

HUNGER AND CONTRAST IN A MULTIPLE SCHEDULE¹

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Pigeons working for food on a multiple variable-interval 1-min—variable-interval 4-min schedule were subjected to variations in body weight, presumably causing changes in hunger. The proportion of responses in each component approached and eventually reached the proportion of reinforcements as body weight increased. This effect follows from the matching-law interpretation of contrast in multiple schedules.

According to one interpretation (Herrnstein, 1970), the interactions within a multiple schedule are just like those in a concurrent schedule, only less so. In concurrent procedures, reinforcement for each alternative affects all alternatives. In fact, the net change in behavior is zero, since each increment in behavior caused by reinforcement is precisely counterbalanced by decrements in the behavior's competitors (Herrnstein, 1974), and *vice versa*. Multiple schedules lack such tidiness, for their interactions are sub-maximal. An increase in the reinforcement in one component may—and usually does—result in a smaller compensating decline in other components (Shimp and Wheatley, 1971; de Villiers, 1974). By this interpretation “contrast” effects in concurrent schedules define the limiting values for multiple schedules, using that term in the sense of a reciprocal relation between responding in one component and reinforcement in the other (Herrnstein, 1970).

The responding in any component of a multiple schedule has been described by the equation

$$P_1 = \frac{k R_1}{R_1 + m R_2 + R_e} \quad (1)$$

Various simplifying assumptions go into this form of the multiple schedule equation (see

Herrnstein's (1970) discussion of equation 20 in that paper). P_1 is the responding during the component over some unit of time; R_1 is the reinforcement forthcoming (obtained, not scheduled). Responding in a second component earns reinforcement, R_2 . However, this alternative reinforcement is weighted by a parameter, m , assumed to fall in the range 0 to 1.0. When $m = 0$, the alternative reinforcement, R_2 , fails to exert any effect on P_1 , which means that there are no contrast effects. When $m = 1.0$, the alternative reinforcement exerts its full value, which means maximal contrast. With $m = 1.0$, the multiple schedule becomes indistinguishable from a concurrent schedule, and matching of response to reinforcement should be found.

The two further quantities, k and R_e , have standard interpretations (see Herrnstein, 1974). The parameter k is the asymptotic level of P_1 , achieved when all of the subject's reinforcement is encompassed in R_1 . The reinforcement from all sources other than R_1 and R_2 is contained in R_e . Ordinarily, both k and R_e are curve-fitting parameters.

The present study addresses a straightforward, narrow implication of equation 1, and, at the same time, sheds some light on the relation between motivation and contrast. In a conventional multiple schedule, a hungry animal may work for food in two components, perhaps receiving two rates of reinforcement. Those rates would appear in equation 1 as the values for R_1 and R_2 . The reinforcement from all other sources, R_e , would not be food. Whatever it might be, it should not covary with hunger the way R_1 and R_2 must. Making the subject hungrier should increase the value of

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$R_1 + R_2$ relative to R_e ; making it less hungry should do the opposite. We need not know what goes into R_e in order to conclude that it is likely to become a larger or smaller fraction of the denominator as the subject gets less or more hungry, respectively.

The case may be put exactly. Assuming that we can change the reinforcing value of $R_1 + R_2$ without also changing k , m , and the value represented by R_e , we obtain a family of curves relating $P_1/P_1 + P_2$ to $R_1/R_1 + R_2$, as shown in Figure 1. By varying the subject's

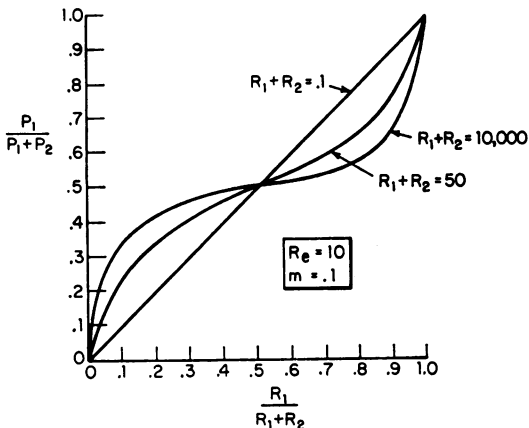


Fig. 1. Plotting equation 1 (see text) with $R_1 + R_2$, in arbitrary units, as the parameter. For each curve, $R_e = 10$ and $m = 0.1$.

hunger—and nothing else—we can approach matching (the straight diagonal) more or less. With larger values for R_e , the more quickly matching is approached by reducing hunger. In Figure 1, the curve for $R_1 + R_2 = 0.1$ is virtually indistinguishable from matching, although strictly speaking it is not quite identical.

