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WHAT IS THE NECESSARY AND SUFFICIENT CONDITION FOR REINFORCEMENT IN THE CONTINGENCY SITUATION?[1]

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A set of experiments was initiated to test Premack's hypothesis that any more probable response will reinforce any less probable response. In the 1st experiment, the more probable response reinforced the less probable response only when the contingent behavior was suppressed beneath the free-performance level. Hypothesizing the necessary and sufficient condition for reinforcement to be the animal's necessity of increasing instrumental responding if it is to maintain contingent responding at the free-performance level, it was correctly predicted that upon establishing such a condition the less probable response would reinforce the more probable response. The general conditions underlying such "response suppression" are denoted mathematically, and the specific conditions associated with the reinforcement effect in Premack's confirmatory experiments are derived as a special case of response suppression.

Premack (1959, 1961, 1965) hypothesized any more probable response will reinforce any less probable response, the response probabilities being assessed when the animal may freely perform either behavior ("operant period"). Predictions based on this hypothesis led to the demonstration that traditional goal behaviors could themselves be reinforced. Recording the amounts of candy eating and pinball-machine manipulation in an operant period, Premack (1959) reported that in accord with the traditional hedonistic viewpoint, some children (those with the higher operant probability of eating than manipulating) subsequently increased manipulation above operant level for the opportunity to eat and did not increase eating for the opportunity to manipulate. However, those children with the higher probability of manipulating than eating, increased eating above operant level for the opportunity to manipulate and did not increase manipulation for the opportunity to eat. Further, using a Cebus monkey, manipulatory responses were shown to reinforce other less probable manipulatory responses, but not more probable manipulatory responses (Premack, 1963). And, to show that the reinforcement relation between two behaviors could be reversed for the individual *S*, parameters were manipulated to make activity-wheel running by rats more probable than drinking and, in

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Some of the results were presented in a paper at the Western Psychological Association Convention, Long Beach, April 1966. The first three experiments were performed at California State College, Los Angeles, the fourth experiment at University of California, Santa Barbara. Of the junior authors, Karpman aided in the planning and execution of Exp. I and Trattner in preliminary exploratory studies.

the same *S*s at another time, drinking more probable than running. In both situations, upon instituting a contingency, the more probable response reinforced the less probable response (Premack, 1962).

Experiment I

Previous experiments utilized rats, monkeys, and young children at low or moderate operant probabilities of the instrumental response (less than .15, where reported: see Premack, 1963; Schaeffer, 1965). Experiment I used young adults and tested whether probability differential (i.e., the higher free-performance probability of the contingent response than instrumental response) is sufficient for reinforcement at both high and low probabilities of the instrumental response.

Method

Subjects and apparatus.—Thirty-nine college students, most of whom were enrolled in introductory psychology courses and a few with no course work in psychology, served as *S*s. A Wahman activity wheel was equipped with a solenoid-operated brake which, when deactivated, made contact with the wheel. The brake was not visible to *S*s. A wooden handle was attached to the rim of the wheel, and a bar press was placed nearby; turning the wheel by its handle and pressing the bar were intended as manipulatory responses. A specially designed control panel allowed *E* to provide *S*s with an operant period (unlocked bar and wheel) or to set an instrumental requirement (a given number of bar presses required of *S*s to unlock the wheel, and duration of time the wheel subsequently remained unlocked). Bar presses and wheel turns were recorded on digital counters and on an Esterline Angus recorder. Duration of time spent turning the wheel was recorded on a Standard electric timer.

Procedure.—Each *S* was seated in front of the wheel and bar press, and told:

> Please sit and remain in this chair until you are told the experiment is over. Before you, you see a wheel with a wooden handle on it and also a metal bar. [Experimenter pointed to each of the items as he named it.] When I say to you "go ahead," you may, with either one or both hands, press the metal bar or turn the wheel by its handle. How you spend your time is up to you so long as you remain seated. You may press the bar; you may turn the wheel; you don't have to press the bar; you don't have to turn the wheel; or you can do both at the same time. I repeat—*you may press the bar; you may turn the* wheel; you don't have to press the bar; you don't have to turn the wheel; or you can do both at the same time.
>
> Do you have any questions about these directions?
>
> All right. Go ahead.

