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THE RELATIVE LAW OF EFFECT: EFFECTS OF SHOCK INTENSITY ON RESPONSE STRENGTH IN MULTIPLE SCHEDULES[1]

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Key pecking of four birds was reinforced with food according to a two-component multiple variable-interval 1-minute variable-interval 4-minute schedule. In addition, key pecking was punished by a brief shock according to a variable-interval 30-second schedule during both components of the multiple schedule. The intensity of the shock was varied. For all birds, punishment had a stronger suppressive effect on the responding maintained by the leaner food schedule, and the ratio of responding during the two components of the multiple schedule became closer to the ratio of reinforcement as shock intensity was increased, as the relative law of effect predicts. At the higher shock intensity, there was some evidence that the ratio of responses overmatched the ratio of reinforcements.

Key words: punishment, relative reinforcement, response strength, relative law of effect, overmatching, multiple schedules, key peck, pigeons

The relative law of effect as formulated by Herrnstein (1970), accounts for the relation between two responses simultaneously available (concurrent schedules) or available only in alternation (multiple schedules) by the same input–output rule. According to this interpretation, the strength of a response is a function of the reinforcement it produces relative to all the sources of reinforcement simultaneously available plus a fraction of all other reinforcers obtained in preceding related situations. Formally, this rule is described by the equation:

$$R_1 = \frac{kr_1}{r_1 + mr_2 + r_e}. \qquad (1)$$

R_1 is the rate of the response under consideration, r_1 is the frequency of reinforcement contingent on R_1, r_e is the rate of all the other reinforcers simultaneously available, r_2 is the reinforcement frequency obtained in preceding related situations, m is a parameter determining what fraction of r_2 affects R_1, and k is a parameter dependent on the units of measurement and represents the asymptotic response rate as r_1 becomes very large.

In a concurrent schedule, when r_1 and r_2 are simultaneously available, the reinforcement interaction is maximal ($m = 1$), and it can be shown that the relation between the responses R_1 and R_2 associated respectively with r_1 and r_2, is described by the equation:

$$R_1 = R_2\,(r_1/r_2), \qquad (2)$$

which is just another way of saying that the proportion of responding matches the proportion of reinforcement.

Equation 2 predicts that as long at the ratio (r_1/r_2) is not altered, the relation between R_1 and R_2 will remain unchanged in the face of interventions that modify the value of r_1 and r_2, and of changes in the value of alternative sources of reinforcement (r_e). For example, McSweeney (1975) found that in concurrent variable-interval variable-interval schedules, varying the level of deprivation of pigeons did not disrupt the matching of relative responding to relative reinforcement.

On the other hand, when the two responses are not simultaneously available, Equation 1 predicts that if there is no reinforcement interaction across components ($m = 0$), the relation

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between R_1 and R_2 will be described by the equation:

$$R_1 = R_2(r_1/r_2)(r_2 + r_e)/(r_1 + r_e). \qquad (3)$$

If there is reinforcement interaction but at submaximal values $(0 < m < 1)$, Equation 1 predicts that the relation of R_1 to R_2 will be described by the equation:

$$R_1 = R_2(r_1/r_2)(r_2 + mr_1 + r_e) \div (r_1 + mr_2 + r_e). \qquad (4)$$

When R_1 is plotted as a function of R_2 in log log coordinates, Equations 3 and 4 produce a family of straight lines, parallel to the matching line (Equation 2); each straight line with a slope of one, and an intersection given by the ratio of reinforcers when R_2 equals one response per minute. The distance between a given straight line and the matching line decreases as the size of both m and r_e, relative to r_1 and r_2, increases. Furthermore, Equation 1 imposes the matching line as the limiting condition; that is, R_1 cannot be larger than the value R_2 (r_1/r_2).