A prediction of equation 1, then, is that a subject's performance in a multiple schedule should become progressively more like the performance in a concurrent schedule as the motivation for the scheduled reinforcements declines. It is this prediction in particular that we test here. A positive result would not confirm equation 1 in its entirety, only that aspect of it that leads to the prediction in question.

METHOD

Subjects

Five adult male White Carneaux pigeons, all with experimental histories in various pro-

cedures, worked here at a variety of body weights, as outlined below.

Apparatus

A standard, single-key operant conditioning chamber was used. The response key was centered on one wall at a height of about 9 in. (22.5 cm) and required a force of about 15 g (0.15 N) to activate the electrical circuitry. Each peck on the key also operated a feedback relay in the chamber. The key could be transilluminated with lights of different colors. Beneath the key was an opening into the standard feeding magazine, which was lit with white light when food was available. The chamber was continuously illuminated with a pair of 7-W white bulbs and continuous white noise was piped in to mask extra-experimental sounds.

Procedure

The basic procedure for the entire experiment was a two-component multiple schedule consisting of a variable interval of 4 min and a variable interval of 1 min. The components changed every 2 min. The VI 4-min was signalled by a red light on the key; VI 1-min by a white light. Sessions started randomly during either component and terminated when the feeding magazine had operated for 180 sec. Each operation of the feeder lasted 3.5 sec.

The five subjects started the experiment at 80% of free-feeding weights; thereafter, they progressed through a variety of other body weights. These are summarized in Table 1, along with the order of, and number of sessions between, each change. For example, Subject 321 spent 57 sessions at a body weight of about 80% (within 3%). Then, it was fed a daily supplement of no more than 20 g after each experimental session until its weight rose to 95% of *ad lib*. It worked its regular stint in the experimental chamber during the few transitional days while its weight was rising. The 51 sessions at 95% include these transitional sessions. Next, food supplements increased its weight to 100%. This phase lasted 154 sessions. The next phase, lasting 24 sessions, included the transitional days while its weight was being brought down by the withholding of supplements. The amount of food earned in the chamber itself was consistently too little to prevent weight loss. As before, the subject worked during the transitional days.

Table 1
Experimental Treatments for Five Subjects

5		259		321		367		394	
% Body Weight	Sessions	% Body Weight	Sessions	% Body Weight	Sessions	% Body Weight	Sessions	% Body Weight	Sessions
80	55	80	57	80	57	80	54	80	54
95	51	95	52	95	51	95	51	95	51
100	58	100	58	100	154	100	58	100	57
105	97	105	106	80	24	80	105	105	106
80	110	110	72	FF* (103)	22	FF* (92)	22	110	71
FF* (105)	22	80	24					80	24
		FF* (110)	22					FF* (103)	22

*Free feeding (full cup of food in experimental chamber).

The final condition for all subjects, lasting 22 sessions, started when they were at 80%. During the session, a full cup (eight fluid ounces) of food sat in the chamber, from which the subjects could eat freely. On no occasion did a subject empty the cup during the course of a session. Within 10 days, the subjects appeared to have reached stable weights, which are shown in parentheses as percentages of *ad lib* weight.

RESULTS

Rates of responding during both components are shown for each subject in Figure 2. The final 10 sessions at each body weight were used to take an average. For the points at 80%, the two determinations were combined (see Table 1), but each value appears as a horizontal dash. The spread gives some indication of the repeat-reliability of the rates of responding, which was quite high in most cases. The arrow arising from each data point extends to the value predicted by the matching law, by a calculation described below. In virtually no case for any subject did the obtained rates of responding for the two components differ by more than the matching value. As body weight rose, the obtained rates approached, and often reached, the separation called for by the matching value, but virtually never exceeded it.