Each *S* thereupon received a 5-min. operant period, followed by a 5-min. contingency period in which the wheel could be unlocked for 10 sec. at a time by one press of the bar. The sound of the brake clearly signaled the locking and unlocking of the wheel during the contingency period. Each succeeding instrumental requirement could be met only after the wheel had relocked; keeping the wheel unlocked for the full 5 min. would have necessitated one bar press every 10 sec., for a total of 30 presses.

Results

Premack's probability differential hypothesis predicted reinforcement for *S*s having the higher free-performance probability of the contingent response (wheel turning) than instrumental response (bar pressing). Of the 39 *S*s, 36 spent more time in the operant period turning the wheel than pressing the bar, and therefore had a higher average probability of wheel turning than bar pressing. These 36 *S*s were divided into two groups, the higher-than-median operant bar pressers and the lower-than-median operant bar pressers. The "High" bar press group had a median operant probability of bar pressing of .22; the "Low" bar press group's median probability was .01. A statistically significant proportion of the Low bar pressers increased their number of bar presses from the operant to contingency period, 14 out of 18 *S*s with 1 not changing, $p < .01$, one-

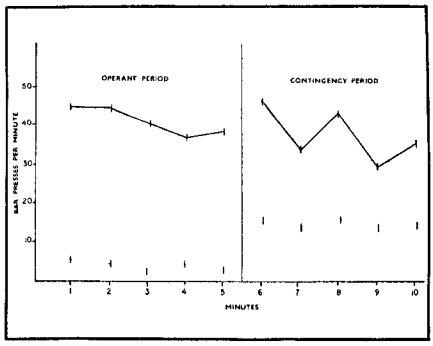

FIG. 1. Mean number of bar presses (instrumental response) performed by the High bar pressers (solid line) and by the Low bar pressers (dotted line) each minute of the operant and contingency periods. (Data was available for 15 of the 18 High bar pressers and all 18 of the Low bar pressers.)

tailed binomial sign test. However, the proportion of High bar pressers showing an increase did not exceed that expected by chance alone, 7 out of 18 *S*s, $p = .6$, one-tailed binomial sign test. The proportion of Low bar pressers surpassing their operant rate was significantly greater than that of the High bar pressers, $\chi^2 (1) = 8.7$, $p < .005$ (Fig. 1 shows for each group the mean number of bar presses performed each minute of the operant and contingency periods). Thus the more probable response was demonstrated to reinforce the less probable response only for *S*s having a relatively low free-performance probability of the instrumental response.

Previous experiments (Premack, 1961, 1963) suggested two plausible explanations, still assuming validity of the probability differential hypothesis, for failure to detect the reinforcement effect among High bar pressers. First, the method of determining if a given *S* had a higher free-performance probability of wheel turning than bar pressing was to compare the total operant durations of the two responses. Such an approximation would not be sensitive to some reversals of response-probability order near the close of the operant period. As a test for response-probability reversals among *S*s who did not increase instrumental responding from the operant to contingency period, each such *S*'s difference in duration of time spent wheel turning and bar pressing for the first operant minute was compared with his difference for the last operant minute. The necessary data was available for 13 of the 15 *S*s who showed no increase in instrumental responding. For none of these *S*s was there a reversal of response-probability order: 8 *S*s increased their margin of wheel turning over bar pressing, 3 still maintained a difference of over 100%, 1 a difference of 87%, and 1 a difference of 3%.