Equation 1 implies that there are three ways by which response rate moves in the direction of the matching line. All involve an increase in either the size of m, the absolute value of r_e, or its value relative to r_1 and r_2. Each of these possibilities has been tested, and in each case, the proportion of R_1 to R_2 approached but did not exceed matching to reinforcement. Shimp and Wheatley (1971) and Todorov (1972) increased the value of m by decreasing the duration of the components of the multiple schedule. Nevin (1974*b*) increased the absolute value of r_e by presenting response-independent food in one of the components of a three-component multiple schedule; and finally, Herrnstein and Loveland (1974) changed the value of r_e relative to r_1 and r_2 by increasing the bird's body weight.

According to the negative law of effect as formulated by Rachlin and Herrnstein (1969), punishment would be another possible operation to decrease the value of contingent reinforcers. In this formulation, the effects of punishment are regarded as symmetrical to those of reinforcement. However, the precise form this relation takes has not been specified. In multiple schedules, if punishment suppresses absolute responding by a proportion of the contingent reinforcement associated with each response, Equations 3 and 4 predict that as punishment value is increased, R_1/R_2 will approach but not exceed r_1/r_2. Church and Raymond (1967) obtained evidence in favor of this relation. Working with groups of rats, a single response and one shock intensity, they found an inverse relation between the reduction in responding produced by punishment and reinforcement density. Mathematically, this interaction can be expressed as

$$R_1 = \frac{\dfrac{r_1}{p_1}}{\dfrac{r_1}{p_1} + m\left(\dfrac{r_2}{p_2}\right) + r_e}, \qquad (5)$$

where p_1 and p_2 represent the value of punishment associated with given frequencies and intensities of shock and are both larger than zero. The relation between R_1 and R_2 at different values of m would then become:

$$R_1 = R_2\left(\frac{r_1p_2}{r_2p_1}\right)\left(\frac{\dfrac{r_2}{p_2} + r_e}{\dfrac{r_1}{p_1} + r_e}\right) \quad \text{if } m = 0 \quad (6)$$

$$R_1 = R_2\left(\frac{r_1p_2}{r_2p_1}\right)\left(\frac{\dfrac{r_2}{p_2} + m\dfrac{r_1}{p_1} + r_e}{\dfrac{r_1}{p_1} + m\dfrac{r_2}{p_2} + r_e}\right) \quad \text{if } 0 < m < 1 \quad (7)$$

$$R_1 = R_2\left(\frac{r_1}{r_2}\right)\left(\frac{p_2}{p_1}\right) \quad \text{if } m = 1\,. \quad (8)$$

Equation 5 predicts that given $p_1 = p_2$ and $m < 1$, as the shock value is increased R_1/R_2 will approach but will not exceed r_1/r_2 (Equations 6 and 7). Equation 8, on the other hand, shows that at $m = 1$ matching is not affected by shock value.

Although the amount of the available evidence relevant to the problem of the relation between punishment and reinforcement is not very large, most of it is inconsistent with Equation 5. Varying shock intensity, Holz (1968) found continued matching in pigeons responding on a concurrent variable-interval 1.9-min variable-interval 7.5-min food schedule when each response produced an electric shock; varying relative rate of reinforcement, Tullis and Walters (1968) also found that relative response rate in a multiple schedule remained unchanged after punishment for each response was introduced. Since the matching of response ratios to reinforcer ratios means that the responses per reinforcer were equal for the two alternatives, a procedure where each response was punished implies that the ratio of punishment was equal to the ratio of reinforcers, and in such cases Equation 5 predicts a movement toward indifference.

Another representation of the interaction between reinforcement and punishment is provided by the following equation:

$$R_1 = [(kr_1)/(r_1 + mr_2 + r_e)] \\ [(r_1)/(r_1 + p_1)]. \tag{9}$$

From Equation 9, the following relations between two responses, R_1 and R_2, should hold as the parameter m is varied:

$$R_1 = R_2(r_1/r_2)^2[(r_2 + p_2)/(r_1 + p_1)] \\ [(r_2 + r_e)/(r_1 + r_e)] \quad \text{if } m = 0 \tag{10}$$

$$R_1 = R_2(r_1/r_2)^2[(r_2 + p_2)/(r_1 + p_1)] \\ [(r_2 + mr_1 + r_e)/(r_1 + mr_2 + r_e)] \\ \text{if } 0 < m < 1 \tag{11}$$

