing C_2 alone (Subject R-6) and by changing I_2 and C_2 in opposite directions (Subject R-2), and negative contrast was obtained by increasing C_2 alone (Subject R-5) and by increasing I_2 and C_2 proportionally (Subject R-9).

It has already been shown that the lever pressing done in the contingency session cannot be viewed as a means of performing the baseline amount of drinking. The induction effects obtained for Subjects R-7 and R-8 show further that the lever pressing done on the Phase B schedule cannot be viewed as a means of performing the amount of drinking done on the Phase A schedule. Relative to Phase A, Subject R-7 showed an increased amount of drinking in both components, and Subject R-8 showed a decreased amount of drinking in both components. Each of these effects would contradict a model that holds that the subject conserves the total amount of drinking. Each is consistent with a model that assumes that the subject conserves the total amount of a dimension apportioned to lever pressing and drinking, each entailing a positive amount of the dimension.

Lever Pressing in Postcontingency Baseline

Each contingency session started with the same sequence of recorded events—about 10 sec of lever pressing, followed by about 10 sec of drinking. Given 17 to 29 contingency sessions, each starting the same way, it might be expected that the subject would learn to begin the session with several seconds of lever pressing, and that this tendency would carry over into at least the first postcontingency baseline session. This hypothesis would explain why every subject did more lever pressing in postcontingency baseline than in precontingency baseline (see Table 2).

Some incidental observations recorded in postcontingency baseline sessions suggest that this explanation is not adequate. For example, in the first postcontingency baseline session, Subject R-9 performed 47.5 sec of lever pressing, but the first lever press did not occur until about 15 min into the session, at which time the subject had already performed over 3000 licks. The second session contained 47.0 sec of lever pressing. The first lever press occurred about 9 min into the session, after more than 2000 licks, and the second occurred about

19 min later, after about 3000 more licks. This pattern was typical of the two remaining sessions, and of the other four subjects for which these incidental observations were recorded.

More formal observations in discrete-trials experiments have also shown that behavioral sequences enforced during contingency training may not transfer to the paired baseline condition (Allison and Timberlake, 1975). No alternative explanation is attempted now, mainly because the results show clearly that to obtain an adequate account of the total amount of responding in baseline sessions following contingency training, it will be necessary to pay considerably more attention than is normally paid to the sequential characteristics of the behavior.

DISCUSSION

Strict usage would limit the present analysis to schedules defined in terms of measured responses, such as lever pressing (Response *i*) and drinking (Response *c*). This would put nearly all of the archival literature out of reach, because schedules have generally been defined in terms of a measured instrumental Response *i*, and a measured contingent environmental event. A common example is the simple fixed-ratio schedule defined in terms of the delivery of a certain amount of food, as opposed to the occurrence of a certain amount of eating, following a fixed amount of lever pressing.

Even so, there are several such cases in which it is safe to apply the analysis. For example, it is reasonable to assume in the case of a hungry rat pressing a lever that the delivery of a food pellet will soon be followed by eating, and that the amount of eating is directly related to the weight of the pellet. It is then reasonable to identify Response *c* as eating, even though eating may not be measured directly, and to identify the schedule parameter *C* with the weight of the food pellet. Further tests of conservation theory can be found in several experiments of this kind. To evaluate the evidence, it is necessary to examine some functional relations derived from the model for this type of schedule.

Since the simple fixed-ratio schedule has only one component, the schedule parameters need not be subscripted. The conservation

model for this type of schedule can therefore be expressed as

$$N(kI + C) = kO_i + O_c, \quad (10)$$

from which the dependent variable *N* will be

$$N = \frac{kO_i + O_c}{kI + C}. \quad (11)$$

Then the model predicts that the total amount of Response *i* in the contingency session will be approximately

$$\begin{aligned} NI &= \frac{I(kO_i + O_c)}{kI + C} \\ &= \frac{kO_i + O_c}{k + (C/I)}, \end{aligned} \quad (12)$$

and the total amount of Response *c* will be approximately

$$\begin{aligned} NC &= \frac{C(kO_i + O_c)}{kI + C} \\ &= \frac{kO_i + O_c}{1 + (kI/C)}. \end{aligned} \quad (13)$$

Given that *k* is greater than zero, Equations 12 and 13 predict that if either schedule parameter is increased, the total amount of the corresponding response will increase, and the total amount of the other response will decrease. In terms of the model, as *I* increases, *NI* will increase, and *NC* will decrease. As *C* increases, *NC* will increase, and *NI* will decrease.