A second plausible explanation was that the reinforcement occurring for High bar pressers was masked, due to a decline throughout the experimental session of the free-performance level of the instrumental response (bar pressing). To control for such a possibility, for each *S* in the High and Low bar-press groups the change in number of bar presses from that in the first operant minute to that in the last operant minute was extrapolated to the last minute of the contingency period. The *S*s whose number of bar presses in the last minute of the contingency period exceeded their extrapolated operant rate, were counted as having been reinforced. Of the 18 Low bar pressers, 15 surpassed their extrapolated rate, 1 fell below it, and 2 equaled it, $p < .005$, of as high a proportion by chance alone, one-tailed binomial sign test. Of the 15 High bar pressers for which the necessary data was available, 7 surpassed their extrapolated rate while 8 fell below it, $p = .7$, of as high a proportion by chance alone, one-tailed bi-

nomial sign test. Further, the proportion of Low bar pressers exceeding their extrapolated rate was significantly greater than that of the High bar pressers, χ^2 (1) = 5.2, p <.025. Thus, use of a reinforcement criterion sensitive to changes in free-performance level of instrumental responding did not eradicate the failure to demonstrate reinforcement for *S*s having the high free-performance level of instrumental responding.

Experiment II

This failure suggested three alternative reformulations of the necessary and sufficient conditions for reinforcement:

1. *Probability differential-low instrumental probability.* In addition to the higher probability of the contingent response than instrumental response, the probability of the instrumental response must be sufficiently low.

2. *Probability differential-response suppression.* In addition to probability differential, the instrumental requirement must be sufficient to suppress contingent responding beneath its free-performance level.[2] Such "response suppression" did not occur for most of the first experiment's High bar pressers; their operant bar-press level was sufficiently high and the instrumental requirement sufficiently low that without increasing instrumental responding above operant level, the *S*s were still able to turn the wheel for as long a duration of time, on the average, in the contingency period as they had in the operant period (see Fig. 1 and 2). By definition, response suppression occurs when it is necessary for an individual to increase instrumental responding above free-performance level if he is to be able to perform the contingent response the same amount in the contingency period as he would in the free-performance situation.

3. *Response suppression.* The necessary and sufficient condition for reinforcement is response suppression. Any response serving to overcome response suppression will be reinforced.

This experiment tested between the alternative hypotheses.

Method

Subjects and apparatus.—Twenty-seven college students, enrolled in introductory psychology courses, served as *S*s. Equipment used was the same as in Exp. I.

Procedure.—Were the *response suppression* hypothesis correct, by establishing response suppression the high-probability response would be reinforced (vs. Hypothesis 1) and the less probable response would reinforce the more probable response (vs. Hypotheses 1 and 2). Wheel turning was now used as the instrumental response, with bar pressing as the contingent response. This new contingency arrangement was appropriate since judging by the first experiment, most *S*s would be expected to have

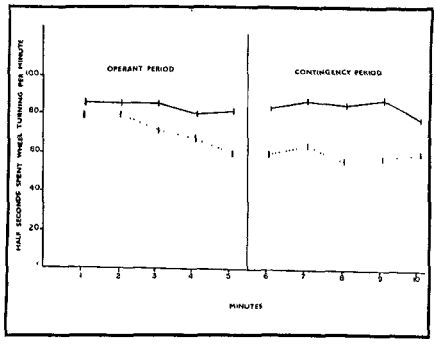

Fig. 2. Mean duration of time spent turning the wheel (contingent response) by the High bar pressers (solid line) and by the Low bar pressers (dotted line) each minute of the operant and contingency periods. (Data was available for 14 of the 18 High bar pressers and 15 of the 18 Low bar pressers.)