$$R_1 = R_2(r_1/r_2)^2(r_2 + p_2)/(r_1 + p_1) \\ \text{if } m = 1. \tag{12}$$

Equation 9 accounts for the absence of a punishment effect on relative response rates (Holz, 1968; Tullis and Walters, 1968), since it predicts that the relation between R_1 and R_2 will not be affected as long as $r_1/r_2 = p_1/p_2$ (Equations 11 and 12), a condition that was satisfied in those experiments. On the other hand, if $p_1 = p_2$, two relevant predictions follow from Equation 9 as shock value is increased independently of the value of m. First, of two response rates, the one associated with the leaner schedule of reinforcement will decrease faster. This prediction is consistent with the data reported by Church and Raymond (1967). Second, the relation between R_1 and R_2 will approach but will not exceed $(r_1/r_2)^2$.

In the present experiment, the effects of varying the intensity of response-dependent electric shock on the relation between two responses of a two-component multiple schedule were evaluated. The two responses were maintained by different reinforcement densities, but both produced an equal shock rate. Assuming that relative response rates follow Herrnstein's matching equation, the two equations (5 and 9) relating reinforcement and punishment parameters to response strength predict that as shock intensity is increased, the response rate producing the lowest reinforcement density will decrease faster. However, they also predict different limiting values for the relation between R_1 and R_2. Whereas Equation 5 sets matching as the limit, Equation 9 allows for overmatching and sets the limit at $(r_1/r_2)^2$.

METHOD

Subjects

Four adult White Carneaux pigeons with experimental experience in discrete trial procedures, were maintained at approximately 80% of their free-feeding body weights.

Apparatus

A standard three-key experimental chamber 32 cm long, 29 cm wide, and 29 cm high was used. The two side keys were covered, and the center key, 2 cm in diameter, required a minimum force of 0.15 N to be operated. Each effective peck resulted in feedback from a relay. The key could be transilluminated by red or green lights. Continuous diffuse illumination was provided by a houselight at the back of the chamber. Below the center key there was an opening into a standard feeding magazine. During reinforcement, the keylight and the houselight went off, while the magazine was lit with white light. Reinforcement consisted of 3-sec access to mixed grain. The punisher was a 35-msec pulse of 60 cps ac through a series of fixed and variable resistances to two gold wires implanted around the pigeons' two pubic bones (Azrin, 1959). Extraneous noises were masked by continuous white noise. Programming and recording equipment were located in an adjacent room.

Procedure

Key pecking produced food according to a two-component multiple variable-interval 4-min variable-interval 1-min (*mult* VI 4-min VI 1-min) schedule. The components alternated every 4 min and were signalled by the illumination of the key by a red light (VI 1-min component) or a green light (VI 4-min component). Each daily session ended after 16 components had been presented.

After a stable response rate was obtained in this condition, a punishment contingency was superimposed. During both components of the multiple schedule, key pecking produced a brief shock (0.35 sec) according to a VI 30-sec schedule. Each of the tapes scheduling food and shock consisted of 12 intervals taken from the progression developed by Fleshler and

Table 1

Sequence of conditions, magnitude in mA of shock intensity, number of sessions, and standard deviations of the response rate during the last five days of each condition (in parenthesis). Responding was maintained by a *mult* VI 1-min VI 4-min schedule of food reinforcement.