The predicted values shown by the arrows in Figure 2 were obtained by apportioning the total responses by the same ratio as the reinforcements in the two components. Since the

schedules were VI 1-min and VI 4-min, the reinforcements should have fallen close to a 0.8 to 0.2 ratio, and they did. However, to calculate the predicted values for Figure 2, actual, rather than nominal, reinforcement frequencies were used. The largest spread of actual frequencies for these points was 0.84 to 0.16, and the smallest was 0.78 to 0.22. The median values were close to 0.8 and 0.2. These actual proportions, multiplied by the total response rate, give the predicted response rates for each component, assuming matching. Thus, if a pigeon pecks 1000 times in a session containing equal exposure to VI 1-min and VI 4-min, and if, furthermore, it gets 0.8 of the reinforcements in the former and 0.2 in the latter, then matching dictates 800 pecks for the VI 1-min component and 200 pecks for the VI 4-min component.

The free-feeding results do not appear in Figure 2. Instead, they are shown as bar graphs in Figure 3, using data averaged over the final 10 sessions of free feeding for each pigeon. The higher bar comes, in each pair, from the VI 1-min. Next to each bar is a vertical line rising from the abscissa to a certain height. These lines show the matching rates, calculated by the same procedure as for Figure 2. The numbers in parentheses above the lines give the proportion of reinforcements from the VI 1-min for each subject. The value for the VI 4-min is just the complement. The nominal value was again 0.8 and 0.2, but because the rates of pecking had fallen to the range where rates of reinforcement begin to interact significantly with rates of pecking, the

