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# *EFFECTS OF QUALITATIVELY DIFFERENT REINFORCERS ON THE PARAMETERS OF THE RESPONSE-STRENGTH EQUATION*

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This experiment examined the relationship between two qualitatively different reinforcers and the parameters of a quantitative model of reinforced responding, referred to as the response-strength equation or the Herrnstein equation. A group of rats was first food deprived and later water deprived. An 11.5% sucrose solution served as the reinforcer in the food-deprivation condition, and water was the reinforcer in the water-deprivation condition. Each experimental session consisted of a series of seven variable-interval schedules, providing reinforcement rates that varied between 20 and 1,200 reinforcers per hour. The response rates increased in a negatively accelerating function in a manner consistent with the response-strength equation. This equation has two fitted parameters, $k$ and $R_e$. According to one theory, the $k$ parameter is a measure of motor performance, and $R_e$ is indicative of the relative reinforcement efficacy of the background uncontrollable sources of reinforcement in relation to the experimentally arranged reinforcer. In this study, $k$ did not change as a result of the different reinforcers, but $R_e$ was significantly larger in the sucrose-reinforcement condition. These results are consistent with the interpretation that $k$ and $R_e$ measure two independent and experimentally distinguishable parameters and provide further evidence that absolute response rate is a function of relative reinforcement rate, as implied by the derivation of the response-strength equation based on the matching law.

*Key words:* response-strength equation, matching law, water deprivation, food deprivation, lever press, rats

The matching law equation, introduced by Herrnstein (1970), has generated considerable interest to researchers studying behavioral psychology, psychopharmacology, animal behavior, and economic theory. Nonetheless, a number of issues concerning this equation and its underlying assumptions remain to be addressed. In his paper, Herrnstein demonstrated that relative response rate is a function of relative reinforcement rate when two reinforcement sources are concurrently available. The equation for relative response rates is

$$B_1/(B_1 + B_2) = R_1/(R_1 + R_2),$$

where $B_1$ and $R_1$ are response and reinforcement rates, respectively, at Alternative 1. This equation has come to be known as the matching law. Herrnstein further demonstrated that, when only one source of reinforcement is available, absolute response rate is a hyperbolic function of the absolute rate of reinforcement, in the form

$$B = kR/(R + R_e), \qquad (1)$$

where $k$ and $R_e$ are fitted parameters.

Herrnstein (1970) considered Equation 1 to be a version of the matching law. His underlying assumption was that choice is inherent in all behavior. Experimental environments contain uncontrollable sources of reinforcement that compete with the experimentally arranged task. Thus, even a rat in a one-lever situation has the opportunity to engage in activities other than lever pressing, such as sniffing, grooming, or resting. These background activities are also assumed to be maintained by reinforcement. Consequently, the effectiveness of the experimentally arranged reinforcer is relative to these background sources of reinforcement.

By this account, $k$ quantifies the topography of the reinforced response and $R_e$ measures the efficacy of the background reinforcers relative to the arranged reinforcer (Herrnstein, 1970, 1974). In studies in which estimates of $R_e$ have systematically decreased while $k$ has remained constant (Bradshaw, Ruddle, & Szabadi, 1981; Bradshaw, Szabadi, & Bevan, 1978a; Brad-

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shaw, Szabadi, Ruddle, & Pears, 1983; Conrad & Sidman, 1956; Guttman, 1954; Hamilton, Stellar, & Hart, 1985; Heyman & Monaghan, 1987; Kraeling, 1961; Logan, 1960; see de Villiers & Herrnstein, 1976, for parameter estimations for studies published before 1976), the magnitude of the arranged reinforcer was increased (i.e., in volume or concentration, or as an increase in deprivation level). Likewise, studies that have demonstrated systematic changes in $k$ and no alterations in $R_e$ have altered response requirements by, for example, adding weights to levers (Bradshaw, Szabadi, & Ruddle, 1983; Hamilton et al., 1985; Heyman & Monaghan, 1987; McSweeney, 1978; Porter & Villanueva, 1989). Such experimental evidence has led to the interpretation that $k$ and $R_e$ measure independent parameters of response rate: motor performance and relative reinforcement efficacy.

