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Rat toys, reinforcers, and response strength: An examination of the R_e parameter in Herrnstein's equation

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Abstract

The response-strength equation is a mathematical model used to explain responding on variable-interval (VI) schedules. This equation has two fitted parameters, k and R_e. Empirical research suggests that k is a measure of motor performance and R_e is a measure of background sources of reinforcement relative to the arranged reinforcer. This experiment examined the interpretation of the R_e parameter by augmenting the background reinforcement with a qualitatively different source of background reinforcement. Rats were food deprived and received sucrose solution for lever responding. Each experimental session consisted of a series of seven VI schedules, providing reinforcement rates that varied between 20 to 1200 h^{-1}. Occasionally, cardboard tubes were introduced into the experimental chambers in order to provide the rats with another source of reinforcement distinct from the lever-response specific sucrose reinforcer. The k parameter did not change systematically as a result of the experimental manipulations, but R_e was significantly larger when tubes were introduced into the chambers. These results are consistent with the interpretation that k and R_e measure two independent and experimentally distinguishable parameters and that R_e is a measure of reinforcement of background sources to the arranged reinforcer. © 1997 Elsevier Science B.V.

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In studies with two, concurrently available, reinforcement sources, relative response rates approximate relative reinforcement rates (Herrnstein, 1970; Williams, 1988). The data are approximated by the equation:

$$B_1/(B_1 + B_2) = R_1/(R_1 + R_2), \quad (1)$$

where B_i and R_i are response and reinforcement rates, respectively, at alternative i. In studies in which the experimenter arranges only one reinforcement source, absolute response rate is a negatively

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accelerated function of reinforcement rate. These data are best approximated by the hyperbolic equation

$$B = k\mathrm{R}/(R + R_e), \tag{2}$$

where B is response rate, R is reinforcement rate, and k and R_e are fitted parameters (de Villiers and Herrnstein, 1976).

A wide body of empirical and theoretical evidence supports the interpretation that k is a measure of asymptotic responding or motor performance. This parameter has been altered and R_e unaffected when weights are added to the levers (Bradshaw et al., 1983a; Bradshaw et al., 1983b; Hamilton et al., 1985; Heyman and Monaghan, 1987) and when response requirement changes from a lever to a treadle press (McSweeney, 1978).

According to the theory (Herrnstein, 1970; Herrnstein, 1974) that relative response rate (Eq. (1)) and absolute response rate (Eq. (2)) are both functions of relative reinforcement rate, R_e has two definitions. First, by virtue of the structure of Eq. (2), R_e is equal to the rate of reinforcement that maintains half maximal response rate. For example, if response rate B is set equal to $k/2$, then reinforcement rate R must equal R_e. A treatment that alters R_e would thus change the rate of reinforcement necessary for maintaining half-asymptotic responding. This definition of R_e has been the subject of much investigation (e.g., Bradshaw et al., 1981; Bradshaw et al., 1978; Bradshaw et al., 1983a; Bradshaw et al., 1983b; Hamilton et al., 1985; Heyman and Monaghan, 1987; Heyman and Monaghan, 1994; Petry and Heyman, 1994; Porter and Villanueva, 1989). For example, increases in deprivation (Bradshaw et al., 1983a; Bradshaw et al., 1983b; Heyman and Monaghan, 1987) and reinforcer magnitude or concentration (Bradshaw et al., 1981; Bradshaw et al., 1978; Heyman and Monaghan, 1994), changes in type of reinforcer (Petry and Heyman, 1994), and low doses of amphetamine (Heyman and Monaghan, 1987) have all decreased R_e.

Herrnstein (1970) derivation of this equation adds a second concept to the interpretation of R_e. Herrnstein proposed that R_e is a measure of inferred, background reinforcement as compared to the experimenter-arranged reinforcer (see also Hinson and Staddon, 1978). The R_e parameter may represent sources of reinforcement other than those arranged by the experimenter, such as those that accrue from resting or exploring the chamber. Thus, responding in a single lever schedule is also a choice between responding and not responding. The k parameter may represent the sum of $B_1 + B_2$, such that both represent asymptotic rates of responding. Given these conditions, Eqs. (1) and (2) are simply rearrangements of one another.