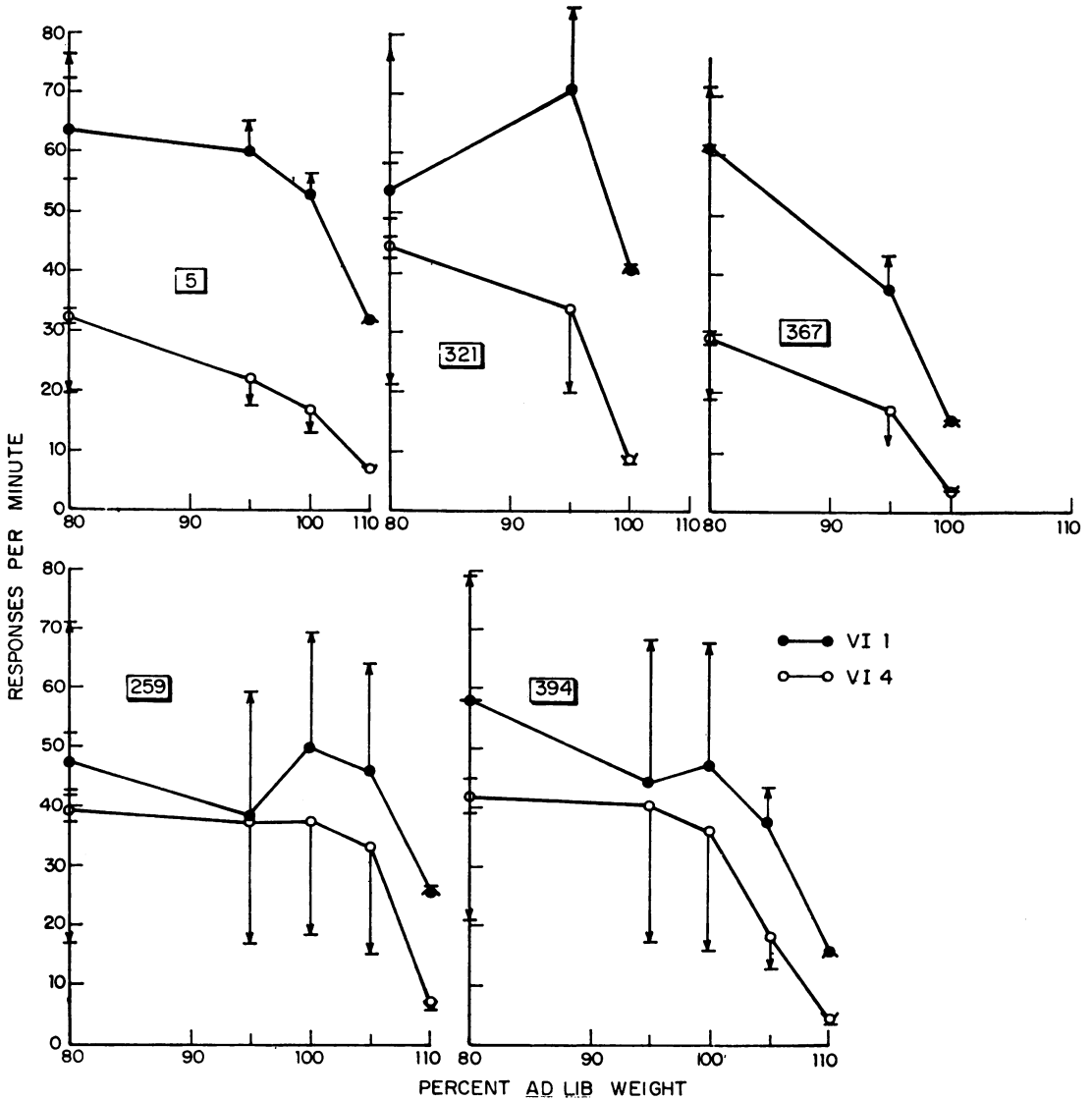


Fig. 2. Each panel is for one subject. The rates of responding for VI 1-min (filled points) and VI 4-min (open points) are shown as functions of per cent *ad lib* body weight. The arrows are drawn to the rates that would conform to matching between relative responses and relative reinforcements.

actual rates of reinforcement deviate appreciably in at least one instance. Subject 5, whose VI 4-min rate of pecking had fallen well below one per minute, received only 10% of its reinforcements from that component, instead of the nominal 20%.

Figure 3 nevertheless supports the main finding in Figure 2. Even though pecking is reduced to low levels (for pigeons), the proportion emitted in the two components approaches, but does not exceed by more than 3%, the ratio predicted by matching.

Figure 4 plots the approach to matching using proportions, instead of absolute rates of pecking. The ordinate is the obtained proportion of pecking for the VI 1-min minus the proportion that would have given perfect matching. The VI 4-min would be complementary and is therefore omitted. The same 10-session averages were used here as for the two preceding figures.

Negative ordinates in Figure 4 mean that responding in the two components differed by less than predicted for matching. The large

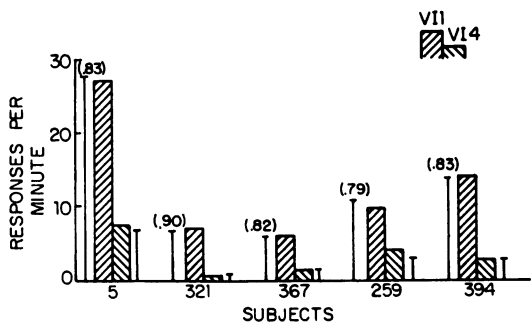


Fig. 3. Showing, for each subject, the rates of responding for VI 1-min and VI 4-min during free feeding. The lines next to the bars shows the rates that would conform to matching between relative responses and relative reinforcements.

majority of data points, for all subjects, fall below zero. With increasing weights, the points rise towards zero—i.e., towards matching—but rarely cross the line. Altogether, four points exceed the matching ratio—one at 3% and three at less than 2%.

The approach to matching shown in Figure 4 more or less parallels a decline in over-all responding, shown in Figure 5. The same 10 sessions were used to obtain the average rate of responding, summed across both components. The fall-off in responding with increasing weights varies from subject to subject, so that an average across the group might be somewhat misleading. The variation from subject-to-subject is at a minimum at 80% and increases thereafter. Some, but not all, of the subject-to-subject agreement at 80% reflects the sampling. At 80% there were two determinations, which have been averaged here, as for Figures 2 and 4. To a first approximation, the

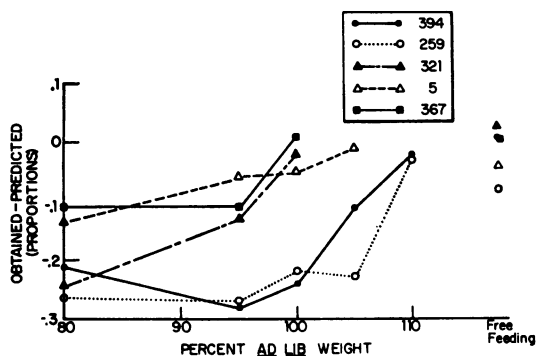


Fig. 4. The proportion of responses to the VI 1-min minus the proportion that would have given matching, for each subject. All body weights, plus free feeding are plotted.

