RATS' LEVER-PRESS DURATIONS AS PSYCHOPHYSICAL JUDGMENTS OF TIME[1]

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Hungry rats received food following lever-press durations exceeding a minimum value, which ranged from 0 to 6.4 sec. When no intertrial intervals separated successive presses, modal press durations remained at very short values as the minimum value required for food was increased. This was particularly true immediately after a food presentation. When an 8-sec intertrial interval followed each lever release, modal press durations were always at or beyond the minimum value required for food, and outcome of the preceding press had no effect on press duration. Possible reasons for the effects of intertrial intervals included punishment of short presses, increased delay of reinforcement of short presses, and reduced density of reinforcement. In addition, functions relating discrete-trials lever-press duration to minimum duration required for food were found to be qualitatively and quantitatively similar to the power functions recently proposed by Catania (1970) for interresponse time and response latency. This similarity was taken as support for a general psychophysical law of temporal judgments.

Temporal duration is a property of both the environment and the behavior of an organism, and there is no shortage of examples of psychophysical relationships between these two classes of temporal variables. Within the context of animal conditioning, some of the most interesting of such relationships are those in which the environment selectively applies consequences on the basis of temporal properties of an organism's behavior. The resulting differentiation of these temporal properties is very amenable to study by psychophysical production techniques in which responses are differentially reinforced according to their value on a particular temporal dimension.

Probably the most frequently studied dimension of response differentiation in animals has been interresponse time (IRT), or the time between two adjacent occurrences of the same response class (Kramer and Rilling, 1970). Although differentiation of other temporal dimensions of behavior, such as the latency of a single response (Catania, 1970) and the time between adjacent occurrences of two different response classes (Mechner and Guevrekian,

1962) has been investigated, all of these dimensions involve measurement of a temporal interval during which the organism's behavior is not specified by the experimental dependencies. During an IRT, for instance, the only requirement placed on a subject is that it *not* emit an instance of the response class that terminates the IRT. It is possible that IRTs may be influenced by a wide variety of uncontrolled variables so as to yield an unnecessarily complex and variable index of temporal differentiation. The fact that an IRT may be filled by almost any behavior in the subject's repertoire could be expected to contribute considerable variance to the IRTs actually observed. Although it has commonly been reported (Kramer and Rilling, 1970) that IRTs are filled with fairly stereotyped behaviors, it is also reported that these behaviors are usually different for different subjects and vary over time within a subject.

Another temporal response dimension that has been used to study differentiation is response duration. Although the duration of a response may also be filled with a variety of other behaviors, the range of such behaviors that would not terminate the measured response would usually be considerably narrower than in the case of an IRT or a latency. Another potential advantage of response duration is that values obtained when long durations are differentially reinforced seldom occur un-

der conditions in which duration is not specified by the reinforcement dependencies (Skinner, 1938). This suggests that differentiation of response duration may be considerably less contaminated by nondifferential effects of reinforcement than is IRT or latency differentiation. That is to say, reinforced occurrences of a response may decrease its IRT while non-reinforced occurrences tend to increase subsequent IRTs so that any additional effects of differentially reinforcing specific IRTs or latencies are difficult to isolate (Norman, 1966). The considerably smaller effects of nondifferential reinforcement and nonreinforcement on response durations potentially diminish this type of interpretive difficulty.

In spite of the possible advantages of response duration for studies of differentiation of temporal properties of behavior, surprisingly few data are available using this dimension. Most studies that have examined differentiation of response duration have examined the effects of only one or two values of duration required for reinforcement during asymptotic performance (McMillan and Patton, 1965; Notterman and Mintz, 1965). The sole exception to this statement is a study by Ferraro and Grilly (1970) in which six values of duration required for food were examined. However, the largest of these values was only 1.6 sec, and each rat was exposed only to a single value. Interpretation of these results was somewhat complicated by the nonreinforcement of press durations more than 0.2 sec longer than the minimum value required for reinforcement, regardless of that value. This resulted in rapidly diminishing probabilities of reinforcement as the minimum value required for reinforcement became larger.

The primary purpose of the present studies was to obtain parametric, asymptotic data on durations of rats' lever presses at a number of different values of minimum reinforced duration, and to compare the resulting functions to those reported for differentiation of other temporal response properties.

EXPERIMENT I
METHOD
Subjects

Five male albino rats, obtained from the Holtzman Company, were approximately 120 days old and had free-feeding weights from 415 to 463 g at the beginning of the experi-

ment. Throughout the experiment, each rat was maintained at 85% of its free-feeding weight by supplemental rations of Purina Lab Chow administered in the home cage immediately after each experimental session.

Apparatus

A single Foringer rat chamber and enclosure was equipped with a Hawley retractable lever that required a force of 0.294 N to activate its microswitch. The levers could be fully extended or retracted in 0.4 sec. A Foringer pellet magazine dispensed 45-mg Noyes rat food pellets into a tray immediately adjacent to the response lever. Houselights were two, No. 1819 pilot lamps mounted above and to either side of the lever. Schedules were arranged by solid-state logic, and response durations and IRTs were recorded with 0.1 sec resolution on punched paper tape.

Procedure

Rats were initially trained to press the lever in a single session by being placed into the experimental chamber with several pellets in the food tray, the lever extended, and the houselights illuminated. Any lever release was followed by the delivery of one food pellet. A lever release was any opening of the lever microswitch for at least 25 msec. All daily sessions throughout the experiment consisted of 100 food presentations. Following this initial training, all rats received 14 additional sessions in which each lever release produced a food pellet (CRF).

