

*TIME-DEPENDENT CONTRAST EFFECTS IN A  
MULTIPLE SCHEDULE OF FOOD REINFORCEMENT<sup>1</sup>*

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Four rats were rewarded for running in a wheel under two alternating conditions of food reinforcement. These periods of frequent and infrequent reinforcement, each accompanied by a particular stimulus, were presented a number of times in each daily session. Following shifts from high to low frequency of reinforcement, responding decreased suddenly and markedly, and then recovered within the next few minutes. The magnitude of this temporary depression was an increasing function of the duration of the immediately preceding component of high-frequency reinforcement. A transient elevation in performance, which did not vary with the duration of the prior component, was noted in two subjects following shifts from low to high frequency of reinforcement. The elevation and depression effects did not appear simultaneously during the 48 experimental sessions. A possible relation between the difficulty of the discrimination and the extent of contrast effects is discussed.

A multiple schedule is a type of successive discrimination in which two schedules of reinforcement are presented in alternation, each being accompanied by a distinctive stimulus. As a rule, behavior in the presence of each stimulus is appropriate to the associated schedule (Ferster and Skinner, 1957). In other words, performance in a particular component of the multiple schedule is almost identical to performance when that schedule is the only one in force. Despite this relative independence, certain reliable interactions have been observed between the components of multiple schedules. Thus, Reynolds (1961*a*, 1961*b*, 1963), (see also Bloomfield, 1966) has shown that rate of responding in one component of a multiple schedule is influenced by frequency of reinforcement in the other component. The direction of the interaction is opposite to what would be expected on the basis of generalization: in fact, rate in one component varies inversely with frequency of reinforcement in the other. These "behavioral contrast" effects seem similar to the "induction" phenomena reported by Pavlov (1927).

Another characteristic of multiple schedule contrast, which more closely resembles Pavlovian induction in that it follows a definite time course, has been reported by Williams (1965*a*). In a study using rats running in a wheel for brain stimulation, he found time-dependent depression following the change from a high- to a low-reinforcement frequency component in a multiple schedule. That is, immediately after the change of components, responding fell almost to zero and recovered to an apparently asymptotic level within approximately 90 sec. The magnitude of the temporary depression in responding was somewhat greater when the prior high frequency of reinforcement component had been in force for a relatively long period of time. Both these effects were observed even when responding in high-frequency components was not permitted but reinforcers were still presented (see also Reynolds, 1961*a*; Catania, 1961). No evidence was obtained for the existence of a complementary rate elevation on transition to high-frequency components.

Nevin and Shettleworth (1966) have reported a study using pigeons and food reinforcement in which either positive or negative time-dependent contrast effects were produced on a single schedule, depending upon the preceding component (either a higher frequency of reinforcement or extinction). They presented a period of time out after the critical schedule to minimize the possibility of adven-

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titious reinforcement. The extent to which time-dependent contrast accounted for Reynolds' data cannot be assessed, since he did not report response rates as a function of time since schedule change. Although Catania and Gill (1964) reported both positive and negative time-dependent contrast in a multiple schedule of fixed-interval reinforcement and extinction, there are certain perplexing aspects to their study. The elevation effect they reported was present in only the first of six successive 1-min fixed intervals. Perhaps the first fixed interval did not show the typical early pause (Ferster and Skinner, 1957) because it was not preceded by reinforcement. Also, it is doubtful that responding would have continued unabated for 52 days in the extinction component unless it had been maintained by the non-contingent changeover to the reinforced component. Thus, the effects they observed may represent a diminished postreinforcement pause on the one hand, and an example of adventitious chaining on the other.

The present study was designed to explore the time-dependent contrast effect in rats, using conventional food reinforcement rather than central stimulation, which had been used in the earlier report. The particular focus of the study was on the relation of time-dependent depression to the duration of the preceding component, and on the development of positive and negative time-dependent contrast effects in the course of training.

## METHOD

### *Subjects*

Four experimentally naive Sprague-Dawley male rats, obtained from Huntingdon Farms, were maintained between 80% and 85% of free-feeding weight throughout the course of this study.

### *Apparatus*

A low-inertia running wheel, 6 ft in circumference, was used. A ratchet permitted the wheel to turn in only one direction. Available stimuli included a steady tone produced by a loudspeaker and an oscillator; a 10-per-sec train of clicks produced by a relay; and the 4-per-sec flashes of a pair of lights located at the same level as the lower rim of the wheel, 6 in. in front of and behind it. A feeder deliv-

ered 45-mg Noyes pellets to a small bin which protruded into the wheel at about 8 in. along the circumference from the bottom. The direction that the wheel turned prevented the animal from reaching the feeding bin except when a solenoid-operated brake locked the wheel. The entire apparatus was enclosed in a sound-attenuating wooden box, and control equipment was located in a different room.

