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EFFECT OF PUNISHMENT ON HUMAN VARIABLE-INTERVAL PERFORMANCE

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Three female human subjects pressed a button for monetary reinforcement in a range of variable-interval schedules specifying different frequencies of reinforcement. On alternate days, responding was also punished (by subtracting money) according to a variable-ratio 34 schedule. In the absence of punishment, rate of responding was an increasing negatively accelerated function of reinforcement frequency; the relationship between response rate and reinforcement frequency conformed to Herrnstein's equation. The effect of the punishment schedule was to suppress responding at all frequencies of reinforcement. This was reflected in a change in the values of both constants in Herrnstein's equation: the value of the theoretical maximum response-rate parameter was reduced, while the parameter describing the reinforcement frequency corresponding to the half-maximal response rate was increased.

Key words: Herrnstein's equation, response rate, reinforcement frequency, variable-interval, variable-ratio punishment, button pressing, humans

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Herrnstein (1970) proposed an equation of the following form to describe the relationship between response rate and reinforcement frequency in variable-interval (VI) schedules of reinforcement

$$R = R_{max} \cdot r/(K_H + r),$$

where R is the rate of responding and r is the frequency of reinforcement, and where the constants R_{max} and K_H express the maximum response rate and the reinforcement frequency corresponding to the half-maximal response rate, respectively (Bradshaw, Szabadi, and Bevan, 1976*b;* Herrnstein, 1974). This equation defines a rectangular hyperbola. Using the data of Catania and Reynolds (1968), Herrnstein (1970) showed that Equation (1) accurately describes the behavior of pigeons in VI schedules. We have recently reported that the behavior of human subjects in VI schedules also conforms to this equation (Bradshaw *et al.*, 1976*a, b*).

Several disparate experimental variables are known to suppress responding in VI schedules. These include punishment with electric shock (Azrin, 1960), an increase in effort requirement (Chung, 1965), and the concurrent availability of an alternative source of reinforcement (Bradshaw *et al.*, 1976*b;* Catania, 1963). On the basis of Equation (1), a variable that suppresses responding in VI schedules may be assigned to one of the following three categories: (i) variables that reduce the maximum response rate (R_{max}), (ii) variables that increase the reinforcement frequency needed to obtain the half-maximal response rate (K_H), and (iii) variables that do both. (Note that the suppression of responding brought about by variables belonging to any of these three categories may also reduce the frequency of reinforcement delivery.)

In a previous study of human VI performance, we found that a concurrent schedule of reinforcement belongs to the second of these categories (Bradshaw *et al.*, 1976*b*). In the present paper, we report that punishment, in the form of response-cost delivered on a variable-ratio (VR) schedule, belongs to the third category.

METHOD

Subjects

Three female volunteer subjects (BJ, JL, VG) aged 30 to 34 yr, were all experimentally

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naive at the start of training, and had no previous training in psychology.

Apparatus

Experimental sessions took place in a small room. The apparatus used was similar to that described previously (see Bradshaw *et al.*, 1976*b*, Figure 1). The subject sat at a desk facing a sloping panel (40 cm wide and 30 cm high), on which were mounted a row of five amber lights (labelled 1 to 5, from left to right) 2 cm from the top of the panel, a digital counter situated in the center of the panel, and a green and a red light mounted side by side 1 cm below the counter. The green and red lights were labelled "WIN" and "LOSE" respectively. In front of the panel was a button that could be depressed by a force of approximately 6 N. Auditory response feedback was provided by a relay situated behind the panel. Pinned to the wall facing the subject was a notice on which was written either "GOOD DAY" or "BAD DAY", referring to the presence or absence of the punishment schedule (see below, Procedure).

Conventional electromechanical scheduling and recording equipment was situated in another room, judged by the experimenters to be out of earshot from the experimental room. Additional masking noise was provided by a radio.

Procedure

On the first day of training, the subjects were instructed as follows:

> This is a situation in which you can earn money. You earn money simply by pressing this button. Sometimes when you press the button the green light will flash on: this means you will have earned one penny. The total amount of money you have earned is shown on this counter. You will start each day with 25p registered on the counter; every time the green light flashes it adds one point to the total score. (Please ignore the red light; it will not apply to you for the first two days). When operating the button make sure you press hard enough. You can tell whether you have pressed hard enough by listening for a slight click coming from inside the box. Now look at these orange lights. When one of the orange lights is on, it means that you are able to earn money. At the beginning of the session one of the lights will come on and will stay on for 10 minutes and throughout this time you may earn money. At the end of 10 minutes the light will go off for 5 minutes and during this time you should rest. After the rest period, another light will come on, again for 10 minutes, and you may earn some more money. Then there will be another rest period, and so on until each of the five orange lights has been presented. At the end of the session we will take the reading from the counter and note down how much you have earned. You will be paid in a lump sum at the end of the experiment.