All further sessions of the experiment involved differential reinforcement of lever-press durations. All lever releases following press durations greater than a specified time (t) produced a food pellet. All other lever presses were without scheduled consequences. The successive values of t employed were 0.4, 0.8, 1.6, and 3.2 sec. The number of sessions at each value of t were 10, 24, 14, and 14, respectively. These numbers of sessions ensured that no rat showed more than ±0.05 variation in the probability of food presentation per lever press over the last three sessions. Transitions between successive values of t were made directly, with no intermediate values being employed.

RESULTS

All data analyses were based on lever presses between the fifth and the fiftieth food presen-

tations on each of the last three sessions under each experimental condition. Presses before the fifth food presentation were not considered because press durations at the beginning of a session tended to be much more variable than those later in the session. Presses beyond the fiftieth food presentation of a session were omitted from consideration to avoid possible fatigue or satiation effects. Although press durations showed little, if any, indication of such extended within-session effects, press IRTs sometimes became longer late in a session.

Figure 1 displays relative frequency distributions of lever press durations for each rat under each value of t. Solid bars indicate presses followed by food. Under CRF, all rats displayed rapidly decaying relative frequencies of presses across duration values with various rats placing 68 to 77% of their presses at or below 0.6 sec. Making food presentations dependent on press durations longer than 0.4 sec produced only slight changes in the press-duration distributions. These changes consisted mainly of decreases in relative frequencies in the first class interval (0.2 sec and below). Changes also occurred in the extent of the

positive tails of the distributions, but the direction of change was inconsistent across individual rats.

Further increases in the value of t produced corresponding increases in the relative frequencies of longer presses. In spite of these changes, however, all rats at all values of t continued to display a mode in one of the first three class intervals (0.6 sec and below) of their duration distributions. With the exception of Rat #5 at $t = 3.2$ sec, the height of this mode decreased as t increased. For some rats, at some values of t, a secondary mode developed in the duration distribution near the value of t. This secondary mode can be seen in Rats #1, 4, and 5 at $t = 0.8$ sec and in Rats #1, 2, 3, and 5 at $t = 1.6$ sec.

In order to obtain more statistically manageable descriptions of the rats' behavior, several summary statistics were computed and submitted to analyses of variance. Table 1 shows the means and ranges of individual rats' median press durations at each value of t. Separate values are shown for presses immediately preceded by food and for those that were not. An analysis of variance (Lindquist, 1953,
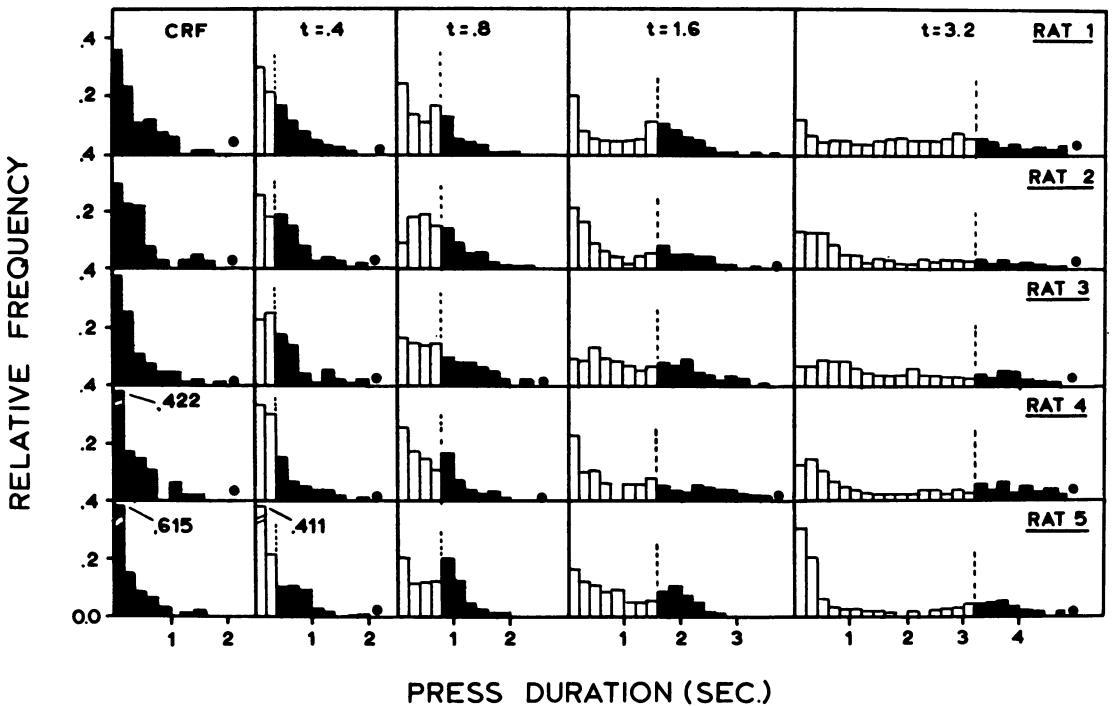

Fig. 1. Relative frequency distributions of lever-press durations with various minimum durations (t) required for food. Class intervals are 0.2 sec wide. Solid bars represent presses followed by food and filled circles are overage classes.

p. 237) of this data yielded significant F ratios for the effects of t value, outcome of the previous press, and the interaction of these two variables. Median press duration increased with the value of t; F (3, 12) = 13.73, $p <$ 0.001; but progressively undershot the value of t. Median press durations were also longer when the previous press was not followed by food; F (1, 4) = 9.23, $p < 0.05$; and the magnitude of this effect increased with the value of t; F (3, 12) = 3.65, $p < 0.05$.