Nonetheless, a number of other studies that have seemingly involved altering the quantity or quality of the reward have led to changes in both parameters. For example, Bradshaw, Szabadi, and Bevan (1978b) found that both $k$ and $R_e$ changed as the sucrose concentration was increased from 0% to 40% (but see Heyman & Monaghan, in press). McDowell and Wood (1984) found changes in $k$ associated with a shift in monetary reward for humans, and Snyderman (1983) reported that alterations in body weight affected both parameters. Although some feel that these discrepant results disprove the matching law (Davison & McCarthy, 1988), Williams (1988) and Heyman and Monaghan (1987, in press) have noted methodological difficulties that make the data more difficult to understand.

Because no experiments to date have studied the effects of two qualitatively different reinforcers on the parameters of the response-strength equation, the purpose of the present experiment was to examine the effects of both sucrose and water reinforcement on $k$ and $R_e$. Initially, rats were food deprived, and sucrose served as the reinforcer. After responding had stabilized, the same group of animals was water deprived, and water was the reinforcer. Some evidence suggests the that both parameters may change with these experimental manipulations. Hull (1977) found that food and water reinforcers elicited different topographical responding in rats, and studies of autoshaping have noted that both rats and pigeons develop topographically distinct lever pressing or pecking responses depending upon the type of reinforcer arranged (Jenkins & Moore, 1973; Peterson, Ackil, Frommer, & Hearst, 1972). These studies suggest that $k$ may change as a function of the different reinforcers. It is also not unreasonable to assume that different reinforcers have different relative rewarding efficacies. Changing the reinforcement from sucrose to water may be similar to alteration of reinforcer quantity, thereby altering $R_e$.

These systematic changes in both $k$ and $R_e$ are not necessarily inconsistent with the matching law (Equation 1). Herrnstein's interpretation simply states that the two parameters measure response topography and relative reinforcement efficacy, and that these factors are independent determinants of responding. This interpretation does not specify what type of experimental manipulation will alter either of these parameters, nor does it state that a single manipulation will necessarily affect only one. This is an empirical question.

## METHOD

### *Subjects*

Seven male Wistar rats served as subjects. They were housed individually in a colony room illuminated 12 hours a day, with lights on at 7:30 a.m. All had been subjects in a previous unpublished study of the response-strength equation. After arrival in the laboratory, the rats were allowed free food until they reached approximately 3 months of age and weighed between 315 and 380 g. The rats were then gradually reduced to 85% of their free-feeding body weights. Water was freely available at all times in the home cage throughout this phase of the experiment. During experimental sessions in the first phase of this study and in the previous unpublished study, the rats 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 free-feeding weights (about 8 to 12 g per day). In the second phase of this experiment, the rats had free access to food in the home cage. Water served as the reinforcer, and water bottles were removed from the home cages except for 10 min following experimental sessions. Animals were studied 6 to 7 days per week.

### *Apparatus*

The experiments were conducted in seven standard rat chambers (22.0 cm by 28.5 cm by 20.5 cm). Each chamber was equipped with two levers (4.5 cm wide) located 7.0 cm from the floor and 4.5 cm from the right and left walls, as measured from the lever midpoint. Presses requiring approximately 0.2 N on the right lever were reinforced according to variable-interval (VI) schedules, and 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 dipper (0.1 mL) of solution. The dipper rested in a trough and was raised when the rat had fulfilled the reinforcement requirement. Above the right lever was a stimulus light (28 V, 0.04 A) that signaled periods during which a level press could be reinforced. Each experimental chamber sat in a pressboard shell equipped with a houselight (28 V, 0.04 A) and a fan for ventilation and masking extraneous noise. Relays interfaced to a computer were used to record responses and control the stimulus lights and dipper. MED-PC® software was used to program the experimental events and collect data (Tatham & Zurn, 1989).