[2] Premack (1965), using rats, reported "response suppression" a necessary condition for reinforcement in the contingency situation. Integrating this finding with his probability differential principle would yield the *probability differential-response suppression* hypothesis discussed here.

a high operant wheel-turn probability, with wheel turning more probable than bar pressing. A 5-min. operant period was followed by a 5-min. contingency period in which a high instrumental requirement was employed (each 10 wheel revolutions afforded *S*s the opportunity to press the bar once), helping ensure suppression of the contingent response well beneath its free-performance level. The instructions to *S*s preceding the operant period remained unchanged from the first experiment, except *S*s were now instructed not to turn the wheel and press the bar at the same time. Following the operant period, each *S* was told:

> Please stop until told to proceed. From now on, you do not have to turn the wheel; you may turn the wheel whenever you wish; you do not have to press the bar; you may press the bar whenever you wish. But for each bar press you wish to make, you must first turn the wheel 10 complete revolutions. I repeat—for each bar press you wish to make, you must first turn the wheel 10 complete revolutions. You may turn the wheel without pressing the bar, but you must make at least 10 revolutions for each bar press. You may only press the bar once at a time.
>
> Do you have any questions about these directions?
>
> All right. Go ahead.

Results

During the contingency period each 10 wheel turns permitted 1 bar press. Response suppression occurred for *S*s performing more than one-tenth as many operant bar presses as operant wheel turns; such *S*s would have to increase wheel turning above operant level if they were to have the opportunity to press the bar as many times in the contingency period as they had in the operant period. The crucial *S*s were those undergoing response suppression and also having a higher operant probability of the instrumental response than contingent response. The two conditions were met by 21 of the 27 *S*s. The median operant probability of wheel turning (instrumental response) for the 21 *S*s was .35, compared to the operant probability of .22 for *High* bar pressers in the first experiment. Thus the *probability differential-low instrumental probability* hypothesis and the *probability differential-response suppression* hypothesis predicted absence of the reinforcement effect, while the *response suppression* hypothesis did predict reinforcement. Of the 21 crucial *S*s, 16 performed more wheel turns in the contingency period than operant period, $p < .005$, of as high a proportion by chance alone, one-tailed binomial sign test. The median number of 45° wheel movements rose from 323 in the operant period to 695 in the contingency period. The *response suppression* hypothesis was therefore supported.

Experiment III

Using rats, it has been reported that eliminating the opportunity to engage in a normally performed behavior may increase the daily free-performance levels of alternative behaviors (Premack & Premack, 1963); it was therefore possible that the increase in wheel turning in Exp. II stemmed merely from *S*s' reduced opportunity to press the bar during the contingency period, and not from wheel-turning's instrumental function of allowing bar pressing. As a control, this experiment tested the effect upon wheel turning of merely limiting the opportunity to press the bar.

Method

Subjects and apparatus.—Eleven college students, enrolled in introductory psychology courses, served as *S*s. Equipment was the same as in the first two experiments.

Procedure.—The *S*s received the same initial instructions and preliminary 5-min. operant period as in Exp. II. Immediately thereafter, a 5-min. "limited" operant period ensued in which *S*s were allowed to turn the wheel, but not press the bar. Each *S* was told prior to the limited operant period:

Please stop until told to proceed. From now on, you do not have to turn the wheel; you may turn the wheel whenever you wish; but you must not press the bar. I repeat—you do not have to turn the wheel; you may turn the wheel whenever you wish; but you must not press the bar.

Do you have any questions about these directions?

All right. Go ahead.

Results

The crucial *S*s were those who in the first operant period performed more than one-tenth as many bar presses as wheel turns, such having been the criterion for selecting the second experiment's crucial *S*s. If the increase in instrumental responding (wheel turning) in the second experiment were not merely the result of limiting the opportunity to press the bar, the present experiment's *S*s would be expected to show a lesser increase in number of wheel turns from the initial operant to limited operant period than the previous *S*s' increase from the operant to contingency period. Sixteen of the 21 crucial *S*s in the former experiment increased their number of wheel turns, while all 8 crucial *S*s in this experiment showed decreased wheel turning. The median number of 45° wheel movements rose from 323 to 695 in Exp. II, while declining from 226 to 106 in this experiment. Thus the increase in instrumental responding in the former experiment was not attributable to the effect of merely limiting the opportunity to perform the contingent response.

