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DIFFERENTIAL REINFORCEMENT OF VOCAL DURATION[1]

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The effects of differential reinforcement of vocal duration were examined in a series of experiments in which each of 28 subjects (*Ss*) emitted a vowel whenever a light was flashed. In the first phase of each experiment, a penny was dispensed after each of 20 responses. In the second and subsequent phases, only those responses whose durations exceeded a criterion were reinforced; when 10 successive reinforcements were presented, one phase was terminated and the next begun. The criterion for reinforcement in each phase was determined by a different schedule in each of six experiments; it ranged from 80 to 120 per cent of the mean duration of the 10 terminal responses in the prior phase. Differential reinforcement effected a large and systematic change in the duration of vocal responses as long as the responses selected for reinforcement had a sufficiently high probability of occurrence. This requirement was formulated as the difference between the criterion duration and the mean duration of the terminal responses in the prior phase, divided by their standard deviation. This statistic, named the shaping index, was correlated with the number of responses emitted before each phase was terminated. It was found to be large whenever the shaping process failed. Many *Ss* failed to tact the reinforcement contingency despite marked changes in their vocal behavior and extensive probing by a questionnaire, administered at the end of each session.

An excellent description of the procedure for differential reinforcement of responding has been given by Keller and Schoenfeld (1950):

"We select one (or more) of the 'natural' variations of a well-conditioned response and give it *exclusive* reinforcement; the remaining variations are subjected to *extinction*. If we pick out, in advance, a variation that has been of fairly frequent occurrence, and if we apply this selective reinforcement rigorously, we can soon produce an increase in the frequency of the response that possesses the property . . . we have chosen. At the same time we decrease the frequency of those responses that do not meet our specifications."

In the experiments to be reported, the well-conditioned response selected was the emission of the vowel /u/ by human adults. The natural variants, given exclusive reinforcement, were durations of the vocal response greater than a criterion duration. The value of the criterion was an experimental variable; fairly frequent variants were picked out in some studies, less frequent ones in others. Selective reinforcement was applied rigorously to every variant above criterion. There was an increase in the frequency of responses whose duration exceeded criterion and a decrease in the frequency of those variants that were not reinforced.

METHOD

Techniques of measuring the parameters of the vocal operant have been discussed previoulsy (Lane and Shinkman, 1963). The method employed to measure response duration will be summarized here.

The vocal response was transduced by a dynamic throat microphone (Rye TM 1), amplified, and processed by an average speech power circuit (Peterson and McKinney, 1961). The output waveform was applied to a dc amplifier (Krohn-Hite) and then to the time-interval section of a frequency counter (Hewlett-Packard 523D). The system was calibrated with pure-tone pulses of known duration, prepared with electronic timers and switches. The

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duration was read in msec by the counter and recorded by a parallel printer and a card punch (IBM).

Subjects and Procedure

Twenty male and eight female subjects served individually in sessions lasting approximately 2 hr. The *S* was seated in a sound-attenuating booth in front of a panel containing a light and a coin dispenser.

These instructions were read to *S*: "In this experiment you can earn money simply by saying /u/ when the light in front of you flashes. You will know that you have earned money when a penny falls into the tray; at the end of the experiment you may take home all the pennies you have earned. This is your only pay. Occasionally the light will not flash for a period of time. When the light is off, please do not respond."

An electronic timer flashed the stimulus light at 5-sec intervals. After each of the first 20 responses emitted by *S*, the experimenter (*E*) presented reinforcement and entered the response duration on a desk calculator. Then, *E* reset the timer and computed the reinforcement criterion for the next phase of the experiment. In the second and later phases, only those responses with a duration exceeding the criterion were reinforced. Each phase was continued until 10 successive reinforced responses occurred; the timer was reset, a new criterion computed, and the next phase initiated.

Criteria for differential reinforcement. The duration criterion for reinforcement varied according to the schedule shown in Table 1. In Exp. I, the criterion for each phase equalled the mean duration of the 10 responses that terminated the preceding phase, plus their average deviation.

Following this experiment, the research detoured to obtain a preliminary estimate of the Weber fraction for produced vocal duration. Five *S*s were instructed to produce 90 pairs of the vowel /u/ such that the responses in each pair had equal duration. Thirty pairs were obtained from each *S* at "short" durations, and a like number at "moderate" and at "long" durations. When the absolute value of the difference in duration between the responses in each pair was plotted as a function of the shorter response, the 450 determinations were well fit by a straight line with a slope of 0.1 (determined by the method of least squares).[2]

In Exp. II through VI, the criterion for reinforcement in each phase equalled the mean duration of the 10 terminal responses in the preceding phase plus (or minus) some per cent of that mean. The step size or increment in the criterion ranged from half the value of the Weber fraction (5 per cent) to twice that value (20 per cent).

