Does CS intensity determine CR amplitude?

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The nictitating membrane response of three groups of eight rabbits, Groups LS, LM, and SM, was classically conditioned to different pairs of loud (95 dB), medium (82 dB), or soft (75 dB) CS intensities (within-S design). In agreement with Grice's variable threshold (VT) model, CR frequency and latency were functions of CS intensity, and the use of extended (1,000 msec) CS-alone test trials in Group LS indicated that a proportionately greater number of CRs to the soft tone were being obscured by UCS. However, these test trials also indicated that CR amplitude is significantly increased by CS intensity, a result unexpected from the VT model.

The work of Grice (1968) and his associates (Grice & Hunter, 1964; Grice, Hunter, Kohfeld, & Masters, 1967; Grice, Masters, & Kohfeld, 1966) has uncovered many of the effects which characterize the CS intensity variable in classical conditioning. Foremost among these effects is the larger performance differential obtained when Ss experience two intensity levels within a given session (the "within" design), as opposed to the case in which only a single intensity is presented during a session (the "between" design). Frey (1969) has demonstrated similar effects in infrahuman Ss (rabbits).

Grice has interpreted these findings within the framework of a variable threshold (VT) model which emphasizes the signal detection aspects of experiments involving CS intensity. This VT model, modified from an earlier model for reaction time (McGill, 1961, 1963), characterizes sensory input (CS) as a cumulative series of impulses which must surpass an oscillating detection threshold in order for a response (CR) to occur. By relating impulse rate and mean threshold value to intensity, the model is able to account for obtained experimental differences in CR frequency and latency without assuming any energizing or excitatory properties related to CS intensity. Grice has shown that the threshold assumptions alone provide an adequate account for the different effects obtained with "between" and "within" designs. The success of the VT model suggests that it is worth considering in greater detail. Two points on which further clarification is needed are these: (1) To what extent

would the effects of CS intensity disappear if extra time were given to respond, i.e., would all intensities tend to evoke responses (become suprathreshold) when the CS was extended and the UCS is omitted or delayed? (2) On trials in which the CS is known to be suprathreshold by virtue of S's having made a CR, would CS intensity effects still persist if evaluated by, say, an amplitude measure? Care must be taken, however, to measure CR amplitude independent of CR latency. That is, the model would expect amplitude differences if part of the longer latency CR to a soft CS was "clipped" by UCS onset. Also, non-CRs must not be scored as 0 amplitude, since such trials might conceivably be classified by the model as a failure to detect the softer tone. If amplitude differences persist despite these precautions, it would appear that the VT model must be modified or expanded to account for such differences and that an energizing concept, such as Hull's (1949) stimulus intensity dynamism variable, might be necessary. The present experiment was designed to provide data on these issues.

METHOD

Three groups of eight naive New Zealand rabbits were prepared for nictitating membrane (NM) conditioning, using techniques similar to those described by Gormezano (1966). Ss were conditioned four at a time in separate sound-attenuation chambers (Scientific Prototype, SPC-300), with gross body movements restricted by a restraining box. The CS was a 75-, 82-, or 95-dB (re: .0002 dynes/cm²) 1,000-Hz pure tone, depending on the different conditions. These intensities were selected on the basis of a previous experiment (Ison & Leonard, 1971). Tone duration was, with one exception, as explained below, constant at 300 msec, with a 50-msec 10-mA spike of electric shock overlapping the last 50 msec of the tone on reinforced trials. The shock UCS was delivered circumorbitally via shock electrodes fastened above and below S's right eye.

On Day 1, all groups received a total of 240 CS-UCS pairings, 120 at each of two CS intensities in a repeating A B A A B B A A B B B sequence. Group LM received half its trials with the loud intensity CS (95 dB) and half with the medium intensity CS (82 dB). Groups MS and LS received identical treatment, except that medium and soft and loud and soft tones were employed, respectively.

On Day 2, all Ss received an additional 20 trials under the Day 1 conditions and were then shifted to an irregular partial reinforcement (PR) schedule on which US was omitted for half the trials at each intensity. The Ss received 180 total trials under the PR schedule, including 45 nonreinforced trials at each of the two tone intensities employed. The CS duration remained constant at 300 msec in Groups LM and MS but was lengthened, on nonreinforced trials only, to 1,000 msec in Group LS. The purpose of this lengthened CS was to extend the response observation interval and permit measurement of CR frequency, latency, and amplitude, uncontaminated by the UCR.

Responses were recorded on a Grass Model 7 polygraph at a paper speed of 100 mm/sec. Pen deflections of 1 mm or more in the 0- to 250-msec interval following CS onset were scored as CRs. Intertrial interval varied from 47 to 60 sec throughout. All programming was timed and controlled automatically by a PDP-8/S computer, interfaced for this purpose.

