

DISTRIBUTIONAL PROPERTIES OF OPERANT-LEVEL LOCOMOTION IN THE RAT¹

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Four rats had continuous access to activity wheels first, then access for 1 hr per day, and, subsequently, continuous access. Limiting *S*'s access to the wheel substantially increased the total frequency of running. A distributional analysis of response duration, burst duration, and interburst interval showed that the increased frequency arose almost entirely from a shortening of the interval between successive bursts. In contrast, speed of the individual response and number of responses per burst changed only negligibly. If *S* were running, the probability that it would either stop or continue did not differ appreciably for the conditions of continuous or limited access to the wheel. But if *S* were not running, the probability that it would start running was appreciably greater for limited than for continuous access.

In attempting to use wheel running in rats as both a reinforcing and reinforced response (Premack, 1959, in press), we found rat locomotion to be marked by a number of unsuspected constancies. Certain of these are shown here in terms of the frequency distributions of response duration (RD), burst duration (BD), and interburst interval (IBI). In addition, these properties are compared for conditions of continuous *vs.* limited access to the wheel. Limiting *S*'s access to the wheel to 1 hr per day substantially increases the amount of running in that hour relative to the continuously available wheel. Accordingly, by comparing the distributional properties for the two conditions, it is possible to determine whether changes in RD, BD, or IBI, individually or in combination, account for the gross increase in frequency.

METHOD

Subjects

The *Ss* were four female albino rats, about 100 days old, of the Sprague-Dawley strain. They had been rejected from a saccharine bar-press experiment for failure to magazine train. During this time, they had been food deprived; however, for 2 weeks before and throughout the present experiment, they had free access to Purina mash and water. The *Ss*

were housed individually in small (10 by 6 by 5 in.) wire mesh cages attached to the outside of the wheel.

Apparatus

Four standard Wahmann activity wheels were used; they were not equated for force because each *S* served as its own control and always ran in the same wheel. The wheels were housed in individual compartments of a sound-deadened, ventilated cabinet; each unit was illuminated by a 15-watt overhead bulb. Temperature in the experimental room varied from approximately 70 to 75 degrees F.

Procedure

All four *Ss* were treated alike. (a) During 6 days of adaptation, the sliding door at the rear of the cage was open, and *S* had continuous access to the wheel. (b) During 3 additional days of the same treatment which followed, measures of running were taken. (c) At 9:00 AM on Day 9, each *S* was removed from its wheel; doors to the wheels were closed; and *S* was confined in the small, attached cage until 8:00 AM of the following day. From 8:00 to 9:00 AM, the *S* was allowed access to the wheel; but after this period, it was again confined as before. This procedure was repeated on 3 successive days. (d) At 9:00 AM on Day 12, doors to the wheels were not locked. Instead, *S* was allowed continuous access to the wheel for 3 days exactly as in the adaptation period. From 8:00 to 9:00 AM in

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all periods except that of adaptation, an Esterline Angus operations recorder was used to take wheel records. Data presented here are those of Days 7, 10, and 13: Day 7 is the first day after 6 adaptation days; Day 10 is the first wheel period following 23-hour confinement in the small cage; and Day 13 is the first day after 23-hour return to continuously available wheel. To increase running during the measurement period, the room was darkened between 8:00 and 12:00 AM, but illuminated at all other times.

A "response" has been arbitrarily defined as a 360-degree turn in either direction. This unit is not necessarily related to any topographic unit; it is justified by tradition, but more importantly by preliminary observations which suggest that few runs occur that are less than one revolution. Inevitably, constancies are qualified by the level of measurement, and the present level was considered sufficient for a first investigation.

The concept of "burst" represents an intuitive reaction to the situation in which events are *not* evenly distributed in time; here, a "burst" was defined as collections of one or more responses separated by an interval of at least 2.5 sec. Records for the four Ss were sufficiently alike so that the same criterion could be applied to all Ss. The definition represents the usual compromise between minimizing time between successive responses while maximizing time between successive groups of responses.