This interpretation that R_e reflects the rate of background, uncontrolled sources of reinforcement in relation to the experimentally arranged reinforcer has not received much attention. In three experiments (Belke and Heyman, 1994; Bradshaw, 1977; White et al., 1986), researchers introduced a second schedule of reinforcement to assess if the additional reinforcement rate increased the R_e parameter. Thus, a single alternative procedure was transformed into a concurrent schedule procedure. In each study the addition of a second source of reinforcement increased R_e. However, the increase in R_e was not of the predicted magnitude in two of these studies (Bradshaw, 1977; White et al., 1986). In both these studies, rats were exposed to a single VI schedule or pair of concurrent VI schedules each session. Following stabilization on a schedule, the subjects were moved to another schedule. Estimates of k and R_e were not made until rats had progressed through the series of VI schedules. In contrast, the study by Belke and Heyman (1994) employed a within-session procedure in which rats experienced an entire series of VI schedules within a single session. This within-session procedure has produced reliable results in studies of environmental (Bradshaw et al., 1978; Bradshaw et al., 1983a; Bradshaw et al., 1983b; Heyman and Monaghan, 1987; Petry and Heyman, 1994) and pharmacological manipulations (Hamilton et al., 1985; Heyman, 1983; Heyman, 1992; Heyman et al., 1986). Furthermore, several studies show that parameter estimates are independent of the order of VI schedules using the within-session procedure (e.g., Heyman et al., 1986; McSweeney et al., 1995). One major advantage of this within-session procedure is that experiments can be conducted more quickly. Using this within-session procedure, Belke and Heyman (1994) found that changes in R_e were both qualitatively and quantitatively consistent with the interpretation of R_e as an estimate of the background sources of reinforcement.

Only one known study (Dougan and McSweeney, 1985) has examined the addition of a quantitatively different source of background reinforcement on parameter estimates. Three groups of pigeons were food deprived, and keypecking was reinforced by food. Free access to water was introduced into the experimental apparatus for two of these groups, one of which was water deprived as well as food deprived. The third group had no water added to the background sources of reinforcement. As predicted by Herrnstein's interpretation of the parameter, R_e was highest in the water-deprived group, and lowest in the group which received no water in the experimental apparatus. However, Eq. (2) accounted for as little as 4.1% and up to 91.2% of the variance in the individual data. The low amount of variance accounted for may be related to the practice of providing only single VI schedules in each session and allowing for a relatively small range of programmed reinforcers across the different VI schedules (between 2 and 50).

The experiment described in this report, similarly to that of Dougan and McSweeney (1985), tested the idea that R_e measures background sources of reinforcement. However, this study differs in that a within-session procedure was employed, a different source of background reinforcement was examined, and a larger range of reinforcement schedules were included. Essentially two conditions were compared. In one, lever presses were reinforced with sucrose according to a series of within-session VI schedules. In the second, the same series of sucrose-rewarded VI schedules were in effect, but a cardboard paper tube ('rat toy') was added to the setting such that the background source of reinforcers would increase. The rats typically handled and chewed the tube, thereby dividing their time between the lever and the tube. According to Herrnstein's derivation of Eq. (2), the tube should increase R_e since the reinforcement from the background setting should be enhanced. The predictions for k are not explicit. The simplest interpretation is that k should not be systematically affected, but it is possible that the act of inserting the toy may disrupt the subjects and indirectly alter k. This experiment, therefore, enriched the experimental context. The additional stimuli were qualitatively different from the experimenter-controlled reinforcement source, and accordingly, the additional activity was qualitatively different from the experimenter-arranged activity.

1. Methods

1.1. Subjects

Seven, male Wistar rats from Charles Rivers Breeders (Wilmington, MA) served as subjects. At the start of the experiment, they were approximately a year old and weighed between 265 and 310 g.

They had all been subjects in previous experiments; three rats (42, 43, and 46) were subjects in a study of quantitatively different reinforcers (Petry and Heyman, 1994), and the other four (41, 44, 45, and 47) were used in a study of extraneous and signaled reinforcement (Belke and Heyman, 1994). Water was freely available at all times in the home cage. During experimental sessions, they had access to an 11.5% sucrose solution as a reinforcer, and after each session they were fed Purina rat chow in amounts calculated to maintain them at 85% of their weight, about 8 to 12 g per day. The rats were housed individually in a colony room illuminated 12 h a day. Animals were typically run seven days per week at approximately the same time each day.

1.2. Apparatus

The experiments were conducted in 7 standard, top loading rat chambers (22.0 × 28.5 × 20.5 cm, Med Associates). Both the rats and the tubes were placed into the chambers by lifting a lid situated on the top of each chamber. Each chamber was equipped with two 4.5 cm wide levers located 7.0 cm from the floor and 4.5 cm from the right and left walls. Presses requiring approximately 0.2 N on the right lever were reinforced according to variable-interval schedules. Presses on the left lever had no experimentally arranged consequences. Midway between the two levers on the front panel was an opening at floor level that allowed access to a 0.1 ml dipper of solution. The dipper rested in a trough and was raised when the rat had fulfilled the schedule requirement. Above the right lever was a stimulus light (28 V, 0.04 A), that signaled periods during which lever presses could be reinforced. Relays interfaced to an IBM PC clone were used to record responses and control stimulus lights and dipper. MED-PC software (Med Associates) was used to program experimental events and collect data (Tatham and Zurn, 1989).