The running response was a continuous rather than a discrete response. A criterion speed of 1 in. per sec (well below normal running speed of 20 in. per sec) was established. Time running, rather than number of responses, was the primary unit of data. The running wheel turned a small generator, and a voltage-sensing device set the criterion speed which defined the response. A perforated disc and a photocell provided one count per foot to measure distance run. Distance counts were recorded only when the wheel was moving above the criterion speed.

### *Procedure*

Eight days of pre-training preceded the main experiment. On the first day, all subjects were given 20 min of free running in the unlocked wheel, with no reinforcement available. The following day they were placed in the locked wheel for 45 min. Fifteen pellets were left in the food bin before this session. During the next two days the wheel remained locked and pellets were dropped into the bin at irregular intervals averaging 30 sec. At the end of the fourth day, and on the next three days, running in the wheel was reinforced with food. A period of time during which the wheel was locked accompanied the delivery of each pellet, and as the subjects learned to run up to the bin this period was gradually reduced to 5 sec. Throughout the experiment reinforcements were programmed on a "time schedule" (Williams, 1966) such that the accumulation of a certain amount of time spent running produced each reinforcement. Continuous running was not necessary. In other words, whenever the wheel was turning at more than 1 in. per sec a clock was running. If the wheel stopped turning above criterion speed, the clock stopped but did not reset. When the clock timed out, a reinforcer was delivered and a new interval began. On the last day of pre-training all subjects ran for 30

min on a variable time schedule (VT 15-sec) consisting of intervals averaging 15 sec.

For the rest of the experiment, reinforcement was available on a multiple VT 60-sec VT 10-sec schedule. Each variable time represents an arithmetic average; on both schedules the shortest duration programmed was 5 sec. The distinctive stimuli which marked each component of the multiple schedule are shown in Table 1.

Table 1

Stimuli presented during each schedule for different subjects.

Subject	Schedule	
	VT 10-sec	VT 60-sec
R54	tone	click
R55	click	flash
R56	click	tone
R60	flash	click

Each day began with a 10-min warm-up period in which each schedule was presented twice. The remainder of the daily session was composed of 1-, 3-, and 5-min components, presented in six different sequences from day to day, which allowed a 3- or 5-min component of each schedule to be preceded once each day by a 1-, 3-, or 5-min component of the other schedule, and which counterbalanced serial order of such presentations over each six-day period. At the end of the session the last component in force was continued for a period of 7, 9, or 12 min to make the total session length 45 min. The 5-sec periods when the wheel locked for reinforcement did not count either for component or for total session duration.

When the component changed, accumulated running time did not carry over to the next component nor to the next presentation of the same schedule. However, each new component began with a random amount of time credited toward the first reinforcement, so that the probability of reinforcement at the beginning of each component was no lower than the average probability at any time during it. Time and distance run were recorded every 30 sec (again ignoring time when the brake was on) throughout the session.

RESULTS

A summary of the major findings is presented in Fig. 1. The ordinate represents the

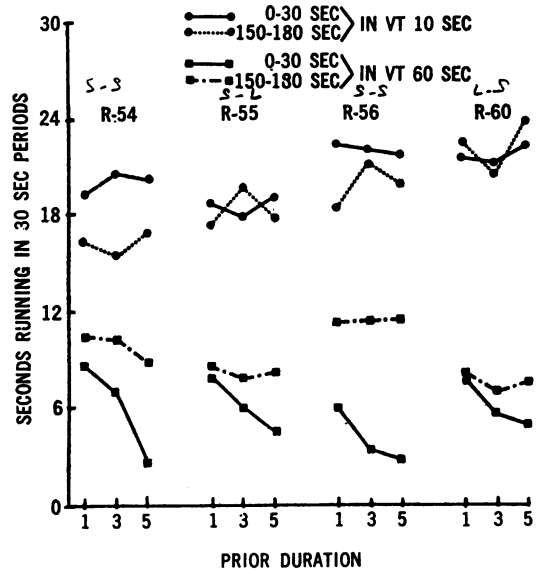


Fig. 1. Mean time spent running in each of four 30-sec periods as a function of duration of the prior component. Data from all but the first six days are included.

number of seconds spent running in a 30-sec period. From each 3- or 5-min component, two 30-sec periods were sampled: the first 30 sec of the component and the last half of the third minute. The four curves drawn for each subject represent the level of running early and late in high-reinforcement frequency and in low-reinforcement frequency components. To assess the importance of the duration of the component which preceded that from which a particular score was obtained, three separate points are plotted along the abscissa for 1-, 3-, and 5-min prior durations. Figure 1 presents the means of the data from all but the first six of the 48 experimental days.