The Esterline Angus was run at a speed of 12 in. per min, such that the smallest tape unit equalled 0.5 sec. All fractions of this smallest unit were read to the nearest integer tape-unit.

RESULTS

Response Duration

Figure 1 shows the distribution of RD's for each S for each of the three 1-hr periods (continuous, limited, return to continuous access). Response duration appears essentially constant, both among Ss and among conditions. With the possible exception of S₄, whose Period 3 sample is too small to warrant characterization, both the median and modal RD for all Ss and all conditions was 1 sec, with a range of 1 to 3 sec. Thus, although limited

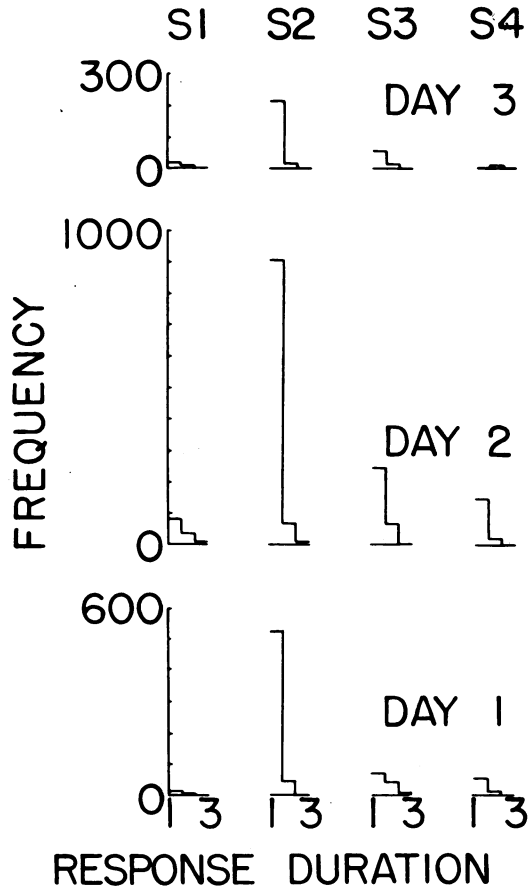


Fig. 1. Frequency distributions of response duration (RD) for each S for the three conditions.

access to the wheel visibly increased the total number of responses, it affected neither the central tendency nor the range of RD's.

Burst Duration

Figure 2 shows the distribution of BD's (number of responses in a burst) for each S for each of the three 1-hr periods, while Table 1 presents three measures of central tendency for each S for each period. Although the inter-S variability is greater here than in RD (mainly with regard to range), the similarity among Ss and conditions is substantial. In 9 of the 12 possible cases, the modal BD was 1 response, and the range of modal BD's, from 1 to 3 responses. Most striking is the fact that although the condition of limited access grossly increased frequency, it did not tend to increase the number of responses in a burst. The one S showing a slight increase in burst length was completely countered by the other