1.3. Procedure

The procedure was similar to ones used in previous studies (e.g., Belke and Heyman, 1994; Hamilton et al., 1985; Heyman, 1983, Heyman, 1992; Petry and Heyman, 1994). Daily sessions consisted of a series of seven different variable-interval (VI) reinforcement schedules. The list of intervals that comprised each VI schedule approximated a Poisson distribution (Fleshler and Hoffman, 1962) so that the conditional probability of reinforcement was constant. Each schedule was constructed by multiplying a list of interval values with a mean of 3 s by a multiplier. The mean programmed inter-reinforcement intervals were: 108, 75, 48, 27, 5, 6, and 3 s, which correspond to reinforcement rates of 33, 48, 75, 133, 240, 600, and 1200 h^{-1}. These schedules were chosen because they provided a wide range of VI schedules and have resulted in stable estimates of k and R_e parameters in past experiments (e.g., Petry and Heyman, 1994). The schedules were run in an ascending-descending order: VI 108, 48, 15, 3, 6, 27, 75. A fixed order of VI components presentation was used so that habituation effects to the toy could be assessed. A stimulus light above the lever signaled when a schedule was in effect, and each component was separated by a 7.5 s blackout period, with no lights on.

Each VI schedule component began with an initial period of brief exposure to the schedule in effect during that component. The durations of initial periods of exposure were 108, 60, 35, 12, 30, 50, and 80 s. These initial exposure periods were excluded to minimize effects of behavioral contrast resulting from differing VI schedules of reinforcement (e.g., Heyman, 1983; Heyman, 1992). Immediately following each initial period, a terminal period commenced. Reinforcers, time, and responses were collected during this terminal period and used in determination of response and reinforcement rates. Terminal period component durations were 980, 540, 305, 160, 208, 410, and 736 s. Durations of components and initial periods were monotonically related to reinforcement rates (e.g., Belke and Heyman, 1994; Heyman, 1983; Heyman, 1992; Petry and Heyman, 1994).

Different component times were employed to ensure that each component provided a minimum of eight reinforcers per component. When each period is fixed, for example, at five minutes, expected number of reinforcers per session in the leanest component would have been less than three, while expected number of reinforcers in the richest component would have been about 40. The component lengths used in this study allowed approximately 8 reinforcers in the leanest component and about 20 in the richest.

Twenty sessions of stable baseline performance were conducted prior to commencing with experimental conditions. Stable performance was defined by less than 15% variability in responding in any of the seven VI components and no increasing or decreasing trends in k or R_e estimates for three consecutive sessions. In the experimental conditions, cardboard tubes were introduced into the chambers during the 7.5 s time out periods preceding a new VI schedule. Rather than only introducing the toys at the beginning of the sessions, tubes were introduced immediately prior to different VI schedules. In this manner, estimations of k and R_e could be determined independently using different numbers of VI components in the analysis. Habituation effects to the toys could be quantified by providing the toy during these different components. In other words, we can examine whether the toys only suppressed responding in the first, leanest component or the first ten minutes of the session or whether the toy decreased responding throughout the entire session.

The VI components prior to which tubes were introduced were chosen so that the toys remained in the chambers for at least five VI components. Five VI components are sufficient to provide k and R_e parameter estimations. Thus, tubes were introduced immediately prior to 108-, 48-, and 15-s VI components and, once introduced, remained in the chambers for the duration of the session. For example, when the tubes were presented just prior to the VI 15-s component, response rate data could be obtained from the VI 15-, 3-, 6-, 27-, and 75-s intervals and provide k and R_e estimations. These three different points of tube introduction will be considered the three experimental conditions.

Each rat was exposed three times to each of the three experimental conditions, for a total of nine experimental conditions. The conditions are referred to by how many VI components the toys were in the chambers. For example, when toys were introduced at the beginning of an experimental session, they remained in the chambers throughout seven VI components, and this condition was termed a 7-component toy session. When they were introduced just prior to the VI 48-s and VI 15-s schedules, they remained for six and five schedules and were termed 6-component and 5-component toy sessions, respectively.