Several important aspects of the results are evident in Fig. 1. First, it is clear that the two schedules sustained markedly different levels of running. Secondly, all subjects showed a pronounced transient depression in responding at the beginning of low-reinforcement periods: the amount of running in the first 30 sec of VT 60-sec components was substantially below the level reached at the end of the third minute. The magnitude of this transient contrast effect was directly related to the duration of the prior high-reinforcement component. Specifically, there was less running at the beginning of VT 60-sec components following relatively longer presentations of the VT 10-

sec schedule. Of the four curves plotted for each subject only that for the first 30 sec in VT 60-sec shows a consistent relation to the duration of the preceding component. A Friedman two-way analysis of variance by ranks indicates that there was a reliable effect of prior duration at 0 to 30 sec in VT 60-sec components ( $\chi^2 = 8.0$ ,  $k = 3$ ,  $N = 4$ ,  $p < 0.005$ ), but not at other times. Whereas all subjects showed a depression on transition to the low-reinforcement schedule, only two (R-54 and R-56) revealed an analogous overshoot in level of responding at the beginning of high-reinforcement frequency components.

The effects of training are shown in Fig. 2 with the data broken down into counterbalanced six-day training blocks, and including

as Block 1 the first six experimental days. To simplify the figure the scores at 150 to 180 sec in both components have been averaged across the prior durations and are pictured as a horizontal line. Since there was no reliable effect of prior duration at this time, and since these scores were similar to those subsequently observed up to 12 min after a shift, this single average is an estimate of the final level of running reached after recovery from the transient effects of schedule change. Figure 2 corroborates the principal points made by Fig. 1. In addition, it shows that the contrast effect developed after about six days of training. Individual records from the initial days on the multiple schedule showed little effect of component change: performance persisted unin-