Probing for a Tact of the Reinforcement Contingency. At the end of each session in Exp.

[2]The average value of the Weber fraction, $\frac{D_1 - D_2}{D_1} = .1$, turned out to coincide with the average coefficient of variation (σ/M) for the duration of responses emitted under continuous reinforcement.

Table 1

Successive Criteria for Differential Reinforcement of Vocal Duration

Exp.		*Step*	*Phase Number*								
No.	*Subjects*	*Size*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
I	1-10		CRF	M_1+	M_2+*	M_3+	M_4+	M_5+	M_6+		
		+		AD_1	AD_2	AD_3	AD_4	AD_5	AD_6		
II	11-15		CRF	M_1+	M_2+	M_3+	M_4+	M_5-	M_6-	M_7-	M_8-
	& 20	+, +		$.05M_1$	$.10M_2$	$.15M_3$	$.20M_4$	$.05M_5$	$.10M_6$	$.15M_7$	$.20M_8$
III	16-19		CRF	M_1+	M_2+	M_3+	M_4+	M_5-	M_6-	M_7-	M_8-
		+, −		$.05M_1$	$.10M_2$	$.15M_3$	$.20M_4$	$.20M_5$	$.15M_6$	$.10M_7$	$.05M_8$
IV	21-23		CRF	M_1+	M_2+	M_3+	M_4+	M_5-	M_6-	M_7-	
		Const.		$.05M_1$	$.05M_2$	$.05M_3$	$.05M_4$	$.05M_5$	$.05M_6$	$.05M_7$	
V	24-25		CRF	M_1+	M_2+	M_3+					
		Const.		$.20M_1$	$.20M_2$	$.20M_3$					
VI	26-28		CRF	M_1-	M_2-	M_3-					
		+		$.05M_1$	$.10M_2$	$.15M_3$					

*Mean duration of the 10 terminal responses in phase 2 plus their average deviation.

II-VI, *S* was given a three-item questionnaire. The response to each item was completed before the next was presented. The questions were: (1) What do you think was the point of this experiment? (2) Did you know what it was about your responding that earned pennies for you? (3) Did you know that you received pennies depending on the length or duration of your response?

If the words "duration" or "length" never appeared in *S*'s response, and if the word "no" was part of the response to questions (2) and (3), the questionnaire was scored "negative".

RESULTS AND DISCUSSION

Experiment I

Shaping Longer Durations; Step Size Constant. The relation between the criterion for differential reinforcement and the mean response duration in each phase is shown in Fig. 1 for a representative *S*. The terminal 10 reinforced responses, which ended each phase (filled triangles), the non-terminal reinforced responses (open triangles) and the unreinforced responses (inverted triangles) are plotted separately.

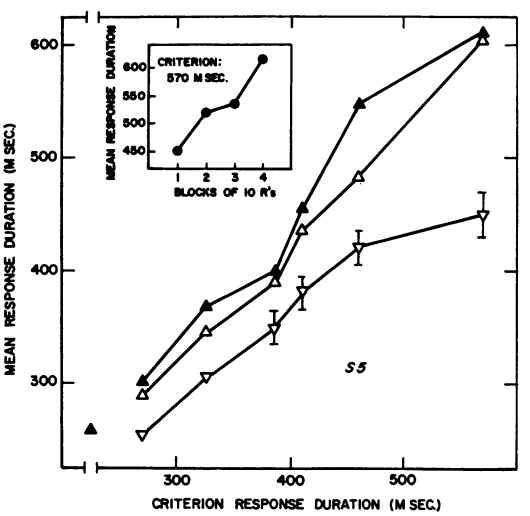

Fig. 1. Shaping longer vocal duration; step size constant (Exp. I, *S5*). The relation between the criterion response duration for differential reinforcement and the mean response duration. Unreinforced responses (inverted triangles), non-terminal reinforced responses (open triangles) and the 10 terminal reinforced responses (filled triangles) are plotted separately for each phase of the experiment. The baseline duration under continuous reinforcement is shown by the symbol at lower left. The vertical lines represent one standard deviation. The insert shows the mean duration of successive blocks of 10 responses in the last phase.