The order of the conditions was randomized for each rat. Between each experimental session, at least three days of baseline data were collected. Baseline sessions were similar to experimental sessions, but no tubes were introduced into the chambers. In the baseline sessions similarly as in experimental sessions, the lids to the chambers were opened and closed during randomly-determined blackout periods signifying different VI components. However, no tubes were placed inside during the baseline sessions. Tubes were reintroduced following three baseline sessions when no systematic upward or downward trends in k and R_e were noted for three consecutive days. Mean number of baseline sessions between experimental conditions was 4, and range was 3 to 11.

Table 1
Mean response and reinforcement rates for individual subjects in baseline and toy conditions

Rat	Baseline (reinf/h)	(Resp/min)	7 component toy (reinf/h)	(Resp/min)	6 component toy (reinf/h)	(Resp/min)	5 component toy (reinf/h)	(Resp/min)
141	31.65	14.98	24.12	4.13				
	42.70	19.72	40.06	18.56	42.13	17.64	48.50	21.33
	73.33	43.73	70.92	16.17	48.40	11.64		
	132.16	50.56	134.81	56.68	98.85	26.33	97.80	25.57
	235.03	71.27	255.31	58.82	163.81	21.94	146.38	20.98
	585.42	92.25	565.70	92.77	608.35	90.63	538.29	69.39
	1136.27	106.68	1123.41	106.00	854.86	62.40	563.93	48.09
142	29.97	16.49	24.13	7.72				
	41.63	25.69	40.12	21.30	48.51	28.04	54.98	21.43
	76.61	52.52	70.92	26.40	46.42	19.19		
	127.74	66.48	129.99	65.85	114.95	48.25	119.87	49.44
	243.35	89.44	246.04	82.43	180.43	52.74	193.13	42.13
	579.02	105.41	588.55	120.62	459.33	88.54	554.66	112.24
	1109.09	112.25	1167.83	119.54	964.94	95.15	1282.39	118.43
143	29.15	14.47	25.83	9.39				
	49.60	31.10	52.87	30.10	50.95	23.61	50.95	20.71
	73.51	32.80	80.18	32.95	55.85	11.98		
	132.26	57.30	115.68	55.17	131.33	44.74	97.77	33.76
	247.99	64.55	262.78	68.55	213.75	31.89	182.43	30.45
	609.29	91.19	589.78	91.47	551.63	83.93	572.07	80.11
	1108.05	109.65	1110.77	113.37	1010.20	87.96	1002.36	89.55
144	28.71	12.33	25.75	4.89				
	47.75	21.59	46.37	13.46	46.36	20.72	46.39	15.44
	72.45	28.08	58.94	12.72	59.01	8.07		
	142.64	37.86	110.70	32.25	120.90	30.66	97.51	20.35
	251.11	59.17	196.55	27.30	149.75	17.04	197.30	26.49
	576.86	72.78	578.75	67.60	475.09	55.36	502.39	48.81
	1084.13	90.44	818.09	59.75	715.24	45.68	619.08	36.62
145	28.31	18.70	24.20	8.47				
	46.45	35.77	48.48	35.31	50.63	26.94	42.22	32.51
	73.40	44.38	77.17	28.32	61.76	17.31		
	137.72	71.74	124.72	79.10	120.56	60.46	115.79	61.57
	238.99	83.08	252.69	68.44	216.61	42.46	194.87	45.85
	606.62	117.28	569.62	122.99	595.82	117.92	535.12	107.10
	1210.80	124.76	1044.48	123.54	1149.04	116.42	1127.83	114.71
146	27.06	7.94	24.37	5.48				
	52.84	22.97	52.76	9.84	44.27	19.88	44.30	15.57
	75.65	39.53	64.87	12.08	83.59	27.41		
	130.66	44.51	106.36	34.85	115.48	31.43	129.97	38.17

Table 1 (continued)

Rat	Baseline (reinf/h)	(Resp/min)	7 component toy (reinf/h)	(Resp/min)	6 component toy (reinf/h)	(Resp/min)	5 component toy (reinf/h)	(Resp/min)
	244.88	71.97	229.48	48.74	215.80	61.61	230.90	57.39
	528.22	77.11	603.09	79.80	570.94	76.04	547.85	80.18
	1122.78	92.74	1012.55	95.59	1178.81	101.17	1124.99	93.44
147	29.56	22.39	20.98	4.51				
	51.25	36.07	29.25	14.99	44.37	9.20	39.99	8.64
	82.76	54.87	61.75	14.23	24.18	2.47		
	133.05	55.24	106.58	28.59	92.93	21.70	59.87	14.02
	261.99	91.96	201.28	32.20	64.70	2.75	34.35	0.99
	570.13	122.66	635.03	112.09	510.87	70.78	341.32	45.31
	1172.49	147.65	1252.86	115.50	649.99	43.85	199.61	10.26

1.4. Data analysis

To obtain estimates of k and R_e, Eq. (1) was fitted to response- and reinforcement-rate pairs using a weighted least-squares method developed by Wilkinson (1961). This technique provides standard errors for the parameter estimates. Actual reinforcers obtained, as opposed to reinforcers programmed, were used in these analyses.