Table 1

Mean and range of individual rats' median lever-press duration as a function of t and outcome of the preceding press.

Condition	After No Food		After Food	
	Mean	Range	Mean	Range
CRF			0.3	(0.2-0.4)
$t = 0.4$	0.4	(0.3-0.5)	0.4	(0.4-0.5)
$t = 0.8$	0.7	(0.4-0.8)	0.6	(0.6-0.8)
$t = 1.6$	1.4	(1.2-1.6)	0.8	(0.4-1.1)
$t = 3.2$	1.8	(1.1-2.1)	1.1	(0.3-2.5)

Table 2 shows the means and ranges of individual rats' median IRT at each value of t. An IRT was the time from releasing the lever to its next depression. Separate values are shown for IRTs initiated by food presentation and for those that were not. Although IRTs tended to be longer when the preceding press had produced food, analysis of variance of the IRT data with t value and outcome of the preceding press as main effects yielded no statistically significant F ratios. In addition, no consistent relationships between press durations and IRTs were found. A product-moment correlation coefficient was computed between IRTs and durations for each rat at each value of t. The individual coefficients ranged from -0.22 to $+0.40$ with no systematic relationship to the value of t, and little consistency within a rat across t values. The mean of all coefficients computed was $+0.05$.

A final set of analyses attempted to elaborate the manner in which increases in the value of t increased the dependence of press durations on the outcome of the preceding press. Table 3 shows the means and ranges of individual rats' relative frequency of a press being followed by food, along with the mean relative frequencies of food conditionalized on outcome of the preceding press, for each value of t. Analysis of

Table 2

Mean and range of individual rats' median lever-press IRT as a function of t and outcome of the preceding press.

Condition	After No Food		After Food	
	Mean	Range	Mean	Range
CRF			1.2	(0.6-2.1)
$t = 0.4$	0.4	(0.2-0.9)	0.7	(0.3-1.7)
$t = 0.8$	0.3	(0.2-0.4)	0.5	(0.2-1.5)
$t = 1.6$	0.4	(0.2-0.6)	0.6	(0.1-1.8)
$t = 3.2$	0.4	(0.2-0.5)	0.8	(0.2-1.3)

variance (Lindquist, 1953, Ch. 6) of the unconditional relative frequencies indicated a significant decrease across t values; F (3, 12) = 4.82, $p < 0.025$. This decrease merely reflects the progressive undershooting of t displayed by the median press durations. An analysis of variance of the conditional relative frequencies supported the obvious result that the decrease in unconditional relative frequency was almost entirely attributable to presses immediately following food presentations. Thus, significant effects were found for t values; F (3, 12) = 7.36, $p < 0.005$; and for the interaction of t value with outcome of the preceding press; F (3, 12) = 4.84, $p < 0.025$. That this strong negative sequential dependency was attributable to outcome of the preceding press, rather than a direct sequential property of press durations, is suggested by a lack of relationship between press durations separated by the same outcome event. Two autocorrelation coefficients were computed for each rat at each value of t. One of these coefficients represented the regression of press duration following food presentation onto the press duration that produced the food. The other coefficient represented the correlation between adjacent press durations not separated by food presentation. These coefficients ranged from -0.25 to $+0.20$ and showed no systematic relationship to the value of t or to whether or not a food presentation separated two successive presses. Furthermore, the mean of the 40 coefficients computed was $+0.02$.

DISCUSSION

The present experiment demonstrated some control of the duration of rats' lever presses by the minimum duration followed by food. It is also clear that this control was to some extent temporal in that the obtained press-dura-

Table 3

Mean and range of individual rats' relative frequency of a press being followed by food and relative frequencies conditionalized on outcome of the preceding press.

Condition	P (Food)		P (Food/No Food)		P (Food/Food)	
	Mean	Range	Mean	Range	Mean	Range
t = 0.4	0.47	(0.37-0.57)	0.45	(0.34-0.52)	0.50	(0.38-0.62)
t = 0.8	0.43	(0.36-0.46)	0.45	(0.29-0.53)	0.40	(0.29-0.48)
t = 1.6	0.37	(0.33-0.41)	0.46	(0.34-0.54)	0.22	(0.07-0.39)
t = 3.2	0.33	(0.24-0.40)	0.39	(0.27-0.47)	0.21	(0.02-0.42)

tion distributions contained much higher relative frequencies of long presses than could be expected on the basis of a constant conditional probability of press termination across values of duration. This conclusion is particularly clear in those press-duration distributions that show a secondary mode near the value of t, but essentially all of the obtained distributions show more gradual slopes than the geometric decay that would result from lever releases that were random with respect to time.