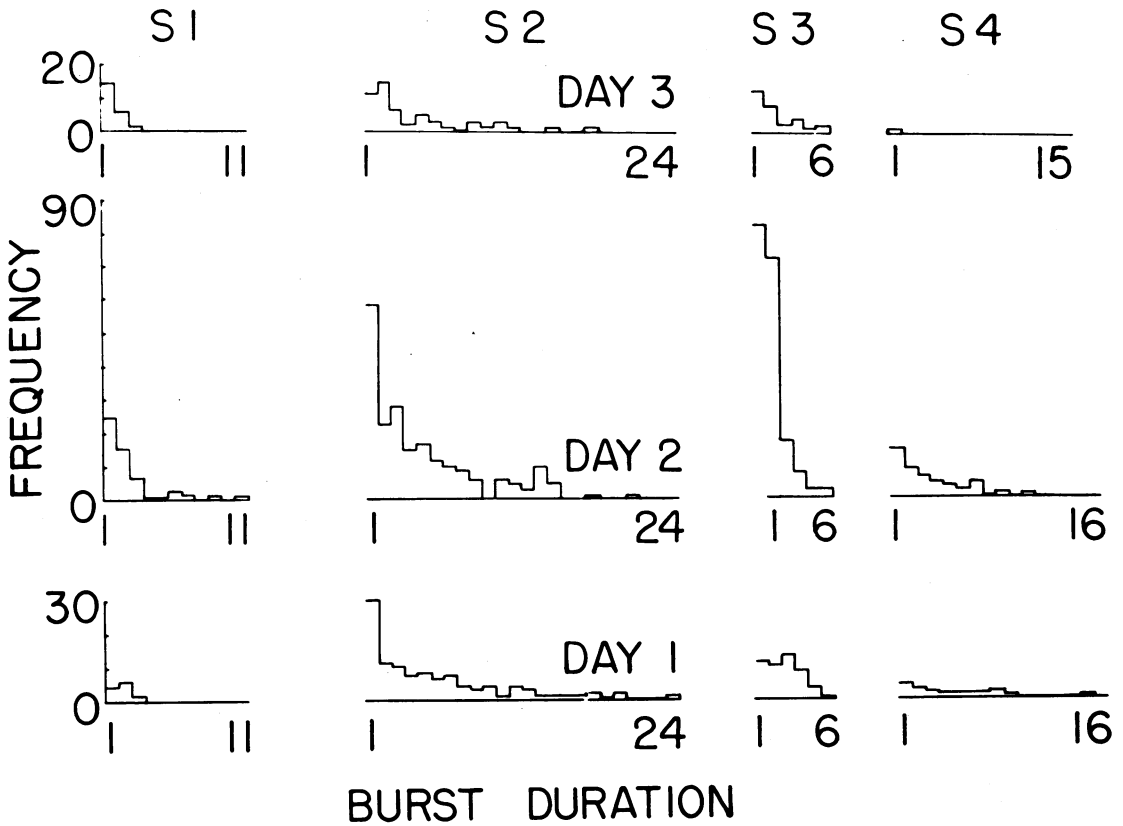


Fig. 2. Frequency distributions of burst duration (BD) for each S for the three conditions.

TABLE 1
Central Tendency of BD

	S ₁	S ₂	S ₃	S ₄
Period 1, Continual Access				
Mean	1.7	5.5	2.6	4.6
Median	2	4	3	3
Mode	2	1	3	1
Period 2, Limited Access				
Mean	2.4	4.8	1.8	3.5
Median	2	3	2	3
Mode	1	1	1	1
Period 3, Continual Access				
Mean	1.4	4.4	2.2	only 1
Median	1	3	2	burst of 1
Mode	1	2	1	response

three Ss showing a decrease. Thus, neither changes in BD nor RD can account for the increased running of Period 2.

Interburst Interval

Figure 3 shows the distribution of IBI's for each of the three 1-hr periods, while Table 2 presents both measures of central tendency and range for each S for each period. The smallest possible IBI is (by definition) 2.5 sec, and the largest is of the order of 1 hr (length of the session minus the time required for the occurrence of at least two responses). The only possible conclusion is that this property must account for the increased frequency of Period 2. The question is: How? This is answered in Table 2 and Fig. 3. First, the general shapes of the distributions did not change drastically from Period 1 to 2. The only notable change was that the especially long IBI's of Period 1 dropped out in Period 2; this is reflected in the reduced range for all Ss in Period 2. Second, the mean IBI of Period 2 was greatly reduced in all Ss, whereas the median and