RESULTS AND DISCUSSION

The frequency of conditioned responses was clearly influenced by CS intensity, since all 24 Ss in the experiment made fewer CRs to their lesser intensity tone on Days 1 and 2 ($p < .001$). Due to variance in individual performance levels, however, response frequency to a given intensity CS was not significantly related to the intensity of the alternate CSs experienced by the various groups. These data appear in Table 1, which presents the relative CR frequency of individual groups to each tone intensity during the last 180 trials of Day 2. One S in Group MS uncharacteristically failed to show much evidence of conditioning to either tone intensity (five total CRs), thereby lowering the overall response

Table 1
Percent CRs to Each CS Intensity on Day 2

Group	Stimulus		
	L (95 dB)	M (82 dB)	S (75 dB)
LS	92.3		70.6
LM	86.3	74.8	
MS		70.4 (80.4)	54.6 (62.4)

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Fig. 1. Percent of CRs to each intensity level on the last half of Day 1 (60 trials to each CS) and Day 2, combined over groups.

level in this condition. With this S removed, the CR probability increased to 80.4% for the 82-dB tone and to 62.4% to the 75-dB tone, as shown by the figures in parentheses in Table 1. Mann-Whitney U tests revealed no significant differences between any two groups on a CS of the same intensity (all p s > .30). While it is the case that VT theory predicts higher response frequencies on tone of a given intensity when paired with tones of a lesser intensity (due to a lowered threshold), we suspect that the obtained lack of differences represents a lack of sensitivity in the experimental design rather than a critical flaw in the theory.

Since no interactions between the two intensity levels appeared, responses to each intensity level were combined across groups. Figure 1 depicts this performance during the last 120 trials of Day 1 and throughout Day 2. Responses were

Fig. 2. Cumulative CR frequency in Group LS on extended CS-alone trials of Day 2.

scored as CRs on the partial trials of Day 2 only when they appeared in the 0 to 250-msec observation interval. Latency data, however, were taken from the partial trials of Group LS in which the CS remained on for a full second. In agreement with the VT model, all eight Ss in this group ($p < .01$) averaged shorter latencies to their 95-dB CS (148.0 msec) than to their 75-dB CS (175.5 msec). These extended-CS trials of Group LS also provided an opportunity to examine the extent to which response probability would be increased by longer observation intervals. These data are presented in Fig. 2 for each of the intervals 0-250, 0-300, 0-500, 0-1,000 msec. In agreement with VT theory, a greater number of CRs to the soft tone fell outside the usual response observation interval (sign test, one-tailed, $p < .05$), and, as this interval was lengthened, the difference in CR frequency between the two intensity tones decreased from approximately 18% to only 9%. Figure 2 makes one further point, however. If a CR is to occur, it will occur within 50 msec or so after a 250-msec ISI or not at all. Only four CRs in the 720 total observations were found to have a latency greater than 300 msec, given this ISI. In the present version of the VT model, with sensory input accumulating linearly, it is not completely clear why both CSs do not reach threshold over such an extended interval, although certain assumptions about the extent of threshold variance may solve the problem. With the reaction time task for which the model was originally intended, it is reasonable to assume that all

intensities in the ranges employed here would eventually result in a response. This does not seem to be true for the conditioning task. A minor modification of the model which would seem to be more compatible with these data would be to assume that the cumulative impulses of the CS input are exponential, rather than linear, and approach different asymptotic values.

The data which are most problematic for the VT model appear in Fig. 3. Data for this figure were taken from the nonreinforced test trials of Day 2, 45 trials to each intensity. The height of the CR at its highest point was measured, and only trials on which CRs occurred were used; that is, zero amplitudes were not recorded. For each block of 15 CS presentations to each intensity, the mean amplitude of the CR to the louder tone was expressed as a proportion of the mean amplitude of the response to the softer tone, for individual Ss. As shown in Fig. 3, the average size of the CR to the louder tone typically ranged from 10% to 20% larger than the average size of the CR to the softer tone. The only exception occurred during the middle portion of Day 2, when the CR to the 82-dB tone was approximately equal in size to the CR elicited by the 95-dB tone. Of the 24 Ss in this experiment, 19 of 22 (two ties) made larger CRs to the louder of their two CSs when averaged across all test trials on Day 2 ($p < .001$). The fact that CS intensity significantly increases CR amplitude was not completely unexpected. Recent work from this laboratory (Ison & Leonard, 1971) has shown that CS intensity produces considerable increases in the amplitude of the NM UCR to shock. It seems reasonable to expect that the CR would be similarly influenced.

Fig. 3. CR amplitude to the louder of two tones expressed as a proportion of the response to the softer tone for nonreinforced trials, Day 2.

Whether or not the same results can be obtained with the human eyeblink CR, on which the VT model was based, remains a problem for further research. As presently formulated, however, the VT model does not appear to be able to account for such effects.