On the other hand, perhaps the most striking feature of the present data was the relatively poor quality of temporal control obtained. As the value of t was increased, all rats persisted in emitting relatively high frequencies of short presses, in spite of the increased effort and decreased food density that resulted. It should be emphasized that this result is not atypical in that the two other studies that have published rats' press-duration distributions with a minimum duration requirement for food presentation have also reported high relative frequencies of very short presses (Notterman and Mintz, 1965; Stevenson and Clayton, 1970). It is clear that these short duration presses were not due to the unavailability of "temporal stimuli", since Stevenson and Clayton's rats were presented with an 87-dB white noise whenever a press had been in progress long enough to be followed by food. Furthermore, rats for which food or water is made dependent on long IRTs do consistently develop a modal IRT frequency close to minimum requirements at least as high as 60 sec (Kramer and Rilling, 1970).

It might be suggested that failures to obtain temporal control of press durations comparable to that reported for press IRTs and latencies is attributable to the very reasons presented in the Introduction for preferring duration for studies of temporal differentiation.

That is to say that the availability of a wide range of behaviors with which to mediate the interval, or the ability of nonreinforcement to increase the value of subsequent responses on the dimension of differential reinforcement, may be necessary conditions for temporal differentiations. Before accepting such a conclusion as to the mechanisms of temporal differentiation, however, less far-reaching possibilities should be considered and empirically eliminated.

One aspect of the present results that deserves closer attention is the finding that decreases in the relative frequency of presses followed by food with increases in the value of t were almost entirely attributable to presses immediately following food presentations. It was sometimes observed that when the lever was released after being held long enough to produce food, the rat would again depress and immediately release the lever, before emitting the food tray approach occasioned by the sound of the food delivery mechanism. If this occurred frequently, it would inflate the relative frequency of short presses following food presentations.

Even if the differences between relative frequencies of short presses following food and following no food could be eliminated, there remains the fact that relative frequencies of short presses were high even when the previous press was not followed by food. A number of factors might account for the persistence of these short presses. The above described intervention of short presses between some reinforced presses and approach to the food tray may have increased the frequency of short presses through adventitious reinforcement. In addition, the close proximity of short followed by long presses permitted by the free-operant paradigm may have contributed to the high relative frequency of short responses via delayed reinforcement. Finally, the relatively

high density of food presentations permitted by the free-operant paradigm may have made changes in reinforcement density produced by small changes in press duration proportionally too small to exert a strong influence on the rats' behavior. That the effectiveness of a food presentation to modify a rat's response production is inversely related to the overall density of food presentation is strongly suggested by a study of counting behavior in rats (Brandon, 1969).

All of the factors that have been discussed as possibly contributing to the high relative frequencies of short presses could be eliminated or greatly attenuated by using a discrete-trials paradigm in which a period of response prevention follows each lever press. Such intertrial intervals would remove the possibility of short duration presses intervening between a long press and reaction to operation of the food magazine. They would also reduce the overall density of food presentation and increase the delay of food presentation following short presses.

EXPERIMENT II

METHOD

Subjects

Five male albino rats, obtained from the Holtzman Company, were approximately 100 days old and had free-feeding weights from 355 to 389 g at the beginning of the experiment. Throughout the experiment, each rat was maintained at 85% of its free-feeding weight in the manner described for Experiment I.

Apparatus

The apparatus was identical to that described for Experiment I.

Procedure

Rats were initially trained to press the lever by being placed into the experimental chamber with several pellets in the food tray, the lever extended, and the houselight illuminated. Any lever release was followed by delivery of a single 45-mg food pellet and an 8-sec intertrial interval during which the lever was retracted and the houselights extinguished. All experimental sessions consisted of 50 food presentations. The CRF training continued for at

least 10 sessions and until a rat's mean press duration in each of three successive sessions varied less than ±5% from its overall mean for the three sessions.

All further sessions involved differential reinforcement of lever-press durations. All lever releases following press durations greater than a specified time (t) produced one food pellet and an 8-sec intertrial interval. All other presses produced only the 8-sec intertrial interval. The successive values of t employed were 0.4, 0.8, 1.6, 3.2, 6.4, and 0.4 sec. Each value of t was in effect for at least 10 sessions, and until a rat's mean press duration in each of three successive sessions varied less than ±5% from its overall mean for those three sessions. The resulting numbers of sessions for each rat under each experimental condition are shown in Table 4. Transitions between successive values of t were made directly, except where the rat stopped responding. This occurred mainly in going from t values of 3.2 to 6.4 sec where it was necessary to increase t in two or three steps until 10 or 20 food presentations had occurred at each intervening value of t.

Table 4

Number of sessions under each experimental condition for rats in Experiment II.

Rat	CRF	*Successive Values of* t					
		0.4	*0.8*	*1.6*	*3.2*	*6.4*	*0.4*
6	10	12	12	10	16	20	14
7	10	14	12	14	12	20	30
8	10	14	12	14	12	20	30
9	10	12	14	12	14	20	20
10	12	10	14	12	14	20	24

RESULTS

All data analyses were based on the last three sessions under each experimental condition. Presses before the fifth food presentation of each session were again eliminated from consideration because of the high variability sometimes shown by their durations.