Experiment IV

In Exp. II, *S*s were told of the instrumental requirement prior to the start of the contingency period (each 10 wheel turns allowing 1 bar press). It had not been possible to present *S*s with a locked bar, having them discover for themselves the instrumental requirement, because the apparatus was not designed for the turn-in-order-to-press contingency. The question arose whether instructing *S*s as to the instrumental requirement might have "induced" the increase in wheel turning. The present experiment employed new apparatus to eliminate the necessity for such instructions. As an additional reinforcement criterion, this experiment tested whether response suppression would subsequently yield a higher-than-operant rate of instrumental responding in an extinction period (period in which the instrumental response is no longer reinforced). Also, to control for the (possibly reinforcing) sound associated with the locking and unlocking of the apparatus during the contingency period, the sound was presented throughout the experimental session on the same schedule as in the contingency period (after every tenth instrumental response and after each contingent response). The extinction period replicated the operant period in that both the instrumental response and contingent response could be freely performed (vs. the more usual extinction procedure of allowing free performance of the instrumental response, but not contingent response).

Method

Subjects and apparatus.—Twenty-five high-school students, taking an introductory psychology course in a special university program for advanced students, served as *S*s. The present experiment employed a lever manipulandum, knob manipulandum, and apparatus for setting the instrumental requirement and for recording data, all of which have been described in more detail elsewhere (Premack, 1963).

Procedure.—Each *S* was seated in front of the lever manipulandum and knob manipulandum, and told:

Please sit and remain in this chair until you are told the experiment is over. Before you, you see a lever and a knob.

When I say to you "go ahead," you may if you wish manipulate the lever; you may if you wish manipulate the knob; you do not have to manipulate the lever; you do not have to manipulate the knob; but you must not manipulate both the lever and the knob at the same moment. I repeat—you may if you wish manipulate the lever; you may if you wish manipulate the knob; you do not have to manipulate the lever; you do not have to manipulate the knob; but you must not manipulate both the lever and the knob at the same moment. Please do not attempt to take apart the apparatus. How you spend your time is up to you so long as you remain seated.

Do you have any questions about these directions?

All right. Go ahead.

The *E* then left the view of *S*, who was given the 5-min. operant period. After 5 min., *S*'s first lever manipulation activated the contingency, whereupon each 10 knob manipulations unlocked the lever until it was manipulated once. The contingency period lasted 5 min., and was followed by the 5-min. extinction period (unlocked knob and lever).

Results

As in Exp. II, the crucial *S*s were those undergoing response suppression and also having the higher operant probability of the instrumental response (knob manipulating) than contingent response (lever manipulating). As a partial control for a decline in the free-performance level of contingent responding, *S*s whose number of lever manipulations was zero for the last half of the operant period were excluded from the crucial group (it is suggested additional statistical controls, such as those employed in Exp. I, be used for future research). For the 12 *S*s failing to press the lever even once in the last half of the operant period, none of the three alternative hypotheses (see Exp. II) predicted the reinforcement effect. Eleven of these 12 *S*s decreased instrumental responding from the operant to contingency period, and each of 11 *S*s receiving the extinction period (the extinction period was not initiated until after the first few *S*s had been run) performed fewer knob manipulations than in the operant period. The median numbers of knob manipulations for the operant, contingency, and extinction period, respectively, were 3.2, 0.1, and 0.0. One additional *S* was excluded from the crucial group for having a higher operant duration (higher average probability) of lever manipulating than knob manipulating. The remaining 12 *S*s had a higher operant duration of knob manipulating than level manipulating (see Table 1) and also underwent response suppression, having performed more than one-tenth as many operant lever manipulations as knob manipulations. The response suppression hypothesis predicted the reinforcement effect, while the two other alternative hypotheses did not. A nonparametric statistical test sensitive to magnitude of change, the Wilcoxon signed-rank test, was utilized. In accordance with the response suppression hypothesis, there was a statistically significant increase in the number of knob manipulations (instrumental response) from the operant to contingency period, $T = 5$, $p < .005$, one-tailed test. Ten of the 12 *S*s increased their number of knob manipulations, the median number rising from 40.5 to 160. Similarly, there occurred a statistically significant increase in the number of knob manipulations from the operant to extinction period, $T = 10$, $p < .05$, one-tailed test. Of the 10 *S*s receiving the extinction period, 7 increased their number of knob manipulations above operant level, the median number of knob manipulations during the extinction period being 132 as again compared with 40.5 in the operant period. Table 1 lists the number of knob

