

of other enzymes in lysosomes requires further investigation. They may remain at the origin on the Oxoid paper under the conditions studied while the basic protein enzymes migrate toward the cathode (11).

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Running as Both a Positive and Negative Reinforcer

Abstract. *Rats were required to press a bar to activate a motor-driven wheel that forced them to run and subsequently to drink to turn off the wheel. Barpressing and licking increased, showing the onset and offset of running to be positively and negatively reinforcing, respectively. The experimental control of the offset of running, in contrast to the traditional control for onset only, served to demonstrate that since organisms stop such behaviors as they start, self-initiated behaviors will act as negative as well as positive reinforcers.*

The traditional use of two kinds of events for positive and negative reinforcement, respectively, creates the impression that the environment of a species divides naturally into discrete classes of positive and negative events. In fact, this division results more from an experimenter convention than from a relation between the species and its environment. Specifically, it results

from the fact that experimenters instrument only the onset of some behaviors and only the offset of others, rather than using both the onset and offset of any one behavior.

For example, although organisms both initiate and terminate eating, only initiation is used in reinforcement. In the standard food reinforcement case, the organism is required to make an arbitrary response (for example, bar-press) to produce food and thus eat; but it is not required to make an additional response to turn food off and thus stop eating. On the contrary, the food delivered per reinforcement is less than the organism normally eats per burst of eating, and thus the usual disposition to terminate eating does not arise.

On the other side of the coin, only the organism's tendency to turn off (for example) electric shock is used. But will organisms initiate contact with shock and other supposedly negative events? Recent work (1) shows that rats initiate contact with electric shock, and fail to do so only at "high" voltages. Except for the "high-intensity" cases, organisms apparently initiate and terminate responding for all stimuli to which they respond. That is, they not only initiate the traditional positives, and terminate the traditional negatives, but rather initiate and terminate both. Indeed, all free responding is highly discontinuous, there being apparently characteristic burst length and inter-burst length distributions for each behavior (2). Accordingly, to demonstrate the positive and negative capacities of one and the same event requires that there be experimental control of both onset and offset, not one or the other as has been the case.

Of the three cases for which we are currently attempting to establish control of both onset and offset, the one reported here is locomotion. Two findings aided the implementation of this case. (i) Rats choose to press a bar that causes a wheel to rotate and force themselves to run. That is, for the rat, the opportunity to force itself to run is reinforcing; the frequency of the bar-press is increased by such a contingency. (ii) The rat is able to drink while running. These findings led to the following procedure. The rat is placed in a modified Wahmann activity wheel that contains a bar and a drinkometer (3). The wheel is not free to move but is connected to a variable-speed motor.

When the rat presses the bar, the motor is activated, the wheel rotates, and the rat is forced to run. It must continue running until it licks the drinkometer a predetermined number of times, which turns off the motor, stops the wheel, and allows the rat to stop. The rat thus both starts and stops running, the former by the bar-press, the latter by licking.

The base measure for the bar-press is the usual number of bar-presses when the bar-press does not turn on the wheel. The base measure for licking is the duration of licking when licks do not turn the wheel off. That is, in determining the base lick rate, the bar-press turns the wheel on, so that the rat runs, but drinking does not turn the wheel off; instead, the experimenter turns the wheel off after each 5-second interval of running. The base condition was designed as a control for the possibility that running might either induce licking or interfere with and reduce it. In fact, running tends to reduce drinking: the rat drinks most when running is totally precluded (4). Because of this decremental relation, we used the 5-second running burst in the base condition; this value leads to a total duration of running per session (under 200 seconds) that is close to, but less than, the smallest amount of running found in any of the experimental conditions (see Fig. 1). Accordingly, increments in licking computed relative to this base err conservatively, that is, underestimate the increment.

Three female albino rats, about 180 days old, Sprague-Dawley strain, were used. They were maintained on free food and water. An additional question was answered by using a fixed-ratio schedule in conjunction with the "off" response. How does the "difficulty" of turning off a response affect the likelihood of its being turned on? All animals were trained with fixed-ratio lick requirements of 1, 3, 9, 19, and 13, in the order stated. That is, on different sessions the rat was required to complete a different, predetermined number of licks in order to turn the wheel off. On all sessions the drinking tube contained 8 percent sucrose by weight; sucrose was used to facilitate the drinking response. One bar-press always turned the wheel on. All sessions lasted 20 minutes and took place daily.

Figure 1 shows the principal results for one subject, results for the other two being the same in all essentials.