Figure 2 displays relative frequency distributions of lever-press durations for each rat under each experimental condition. Solid bars represent presses followed by food, and the distributions for $t = 0.4$ sec are from the second determination. Under CRF, all rats showed rapidly decaying proportions of
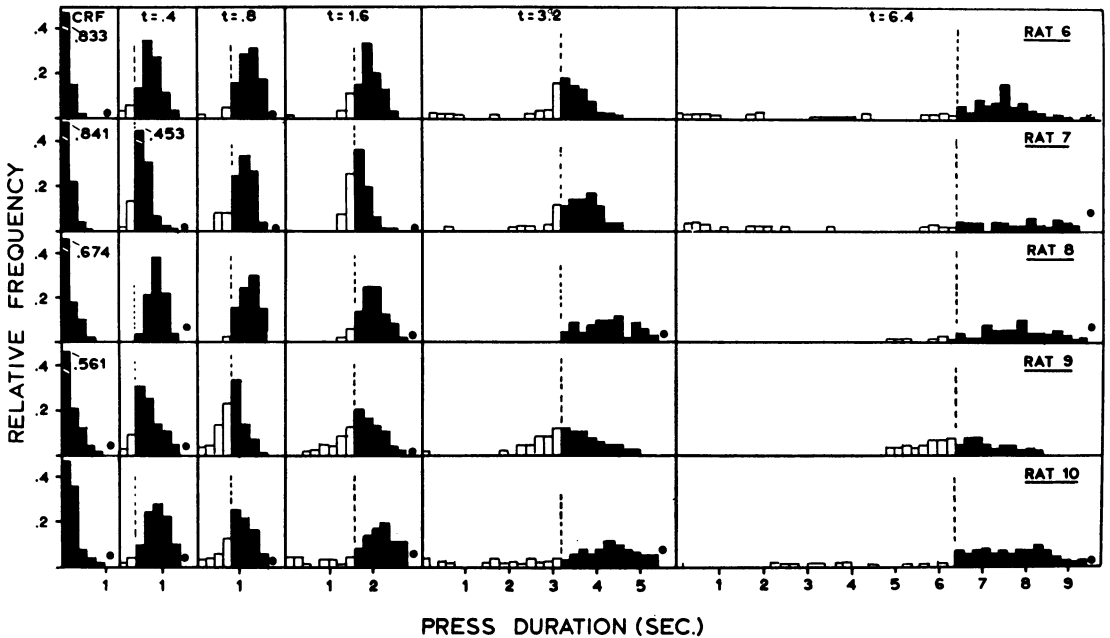
Fig. 2. Relative frequency distributions of lever-press durations with various minimum durations (t) required for food and all presses followed by an 8-sec intertrial interval. Class intervals are 0.2 sec wide. Solid bars represent presses followed by food and filled circles are overage classes.

presses across duration values with 65 to 94% of their presses being at or below 0.3 sec. These CRF distributions were much steeper than those obtained in Experiment I.

Increasing the minimum press duration followed by food produced distributions with modes at or above the lowest class interval followed by food. The dispersion of these distributions also increased progressively, with the exception of those for Rats #6 and #7 at the lowest values of t. In addition to the consistent maintenance of a mode at or beyond all values of t employed, the most striking difference between these distributions and those for Experiment I was the generally low relative frequency of presses in the lowest class intervals. The highest relative frequency of press durations in the first class interval was 0.11, and in all but four cases this relative frequency was no greater than 0.03.

Figure 3 presents each rat's median press duration (T), as a function of minimum duration followed by food (t), in logarithmic coordinates. Logarithmic coordinates were used because Catania (1970) reported that a wide variety of results relating response latencies and IRTs to minimum values followed by food are well described by power functions.

Redeterminations at $t = 0.4$ sec are indicated by open circles, and the group mean function is shown in the lower right-hand frame. The broken lines in Figure 3 indicate best-fitting straight lines to the data points produced by values of t beyond 0.4 sec. In each case, the power function describing this line is also given. As can be seen, the power functions provided good fits to data points associated with t values of 0.8 sec or greater. The coefficients of the fitted power functions ranged from 1.13 to 1.50 and the exponents ranged from 0.82 to 0.98.

An analysis of variance of median lever-press durations using the means of the two determinations at $t = 0.4$ sec yielded a highly significant effect of t; $F (4, 16) = 423.9$, $p < 0.001$. There were no statistically reliable effects of outcome of the previous press; $F (1, 4) = 0.39$; or of the interaction of this variable with t; $F (4, 16) = 2.36$. The large increases in median press durations with increases in t, and the lack of effect of prior outcome were in sharp contrast to the results shown in Table 1 of Experiment I.