Final k and R_e values for baseline sessions were based on average response and reinforcement rates for each session preceding a toy session — nine sessions for each rat. Two additional estimates of baseline k and R_e were also made. In one, the VI 108 component was eliminated from analysis and the remaining six VI components were used to estimate parameters. In the other, both VI 108 and VI 48-s components were excluded so that five components were used in the analysis. The rationale for determining baseline k and R_e estimates with 7, 6, and 5 VI components is to allow direct comparison to experimental sessions in which these same components were used for estimations.

Similarly, k and R_e values were estimated for experimental conditions, using only the data collected when tubes were actually present in the chambers. The three repetitions of each condition were used in these analyses. In the 7-component toy sessions, k and R_e values were determined using all the data from all seven components, as tubes remained in the chambers for the entire session. In the 6-component toy sessions, the values were determined from all but the first VI component (VI 48-, 15-, 3-, 6-, 27-, and 75-s) because the tubes were not in the chambers during the VI 108-s component. Similarly, for the 5-component toy condition, the values were based upon the last five components.

2. Results

Table 1 lists the individual rats' response rates at each VI component in baseline and in the 7-, 6-, and 5-component toy sessions. The x-axis of the top panel of Fig. 1 shows the seven VI components, from leanest to richest, in the daily sessions. Note that the schedules were presented in an ascending-descending order: 108, 48, 15, 3, 6, 27, and 75. On the y-axis, group mean response rates are plotted at each of these individual VI components. Mean baseline rates (plus and minus standard