Support for the two implications concerning *I* can be found in a wide variety of experiments in which Response *i* was pressing a lever or a button, and Response *c* was eating or drinking. As the fixed-ratio requirement *I* is increased up to some large, limiting value, the typical result is a monotonic increase in the total amount of lever or button pressing, accompanied by a monotonic decrease in the total amount of eating or drinking. These two relations have been demonstrated with rats pressing a lever for food in 12-hr sessions (Teitelbaum, 1957), 24-hr sessions (Collier, Hirsch, and Hamlin, 1972), and 30-min sessions (Barofsky and Hurwitz, 1968), with monkeys pressing a lever for food in 1-hr sessions (Hamilton and Brobeck, 1964), with a monkey pressing a button for food or water in 24-hr sessions (Findley, 1959), and with goldfish pressing a lever for food in 1-hr sessions (Rozin and Mayer, 1964).

These two relations clearly contradict the supposition that in increasing the total amount of lever or button pressing, the subject thereby maintains a constant level of food or water intake. It should be mentioned that the latter relation has been reported on occasion (Hirsch and Collier, 1974). For all practical purposes it too is consistent with the conservation model, indicating that k is extremely small in such cases. Equations 12 and 13 show that as k approaches zero, NI will remain highly sensitive to variations in I , but NC will approach complete insensitivity to variations in I . More generally, as k approaches zero the total amount of Response c will approach the baseline amount, O_c , independently of the schedule parameters I and C . If the dimension were energy expenditure, k might be made to approach zero by lightening the lever, by making the fluid in the spout more viscous (Wilcove and Allison, 1972), or the aperture of the spout more narrow.

Equations 12 and 13 predict further that as C increases, NI will decrease, and NC will increase. The relevant experiments include one reported by Klajner (1975), in which rats performed $I = 40$ licks of 0.16% saccharin solution for $C = 4, 8$, or 12 quarter-turns of a running wheel. As C increased across schedules, the total amount of licking decreased significantly and the total amount of running increased significantly as predicted by Equations 12 and 13. Rozin and Mayer (1961) reported similar results, but not quite so uniform, among goldfish pressing a lever on FR 1 for food pellets weighing 0.020 or 0.045 g. As the weight of the food pellet increased, each of the five fish showed a decrease in the total amount of lever pressing, and three showed an increase in the total amount of eating, measured in terms of the total grams of food delivered.

Premack, Schaeffer, and Hundt (1964), studying drinking as Response i and running in an activity wheel as Response c , varied I in one experiment, and C in a second experiment. Fixed-ratio schedules freed the locked wheel for a certain amount of time, C sec, each time the rat performed I licks. One experiment varied I from five licks to 300 licks, holding C constant at 20 sec among schedules. In the second experiment, I was held constant at 10 licks, and C varied from 2 sec to 20 sec among schedules. The results confirmed all four im-

plications of Equations 12 and 13 with respect to the two schedule parameters. An increase in I was accompanied by an increase in the total amount of licking, and a decrease in the total amount of running. The opposite pattern was produced by an increase in C —a decrease in total licking, and an increase in total running.

Another kind of experimental test can be appreciated by examining the model in terms of facilitation and suppression. From Equation 12, the appropriate expression for Response i is

$$\begin{aligned} NI - O_i &= \frac{I(kO_i + O_c)}{kI + C} - O_i \\ &= \frac{IO_c - CO_i}{kI + C}. \end{aligned} \quad (14)$$

From Equation 13, the appropriate expression for Response c is

$$\begin{aligned} NC - O_c &= \frac{C(kO_i + O_c)}{kI + C} - O_c \\ &= \frac{k(CO_i - IO_c)}{kI + C}. \end{aligned} \quad (15)$$

Assuming that k is greater than zero, Equations 14 and 15 imply that the contingency will facilitate Response i , and suppress Response c , if, and only if, IO_c is greater than CO_i . The proof is that only then will Equation 14 be positive (facilitation of Response i), and Equation 15 negative (suppression of Response c).