TABLE 1

OPERANT DURATION OF KNOB MANIPULATING (INSTRUMENTAL RESPONSE) AND LEVER MANIPULATING (CONTINGENT RESPONSE), AND NUMBER OF KNOB MANIPULATIONS IN OPERANT, CONTINGENCY, AND EXTINCTION PERIODS FOR EACH CRUCIAL *S*

Item	Subject											
	1	2	3	4	5	6	7	8	9	10	11	12
Operant Duration of Responding (Sec.)												
Knob	92	30	46	56	49	63	23	132	109	104	68	72
Lever	85	9	11	24	31	37	6	60	49	32	27	25
Number of Knob Manipulations per Period												
Operant	62	17	18	25	60	23	22	34	47	162	131	153
Contingency	138	172	89	292	221	31	9	224	130	363	411	101
Extinction			142	165	123	3	19	245	116	257	156	34

Note.—Extinction period was instituted starting with the third crucial *S*.

manipulations for each *S* in each of the three periods.

DISCUSSION

Under the following conditions, an increase in instrumental responding is required if the individual is to have the opportunity of performing the contingent response as much in the contingency period as he would in the free-performance situation:

$$\frac{I}{C} \times \frac{O_c}{O_i} > 1$$

where I is the required amount of instrumental responding, C is the maximum amount of contingent responding subsequently allowed, O_c is the amount of free-performance contingent responding which would occur were there no instrumental requirement, and O_i is the amount of free-performance instrumental responding which would occur were there no instrumental requirement. The free-performance amounts of O_c and O_i are assessed in the operant period. The response units used to determine whether a particular individual undergoes response suppression are specified by the instrumental requirement; the unit for C being used also for O_c, the unit for I being used also for O_i. For example, for each *S* in Exp. I (where 1 bar press unlocked the wheel for 10 sec. at a time), C would be 10 sec. and O_c would be the number of operant seconds spent turning the wheel, I would be 1 bar press and O_i would be the number of operant bar presses. In Exp. IV (where 10 knob manipulations unlocked the lever for 1 manipulation), C would be 1 lever manipulation and O_c would be the number of operant lever manipulations, I would be 10 knob manipulations and O_i would be the number of operant knob manipulations.

Using the above formula, the specific conditions associated with the reinforcement effect in Premack's confirmatory probability-differential experiments (1959, 1963) may be derived as a special case of response suppression. In those particular experiments, each instrumental response allowed one contingent response; the ratio $I{:}C$ was therefore 1:1. Also, the individual instrumental response took about as long to perform as the individual contingent response (Premack, 1963, p. 88; 1965, p. 141); thus the ratio $O_c{:}O_i$ is changed little by expressing O_i and O_c as durations of responding or as numbers of responses. Placing Premack's instrumental requirement into the response suppression equation, it is seen that for each individual, response suppression occurred when the performance of the more probable response was made contingent upon

the less probable response, but not when the performance of the less probable response was made contingent upon the more probable response.

The present set of experiments suggests the necessary and sufficient condition for reinforcement in the contingency situation is the animal's necessity to increase instrumental responding if it is to maintain contingent responding at the free-performance level.

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