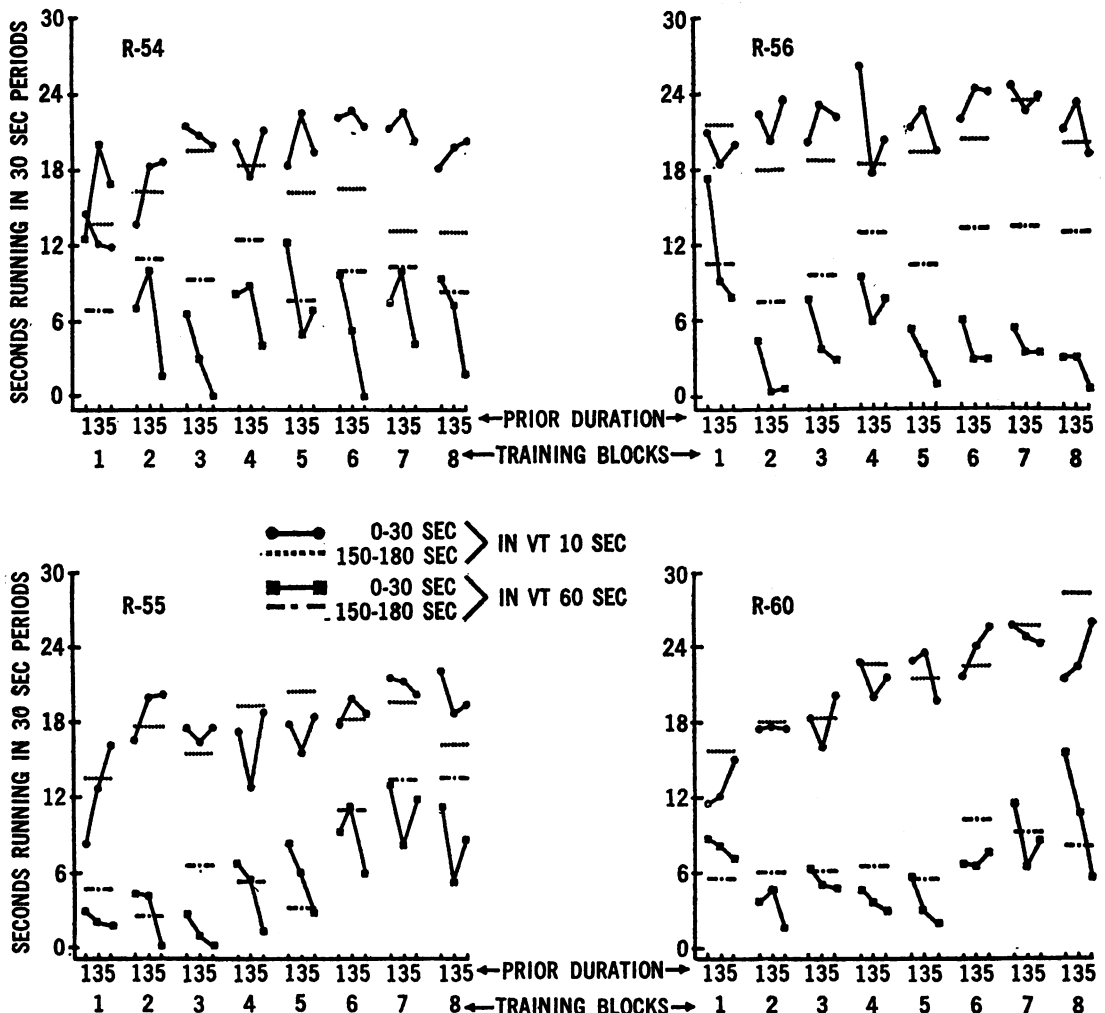


Fig. 2. Same data as Fig. 1 divided into six-day blocks to show training effects, with the first six days included. Horizontal lines show running in the 150- to 180-sec periods averaged over prior component durations.

errupted from one component to the other. This yielded results in a direction opposite to that of the subsequent contrast effect. Data in the first block of Fig. 2 appear to represent a combination of generalization from one component to the next, and of the onset of the depression phenomenon. Note that, with the possible exception of R-56, each subject exhibited a maximal depression in the second or third training block and a diminution of the effect thereafter.

Figure 2 reveals that although only two of the subjects, R-54 and R-56, showed an overall elevation in responding at the beginning of high-reinforcement frequency components, it was a consistent effect for those two. Considering the average data of all preceding durations both subjects showed a higher level of running at 0 to 30 sec than at 150 to 180 sec in all seven of the last seven training blocks (binomial  $p = 0.008$ ). For both R-54 and R-56 there seems to be no correlation in the course of training between the magnitudes of the

elevation effect and the depression effect. Furthermore, the elevation effect differs from depression in that it shows no consistent relation to the duration of the prior component.

A more detailed picture of the phenomena mentioned above is given in Fig. 3 which shows a cumulative record for each rat taken from the middle of the session on the 35th day. Even at this late stage in training all subjects except R-60 showed a pronounced depression effect at the onset of the low-frequency components. Note also the elevation at the beginning of VT 10-sec components for R-54 and R-56. Although the cumulative record is based on distance run (when running speed meets the criterion) and Fig. 1 and 2 are based on time spent running, the fact that running speed is virtually constant makes these two measures interchangeable.

#### DISCUSSION

Throughout the experiment, the two components of the multiple schedule maintained