### *Procedure*

The procedure was similar to ones used in previous studies (e.g., Hamilton et al., 1985; Heyman, 1983, 1992). Daily sessions consisted of a series of seven different VI reinforcement schedules. The mean programmed interreinforcement intervals were 108, 75, 48, 27, 15, 6, and 3 s, which correspond to reinforcement rates of 33, 48, 75, 133, 240, 600, and 1,200 per hour. The schedules were run in an ascending order, from leanest to richest. The availability of a schedule was signaled by the presence of both a stimulus light and a houselight. Consecutive schedules were separated by a 7.5-s blackout period, during which the chamber was dark and responses were recorded but had no programmed consequences. In addition, the stimulus light went off for 4.5 s when a reinforcer had been earned; during this time, the VI timer did not run.

Each schedule was in effect for a period that increased as a function of the average interreinforcement interval (see Heyman, 1992). For example, for the VI 108-s schedule the component duration was 908 s, and for the VI 3-s schedule, it was 160 s. The different component times were employed to ensure that each component provided a minimum number of reinforcers. When each period is fixed at 5 min, for example, the expected number of reinforcers per session in the leanest component (VI 108 s) would have been less than three, whereas the expected number of reinforcers on the richest component would have been about 40. The component lengths in this study were 980, 736, 540, 410, 305, 208, and 160 s, allowing approximately eight reinforcers in the leanest component and about 20 in the richest.

The intervals that comprised each VI schedule approximated a Poisson distribution (Fleshler & Hoffman, 1962). When an interval elapsed, the next lever press operated the dipper for 3 s and turned off the stimulus light. A 1.5-s postreinforcement period with the stimulus light remaining off followed each reinforcement. Thus, after 4.5 s, the light came back on and the timer was restarted with a new interreinforcement interval.

### *Data Analysis*

Each component was divided into two parts: an initial transition period and a longer terminal period. The transition durations for each of the seven schedules, in order, were 108, 80, 60, 50, 35, 30, and 12 s. Thus, for the VI 108-s component, the transition period was 108 s followed by an 800-s terminal period. Only the data from the longer terminal periods were used in analysis. To obtain estimates of $k$ and $R_e$, Equation 1 was fit to response- and reinforcement-rate pairs using a weighted least squares method developed by Wilkinson (1961) for the description of enzyme kinetics. This technique provides standard errors for the parameter estimates. The final $k$ and $R_e$ values were based on the average response and reinforcement rates for 10 randomly selected sessions in each of the two conditions after stability had been reached. Stability was defined as no monotonic trend in $k$ and $R_e$ values for three consecutive sessions. The sucrose-reinforcer condition was in effect for 161 sessions (including lever-press training and the duration of the unpublished study), and the water-reinforcer condition was in effect for 35 sessions. The 10 sessions used in the present