	Shock Intensity (mA)								
	Bird 56		*Bird 29*		*Bird 54*		*Bird 98*		
Conditions	*VI 1*	*VI 4*	*VI 1*	*VI 4*	*VI 1*	*VI 4*	*VI 1*	*VI 4*	*Number of Sessions*
I	0		0		0		0		20
	(7)	(4)	(6)	(8)	(9)	(10)	(10)	(5)	
II	1		2		2		2		20
	(7)	(6)	(5)	(5)	(5)	(5)	(7)	(12)	
III	1.5		3		3		3		20
	(4)	(8)	(5)	(4)	(7)	(7)	(6)	(0)	
IV	2		4		4		1		20
	(9)	(5)	(5)	(8)	(3)	(6)	(2)	(5)	
V	0		5		5		2		20
	(9)	(7)	(8)	(2)	(4)	(3)	(6)	(8)	
VI			6		6		0		20
			(5)	(1)	(7)	(3)	(3)	(3)	
VII			0		0				20
			(6)	(2)	(4)	(4)			

Hoffman (1962). In the case that food and shock were both scheduled for a peck, the first peck produced the reinforcer, and a second peck was required for the shock to be delivered. During the experiment, the intensity of the shock was manipulated. Table 1 shows the order of exposures, number of sessions, and magnitude in mA of the shock intensity. An ascending series of shock intensity was used, except for Bird 98, which stopped responding after only two conditions. For Bird 56, the shock intensity of the first condition was 1 mA instead of 2 mA, because there was evidence from a previous study of its high sensitivity to electric shock. In the final condition, the shock was withdrawn. Each condition was presented for a fixed number of sessions.

RESULTS

The connected points in Figure 1 show for individual birds the effects of varying shock intensity on the absolute rate of key pecking during both components of the multiple schedule. Each point represents the mean absolute response rate during the last five days of each condition. The corresponding standard deviations are presented in Table 1. The continuous line connects the response rates during the VI 1-min component; the broken line connects the response rates during the VI 4-min component. When a point was replicated, the mean of the replications is presented, except for the second baseline condition (no shock), which was presented last and is presented as the unconnected points on the extreme right of each panel in Figure 1. During baseline, the absolute response rate for all the birds was higher during the VI 1-min component than during the VI 4-min, and response rates in both decreased as shock intensity was increased. This relation was smoother during the VI 4-min component. The response rates of Birds 56 and 98 during the VI 1-min component decreased irregularly and abruptly.

Figure 1 also shows the effects of shock intensity on the deviation of relative response rate from the relative obtained reinforcement rate in the two components of the multiple schedule. The procedure suggested by Herrnstein and Loveland (1974) for the analysis of similar data consists in computing for each condition the obtained relative rate of reinforcement during the last five days and the overall absolute rate of key pecking across components. Then, a predicted absolute rate of responding for each component is calculated according to the relative obtained rate of reinforcement for that component. For example, if the obtained relative rate of rein-

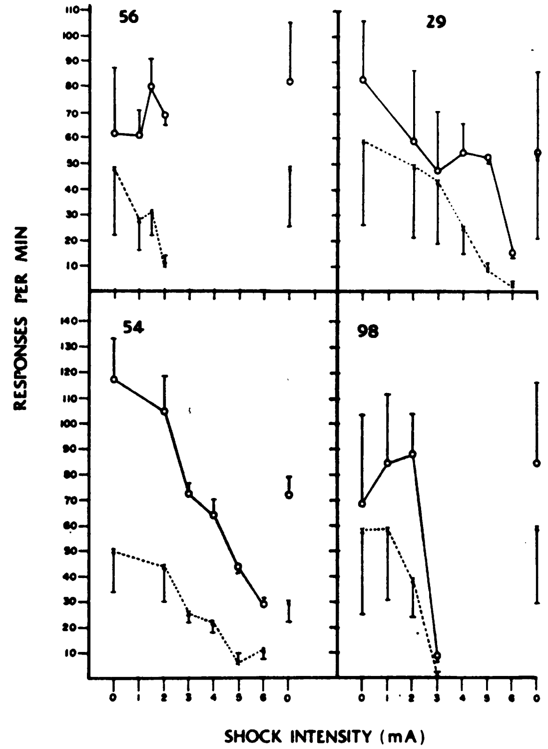

Fig. 1. Each panel shows for a bird the mean absolute rates of key pecking in both components of the *mult* VI 1-min VI 4-min schedule as a function of shock intensity averaged over the last five days of each condition. The end of the vertical lines shows the response rates predicted if matching were obtained. The unconnected points represent the results of a second replication of baseline (no shock).