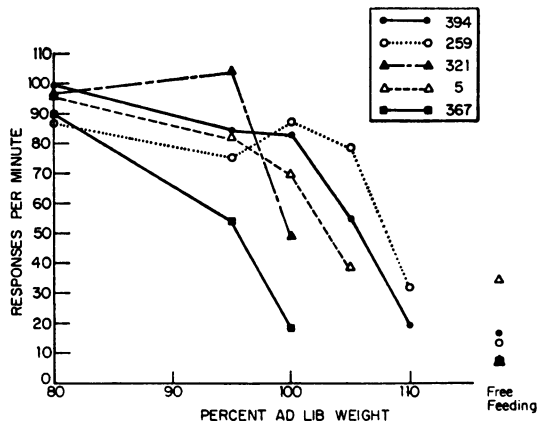


Fig. 5. The total rate of responding, summing across VI 1-min and VI 4-min, as a function of body weight and during free feeding, for all subjects.

effect of body weight appears to be concave downward.

Since over-all responding (Figure 5) and approach to matching (Figure 4) are both decreasing functions of body weight, we should consider the possibility that the two are closely related to each other. Figure 6 tests the possibility in the form of a simple scatter diagram. The ordinates of Figures 4 and 5 are here plotted against each other. There is a clear but imperfect negative correlation—the higher the response rate, the further the deviation from matching. No correlation coefficient has been calculated because there does not seem to be any straightforward way of handling the large inter-subject variability (cf. McSweeney, 1974). Had there been sufficient data, it would have

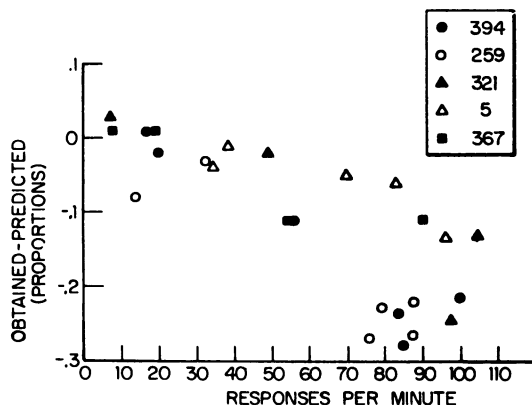


Fig. 6. The ordinate of Figure 4 plotted against the ordinate of Figure 5. In other words, the deviation from matching as a function of over-all rate of responding, for all subjects.

been appropriate to calculate separate coefficients for each subject. The Discussion further considers the relation between matching and response rate.

DISCUSSION

By ordinary standards, Figure 5 comes closest to a motivational relation. The over-all responding on a multiple schedule—an index of activity—is inversely related to body weight—an index of drive. However, Figures 2, 3, and 4 show that beneath that familiar surface, there is a substantially more invariant effect, one that appears in each subject to virtually the same extent, within about 3%. As the subjects' hunger vanishes, the distribution of responses in the two components approaches matching.

The introduction showed why the approach to matching follows from the extension of the matching law to multiple schedules. Equation 1 predicts the responding for each component—herewith repeated for convenience:

$$P_1 = \frac{k R_1}{R_1 + mR_2 + R_e}.$$

As hunger declines, the proportion $P_1/P_1 + P_2$ (or, symmetrically, $P_2/P_1 + P_2$) should approach the proportion $R_1/R_1 + R_2$ (or, symmetrically, $R_2/R_1 + R_2$). Figure 1 plotted hypothetical data showing the approach; Figures 2 through 4 show actual data confirming the prediction for one (nominal) value of $R_1/R_1 + R_2$.