It is apparent that the duration of vocal responding by *S5* was under the control of the reinforcement contingencies. As the criterion was increased, in steps of one average deviation, from 270 to 570 msec, the mean duration of vocal responding was shaped from 258 to 610 msec. In each phase, the mean duration of unreinforced, non-terminal and terminal reinforced responses increased in that order.

This finding largely reflects the increasing duration of vocal responding within the phase, which is shown for a typical phase (the last) in the insert. Note that the last 10 responses in this phase had a mean duration 40 msec greater than the criterion. This "overshoot" is characteristic of the other phases as well. If the mean response durations precisely equalled the criterion, they would appear in the graphs along a line with unit slope, which passed through the intersections of corresponding points on the x- and y-axes. In general, the non-terminal reinforced responses fall near this line, that is, at criterion values, while reinforced responses lie above, and unreinforced responses lie below the line.

Frequency distributions of response durations in each phase are shown for *S5* in Fig. 2. Under continuous reinforcement, response durations are short and their variance is relatively small. The criterion for each phase and for the one that follows are indicated by the symbols C and C_1, respectively. With differential reinforcement, the variance increases

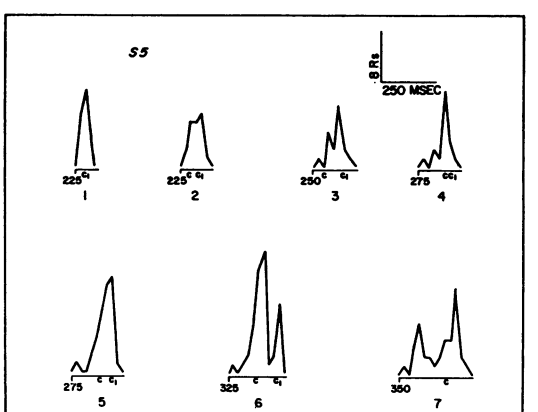

Fig. 2. Frequency distributions of response durations in each phase, for *S5*. The criterion duration for a phase is indicated by C, that for the next phase by C_1.

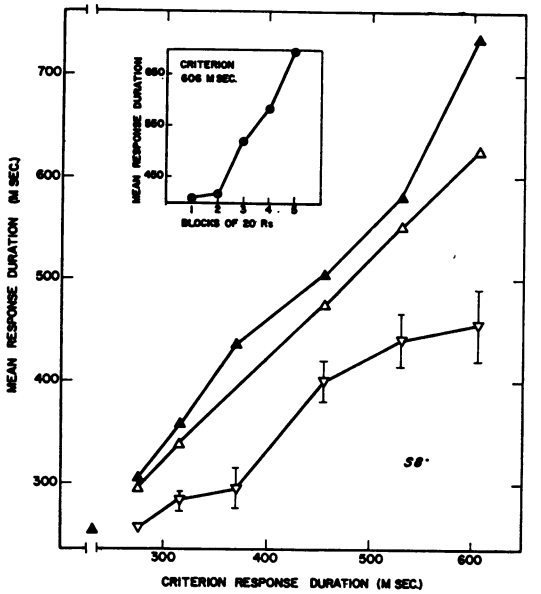

Fig. 3. The relation between the criterion and mean response duration, for *S*8 (Exp. I). The insert shows the mean duration of successive blocks of 20 responses in the last phase.

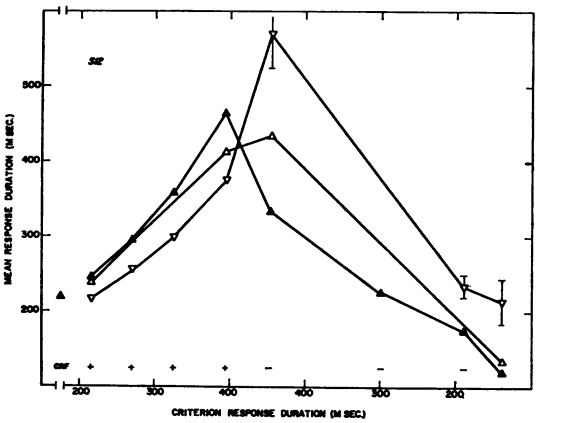

Fig. 4. Shaping longer durations, step size increasing, then shorter durations, step size increasing (Exp. II, *S*12). The relation between criterion and response duration. In phase 6, the sign of the criterion was changed (−), and all responses with duration less than the criterion were reinforced.

and, in the later phases, the frequency distributions become bimodal. For most of the *S*s, the second peak lies at durations greater than the criterion and reflects the "overshoot" occurring toward the end of each phase, described above.