Figure 4 shows the interquartile range of individual rat's press durations as a function of minimum duration followed by food. Redeter-
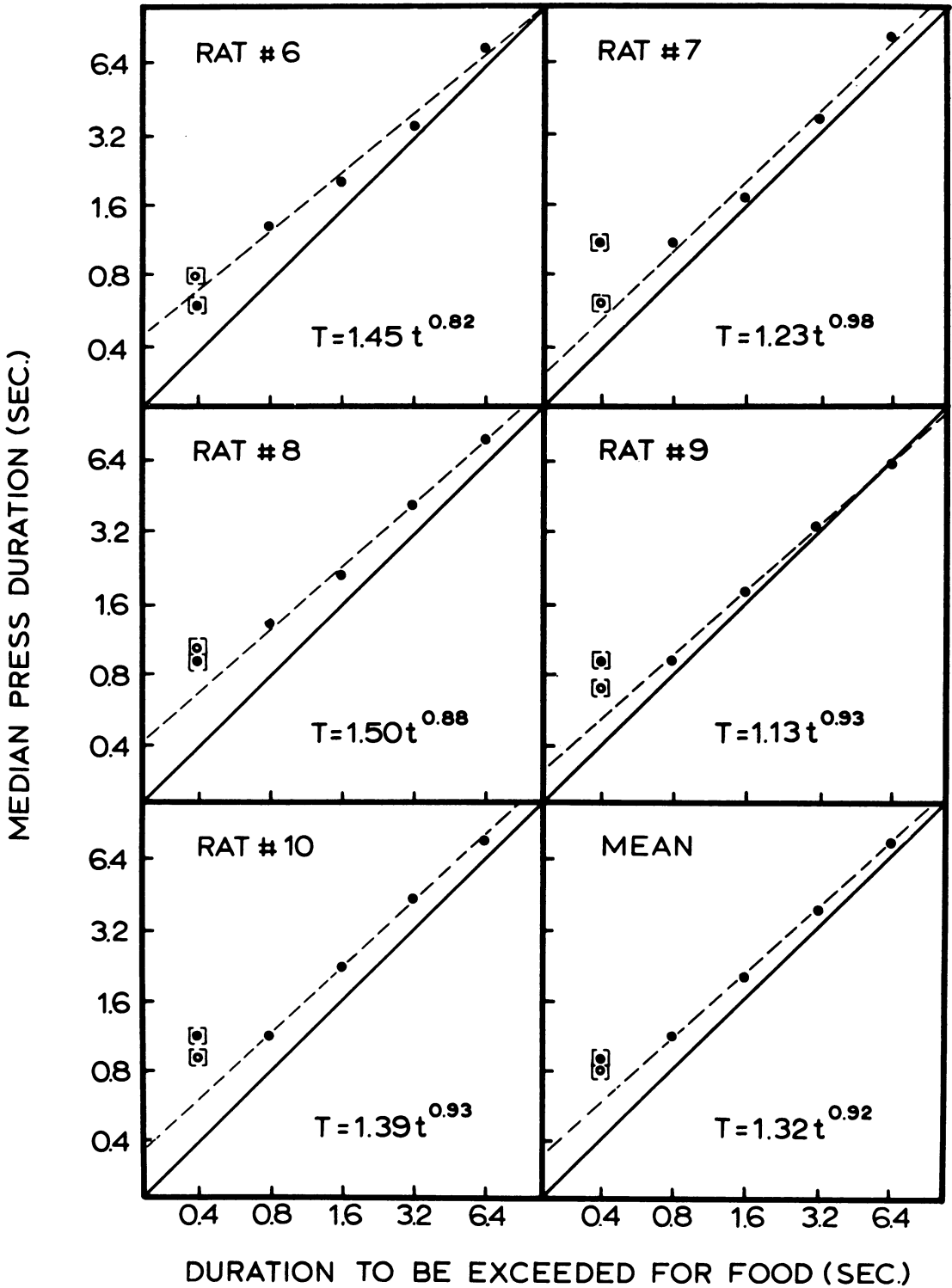
Fig. 3. Median lever-press duration (T) as a function of minimum duration (t) required for food, in logarithmic coordinates. All presses were followed by an 8-sec intertrial interval. Open circles represent redeterminations and bracketed points were not used in fitting the power functions.
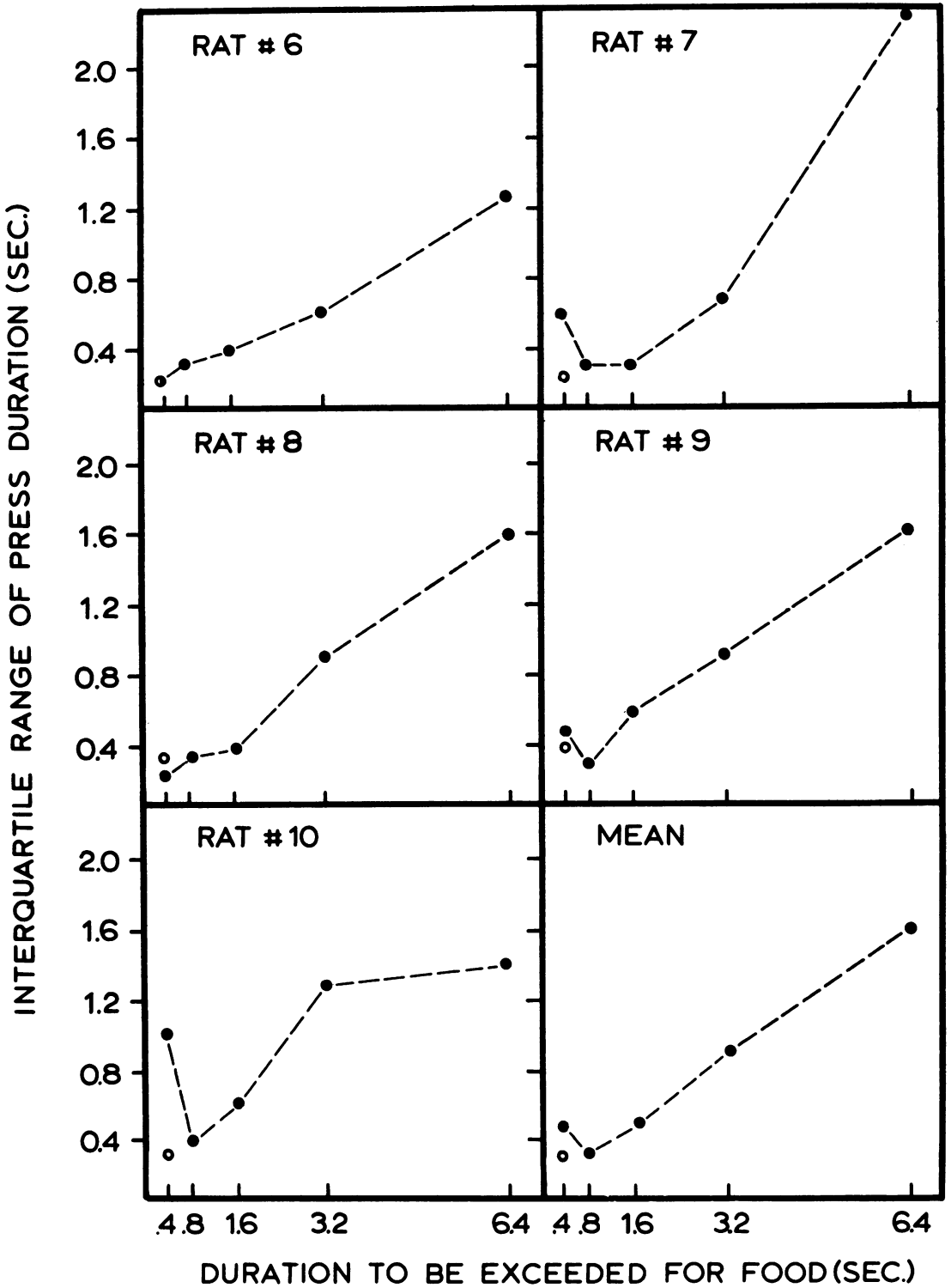
Fig. 4. Interquartile range of lever-press durations as a function of minimum duration required for food. All presses were followed by an 8-sec intertrial interval and open circles represent redeterminations.