TABLE 2

Range and Central Tendency of IBI (seconds)				
	S ₁	S ₂	S ₃	S ₄
Period 1, Continual Access				
Range	3-1314	2.5-827	2.5-884.5	2.5-34875
Mean	163.2	29.8	46	231
Median	9	5	8.5	11
Modal Class	5.5-10	2.5-5	2.5-5	5.5-10
Period 2, Limited Access				
Range	3-600	2.5-311	2.5-525	2.5-2635
Mean	52.2	12.8	17.7	59.6
Median	9	6	6.5	9.3
Modal Class	5.5-10	2.5-5	2.5-5	2.5-5
Period 3, Continual Access				
Range	3-2685.5	2.5-474.5	3.5-1746	
Mean	161.5	28.9	87	only 1
Median	13	6.5	19	burst of
Modal Class	5.5-10	2.5-5	over 30	1 response

modal classes were relatively stable. Individual differences were perhaps the greatest in this property. Thus, S_s differed negligibly in speed of the individual responses, only somewhat more in number of responses per burst, and appeared to differ mainly in the way the bursts were distributed in time. Even so, the modal IBI for all S_s was either 2.5-5.0 or 5.5-10.0 sec.

Frequency per Period

Table 3 shows the total number of responses (and bursts) per S for the 3 days in each of the three periods (continuous, limited, return to continuous access), as well as the relative proportion of the total in the 1-hr measurement session. The distributional data (Fig. 1, 2, and 3) are based upon only the first day of the three that were given at each condition; but Table 3 represents the data for all 3 days given per condition. Percentages for Days 1, 2, 3 and 7, 8, 9 are based upon the total number of responses for the appropriate day, whereas those for Days 4, 5, 6 are based upon the mean for Days 1, 2, and 3 combined. If responding were equally distributed throughout each 24-hr period, approximately 4% of

TABLE 3

Absolute and Percent Frequency of Responses (and Bursts) for Each S for Three 1-hr Measurement Periods

Number of Responses and Bursts				
	S ₁	S ₂	S ₃	S ₄
Period 1, Continual Access				
Responses	19	588	117	78
Bursts	11	106	45	17
Period 2, Limited Access				
Responses	139	993	334	184
Bursts	57	203	183	61
Period 3, Continual Access				
Responses	27	232	63	1
Bursts	20	53	28	1
Percentage of Total Daily Responses in 1-hr Measurement Period				
Days	S ₁	S ₂	S ₃	S ₄
Period 1, Continual Access				
1	9.2	18.8	19.2	14.7
2	7.9	24.3	10.0	8.2
3	3.4	22.9	16.4	3.7
Period 2, Limited Access				
1	25.5	35.9	31.3	12.4
2	29.7	29.1	19.0	10.8
3	13.2	30.9	24.8	16.9
Period 3, Continual Access				
1	4.5	4.9	4.9	0.3
2	0.7	26.0	1.8	0.2
3	3.8	17.9	0.1	1.6

the daily total would be expected in any 1-hr period. However, because the measurement period coincided with a change in stimulation—change in illumination, entry of E, etc.—and a change in stimulation is known to increase running (*e.g.*, Hall, 1956), more than 4% of the total would be expected in the measurement period. Table 3 shows that the amount of running was greatest in Period 2, both in absolute and percent frequency; also, running in the period following a return to the continuously available wheel was somewhat less than in the original period of con-