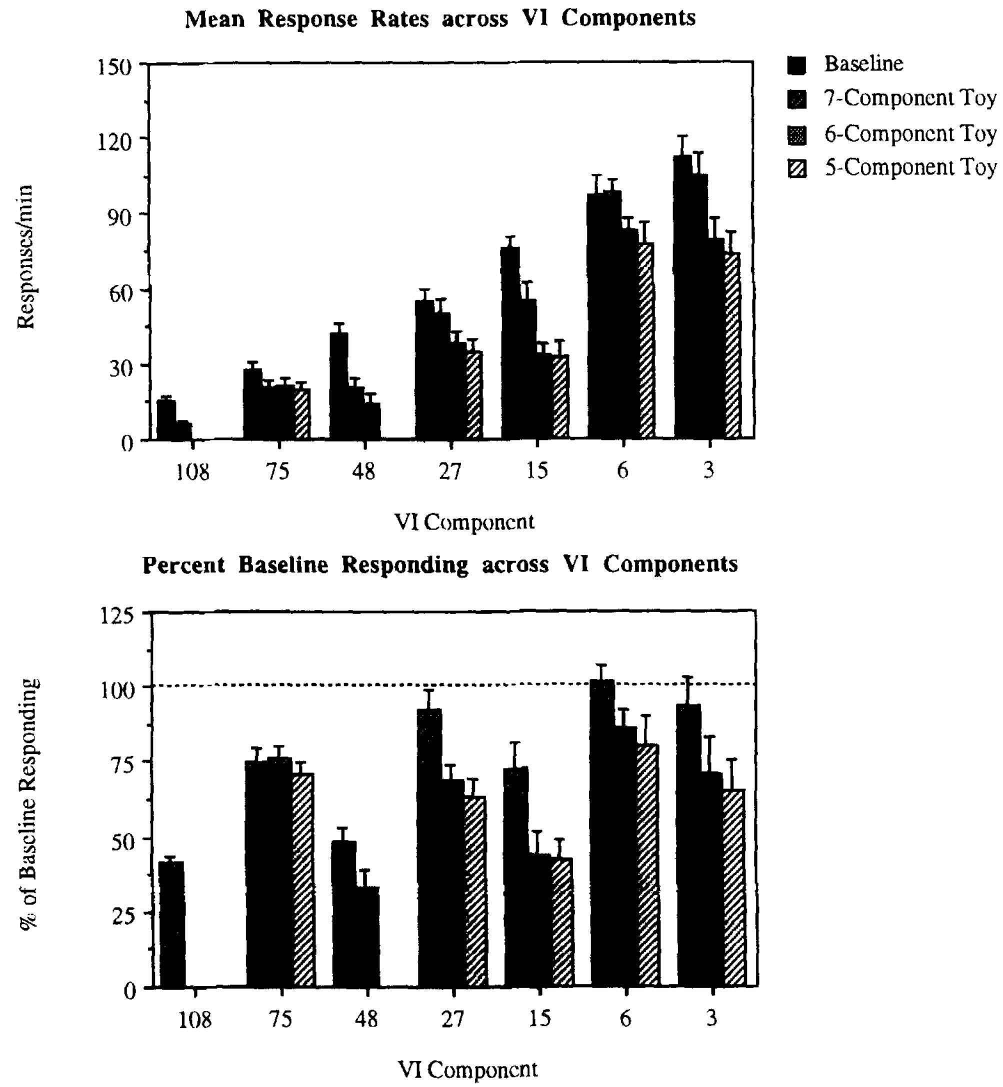

Fig. 1. (Top panel): Mean response rates (± standard errors) for each of the seven variable-interval schedules of reinforcement. Baseline response rates are shown with filled bars, and the 7-, 6-, and 5-component toy conditions are shown with increasingly lighter shading. (Bottom panel): Percent of baseline responding (± standard errors) for each of the seven variable-interval schedules of reinforcement at each of the three experimental conditions.

errors) are shown in the filled bar, and mean rates from the 7-, 6-, and 5-component toy sessions are represented by increasingly lighter shading. Response rates were relatively low in lean VI components and relatively high in rich components.

This figure also demonstrates that responding was most depressed during the component in which the tube was added and those components immediately following. The bottom panel of Fig. 1 shows percent of baseline responding in each of the VI reinforcement conditions for each of the three experimental conditions. Again, responding was suppressed to the greatest degree in the component in which the toy was first added. For example, when tubes were introduced in the VI 108-s component, responding was only 40% of baseline responding during this component. In the 6- and 5-component toy conditions, tubes were introduced just prior to the VI 48-s and VI 15-s components, and responding was reduced by about 60% in each case.

Although responding was most affected in the component in which the tubes was added, responding in experimental sessions was still lower than baseline in the final VI component of the session. Responding in the VI 75-s component decreased to about 75% of baseline responding, regardless of whether the toy had been in the chambers for the entire session, for 39 min of the session or for 34 min.

Table 2
Estimates of k and R_e and variance in data accounted for by Eq. (2) in baseline and experimental conditions. Standard errors of estimates are indicated in parentheses

Components in analysis	Baseline			Toys		
	k	R_e	VAC	k	R_e	VAC
Rat 41						
7	122(5)	173(22)	98	133(12)	263(50)	94
6	120(5)	159(17)	96	110932)	350(210)	72
5	124(4)	193(17)	100	83(22)	238(134)	67
Rat 42						
7	129(6)	128(16)	98	152(12)	213(40)	95
6	127(4)	115(11)	97	116(7)	180(29)	98
5	128(6)	124(18)	98	156(21)	320(91)	91
Rat 43						
7	123(7)	184(27)	98	129(8)	203(32)	98
6	121(7)	171(24)	95	116(17)	283(83)	85
5	121(8)	169(37)	97	119(16)	312(90)	92
Rat 44						
7	106(5)	217(26)	99	87(12)	270(75)	91
6	104(5)	202(22)	96	63(12)	165(62)	60
5	107(7)	227(39)	98	52(11)	146(93)	80
Rat 45						
7	143(4)	152(58)	99	149(17)	182(44)	86
6	141(4)	144(11)	98	152(23)	271(81)	82
5	140(5)	141(16)	99	133(20)	179(68)	83
Rat 46						
7	106(7)	158(27)	96	135(10)	405(61)	96
6	103(6)	141(21)	94	121(9)	265(50)	97
5	106(8)	162(34)	96	115(3)	250(20)	99
Rat 47						
7	172(9)	209(24)	95	178(22)	518(110)	92
6	171(8)	258(32)	99	94(39)	385(304)	73
5	179(8)	265(44)	99	148(86)	678(353)	52

Table 2 shows k and R_e parameter estimations derived from response and reinforcement data for baseline and all experimental conditions. The baseline conditions refer to the days immediately preceding an experimental condition. Baseline estimates of k and R_e were determined three times for each rat. First, baseline k and R_e values were determined using the data from all seven of the VI components. Second, data from the last 6 VI components (excluding VI 108 data) were used to determine baseline k and R_e; these values were used to make a direct comparison to the 6-component toy sessions. Third, baseline data from the VI 108 and VI 45-s components were excluded to derive k and R_e estimates to compare with the 5-component toy sessions. Estimates of k and R_e in the three