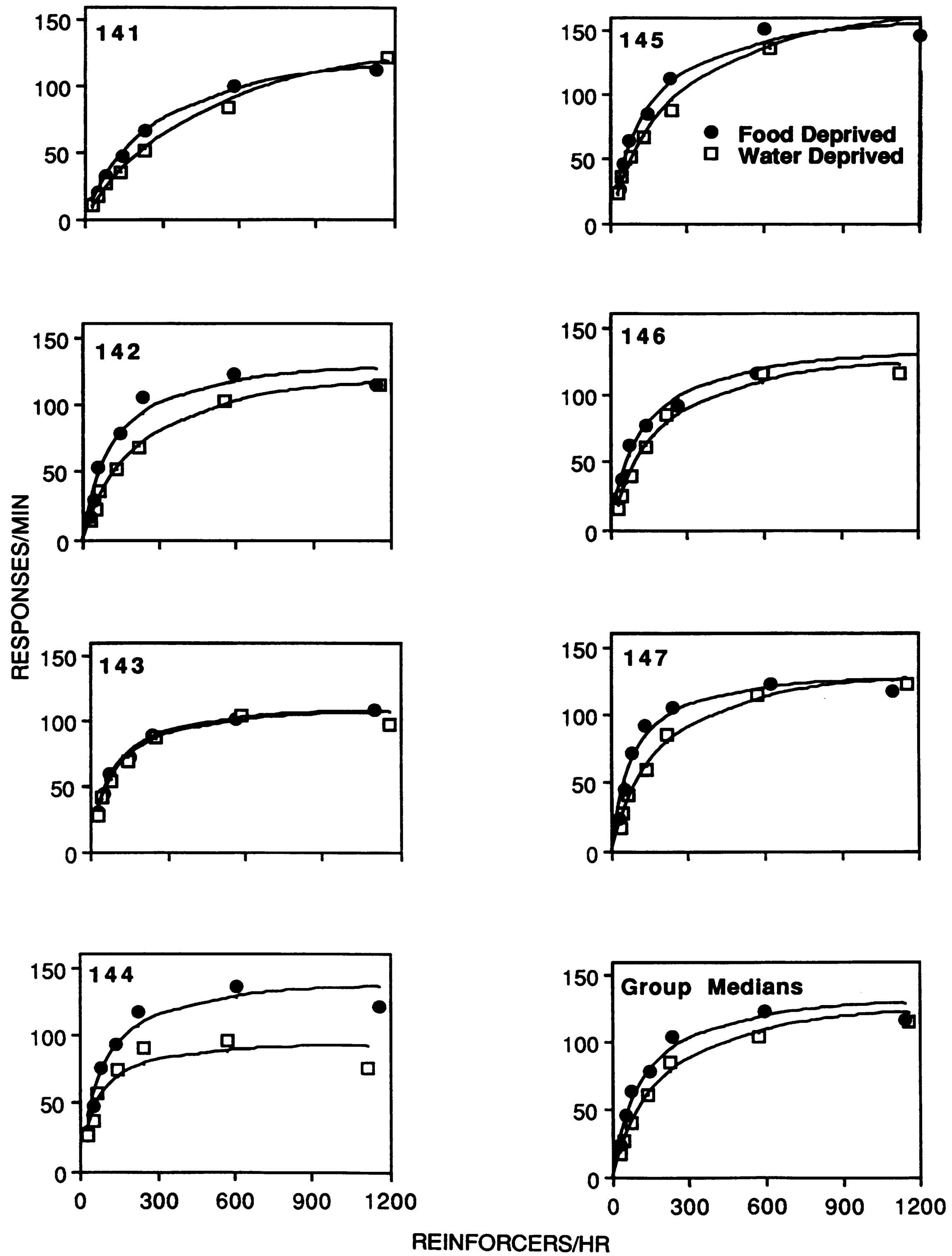

Fig. 1. The effects of food and water deprivation on the relationship between response rates and reinforcement rates for the 7 individual rats and for the group median. The smooth curves were obtained by fitting Equation 1 by Wilkinson's (1961) method.

analysis were randomly selected from the last 22 sessions of the water-deprivation condition and the last 44 sessions of the food-deprivation condition.

## RESULTS

Figure 1 shows response rate as a function of reinforcement rate in the two conditions studied. Data are presented for the 7 individual rats as well as for the group medians. Response rate was a negatively accelerated function of reinforcement rate for all rats. The reinforcement rates ranged from about 20 to 1,200 per hour, and their corresponding response rates varied systematically from about 10 to 150 per hour. Response rate was also a function of the experimentally arranged reinforcer. Within a particular VI schedule, response rates for food usually were higher than those for water, especially in the leaner VIs. This trend is seen in all animals except Rat 143, which showed similar response rates regardless of the reinforcer. The Appendix lists these average response and reinforcement rates for the 10 randomly selected sessions for each rat.

Figure 2 shows the mean percentage changes in $k$ and $R_e$ values between the two conditions for all subjects as well as the group mean. These $k$ and $R_e$ estimates were determined by fitting Equation 1 to the response and reinforcement rates in the Appendix and are shown in Table 1. This equation accounted for between 85% and 99.6% of the variance across subjects and conditions. A paired $t$ test indicated that although the group mean $k$ values were not statistically significantly different between conditions, $t(6) = 0.106$, $p < .919$, the average of $R_e$ values did differ significantly between conditions, $t(6) = 2.51$, $p < .05$. To check the stability of performance over the sessions subsequent to attainment of the stability criterion in each condition, the analysis was repeated with 10 different randomly selected sessions from both conditions. The parameter values for the two determinations did not deviate by more than 7% of the mean for each rat. Again, the same conclusions were drawn from the data—$k$ remained stable and $R_e$ was larger in the water-deprivation condition.