forcement was 0.80 for the VI 1-min component and 0.20 for the other component, and the absolute rate of responding across components was 100 responses per minute, then the predicted absolute rates of key pecking if the animals were matching would be 160 and 40 responses per minute respectively. In Figure 1, the short horizontal line at the end of the vertical lines represents the predicted rates of responding if the animals were matching. For all birds, the higher the shock intensity, the smaller the difference between the actual and predicted rates of key pecking, until they were virtually identical for all birds, except 56. For this bird, at the last shock intensity at which it responded, the direction of the deviation from matching was reversed toward overmatching; that is, the obtained response rate associated with the higher reinforcement density was larger than that predicted, whereas the one associated with the smaller reinforcement density was lower than that predicted. Birds 54 and 29 also showed some overmatching when shock intensity was 5 mA, but their relative response rate went back to matching at the last shock intensity under study (6 mA). For all birds, when the shock was removed, response rate went up; however, only for Birds 56 and 98 did the obtained and the predicted response rates go back to levels found in the first baseline condition.

The effects of shock intensity on matching are presented in a different way in Figure 2. For each bird, the difference between relative response rate and relative obtained reinforcement rate for the VI 1-min component was computed during the last five days of each condition. A value of zero indicates matching. For every pigeon, as shock intensity was increased the value of the difference from matching decreased from about 0.20 to zero or slightly above, but it was never more than 0.05 above matching.

Implicit in Equation 1 is the notion that the approach to matching as shock intensity is increased is a consequence of the higher sensitivity to shock of the response rate associated with the "leaner" component. Figure 3 shows that this is the case. For individual birds, the mean rate of key pecking during each component for the last five days of each condition was computed as a proportion of the mean of the two baseline determinations. For every bird, the response associated with the lower

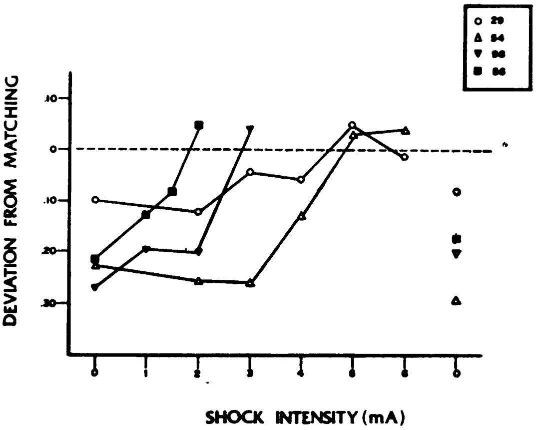

Fig. 2. For each bird is shown the mean difference between the relative rate of responding under the VI 1-min schedule and the predicted relative rate of pecking if the pigeons were matching, averaged over the last five days of each condition.

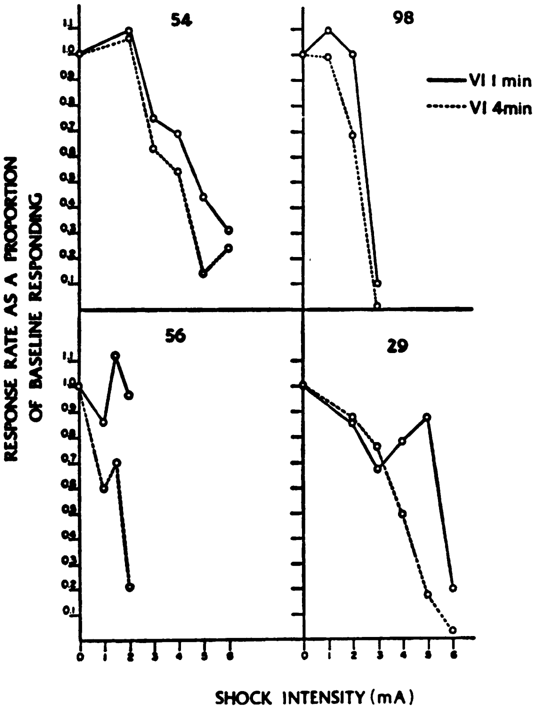

Fig. 3. For each bird is shown the mean absolute rate of key pecking during each component as a proportion of the mean response rate during the two baseline conditions, averaged over the last five days of each condition.

reinforcement frequency was proportionally more suppressed at every shock intensity, except for Bird 29 at 2- and 3-mA shock intensities.