Figure 2 also shows that *S*5 reached the successive criteria rapidly; the number of unreinforced responses ranged from five in phase 2 to a maximum of 20 in the last phase. A useful statistic to consider in this regard is the difference between the criterion duration and the mean duration of the terminal responses in the prior phase, divided by their standard deviation: $(C\text{-}M)/\sigma$. This statistic, which may be called the shaping index, expresses the step size (C-M) in terms of the variability (σ) of current behavior. An infrequent variant of behavior has been selected for differential reinforcement if the shaping index is large, either because the step size is large, or the variability is small, or both. For the 16 *S*s whose data are presented in this article, the shaping index computed for each phase correlated 0.4 with the number of unreinforced responses in that phase (Spearman rho, $p < .01$). The shaping index for *S*5 is roughly constant at about 0.7; this follows from the fact that the criterion increment was one average deviation. (For a normal distribution, the average deviation is approximately seven-tenths of the standard deviation.)

The relation between response duration and the reinforcement criterion is shown for a second *S* in Fig. 3. The shaping index was constant at about 0.7; the criterion ranged

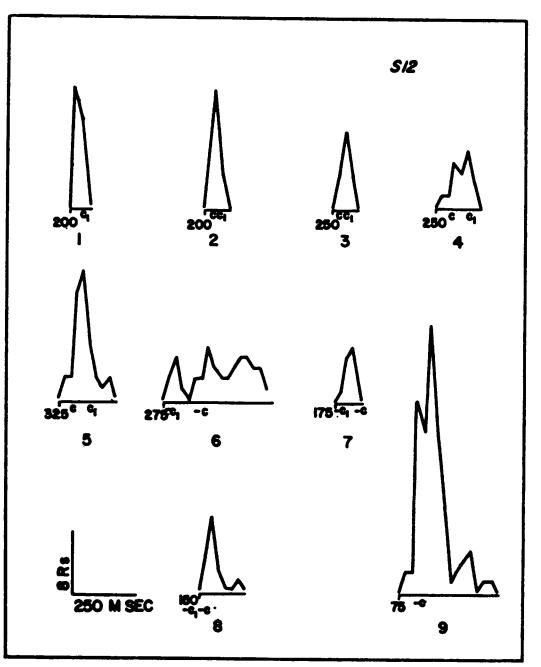

Fig. 5. Frequency distributions of response durations for *S*12. The negative symbols denote reinforcement of responses with duration less than *C*.

from 272 to 606 msec while the average response duration ranged from 256 to 736 msec. Overshoot of the criterion was particularly marked in the last phase, which is shown in greater detail in the insert. There were 72 unreinforced responses, all of which had relatively short durations, continuing a trend established earlier in the session. The mean of the non-terminal reinforced responses was 20 msec greater than criterion, as in earlier phases. The terminal responses in the last phase had a mean duration that exceeded criterion by 130 msec.

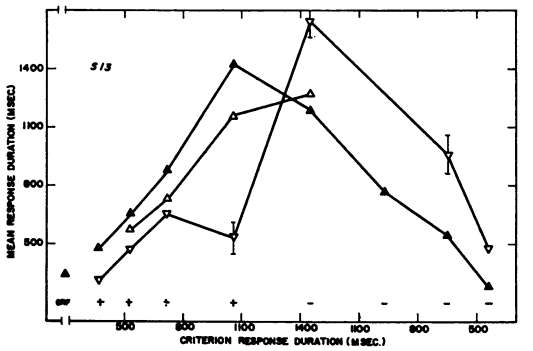

Fig. 6. The relation between criterion and response duration for S13 (Exp. II).

Experiment II

Shaping Longer Durations, Step Size Increasing, Then Shorter Durations, Step Size Increasing. Mean response duration as a function of criterion duration is shown for a representative *S* in Fig. 4; the corresponding frequency distributions of response durations appear in Fig. 5. The mean duration grows steadily during the first five phases and the variability increases proportionally ($\sigma/M = .05$). In phase 6, the criterion for reinforcement changed sign: any response duration less than 446 msec was followed by reinforcement. The relative variability doubled ($\sigma/M = .10$); the mean duration of the unreinforced responses climbed abruptly to 570 msec, while that of the terminal responses fell to 334 msec, an overshoot of 112 msec. The frequency distribution of response durations spread and became trimodal, with peaks corresponding, roughly, to the terminal, non-terminal reinforced and unreinforced responses, respectively. Order was restored rapidly in the next phase, however, where the criterion increment was small and of the same sign. The shaping index for this *S* varied from 1.1 in phase 2 to a maximum of 3.0 in the last phase. The latter value is large because the variability in the preceding phase was small and the step size was 20 per cent of the mean. There were nearly four times as many unreinforced responses in this phase as in any other. The questionnaire, which probed for a tact of the reinforcement contingency, was scored "negative" for this *S*.