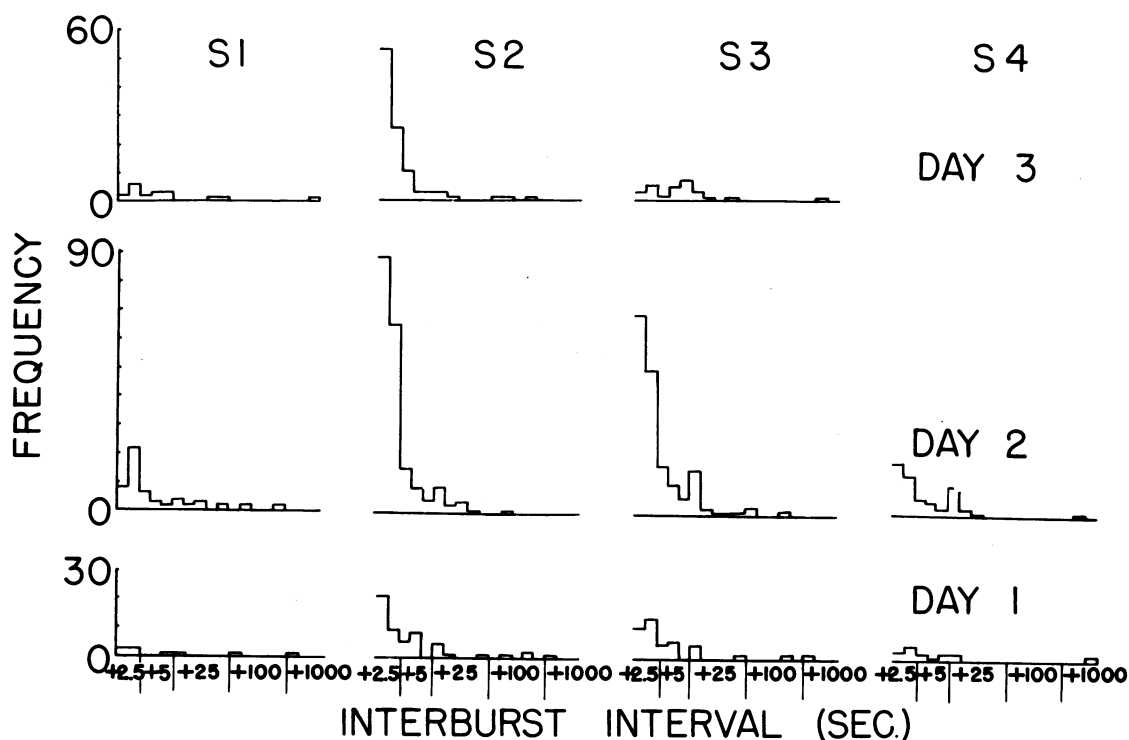


Fig. 3. Frequency distributions of interburst interval (IBI) for each *S* for the three conditions.

tinuously available wheel. At least part of the reduction in Period 3 may occur because the rat tends to "over-eat" when deprived of the activity wheel (Premack & Premack, 1958).

DISCUSSION

The increase in total number of wheel runs produced by limiting *S*'s access to the wheel arose principally from one source: shortening of the interval between successive bursts of running. In contrast, duration of the response and number of responses per burst changed only slightly from Period 1 to 2. Burst duration specifically was largely unaffected: If *S* was in a state of running, the probability that it would either stop or continue was essentially the same for both conditions. On the other hand, the interpretation for the smaller mean IBI of the limited-access condition may be: If *S* was in a state of nonrunning, the probability that it would start running was greater for limited than for continuous access. Thus, what may be termed a start rather than a

continuation factor was what would appear to have been affected by limited access.

The advantage of a distributional analysis is to make possible a finer causal analysis than that contained in the traditional drive-habit distinction. As Gilbert (1958) has noted, for example, not all conditions having the same directional effect upon the frequency of responding may produce their changes in the same manner. Such a suggestion has come recently from studies in progress: Food deprivation, which also produces an increase in running, appears to do so by greatly increasing BD, whereas in the present case, BD was essentially constant. Indeed, the present means of increasing running may itself be analyzed into at least two variables: intersession interval and spatial confinement. For example, when *S* received the wheel only 1 hr per day, it was otherwise housed in a small cage, so that it underwent a degree of confinement greater than when both wheel and cage were available. Confinement *per se* increases running (Hill, 1956), while the intersession interval has

been shown to affect operant-level manipulation in a monkey (Premack & Bahwell, 1959), as well as the bar- and light-contingent bar press in rats (Premack & Collier, in press). Although the intersession interval may also be expected to affect running, it is not yet known whether the interval and confinement variables will have strictly comparable effects upon the distributional properties. Of general interest will be determining which of the several parameters of running can be subsumed by common principles on the grounds of their common effects upon the distributional properties.