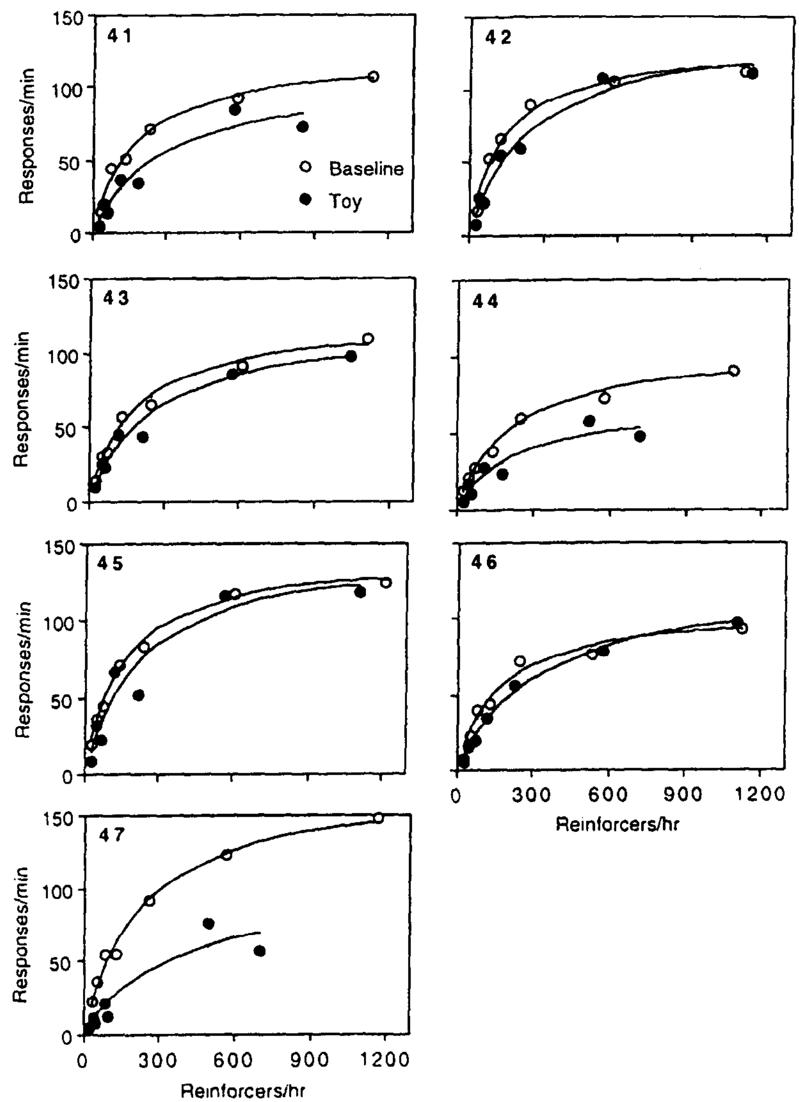

Fig. 2. Response rate as a function of reinforcement rate for individual subjects in baseline sessions and in the combination of all experimental sessions. See text for further details.

experimental conditions were determined similarly by averaging the response and reinforcement rates from each of the three repetitions of each experimental condition. This table shows that k and R_e were similar in baseline conditions, whether all or only some of the seven VI components were used in analysis.

On the right side of Table 2, estimates of k and R_e in toy conditions are shown. The k parameter did not show any systematic trends with the introduction of the tube. In 9 of 21 comparisons, k increased slightly in the experimental sessions compared to baseline sessions. In 12 of the 21 comparisons, k values in toy conditions were lower than their respective baseline values. Again, in most of these cases, the change in k was usually within one standard error. Rat 44 was the main exception; in this rat k values from experimental sessions were always substantially lower than baseline values. The k values in baseline did not differ significantly from those in the 7-component toy condition, $t(6) = 1.53$, $p < 0.20$ Similarly, k values in 6- and 5-component toy conditions did not differ from respective baseline values, $t(6) = 1.33$ and 1.27, $p < 0.25$, respectively.

In contrast to the lack of changes in k, R_e increased with the introduction of the toy. In 19 of the 21 comparisons, R_e increased in experimental compared to control conditions. The R_e values were different in baseline and the 7-component toy condition, $t(6) = 2.83$, $p < 0.05$. Likewise, significant changes were noted in the 6 and 5-component toy conditions compared to their respective baseline estimates, $t(6) = 3.75$ and 2.03, $p < 0.05$.