However, as seen in Figure 1 and the Appendix, response rates in the food-deprivation condition decreased slightly from the VI 6-s to the VI 3-s component for 4 of the rats. This trend is contrary to what would be predicted by Equation 1. Because this richest component occurred at the end of the experimental sessions, response rates may have decreased in the last component due to satiation. The data were thus reanalyzed using the response and reinforcement rates of all but the VI 3-s component. That is, six VI components (instead of seven) were used to determine the values of $k$ and $R_e$. These $k$ and $R_e$ values appear in Table 2. Paired $t$ tests between these $k$ and $R_e$ values indicated the same trend as that obtained by seven VI components. Again, mean $R_e$ was significantly higher in the water-reinforcement condition, $t(6) = 2.51$, $p < .05$, but $k$ was not significantly different between the two conditions, $t(6) = 0.11$, $p < .92$.

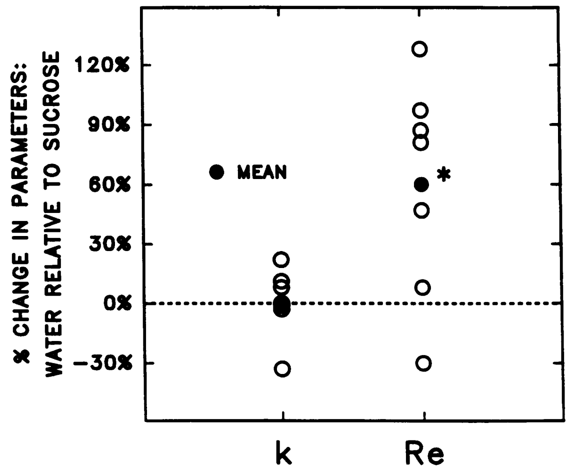

Fig. 2. Changes in $k$ and $R_e$ parameters relative to the food-deprived condition. Individual changes as well as the group mean changes are plotted. The asterisk indicates a statistically significant difference between the two conditions.

## DISCUSSION

A variety of experiments have demonstrated changes in one or both parameters of the response-strength equation following experimental manipulations. However, no experiments to date have examined the effects of two qualitatively different reinforcers in the same group of subjects. In the present study, when rats were food deprived responses were reinforced with a sucrose solution, and when they were water deprived their responses were reinforced with water. Response rate was a negatively accelerated function of reinforcement rate in both conditions. The proportion of vari-

Table 1

Parameters and goodness of fit percentages for Equation 1. Standard errors of estimates are in parentheses.

| Rat | Food $k$ | Water $k$ | Food $R_e$ | Water $R_e$ | Food VAC | Water VAC |
|---|---|---|---|---|---|---|
| 141 | 141 (5) | 172 (11) | 263 (23) | 519 (67) | 100 | 99 |
| 142 | 139 (10) | 137 (4) | 113 (23) | 211 (16) | 95 | 100 |
| 143 | 115 (3) | 111 (4) | 75 (6) | 81 (11) | 99 | 97 |
| 144 | 145 (10) | 97 (9) | 80 (17) | 56 (20) | 94 | 86 |
| 145 | 172 (9) | 191 (8) | 134 (20) | 243 (26) | 98 | 99 |
| 146 | 142 (6) | 142 (8) | 119 (14) | 175 (26) | 98 | 98 |
| 147 | 135 (7) | 146 (6) | 80 (14) | 182 (19) | 96 | 99 |

ance in the data accounted for by Equation 1, ranging from 85% to over 99%, was comparable to that found in previous studies with rats as subjects (Bradshaw, 1977; Bradshaw et al., 1978b, 1981; de Villiers & Herrnstein, 1976; Heyman & Monaghan, 1987, in press).