The five amber lights were each associated with a different VI schedule. Constant probability schedules were used, as described by Catania and Reynolds (1968). The reinforcement frequencies specified by the schedules were as follows: 1: 445 reinforcements per hour (VI 8-sec); 2: 211 reinforcements per hour (VI 17-sec); 3: 70 reinforcements per hour (VI 51-sec); 4: 21 reinforcements per hour (VI 171-sec); 5: 5 reinforcements per hour (VI 720-sec). Reinforcement consisted of a 100-msec illumination of the green light and the addition of one point to the score displayed on the counter.

On the third day, the subjects received the following additional instructions:

> The last two days were "Good Days". Today, and every alternate day from now on, will be a "Bad Day". On "Bad Days" you will not only stand a chance of winning money, but also of losing money. Sometimes when you press the button the red light will flash and one penny will be subtracted from your total score displayed on the counter. As usual, "wins" will be signalled by the green light.

On Bad Days, punishment, consisting of a 100-msec illumination of the red light and the subtraction of one point from the score displayed on the counter, was delivered according to a VR 34 schedule, irrespective of which VI schedule of reinforcement was in operation. Distribution of the ratios in the VR punishment schedule was the same as distribution of the intervals in the VI reinforcement schedule.

If a reinforcement and a punishment were both scheduled for the same response, both the green light and the red light were illuminated, but the score displayed on the counter did not change.

The five VI schedules were presented in a random sequence, with the constraint that each schedule occurred in a different ordinal position on successive days. Experimental sessions took place at the same time each day on at least 30 successive working days (VG: 30 sessions; BJ: 35 sessions; JL: 31 sessions). Visual inspection of the raw data indicated that the behavior of all three subjects had reached stability by this time.

RESULTS

Performance in the Absence of Punishment

The mean response rates (R ± s.e.m.) recorded in each schedule during the last three Good Days (no punishment) were calculated individually for each subject, and were plotted against reinforcement frequency (r). In the case of all three subjects, response was an increasing, negatively accelerated function of reinforcement frequency, approaching an asymptote at high values of reinforcement frequency. Rectangular hyperbolae were fitted to the data by computer using nonlinear regression analysis (Wilkinson, 1961). This method gives estimates (±s.e.est.) of the theoretical maximum response rate (R_{max}) and the reinforcement frequency corresponding to the half-maximal response rate (K_H). Figure 1 (closed circles) shows the data obtained from all three subjects; the estimated values of the constants are shown in Table 1. The index of determination (p^2) was calculated for the curve obtained from each subject (p^2 expresses the proportion of the variance of the y-values that can be accounted for in terms of x, in a curvilinear function [Lewis, 1960].). The values of p^2 were 0.969 (BJ), 0.987 (JL), and 0.986 (VG).