Looking at Figure 6, one might be tempted to conclude that the limiting value of $P_1/P_1 + P_2$ is not matching, which appears there as 0 on the ordinate. The four points above the matching value fall among the five lowest over-all rates of response. A smooth curve drawn by eye and unconstrained by theory might intersect the ordinate at about 0.025, instead of at 0. While we have no way to disprove such a smooth curve, the deviation from theory is minor, even with the most unfavorable extrapolation. Moreover, there may be an artifact favoring those minor deviations at the low rates of responding. When the subjects are pecking fewer than about 10 times a minute, they begin to drive the ratio of reinforcement from 0.8 towards 1.0 in the VI 1-min (and from 0.2 towards 0 in the VI 4-min). If our estimate of the actual proportion of reinforcement hap-

pens to lag behind the true value, then the pigeons will seem to be above the matching line. With 10-session estimates, this is clearly a possibility.

Figure 6 shows something less than a perfect association between over-all responding and deviation from matching. It may seem that a rigorous application of the theory, as stated in equation 1, calls for a perfect association. The reasoning would go something like this. (We will not develop it mathematically here, although it would be simple to do so.) The approach to matching arises because $R_1 + R_2$, relative to R_e , decreases as the subject becomes less hungry. However, any decrease in hunger also reduces the numerator. In fact, it should be obvious that the *relative* decline of the numerator must be larger than that of the denominator (because the latter has a term for nonfood reinforcement, R_e). Consequently, P_1 must fall as matching is approached. Since overall responding is just $P_1 + P_2$, and since the same argument applies to P_2 , the total must fall in perfect association with the approach to matching.

While the foregoing is correct as far as it goes, it contains two tacit assumptions, either or both of which may be wrong. First of all, the argument assumes that the parameter m remains constant. m determines the extent of interaction between the two components. When it grows (approaching 1.0), interaction also grows, but responding falls. We do not know much about the behavior of m , besides the fact that it is smaller in multiple schedules than it is in concurrent schedules. It is therefore possible that it was changing during the course of the experiment, either because of the sheer passage of time or because of the changes in body weight. In any case, shifts in the value of m provide an additional source of variance, perhaps complicating the relations among the dependent and independent variables.

The second tacit assumption concerns R_e , which, in effect, is another parameter in the equation. Up to now, we have dealt with R_e as if it were a given amount of extraneous reinforcement. When hunger declines, R_1 and R_2 shrink relative to R_e , even if R_e stays objectively the same.

However, R_e probably interacts with R_1 and R_2 more directly. Presumably, some part of R_e is itself response-dependent; some part is almost surely reinforcement forthcoming on

ratio schedules. The collection of self-grooming activities contains plausible examples. There is, therefore, an implicit concurrent VI VR schedule built in wherever a subject has an arranged VI: the VI coming from the arranged schedule, the VR coming from at least some of the unscheduled sources of reinforcement in virtually any environment. We know from experiments on explicit concurrent VI VR (Herrnstein, 1971), that subjects will drive up or down the reinforcements obtained from the VR alternative in such choices. As the VI becomes less lucrative, the shift towards VR tends to snowball. The relevance here is clear. As hunger wanes, the subjects probably spend more time at the activities contributing to R_e . By doing so, they increase R_e *absolutely*, not just relative to R_1 and R_2 . To predict quantitatively, equation 1 would need to incorporate both the absolute and relative changes. The downwardly concave curves in Figure 5 suggest that R_e does, indeed, begin to increase rapidly as body weight rises.

The foregoing account of the various interconnected effects of hunger cannot be tested quantitatively at this point, for there are several parameters that may or may not be changing. Hunger certainly changes the reinforcing value of food; it may also change the amount of extraneous reinforcement and the degree of interaction between components. It would take substantially more data even to begin to attach magnitudes to any of those effects. However, the general framework set by equation 1 has been clearly supported by the present data. As noted in the introduction, however, the

data might also support any other theory that extended the matching law to multiple schedules. The basic finding here is simply that contrast varies inversely with drive, but only up to the value predicted by matching.

We should acknowledge, finally, that the persistence of pecking in the face of satiation and even free feeding came as something of a surprise. But no more a surprise than the analogous finding by Neuringer (1969). It is possible that longer exposure to the lesser drives would have reduced pecking further.

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