The change from a food- to water-deprived state was associated with an increase in the $R_e$ parameter and usually no change in $k$. In terms of response rates, increases in responding in the food-deprived state, relative to the water-deprived state, were noted in all but the two richest VI schedules. Responding in these components (VI 6 s and 3 s) was correlated with the $k$ parameter, which also did not differ significantly across the two conditions. Even when the VI 3-s component was excluded from the analysis because of the possibility of satiation, the $k$ values still remained stable, whereas the $R_e$ values were again larger in the water-deprivation condition.

These results are consistent with a number of studies that have shown that changes in reward conditions (e.g., sucrose concentration, electrical brain stimulation, degree of deprivation) can selectively alter $R_e$ but not $k$ (Bradshaw, Szabadi, Ruddle, & Pears, 1983; Hamilton et al., 1985; Heyman & Monaghan, 1987, in press). For example, Bradshaw and colleagues found that when the degree of deprivation was decreased from 80% to 90% of body weight, the $R_e$ parameter increased with no change in the $k$ parameter. In the present study, the type of deprivation was modified. Although the asymptotic response rate (i.e., $k$) was not affected by this alteration, the relative reinforcing efficacy of the arranged reinforcer in relation to the background sources of reinforcement did change.

Table 2

Parameters and goodness of fit percentages for Equation 1, excluding the VI 3-s component from the analysis. Standard errors of estimates are in parentheses.

| Rat | Food $k$ | Water $k$ | Food $R_e$ | Water $R_e$ | Food VAC | Water VAC |
|---|---|---|---|---|---|---|
| 141 | 157 (7) | 137 (9) | 318 (29) | 363 (44) | 100 | 99 |
| 142 | 159 (13) | 146 (7) | 147 (27) | 236 (22) | 97 | 100 |
| 143 | 114 (4) | 120 (4) | 73 (8) | 95 (8) | 99 | 99 |
| 144 | 164 (8) | 114 (6) | 104 (14) | 80 (12) | 98 | 97 |
| 145 | 195 (9) | 178 (13) | 172 (17) | 213 (33) | 99 | 98 |
| 146 | 137 (17) | 164 (9) | 111 (17) | 229 (25) | 98 | 99 |
| 147 | 146 (9) | 157 (9) | 95 (15) | 208 (25) | 97 | 99 |

The curve-fitting definition of $R_e$ is the rate of reinforcement that maintains half-maximal response rate. For example, if reinforcement is set equal to $R_e$, then response rate must equal one half $k$ $[B = k/2 = kR_e/(R_e + R_e)]$. Sucrose yielded a lower $R_e$ than water. Thus, a given frequency of sucrose maintained a greater amount of behavior than the same frequency of water. By this criterion, sucrose was more reinforcing than water. Several factors, none of which exclude the others, may have contributed to this difference. First, it is possible that 23 hr of food deprivation and 23 hr of water deprivation did not produce equivalent motivational states. Had, for example, the subjects been water deprived for 36 hr rather than 24, the values of $R_e$ may have been more similar to one another in the two phases of the study. Second, it is possible that the type of deprivation or nature of the reinforcer influences the background level of reinforcement. Recall that, according to the matching law (Herrnstein, 1970), $R_e$ measures the rate of reinforcement from uncontrolled sources (e.g., resting, exploring the chamber, etc.). It is plausible that these background activities vary as a function of deprivation state. For example, subjects may be more likely to explore the chamber when they are water deprived than when they are food deprived. This difference would affect $R_e$. Put another way, if deprivation elicits activities that compete with the one that the experimenter arranges, then water and food reinforcement may be likely to elicit different competing activities.

Two additional explanations are procedural. In food-reinforcement studies, decreases in body weight have increased response rate

(Clark, 1958; Ferster & Skinner, 1957; Revusky, 1963) and have decreased $R_e$ (Bradshaw, Szabadi, Ruddle, & Pears, 1983). Because the animals were not food deprived in the water-reinforcement phase of the study, body weight increased. The average gain was 88 g (range, 45 to 125 g). Thus, body weight may have influenced $R_e$. The correlation, however, between weight gain and change in $R_e$ between the two conditions in the present experiment was virtually zero ($r = -0.01$). Interestingly, an increase in weight was more closely associated with lower $k$ values ($r = -0.43$). Rat 144, for example, gained the most weight and was the only rat whose $k$ value was lower in the water-deprivation condition. Perhaps this substantial gain in body weight resulted in postural, and hence motoric, adjustments in responding.