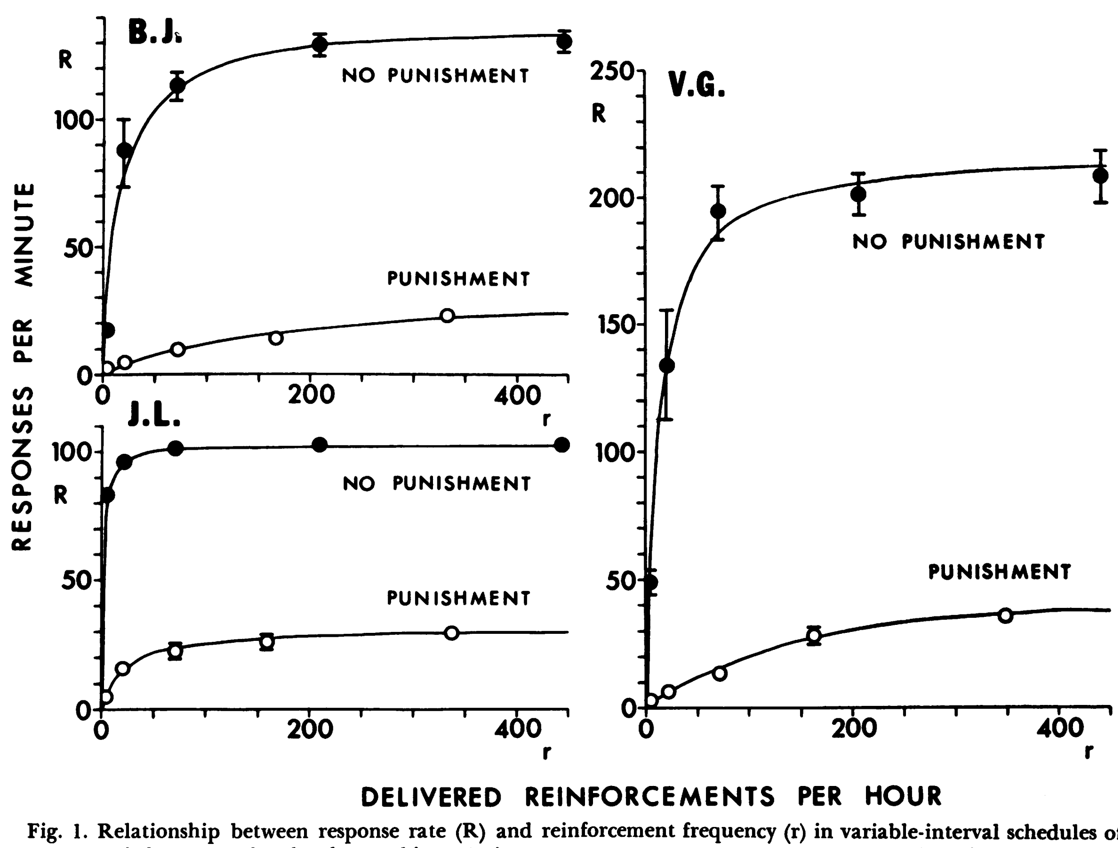

Fig. 1. Relationship between response rate (R) and reinforcement frequency (r) in variable-interval schedules of monetary reinforcement for the three subjects. Points are mean response rates (±s.e.m.) for last three sessions in the absence of punishment (closed circles), and in the presence of VR 34 punishment, (open circles). Curves are best-fit rectangular hyperbolae, fitted by nonlinear regression analysis. (Note that values of r refer to frequencies of delivery of positive reinforcement; punishment frequency has not been subtracted.)

Table 1

Estimated values of the constants, obtained by nonlinear regression analysis from plots of response rate *versus* delivered reinforcement frequency (see Figure 1).

	No Punishment		VR 34 Punishment	
Subject	R_{max} (resp/min)	K_H (rft/hr)	R_{max}' (resp/min)	K_H' (rft/hr)
B.J.	139.3 (±8.5)	16.8 (±5.0)	37.9 (±8.5)***	213.5 (±101.9)*
J.L.	102.5 (±0.6)	1.3 (±0.1)	31.2 (±1.9)***	23.2 (±6.1)**
V.G.	218.8 (±7.6)	13.8 (±2.4)	55.9 (±5.7)***	172.3 (±40.2)**

Significance of changes in the values of the constants (t test):
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Performance in the Presence of Punishment

The mean response rates ($R \pm$ s.e.m.) recorded in each schedule during the last three Bad Days (with VR 34 punishment) were calculated for each subject, and were plotted against reinforcement frequency (r). Rectangular hyperbolae were fitted to the data by the method of Wilkinson (1961). The results obtained from all three subjects are shown in Figure 1 (open circles) and the estimated values of the constants (R_{max}' and K_H') are shown in Table 1. The values of p^2 were 0.959 (BJ), 0.968 (JL), and 0.994 (VG).

For all three subjects there was a marked suppression of responding in the presence of punishment on all five VI schedules. The suppression of responding in the presence of punishment was reflected in a statistically significant decrease in the estimated values of R_{max}, and in a statistically significant increase in the estimated values of K_H (Table 1). The magnitudes of changes in the values of the constants were similar for the three subjects: R_{max} was reduced by 72.8% (BJ), 69.6% (JL), and 74.4% (VG), while K_H was increased by factors of 12.7 (BJ), 17.8 (JL), and 12.5 (VG).

Delivered versus *Scheduled Reinforcement Frequency*

In the absence of punishment, the delivered reinforcement frequency was in every case within 5% of the scheduled reinforcement frequency. In the presence of VR 34 punishment, the delivered reinforcement frequency was within 10% of the scheduled reinforcement frequency in the case of Schedules 3, 4, and 5. However, in the case of Schedules 1 and 2, which specified higher reinforcement frequencies, the delivered reinforcement frequency was up to 25% lower than the scheduled reinforcement frequency.

DISCUSSION

The results obtained in the absence of punishment are in agreement with our previous finding (Bradshaw *et al.*, 1976*a*, *b*) that the behavior of human subjects in VI schedules can be described by Herrnstein's equation.

In the presence of VR punishment, rates of responding under all VI schedules studied were suppressed. Qualitatively similar observations were made by Weiner (1962), using a different experimental procedure. Weiner reported that the responding of humans in VI schedules could be markedly reduced by the introduction of a response-cost procedure in which every response was penalized. The present results indicate that punishment does not change the hyperbolic nature of the relationship between response rate and reinforcement frequency (see eq. [1]); rather, it results in a change in the values of the two constants R_{max} and K_H, the value of R_{max} being reduced and the value of K_H being increased. Response suppression due to punishment thus differs from response suppression due to the concurrent availability of an alternative source of reinforcement, since in the latter case there is an increase in the apparent value of K_H without a reduction in the value of R_{max} (Bradshaw *et al.*, 1976*b*).

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