The data for S13 (Fig. 6) provide a similar picture of the shaping of vocal duration. The criterion ranged upward from 369 to 1,353 msec and then downward to 433 msec; the mean duration of the terminal responses ranged from 348 to 1,424 to 285 msec. The largest shaping index (2.8) occurred in phase 5 and there was a corresponding increase in the number of unreinforced responses (135, or 10 times more than in any other phase). When the sign of the criterion changed in phase 6, an abrupt increase in the duration of unreinforced responses occurred. This finding is obtained whenever the sign of the criterion is changed; it may be related to the observation, reported by Lane and Shinkman (1963), that several parameters of the vocal operant, including duration, increase in extinction after intermittent reinforcement. In all phases but the fifth, criterion was reached rapidly by S13, who described the reinforcement contingency on the first sheet of the questionnaire.

The findings obtained with three *S*s who did not reach criterion in all phases are examined next (Fig. 7 and 8). The data for S15 are anomalous in several respects. The mean duration of the non-terminal reinforced re-

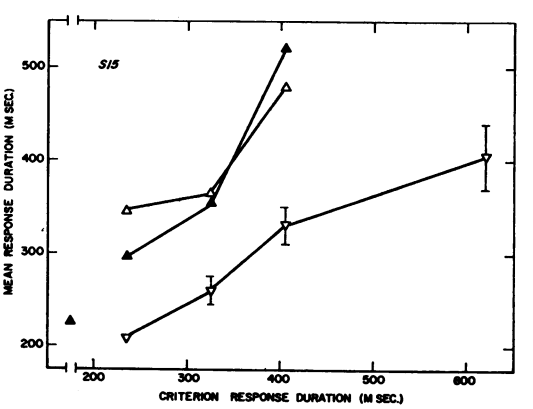

Fig. 7. The relation between criterion and response duration for S15 (Exp. II). In phase 5, S15 failed to reach criterion.

sponses lies above that of the terminal responses in phases 2 and 3. The shaping index was quite large (3.2) in phase 4, but criterion was reached within 50 responses. The 20 per cent increment in criterion in phase 5 was not a large step, in view of the variability in the preceding phase, but S15 failed to receive a single reinforcement in this phase.

The failure to shape the behavior of S14 (Fig. 8) may be largely attributed to the size of the shaping index in the uncompleted phase: 3.8. It is interesting to note that the mean duration of the 290 unreinforced responses in the last phase fell below that mean for the preceding phase. The size of the shaping index similarly accounts for the breakdown of reinforcement control with S20. The step size in phase 4 was moderately large (15 per cent) and there was little variability in the preceding phase; hence, the shaping index took on the exceedingly large value, 8.4. A total of 208 unreinforced responses occurred before the session was terminated by E. The questionnaires for Ss 14, 15, and 20 were all scored "negative".

Experiment III

Shaping Longer Durations, Step Size Increasing, Then Shorter Durations, Step Size Decreasing. The first half of this procedure (phases 1-5) replicates that for Exp. II and the behavior of S16 (Fig. 9, 10) is similar in these phases to that of S12 and S13, presented earlier. The frequency distributions of response durations have greater variance for S16 than for earlier Ss. In phase 6, when the step size was both large (20 per cent) and of opposite sign, the frequency distribution separated into two clusters. One reflects the marked increase in the duration of unreinforced responses, the other the very short durations of the terminal responses, whose mean, 279 msec, exceeded the criterion by 487 msec.

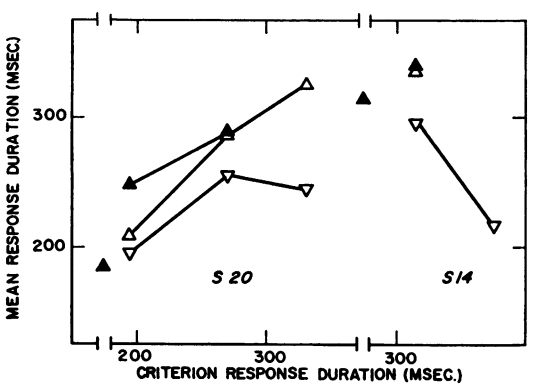

Fig. 8. The relation between criterion and response duration for Ss 14 and 20 (Exp. II). S14 failed to reach criterion in phase 3, S20 in phase 4. The symbols at the break in the abscissa indicate baseline durations for the two Ss.