The order of the schedules should also be considered. Because the VI components ran from lean to rich, the subjects may have become satiated as reinforcement rate increased. This could affect parameter estimates. For example, if satiation increased as a function of session duration, then estimates of $k$ would vary as a function of whether the richest component came early or late in the session. Several lines of evidence, however, suggest that within-session satiation did not influence the basic findings. The data in the Appendix demonstrate that responding in the first VI component differed under food and water reinforcement. Thus, food maintained higher response rates even when satiation could not have been a factor. Table 2 shows $k$ and $R_e$ estimates when the richest reinforcement component was removed from the analysis. The same conclusions can be drawn from the data whether six or seven VI components are used: $k$ remained the same between the two conditions, and $R_e$ was significantly higher in the water-deprivation condition. If within-session satiation did occur during one or both phases, its influence was not large.

Furthermore, comparisons with other studies indicate that the order of schedules within a session has little, if any, effect on estimates of $k$ and $R_e$. For example, similar results were obtained from studies in which schedule order was random, seriated (lean to rich or rich to lean), or bitonic, with the richest schedule coming midsession (Heyman, 1983, 1992; Heyman & Monaghan, 1987, 1990). Results from experiments that provided different VI schedules within and between sessions are also similar (cf. Heyman & Monaghan, 1987, with similar experiments by McSweeney, 1978, Bradshaw, Szabadi, & Ruddle, 1983, and Bradshaw, Szabadi, Ruddle, & Pears, 1983). The generality across procedures is likely due to the common practice of using relatively short sessions, relatively small reinforcers, and body weights below 90%.

Because the food-deprivation condition was run before the water-deprivation condition for all rats, it is possible that the order of the conditions, or fluctuations in responding over the course of several months, may have contributed to the differences in $k$ and $R_e$ values. However, each condition was continued for over 20 sessions after stability criteria were met, and the $k$ and $R_e$ values were determined from 10 randomly selected sessions in each condition. Although there were daily fluctuations in $k$ and $R_e$ values for the individual rats, any effects of long-term alterations in responding due solely to the passage of time, as opposed to the different experimental conditions, would be diminished by the amount of time each of the conditions was kept in effect. That is, if $R_e$ values become higher as rats get older, then water reinforcement itself may not be primarily responsible for the difference noted in this experiment. If this were the case, then, for example, one would expect that $R_e$ values would be higher at the end of the food-deprivation condition, which lasted approximately 2 months, than they were at the beginning of this condition. Paired $t$ tests between the $k$ values and the $R_e$ values determined from the first session and from the last session of each condition, however, indicated no statistically significant differences at alpha $\leq .05$. Moreover, some of the rats were returned to a food-deprivation sucrose-reinforcement state approximately 6 months after the completion of this study, and most returned to similar $k$ and $R_e$ values. Thus, the mostly likely account of why $R_e$ was lower for sucrose includes three factors: Given equal levels of deprivation, 0.1 mL of sucrose was more reinforcing than was 0.1 mL of water; the rats were relatively more food than water deprived; and/or water and food deprivation elicited different, competing background activities.

Despite changes in the relative reinforcement efficacies of the arranged reinforcers, $k$

remained constant in this study. Both theoretical and empirical grounds suggest that *k* indexes response topography or motor performance (Bradshaw, Szabadi, & Ruddle, 1983; Hamilton et al., 1985; Heyman & Monaghan, 1987; McSweeney, 1978; Porter & Villanueva, 1989). For example, in an experiment with rats, Porter and Villanueva found that lever response duration was inversely correlated with *k*. However, Hull (1977) found that the response topographies of water-deprived rats pressing for water differed from those of food-deprived rats responding for either sucrose or food. A number of possible explanations for this apparent discrepancy exist. Reinforcement schedules, stability criteria, and methods of measuring of response topographies were all different in these two studies.