Several experiments have shown that if this condition is satisfied, then the contingency facilitates Response i and suppresses Response c , as the model predicts (Allison and Timberlake, 1974, Experiment 4; Bernstein, 1973; Premack, 1971, 1972).²

²If k were negative, Equations 14 and 15 would predict either facilitation of both responses, or suppression of both, depending on the exact values of k , I , and C . Specifically, the schedule should facilitate both responses if the quantity $(kI + C)$ is positive, and suppress both if $(kI + C)$ is negative. Granted either of these outcomes, the experimenter should then be able to produce the other outcome by manipulating the schedule parameters. No results indicative of a negative k are known to this author, but it is not difficult to imagine circumstances that might give such results. If the dimension conserved were mouth-dryness, eating dry food (Response i) would entail an increase in the dimension, and drinking water (Response c) a decrease, so k would be negative. Either of the predicted outcomes would offer a sharp challenge to recent formulations, which seem to imply that it is impossible for one and the same schedule to facilitate both responses or suppress both (Premack, 1971; Timberlake and Allison, 1974).

The model implies further that the contingency will not facilitate or suppress either response if $IO_c = CO_i$. Evidence bearing on this point is sparse, but appears to support the model (Premack, 1965, p. 171).

Related Formulations: Probability-Differential and Response Deprivation

A recent theory implies that if Response c is more probable than Response i under paired baseline conditions, than a contingency between the two responses will facilitate Response i relative to O_i , and suppress Response c relative to O_c (Premack, 1971). To select one of many that might be cited, an experiment by Premack (1972) clearly supported this probability-differential hypothesis. Running (Response c) was more probable than drinking (Response i) in the baseline condition. The contingency schedules facilitated drinking relative to O_i , and suppressed running relative to O_c . These results are also predicted by the conservation model—not because running was more probable than drinking in baseline, but because IO_c was greater than CO_i (see Equations 14 and 15).

There are several experiments in the literature for which the probability-differential hypothesis and the conservation model make opposing predictions. In some of these experiments, the probability-differential hypothesis would predict no facilitation of Response i , because it is more probable than Response c , but the conservation model would predict facilitation, because IO_c is greater than CO_i (see Equation 14). Another distinguishing case is that in which the probability-differential hypothesis would predict facilitation of Response i , because Response c is the more probable response, but the conservation model would not, because $IO_c = CO_i$ (see Equation 14). Recent reviews of such experiments (Allison and Timberlake, 1973, 1974; Timberlake and Allison, 1974) indicate that the results favor the conservation model. Moreover, it is not clear how the probability-differential formulation would deal with functional relations involving I and C , or with the pattern of contrast and induction effects observed in the present experiment.

A contingency is said to deprive the subject of Response c if performance of Response i at the baseline level, O_i , implies that the sub-

ject will also perform Response c below the baseline O_c (Timberlake and Allison, 1974). In other words, a contingency deprives the subject of Response c if the relation $NI = O_i$ implies the relation $NC < O_c$. It has been hypothesized recently that a contingency will facilitate Response i if, and only if, the contingency deprives the subject of Response c (Timberlake and Allison, 1974). Since a contingency deprives the subject of Response c if, and only if, IO_c is greater than CO_i (Timberlake and Allison, 1974), the response deprivation hypothesis and the conservation model attribute the facilitation of Response i to one and the same condition (see Equation 14).

One major difference is that the response deprivation formulation has no implications for response suppression. Unlike the conservation model, it does not predict the consistent finding that a contingency suppresses Response c when IO_c is greater than CO_i (see Equation 15). Given that condition, the response deprivation formulation merely predicts that the contingency will not facilitate Response c . Suppression of Response c is therefore consistent with the response deprivation formulation, but is not predicted by that formulation.

Both formulations imply that when IO_c is greater than CO_i , the amount of facilitation shown by Response i will increase as I or O_c increases, and decreases as C or O_i increases. One difference in favor of the conservation model is that all of these relations can be derived from the model (see Equation 14), but have only the status of a working hypothesis in the response deprivation formulation (Timberlake and Allison, 1974, p. 156).

Another difference favoring the conservation model is that the response deprivation formulation makes only ordinal predictions of the amount of Response i that will be produced by various schedules. Another is that the response deprivation formulation offers no interpretation of the fact that variations in I or C that increase the total amount of Response i may also decrease the total amount of Response c . Finally, it is not clear how the response deprivation formulation would deal with contrast and induction effects. At present, its one notable advantage is that it has been generalized to a paradigm often used in discrete trials experiments (Allison and Timberlake, 1975), and conservation theory has not.

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