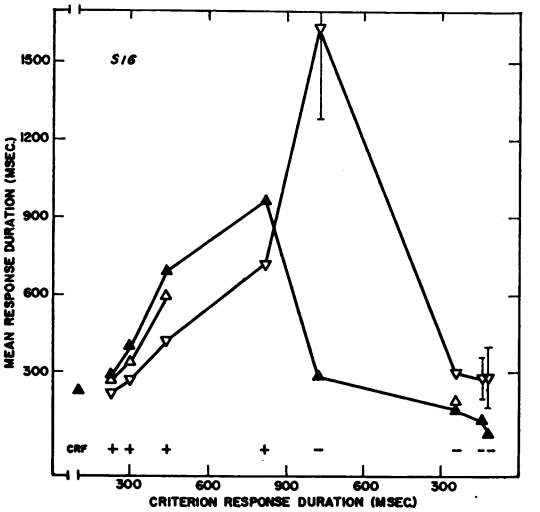

Fig. 9. Shaping longer durations, step size increasing, then shorter durations, step size decreasing (Exp. III, S16). The relation between criterion and response duration.

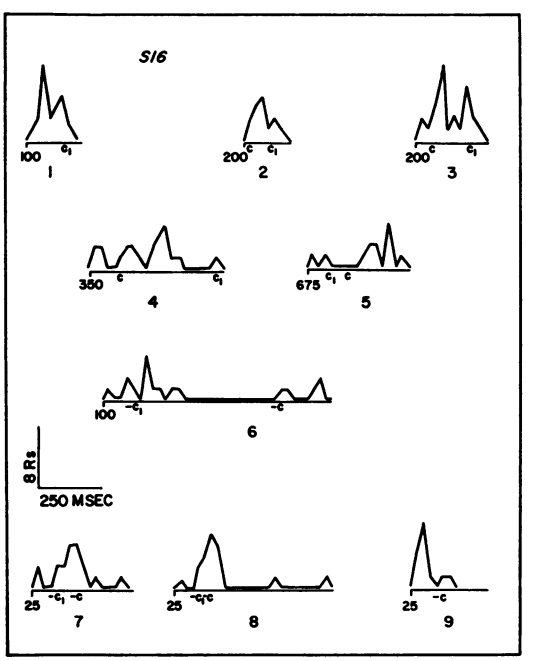

Fig. 10. Frequency distributions of response durations for S16.

The shaping index of 3.3 and the number of unreinforced responses were both larger for phase 6 than for any other phase. The terminal response duration in phases 7-9 was less than the mean duration observed under CRF; it reached as low as 59 msec in the last phase, 157 msec less than the baseline determination.

The findings for *S*19 (Fig. 11) are similar, although the range of response durations is much smaller: 165 to 532 to 94 msec. The shaping index was approximately 1.2 except in phase 5 where, coupled with a 20 per cent step size, the index rose to 4.1; the number of unreinforced responses rose from an average of 25 to a high of 185 in this phase. The mean duration of the terminal responses in phase 9 was 94 msec or 71 msec below the baseline established under CRF. Both *S*16 and *S*19 described the reinforcement contingency on the questionnaire.

Experiment IV

Shaping Longer, Then Shorter, Durations; Step Size Small and Constant. When the shaping index remains small, as in the present procedure, variability remains small, shaping proceeds gradually and the number of steps required to change response parameters over a given range is increased. Subject 21, for example, shows a steady increase in mean duration (Fig. 12) during the first five phases and then rapid decline when shorter durations were reinforced. The step size was five per cent. The shaping index ranged from 0.4 in the first and last phases to approximately 1.0 in the others. Variability remained relatively small, $\sigma/M = .07$, with the notable exception

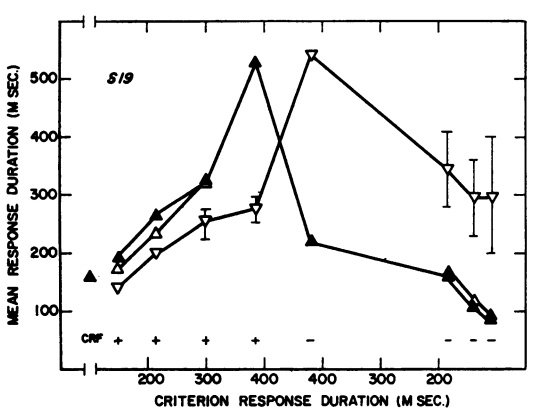

Fig. 11. The relation between criterion and response duration for *S*19 (Exp. III).