Constancies reported for rat licking (*e.g.*, Stellar & Hill, 1952) are the regularities in the excursion and return to resting position of the rat's tongue. Here, however, the constancies concern the distance an object was moved, so that the present reference cannot be strictly to topography. For example, the generally invariant RD means that the wheel was typically moved at a speed of about 3.66 ft per sec, while the modal BD means that the wheel was typically moved 3.66 ft prior to not being moved again for at least 2.5 sec. Nevertheless, constancies in the movement of the wheel imply constancies in the topography responsible for the movement; and even limited observation tends to support this.

From a resting position in which all four paws contact the wheel, the rat initiates running with a trot: Diagonally opposed fore and hind paws contact the surface jointly, and movement involves rotation of the diagonal pairs. Upon reaching a certain speed, *S* may move abruptly to a gallop: Forepaws now move posteriorly together, to a point about laterally adjacent and medial to the rear paws, and then return essentially to resting position. When speed is reduced, the rat returns to a trot. Thus, *S* tends both to enter and leave running from a trot. Although observation has been inadequate to determine whether all bursts contain "gallops," the presence of (at least) two gaits, as well as a tendency for *S* neither to start nor end with a gallop, seems relatively clear; most of the long RD's in Fig. 1 may concern, specifically, trots that start and stop a burst. A dual system recording both topography and distance should permit correlating movement and effect units here, just as licks and volume can presently be correlated by dual recording.

With the addition of the present constancies for running to those already reported for licking, it becomes reasonable to ask whether any behaviors are as variable as the two above are invariant. More generally, can the behaviors of a species be divided into variants and invariants, with the expectation that these will form classes leading to additional differentiae?

Of the behaviors so far examined in a small sample of rats and Cebus monkeys, only manipulation has been found to be highly variable, and in both rats and monkeys. An independent, and possibly more generic, distinction may prove to be associated with the variance-invariance. Under a condition of free access to stimuli (*e.g.*, continuously available food or bar or wheel, etc.), the asymptotic response level of certain behaviors is apparently zero, whereas in others it is substantially greater than zero. Thus, although the asymptote for eating and drinking is obviously greater than zero, that for a light-contingent bar has proved to be essentially zero (Premack & Collier, in press). Interestingly, invariance and variance may themselves prove to be attributes of the recurrent and nonrecurrent classes, respectively (Premack & Collier, in press). That is, behaviors that are recurrent in a species appear to have both constant RD and inter-response interval, and this no less for noningestive (*e.g.*, running) than for ingestive cases. On the other hand, behaviors that are nonrecurrent in a species appear to have both variable RD's and inter-response intervals and also, probably, variable topography.

REFERENCES

- Gilbert, T. F. Fundamental dimensional properties of the operant. *Psychol. Rev.*, 1958, **65**, 272-282.
- Hall, J. F. The relationship between external stimulation, food deprivation, and activity. *J. comp. physiol. Psychol.*, 1956, **49**, 339-341.
- Hill, W. F. Activity as an autonomous drive. *J. comp. physiol. Psychol.*, 1956, **49**, 15-19.
- Premack, A. J., and Premack, D. Increments in ad libitum eating as a function of deprivation for wheel-turning behavior. Paper read at Midwest Psychol. Ass., Detroit, May, 1958.
- Premack, D. Toward empirical behavior laws: I. Positive reinforcement. *Psychol. Rev.*, 1959, **66**, 219-233.
- Premack, D. Reversibility of the reinforcement relation. *Science*, in press.

- Premack, D., and Bahwell, R. Operant-level lever pressing in a monkey as a function of interest interval. *J. exp. Anal. Behav.*, 1959, **2**, 127-131.
- Premack, D., and Collier, G. Analysis of nonreinforcement variables affecting response probability. *Psych. Monogr.*, in press.
- Stellar, E., and Hill, J. H. The rat's rate of drinking as a function of water deprivation. *J. comp. physiol. Psychol.*, 1952, **45**, 96-102.

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