Shown as a function of the fixed-ratio requirement on the off-response are (i) frequency of the on-response, (ii) duration of the off-response, (iii) duration of running. The onset of running clearly increased the frequency of the bar-presses. The base frequency or operant level was zero for all three rats, in contrast to the average of 20 bar-presses that occurred for the minimal offset requirement. Increase in the bar-press was less evident when the "off" requirement was high; in general, frequency of the on-response was inversely proportional to magnitude of the off requirement. Thus, the rat turned the wheel on only about twice per session when it took 19 licks to turn it off, and turned it on about 20 times per session when it took only one lick to turn it off.

The average duration of licking per session, shown in the broken line in Fig. 1, increased moderately with the off requirement. Comparison with the point to the left of the curve, which gives the duration of licking when licks had no effect upon the wheel (base duration), shows that offset of running increased the duration of licking at all values of the fixed ratio. Furthermore, the increase is entirely in instrumental licking. The rat does two kinds of licking in this situation, some when it is running, which is instrumental to turning off the wheel, and some when it is not running, which amounts to drinking-to-drink and which is the kind of drinking that occurs in the base condition. The curve for licking in Fig. 1 includes both kinds; if only instrumental licking were shown the curve would rise still more steeply. That is, since running reduces drinking, and running increased over the fixed ratio, drinking-to-drink actually declined over the same variable. Thus, the increase in purely instrumental licking is somewhat greater than is indicated by Fig. 1, particularly at the larger fixed-ratio values.

The total duration of running per session is shown by the dark line in Fig. 1. Interestingly, it increased with the magnitude of the off requirement despite the fact that the number of times the rat turned the wheel on decreased as a function of the same variable. This is accounted for by the fact that the average burst of running was far longer in the case of the 19-lick off requirement than in the case of the one-lick requirement—an average of

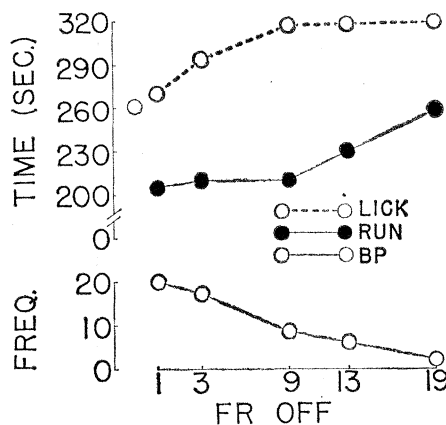


Fig. 1. Shown as a function of the number of licks required to turn off the wheel (fixed ratio off) are (i) average number of bar presses per session, (ii) average duration of licking per session, and (iii) average duration of running per session. The point to the left of the lick curve gives the base duration of licking. Data are for one rat.

140 seconds versus 10 seconds. That is, a high off requirement led to a few extremely long bursts of running, whereas the low off requirement led to numerous short bursts of running, the total duration of running being notably greater for the large than for the small requirement. This difference did not result from the rat "trying" but failing to turn the wheel off in the case of the high off requirement. From the time the animal started running to the occurrence of the first lick averaged only about 10 seconds for the one-lick requirement versus about 134 seconds for the 19-lick requirement. Thus, when faced with a large off requirement, the animal did not "try" and fail, but rather ran continuously for an unusually long period before even initiating the off response. This delay may amount to a fixed-ratio pause for the off-response, analogous to the classical increase in delay of the instrumental response that is produced by increasing the fixed ratio for the on-response.

That subjects would work to turn on and off the same stimulation had, prior to the present data, been shown only for intracranial self stimulation (5). Indeed, the first on-off reinforcement system was discovered with intracranial stimulation, on the basis of the originally puzzling finding that subjects would learn to escape but not to avoid the stimulation (6). Not surprisingly, we find the same relation here: the rat can be trained to escape the al-

ready-moving wheel but not to avoid its onset. The formal parallel between the neural and behavioral evidence is thus increased by the present data. More important, since all self-initiated behaviors—for example, eating, drinking, and copulation, as well as running—are also self-terminated, it is likely that merely technical difficulties will impede showing that all such behaviors are on-off systems, capable of generating both positive and negative reinforcement.

These results indicate how a generalization that was stated originally for positive reinforcement may now be broadened to include negative reinforcement as well. Originally, the generalization read: for any pair of responses, the more probable one will reinforce the less probable one (7). But this fails to distinguish between the onset and offset of an event. The generalization should now read: if the onset or offset of one response is more probable than the onset or offset of another, the former will reinforce the latter—positively, if the superiority is for "on" probability, and negatively, if for the "off" probability. Four reinforcement paradigms can be identified on the basis of the completed generalization: on-on, on-off, off-off, off-on, where the terms of each pair refer to the instrumental and contingent responses, respectively. Thus, the first two paradigms were instanced here by bar-press-run onset and lick-run offset, and represent positive and negative cases, respectively; the other two paradigms remain to be investigated (8).

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