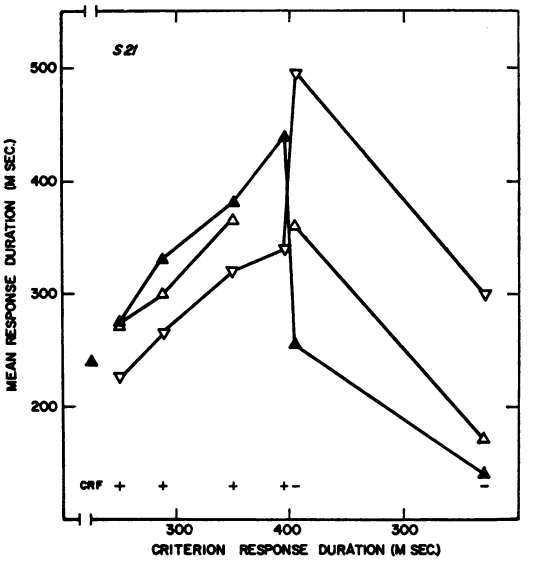

Fig. 12. Shaping longer, then shorter durations; step size small and constant (Exp. IV, *S*21). The relation between criterion and response duration.

of phase 6, where the sign of the criterion changed. Subject 21 responded "yes" to items (2) and (3) on the questionnaire.

The findings for *S*23 (Fig. 13) provide a second example of the result of maintaining a small shaping index. In this case, the index ranged from 0.3 to a maximum of 1.0 in phase 6, where the criterion changed sign. Variability remained small, $\sigma/M = .06$, and the range of

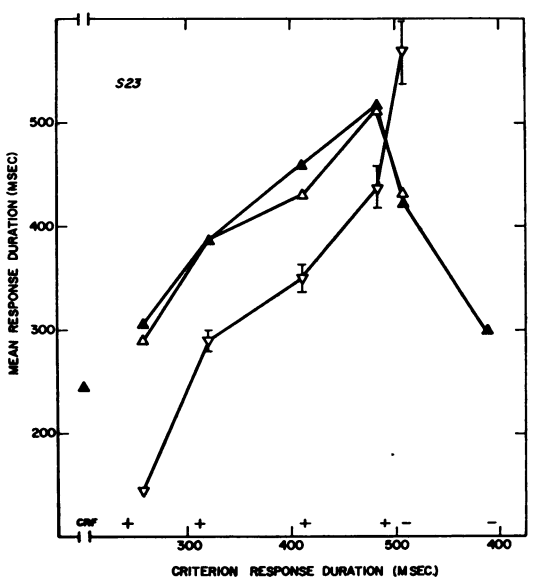

Fig. 13. The relation between criterion and response duration for *S*23 (Exp. IV).

durations for the reinforced responses was limited: 246 to 519 to 300 msec. Shaping took place quite rapidly. In the final phase, the reinforcement criterion was reached immediately, with no unreinforced or non-terminal reinforced responses occurring. The questionnaire for this *S* was scored negative.

Experiment V

Shaping Longer Durations; Step Size Large and Constant. When a step size as large as 20 per cent was employed at the outset of the shaping procedure, *Ss* 24 and 25, whose data are presented in Fig. 14, failed to reach criterion after the first phase of differential reinforcement. The baseline duration for *S*24 was 174 msec; he reached criterion in the second phase, when the shaping index was 2.6. In the third phase, the shaping index rose to 5.0 and no reinforced responses occurred.

The findings for *S*25 are similar, although all the values are larger since his baseline duration was 327 msec. The shaping index in the third phase was 3.8. A total of 273 responses were emitted in this phase, including 24 reinforced responses. It is interesting to note that the last 10 of these reinforced responses had a mean duration 26 msec greater than criterion. However, numerous unreinforced responses were interspersed and the criterion of 10 successive responses with duration greater than 520 msec was never reached. The questionnaire for *S*24 was scored negative whereas that for *S*25 was not.