REFERENCES

- FREY, P. W. Within- and between-session CS intensity performance effects in rabbit eyelid conditioning. *Psychonomic Science*, 1969, 17, 1-2.
- GORMEZANO, I. Classical conditioning. In J. B. Sidowski (Ed.), *Experimental methods and instrumentation in psychology*. New York: McGraw-Hill, 1966. Pp. 385-420.
- GRICE, G. R. Stimulus intensity and response evocation. *Psychological Review*, 1968, 75, 359-373.
- GRICE, G. R., & HUNTER, J. J. Stimulus intensity effects depend upon the type of experimental design. *Psychological Review*, 1964, 71, 247-256.

- GRICE, G. R., HUNTER, J. J., KOHFELD, D. L., & MASTERS, L. Order of presentation, CS intensity, and response latency. *Journal of Experimental Psychology*, 1966, 72, 510-513.
- GRICE, G. R., MASTERS, L., & KOHFELD, D. L. Classical conditioning without discrimination training: A test of the generalization theory of CS intensity effects. *Journal of Experimental Psychology*, 1966, 72, 510-513.
- HULL, C. L. Stimulus intensity dynamism (V) and stimulus generalization. *Psychological Review*, 1949, 56, 67-76.
- ISON, J. R., & LEONARD, D. W. Effects of auditory stimuli on the amplitude of the nictitating membrane reflex of the rabbit (*Oryctolagus cuniculus*). *Journal of Comparative & Physiological Psychology*, 1971, in press.
- McGILL, W. J. Loudness and reaction time. *Acta Psychologica*, 1961, 19, 193-199.
- McGILL, W. J. Stochastic latency mechanisms. In R. D. Luce, R. R. Bush, and E. Galanter (Eds.), *Handbook of mathematical psychology*. Vol. 1. New York: Wiley, 1963.

following the end of the fixed-time interval but also not less than a minimum time since the last response. This had the effect of lowering the running rate without greatly affecting the length of the postreinforcement pause. More recently, other investigators (Killeen, 1969; Neuringer & Schneider, 1968; Shull, 1970) have tampered in various ways with the response-reinforcement contingency on FI schedules with similar results. That is, changes in running rate produced by restrictions on the response-reinforcement relation do not affect the duration of the postreinforcement pause. None of these studies, however, has attempted to manipulate the duration of the postreinforcement pause and to observe the effects of such manipulation on the running rate.

Studies that have manipulated the length of the interval in an FI schedule provide another means of examining the interactions between postreinforcement pause and running rate. In these cases, there is a clear interaction between the two measures of FI performance. For example, Sherman (1959) has shown that the postreinforcement pause is a direct function of interval duration, and Catania & Reynolds (1968) have shown that the running rate in normal FI schedules is also a function of the FI duration. The present study was an attempt to determine if independence between running rate and postreinforcement pause could be obtained by restricting the interresponse times (IRTs) that were followed by reinforcement. The procedure used is similar to that of Farmer & Schoenfeld (1964), with the exception that an upper, as well as a lower, limit is placed on the IRTs that qualify for reinforcement. These schedules are designated as FI pacing schedules of reinforcement. Both FI duration and reinforced IRT bands were separately manipulated, allowing the effects of a restricted response-reinforcement relation upon postreinforcement pause and the effects of FI duration upon running rate to be observed.

METHOD

Two experimentally naive male albino rats served as Ss and were maintained at 85% of their estimated normal body weights, as determined from a growth curve for animals of their strain. Supplementary food was given following each session. In conducting the research described in this report, the investigator adhered to the "Guide for Laboratory Animal Facilities and Care," as promulgated by the Committee on the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal

Independence of postreinforcement pause length and running rate on fixed-interval pacing reinforcement schedules

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Two rats were exposed to a series of fixed-interval pacing schedules of reinforcement requiring a specific interresponse time for reinforcement after a fixed period of time had elapsed since the last reinforcement. Independent manipulations of the length of the fixed interval and the interresponse time required for reinforcement showed that the postreinforcement pause and the running rate on fixed interval schedules could be independently altered. The length of the fixed interval determined the length of the postreinforcement pause, and the reinforced interresponse time determined the response rate once responding began in an interval.

In fixed-interval (FI) schedules of reinforcement, the first response to occur following the elapse of a fixed time interval from the last reinforcement is reinforced. Following exposure to a short (e.g., 30-60 sec) FI schedule, the pattern of response within each interval tends to become break-run. That is, there is a postreinforcement pause (break) followed by a rapid transition to a

steady response rate (run) that is maintained until the next reinforcement (Schneider, 1969; Sherman, 1959).

A number of recent studies have been concerned with the interactions between variables controlling pause length and running rate. In particular, these studies have manipulated the response-reinforcement contingency in various ways, while maintaining the basic FI schedule. Farmer & Schoenfeld (1964), for example, added a contingency to the FI schedule in which, for a response to be reinforced, it must not only occur

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