minations at $t = 0.4$ sec are again represented by open circles, and the group mean function is shown in the lower right-hand frame. Rats 6, 8, and 9 showed essentially linear increases in interquartile ranges with increases in t, except for very low values of t in Rat #9. Rats 7 and 10 departed from linearity in that their interquartile ranges were relatively high at the first determination of $t = 0.4$ sec, and the remainder of their functions displayed positive and negative acceleration, respectively. The group mean function relating interquartile range of press durations to t was approximately linear, particularly if the second determination at $t = 0.4$ sec was used. An analysis of variance using the means of the two determinations at $t = 0.4$ sec statistically supported the effect of t on interquartile ranges; F (4, 16) = 31.14, $p < 0.001$.

Table 5 shows the means and ranges of individual rats' median latency at each value of t. A latency was the period from activation of the lever extension mechanism to closure of the lever microswitch by the rat. Separate values are shown for latencies preceded by food presentation and for those that were not. The only apparent effect in these latencies was a tendency for them to become longer at large values of t. This observation was supported by an analysis of variance using means of the two determinations at $t = 0.4$ sec. The effect of t value on latency was highly significant; F (4, 16) = 9.19, $p < 0.001$. The effect of outcome of the previous press, and its interaction with t value both produced F ratios less than one. In addition, no consistent relationship was found between press latencies and durations, except at $t = 6.4$ sec. A product-moment correlation coefficient was computed between latencies and

durations for each rat at each value of t. Ignoring $t = 6.4$ sec, these coefficients ranged from -0.43 to $+0.30$ with a mean of -0.05. However, when t was 6.4 sec the correlations between latencies and durations ranged from -0.26 to -0.47, with a mean of -0.40. The longer median latencies at $t = 6.4$ resulted from increased positive skewing of the latency distributions. The associated negative correlations between latency and duration resulted because these longer latency presses almost never had durations long enough to produce food.

GENERAL DISCUSSION

Major differences between the results of Experiment I and II occurred with respect to both overall performance and sequential dependencies. In Experiment I, the modes of press-duration distributions remained at low values as the minimum value required for food (t) was increased. In Experiment II, these modes were always at or above the value of t. Furthermore, rats in Experiment I were more likely to emit short presses immediately following a food presentation than at other times, while rats in Experiment II showed no signs of such sequential dependencies.

Both of these differences between the results of Experiment I and II are almost certainly attributable to the addition of an intertrial interval in Experiment II. Other differences between the two experiments, such as number of food presentations per session and definition of stable performance, do not seem adequate to explain the differences in results. The attribution of differences in results between Experiments I and II to the intertrial interval variable is further strengthened by the results of several investigators. Catania (1970) examined the effect of intertrial intervals on the latency of pigeons' key pecks while the minimum latency required for food presentation in different birds ranged from 2.75 to 24.4 sec. As the intertrial interval was reduced from 20.0 to 2.0 to 0.2 sec, the relative frequency of very short latencies increased. Sequential dependencies were not reported. Kramer and Rilling (1969) investigated the effects of error-contingent intertrial intervals on IRTs of pigeons' key pecks. In this study, IRTs longer than 20 sec were followed by food while those shorter than 20 sec were followed by intertrial intervals of 0, 5, 10, or 20 sec. It was found that

Table 5

Mean and range of individual rats' median lever-press latency as a function of t and outcome of the preceding press.