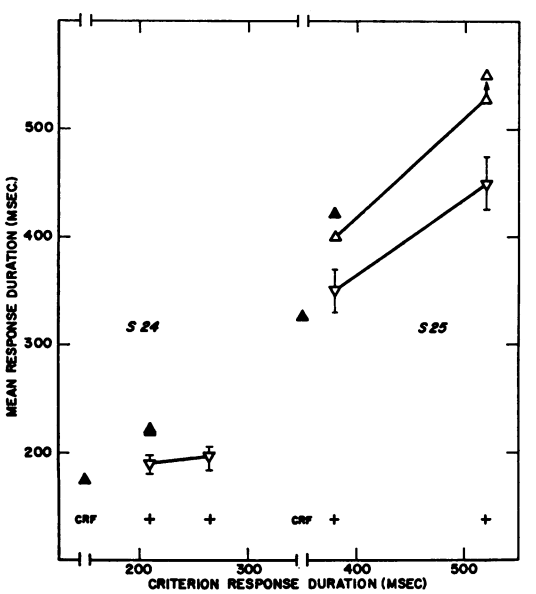

Fig. 14. Shaping longer durations; step size large and constant (Exp. V, *Ss* 24, 25). The relation between criterion and response duration. *S*24 emitted no reinforced responses in the third phase. *S*25 emitted 24 reinforced responses, including 10 that exceeded criterion (arrow) but unreinforced responses were interspersed and criterion was not reached.

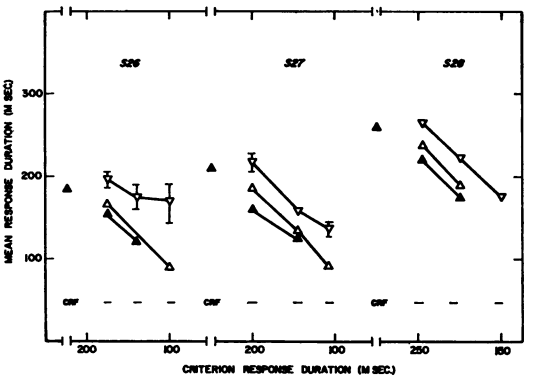

Fig. 15. Shaping shorter durations; step size increasing (Exp. VI, *Ss* 26, 27, 28). The relation between criterion and response duration. None of the *Ss* reached criterion in the fourth phase.

Experiment VI

Shaping Shorter Durations; Step Size Increasing. The attempt to shape downward from

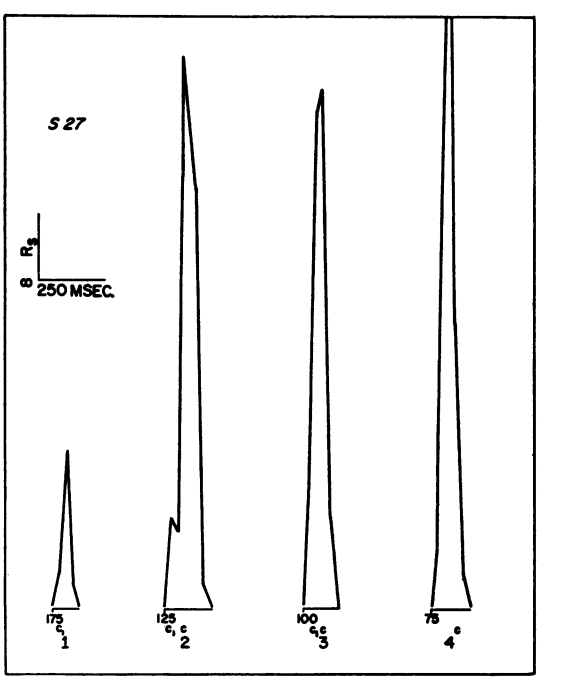

Fig. 16. Frequency distributions of response durations for *S*27 (Exp. VI).

the operant baseline was successful only over a limited range. The findings for three *Ss* are shown in Fig. 15. In phases 2 and 3 the shaping indices for all three *Ss* ranged from 0.5 to 1.5 and differential reinforcement was effective. At the end of phase 3, the mean duration and variability were quite small for all *Ss*. This finding is shown graphically for *S*27 in Fig. 16. As a result, the shaping index for the next phase was relatively large; approximately 2.5 for the three *Ss*. No reinforced responses were emitted by *Ss* 26 and 28 in phase 4. Three responses by *S*27 were reinforced but this did not lead to control over the duration of vocal responding. The questionnaires for all three *Ss* were scored negative.

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