DISCUSSION

Nevin (1974*b*) and Smith (1974) suggested that resistance to change is the best available indicator of response strength. According to this criterion, Figure 3 shows that responding maintained by a VI 1-min schedule is stronger than responding maintained by a VI 4-min, since they were suppressed in different proportions as shock intensity was increased. Implicit in Equation 1 is the notion that as long as $m < 1$, the response associated with the "leaner" reinforcement density will be more susceptible to operations that reduce response strength, such as those used by Nevin (1974*b*) and Herrnstein and Loveland (1974). Nevin (1974*a*; *b*) formalized the notion of resistance to change as a measure of response strength by describing the relation between R_1 and R_2 as a power function of the form $R_1 = R_2^n$. In this equation, the size of the exponent n represents the difference in strength between two responses. This formulation is similar to Herrnstein's, in that both predict that if R_1 is plotted as a function of R_2 in log log coordinates and if R_2 is associated with a lower reinforcement rate, then a straight line with a slope smaller than one will fit the data. The relative law of effect makes two additional predictions: first, if the operation reducing responding does not interact with relative reinforcement, then the ratio r_1/r_2 will be the intercept of the straight line; second, both responses will decrease by the same proportion, that is the slope of the line will be equal to one, when $m = 1$.

In Figure 4, the absolute response rate during the VI 1-min component is plotted against the absolute response rate during the VI 4-min component. Each point represents the mean of the last five days of each condition. A straight line was fitted to the data points by a least-squares procedure. Consistent with Herrnstein's and Nevin's formulations, the slope of the fitted line was less than one. However, contrary to predictions from Equation 1, the intercept of the fitted line is above that of the matching line. This overmatching is consistent with Nevin's power-function formulation.

Nevertheless, overmatching does not necessarily undermine the relative law of effect, since Equation 1 sets matching as the limiting

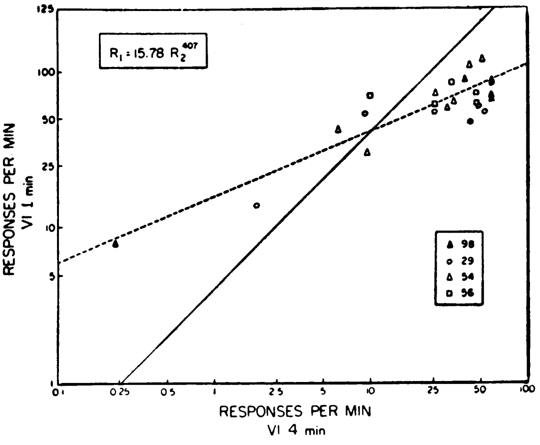

Fig. 4. For each subject, the absolute response rate during the VI 1-min component is plotted against the absolute response rate during the VI 4-min component in log log coordinates. Each point represents the mean of the last five days of a condition. The straight continuous line represents the locus of matching.

condition only when punishment does not alter the ratio of reinforcement -r_1/r_2- as it is expressed by Equation 5 and its derivations. Another type of interaction consistent with the relative law of effect and with overmatching is expressed by Equation 9, here presented again for convenience

$$R_1 = [(kr_1)/(r_1 + mr_2 + r_e)] \\ [(r_1)/(r_1 + p_1)]. \tag{9}$$

Equation 9 and its derivations for different values of m produces a family of straight parallel lines with a slope less than one and an intercept falling within the range delimited by the ratios r_1/r_2 and $(r_1/r_2)^2$. The larger the absolute value of m and the value of r_e relative to r_1 and r_2, the closer will the intercept be to $(r_1/r_2)^2$. The results presented in Figure 4 are well described by Equation 9, the value of the intercept suggesting that either m was very close to one or that punishment had an effect on the absolute value of r_e. DeVilliers (1976, p. 253) provided additional evidence for the superiority of Equation 9 over 5 as a description of reinforcement-punishment interactions. He found that as shock intensity was increased, the relative response rate overmatched the relative reinforcement rate in a concurrent variable-interval variable-interval food schedule, with each response producing an equal frequency of shocks.