Condition	After No Food		After Food	
	Mean	Range	Mean	Range
CRF			1.3	(0.9-1.5)
$t = 0.4$	1.0	(0.9-1.8)	1.1	(0.9-1.4)
$t = 0.8$	0.9	(0.7-1.4)	0.9	(0.8-1.1)
$t = 1.6$	1.1	(0.8-1.4)	1.1	(0.7-1.7)
$t = 3.2$	1.2	(1.1-1.3)	1.1	(0.9-1.4)
$t = 6.4$	1.9	(1.5-2.6)	1.6	(1.1-2.1)
$t = 0.4$	0.9	(0.5-1.3)	0.9	(0.7-1.4)

any of the non-zero intertrial intervals sharply reduced the relative frequency of very short IRTs. Kramer and Rilling attributed this result to a punishing effect of intertrial intervals on short IRTs; however, the results discussed above suggest that the effect does not depend on differential application of intertrial intervals, as might be suggested by the punishment interpretation.

The Discussion of Experiment I offered several possible reasons why intertrial intervals might improve temporal differentiation. These reasons included elimination of adventitious reinforcement of short presses intervening between long presses and eating, increased delay of reinforcement of short presses, and increased marginal gain represented by a food presentation in the context of a lower density of food presentations. To this list could be added the possibility that intertrial intervals may have differentially punished short presses. Unfortunately, these possible mechanisms for the effect of intertrial intervals on temporal differentiation are not mutually exclusive with respect to the present experiments. Further research into the roles of these mechanisms in determining intertrial interval effects should attempt to isolate the effects of intertrial intervals following short presses from those of intertrial intervals following food presentations. The effects of variations in length of intertrial intervals should also be investigated as should the effects of other variables that would be expected to modify reinforcement density. An example of such a variable would be second-order random-ratios imposed on the reinforcement schedules used in the present experiments.

A second aspect of the present results requiring discussion is the similarity of temporal differentiation obtained in Experiment II to that reported by other investigators for IRTs and latencies. It was noted in the Introduction that differentiation of response durations might yield less variable performance than IRTs or latencies because of the much more restricted range of behaviors available for filling the temporal interval. This would mean that IRT and latency might give underestimates of an organism's differential sensitivity on temporal dimensions. In what appears to be the only published study to report differential sensitivity measures for latency or IRT production in animals, Catania (1970) showed

that the critical ratios of standard deviations of pigeons' key-peck latencies to mean peck latencies were approximately constant at 0.30 when the minimum latency required for food ranged from 1.27 to 24.4 sec. In the present Experiment II, the ratios of interquartile ranges of rats' lever-press durations (Figure 4) to median durations (Figure 3) were approximately constant from t values of 0.8 to 6.4 sec. The mean values of this nonparametric critical ratio across t values of 0.8, 1.6, 3.2, and 6.4 sec were 0.28, 0.23, 0.23, and 0.22, respectively. If Catania's parametric critical ratio of 0.30 was converted to a nonparametric ratio with an assumption of normal distributions of peck latencies, a value of about 0.225 would be obtained. This value clearly falls within the range of values obtained in Experiment II. A definitive comparison of relative accuracy of temporal differentiation of latency and duration would require use of similar organisms and equation of other parameters. However, the striking quantitative similarity of Catania's critical ratios to the present ones suggest that the relative accuracy of temporal differentiation of response latencies and durations is probably not much different. On the other hand, the similarity of these results suggests that neither the wide variety of behaviors available for filling a response latency, nor the extreme sensitivity of this measure to nondifferential reinforcement effects are in any way necessary to the demonstration of relatively accurate temporal differentiation. If this is true, it calls into question the usefulness of accounts of temporal differentiation in terms of mediating chains of incompatible behaviors (Reynolds and McLeod, 1970) or of nondifferential effects of reinforcement and nonreinforcement (Logan, 1960, Chap. 7).

Considerably more data are available on central tendencies of temporal productions than on variabilities. Catania (1970) showed that a wide variety of results relating the central tendencies of IRTs or latencies in rats and pigeons to the minimum value required for food, as well as various psychophysical judgments of time in humans, can be described by power functions. Catania reports that in rats and pigeons these power functions tend to have exponents slightly less than 1.0 and coefficients somewhat greater than 1.0, but less than 2.0. In agreement with these generalizations, it has been shown that the relations be-

tween median press durations and *t* values in Experiment II are well described by power functions. It should be pointed out that these relations could have been equally well fit by linear functions over the range of *t* values employed. Best-fitting linear functions would have had intercepts slightly greater than zero and slopes slightly greater than 1.0. The only striking difference between the power functions and linear functions just described would have occurred at larger values of *t*. Linear functions with slopes greater than 1.0 predict that progressively larger values of *t* would have produced median press durations that exceeded *t* by increasing amounts. Power functions with exponents less than 1.0 predict that progressively larger values of *t* would have eventually produced median press durations that were less than *t*. The absence of larger values of *t* in the present study precludes this distinction, but Catania (1970) has clearly shown that the power function prediction holds for response latencies and IRTs. In any case, the close quantitative correspondence between the power functions fitted to the present data and those reported by Catania suggest an invariance across several unrelated species and several different response dimensions that supports appeal to a general psychophysical law of temporal judgments when complications produced by lack of response spacing are eliminated.

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