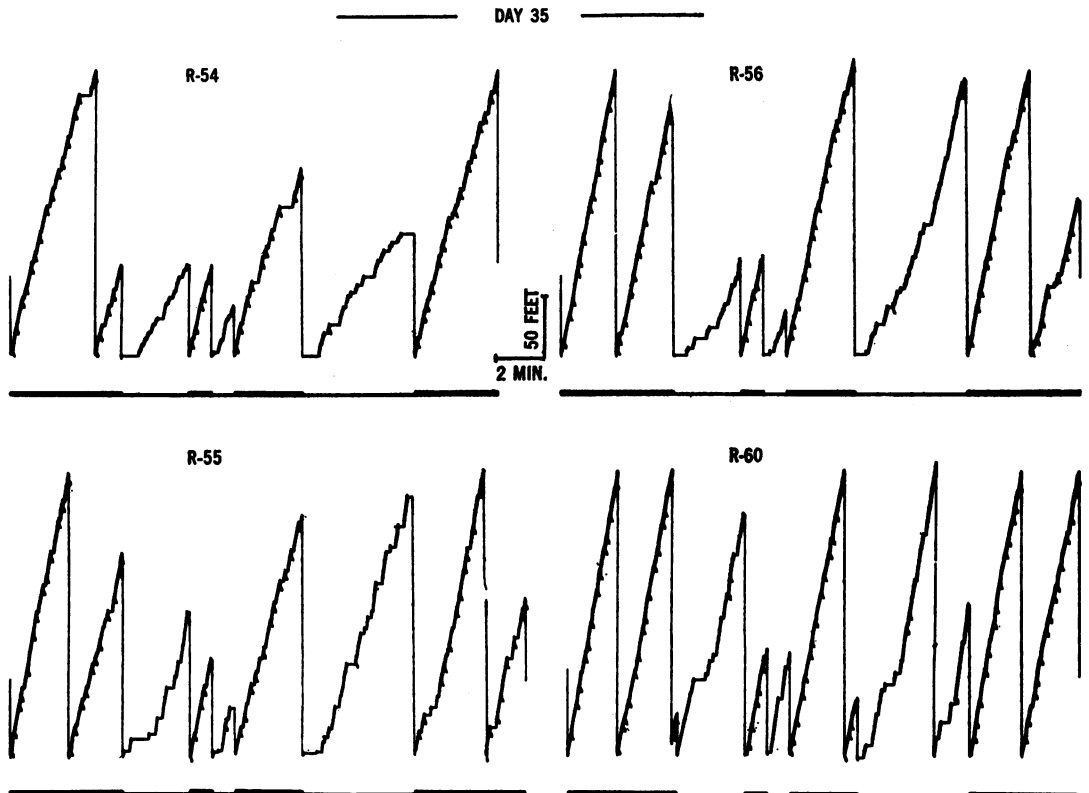


Fig. 3. Cumulative records of running from the middle of the 35th experimental session. Heavy underline marks VT 10-sec components; light underline, VT 60-sec. Pips indicate reinforcements. Note that the pen always resets at component change but also at other times due to limit of pen excursion.

substantially different levels of performance. The change in level of performance following a shift from the high- to the low-frequency component was immediate, but not precise. A change to the low-frequency component reduced running considerably below the level subsequently obtained. This transient depression in performance was greatest following long presentations of the high-frequency component; following short presentations, it was always smaller, and in some instances, not evident at all. With extended exposure to the procedure, the depression effect tended to deteriorate. Two subjects exhibited a time-dependent elevation in running following shifts from the low- to the high-frequency schedule. Unlike the depression phenomenon, however, there was no evidence that the elevation effect was in any way related to the duration of the prior component.

A number of investigators (Pavlov, 1927; Catania and Gill, 1964; Williams, 1965*b*) have noted the similarity of time-dependent contrast effects in behavior to sensory contrast, particularly to visual phenomena such as Mach bands (Ratcliff, 1965). However, two of the findings of this study—the dissociation of the elevation and depression effects in the course of training, and the effect of prior component duration on depression but not on elevation—argue against this supposition. The observed dissimilarities in the elevation and depression phenomena suggest that they are not complementary aspects of a single underlying mechanism, as the retinal analogy would imply.

The two subjects (R-54 and R-56) which exhibited reliable elevation effects, as well as the strongest and most prolonged depression effect, were those for which auditory stimuli accompanied both components of the multiple schedule. Catania and Gill (1964) have reported a "spatial contrast" effect which waned after two or three weeks of training, but could be temporarily reinstated by making the discriminative stimuli less distinct. These findings take on added significance in light of the report by Pavlov (1927) that with easily distinguishable stimuli a well-trained discrimination may fail to produce positive induction, while a finer and more recently acquired differentiation continues to show the effect. Although the present study was not designed to explore stimulus factors, it seems plausible to

assume that the auditory-auditory discrimination was more difficult than the auditory-visual. Perhaps the gradual waning of the effect is a manifestation of a change, presumably a sharpening, in the discriminative control exercised by the stimuli accompanying the components of the multiple schedule. Terrace's (1966) report that errorless discrimination training eliminates the contrast effect is in line with this interpretation, assuming that an easier discrimination resembles an "errorless" discrimination. By this interpretation, the period of initial generalization between the two components of the multiple schedule is crucial to the development of the subsequent contrast effect, and the magnitude of the effect may depend in part on the similarity of the discriminative stimuli.

It is apparent that the action of discriminative stimuli extends beyond their role as cues for the emission of particular responses. Terrace (1966), for example, has shown that discriminative stimuli which control seemingly identical patterns of behavior on a discrimination task are importantly different in terms of generalization gradients, contrast, and drug effects. The contrast effects which Pavlov observed led him to postulate an interaction between excitatory and inhibitory processes. Perhaps operant contrast phenomena can serve as an empirical basis for the development of a theoretical concept of inhibition which will further the understanding of operant behavior.

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