Although Equation 9 accounts fairly well for relative response rates, it does not predict the occasional evidence of behavioral contrast produced by punishment of one alternative in multiple (Brethower and Reynolds, 1962; Terrace, 1968) and concurrent schedules (Deluty, 1976). Working with rats in a concurrent variable-interval variable-interval food and shock schedule, Deluty (1976) found an inverse relation between the effects of punishing a response and the frequency of punishment produced by an alternative response. To account for this contrast effect Deluty suggested the following equation:

$$R_1 = k(r_1 + p_2)/ \\ (r_e + r_1 + r_2 + p_1 + p_2). \tag{13}$$

To evaluate its applicability to the present data, Equation 13 was modified for the case of a multiple schedule, that is, to a form equivalent to Equation 1 as follows:

$$R_1 = \frac{k(r_1 + mp_2)}{r_1 + r_e + p_1 + m(r_2 + p_2)}. \tag{14}$$

The next three equations describe the relation between two responses at different values of m, assuming that Equation 14 holds:

$$R_1 = R_2 \left(\frac{r_1}{r_2}\right)\left(\frac{r_2 + r_e + p_2}{r_1 + r_e + p_1}\right) \quad \text{if } m = 0, \tag{15}$$

$$R_1 = R_2 \left(\frac{r_1 + mp_2}{r_2 + mp_1}\right) \left(\frac{r_2 + r_e + p_2 + m(r_1 + p_1)}{r_1 + r_2 + p_1 + m(r_2 + p_2)}\right) \quad \text{if } 0 < m < 1, \tag{16}$$

$$R_1 = R_2 \frac{r_1 + p_2}{r_2 + p_1} \quad \text{if } m = 1. \tag{17}$$

It can be seen that, contrary to the present results, at all values of $m > 0$ Deluty's equation predicts that when $p_1 = p_2$ the relative rate of responding will move toward indifference (undermatching) as the value of punishment is increased. Furthermore, when R_1 is plotted as a function of R_2 in log log coordinates, the slope of the lines predicted by Equations 16 and 17 are either negative or equal to zero.

Before attempting to modify Equation 9 to account for punishment-produced contrast, the reliability of this phenomenon still has to be established (Bouzas, 1976; Dinsmoor, 1952; Rachlin, 1966). Furthermore, in many of the instances when found, punishment has interacted with reinforcement density (Brethower and Reynolds, 1962; Deluty, 1976). Since according to Equation 9 punishment magnifies the effects of any difference in reinforcement density, it would be possible to account for contrast as a case of overmatching. To evaluate this possibility, Equation 9 was used to compute relative reinforcement and relative responding from Deluty's data, and a straight line was fitted by a least-squares technique. The equation $Y = 1.056X - 0.015$ was thus obtained, which accounts for 85% of the variance, Equation 9 doing as well as Deluty's equation.

The present experiment is silent about the possible reinforcement and punishment interactions across components, and it leaves unanswered the question of the possible effects of punishment on the absolute value of alternative sources of reinforcement (Dunham, 1971; Herrnstein and Loveland, 1974). These are important questions that only further research can answer, but they are immaterial to the purpose and conclusions of this experiment. According to Equations 1 and 9, changes in the parameters m and r_e change only the speed with which matching to either r_1/r_2 or $(r_1/r_2)^2$ is achieved, not the form of the approach nor the fact that these two values are the limiting values. The present results support a view of response strength in which reinforcement and punishment are evaluated within the context of further reinforcement, and show the value of Equation 1 for determining the type of interaction between operations affecting response strength in both multiple and concurrent schedules.

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