The results of this study are relevant to the interpretation of the response-strength equation. Herrnstein's (1970) derivation of Equation 1 from the matching law equation demands that *k* and $R_e$ quantify two independent, and experimentally distinguishable, parameters of response strength. Whereas some studies have demonstrated a relationship between *k* and $R_e$, the parameters were experimentally dissociated in the present experiment. These results are consistent with many other studies on the response-strength equation (e.g., Bradshaw et al., 1981; Bradshaw, Szabadi, Ruddle, & Pears, 1983; Hamilton et al., 1985; Heyman, 1983, 1992; Heyman & Monaghan, 1987, 1990). How these results apply to other qualitatively different reinforcers (e.g., brain stimulation vs. food and/or water reinforcement) remains to be determined.

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# APPENDIX

Listed below are the average response and reinforcement rates for each subject, as well as for the group median, in each of the seven VI schedules for both the sucrose- and water-reinforced conditions. The rates were calculated from 10 randomly selected sessions in each of the two conditions after stability had been reached.

| | | Mean VI interval (s) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Subject | | 108 | 75 | 48 | 27 | 15 | 6 | 3 |
| Rat 141 | | | | | | | | |
| Food | rsp/min | 12 | 21 | 33 | 47 | 67 | 101 | 112 |
| | rf/hr | 28 | 53 | 76 | 146 | 228 | 577 | 1,127 |
| Water | rsp/min | 11 | 18 | 27 | 35 | 51 | 84 | 122 |
| | rf/hr | 29 | 47 | 79 | 134 | 228 | 555 | 1,168 |
| Rat 142 | | | | | | | | |
| Food | rsp/min | 17 | 29 | 53 | 79 | 105 | 123 | 114 |
| | rf/hr | 26 | 46 | 60 | 149 | 234 | 592 | 1,138 |
| Water | rsp/min | 15 | 23 | 36 | 52 | 68 | 103 | 114 |
| | rf/hr | 28 | 49 | 67 | 130 | 218 | 555 | 1,157 |
| Rat 143 | | | | | | | | |
| Food | rsp/min | 31 | 45 | 60 | 73 | 89 | 101 | 108 |
| | rf/hr | 30 | 49 | 69 | 154 | 236 | 565 | 1,098 |
| Water | rsp/min | 28 | 42 | 54 | 69 | 87 | 104 | 97 |
| | rf/hr | 32 | 45 | 76 | 142 | 256 | 587 | 1,154 |
| Rat 144 | | | | | | | | |
| Food | rsp/min | 29 | 48 | 76 | 94 | 117 | 136 | 121 |
| | rf/hr | 30 | 47 | 80 | 138 | 226 | 607 | 1,156 |
| Water | rsp/min | 26 | 38 | 57 | 74 | 90 | 96 | 76 |
| | rf/hr | 27 | 50 | 68 | 141 | 246 | 574 | 1,113 |
| Rat 145 | | | | | | | | |
| Food | rsp/min | 26 | 46 | 64 | 85 | 113 | 151 | 146 |
| | rf/hr | 33 | 50 | 75 | 144 | 233 | 594 | 1,202 |
| Water | rsp/min | 23 | 36 | 52 | 67 | 87 | 136 | 163 |
| | rf/hr | 31 | 46 | 77 | 134 | 243 | 617 | 1,221 |
| Rat 146 | | | | | | | | |
| Food | rsp/min | 24 | 38 | 63 | 77 | 92 | 116 | 132 |
| | rf/hr | 31 | 47 | 75 | 137 | 262 | 568 | 1,215 |
| Water | rsp/min | 16 | 25 | 40 | 61 | 85 | 116 | 116 |
| | rf/hr | 27 | 47 | 79 | 136 | 218 | 592 | 1,126 |
| Rat 147 | | | | | | | | |
| Food | rsp/min | 24 | 46 | 72 | 92 | 105 | 123 | 117 |
| | rf/hr | 29 | 48 | 81 | 132 | 242 | 619 | 1,095 |
| Water | rsp/min | 18 | 28 | 41 | 60 | 85 | 114 | 122 |
| | rf/hr | 35 | 46 | 66 | 139 | 221 | 573 | 1,158 |