Fig. 2 shows response rate as a function of reinforcement rate in baseline and the combination of all conditions in which tubes were present. For baseline, data from all nine sessions preceding a toy session are included. In the experimental condition, the response rate for the VI 108 component includes only data from the 7-component toy condition, since tubes were not present in this VI component in the 6- or 5-component toy conditions. The VI 45-s component averages response rates from the 6 sessions of the 7- and 6-component toy conditions, since tubes were present in the chambers in both conditions. The VI 15-s component averages response rates from all three experimental conditions.

Response rate was a negatively accelerated function of reinforcement rate in both baseline and experimental conditions. Reinforcement rates ranged from about 20 to 1200 h^{-1}, and response rates varied systematically from about 5 to 120 h^{-1}. Each subject demonstrated this same pattern, and Eq. (1) accounted for over 84% of variance in all subjects. This figure shows k decreased in the toy condition for three rats, and it remained unchanged in the other four. R_e increased in the experimental condition in all 7 rats.

3. Discussion

Two major findings emerged from this experiment. First, the data from this experiment demonstrate that the R_e parameter increased significantly with the inclusion of an extraneous background source of reinforcement. Second, the results from this experiment suggest that the k parameter remained unchanged or decreased with the introduction of an additional, qualitatively different source of reinforcement.

Regarding the first of these findings, introduction of novel items on which the rats could chew significantly increased the R_e parameter. In the 7-component toy condition, all subjects demonstrated increases in R_e. Significant increases in R_e were also evident in the 6- and 5-component toy conditions, with six of the seven animals showing increases in R_e estimates. The curve-fitting definition of R_e is the rate of reinforcement that maintains half maximal responding. If reinforcement is set equal to R_e, then response rates must be one half k. In sessions in which no tubes were present, sucrose yielded a lower R_e than in those in which tubes were included. Thus, a given frequency of sucrose maintained a greater amount of lever pressing behavior in baseline conditions than in toy sessions.

Several factors, none of which necessarily exclude the others, may have contributed to this increase in R_e with the addition of the toy to the experimental session. Because order of VI components was fixed and placement of the tube occurred in the early components of sessions, the effectiveness of the tube may have diminished over the course of the session, thereby affecting parameter estimations. Habituation to the tube does seem apparent in Fig. 1; decreases in responding were most pronounced in those components occurring soon after the introduction of the toy. Nonetheless, even in the very last VI component of the session, responding was still suppressed from baseline rates, regardless of whether the toy had been in the chamber the entirety of the session or only part of the session.

McSweeney (1992) and McSweeney and Roll (1993) have shown that rates of responding are not constant throughout a session. Changes in response rates throughout a session clearly could affect parameter estimations in the procedure used in this experiment. However, McSweeney et al. (1995) found that 'responding was approximately equally sensitive to reinforcement at all times during the experimental session' in the within-session procedure. This finding corroborates earlier work showing that schedule order does not influence k and R_e estimates (e.g., Heyman et al., 1986). The practice of providing relatively small reinforcers, short sessions, and transitional periods between VI components may account for the high variance in the data explained by this within-session procedure. Nonetheless, repetition of this experiment in a procedure employing between session presentations of the different VI components would further address the significance of the habituation effect and the applicability of these findings.

Although significant increases in R_e were demonstrated in toy conditions, k did not differ significantly between baseline and experimental conditions. Table 2 and Fig. 2 show that in about half the cases, k values increased slightly and in about half they decreased slightly. In most of the cases in which k decreased, the VAC was also lower. Drawing conclusions about the stability of a parameter may be premature when the equation used to estimate the parameter accurately describes the data in one case, but not the other.

These results are consistent with those from some other studies that manipulated background reinforcement and examined k and R_e estimates. Bradshaw (1977), White et al. (1986) and Belke and Heyman (1994) demonstrated increases in R_e and no change in k when a second lever was added to the experimental context. Dougan and McSweeney (1985) also demonstrated increases in R_e and no change in k when a qualitatively different source of reinforcement was added to the experimental apparatus.

Other studies, however, have not found an independent relationship between the k and R_e parameters following experimental manipulations (e.g., Bradshaw et al., 1978; McDowell and Wood, 1984; McDowell and Wood, 1985), and some have provided additional interpretations of these parameters (e.g., Baum, 1981; Davison and Hunter, 1976; Staddon, 1979). Nevertheless, in the present study, we demonstrated an independent relationship between the two parameters, and the response-strength equation provided a good fit for the data. The generalization of the effects found in the present study to other background, and arranged, sources and schedules of reinforcement remains to be determined.

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