RESPONSE SUMMATION TO A COMPOUND STIMULUS IN A CONTEXT OF CHOICE¹

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Key pecks by two groups of pigeons were reinforced on concurrent schedules. For group $\bar{E}$, pecks were reinforced during either a visual or an auditory stimulus; for group E, an additional, extinction component was available, during which both visual and auditory stimuli were absent. After training, both groups were given a compound test to measure preference among four stimuli, the three used in training plus a compound of the visual and auditory stimulus. Group E showed preference for the compound, emitting more pecks and spending more time in this stimulus than in other stimuli. Group $\bar{E}$ showed no preference between the compound and visual stimulus, nor between the auditory stimulus and the absence of both stimuli, but preferred the former pair over the latter pair of stimuli.

Key words: response summation, compound stimulus, preference, concurrent schedules, overshadowing, key peck, pigeons

Wolf (1963) trained rats to press a bar for food only when either a light or tone were present. During tests in extinction the light, the tone, and a compound of light and tone, were presented in a mixed sequence. The rate of bar pressing during the compound stimulus was greater than during light or tone alone. This phenomenon, response summation, has been replicated many times. Weiss (1971) found that response summation to a compound occurred only if training included periods of extinction correlated with the absence of light and tone; otherwise, the rate of bar pressing during the compound was usually between the rates occurring to light and tone. Following Wolf's study, investigations of response summation have characteristically used multiple schedules for both training and testing, and response rate as sole dependent variable. The present experiment employed concurrent schedules for training, and measured choice between training stimuli and a compound stimulus during a summation test. The effects of including an extinction component in training were also explored.

METHOD

Subjects

Eight experimentally naive homing pigeons were maintained at 80% (± 15 g) of their free-feeding weights. Water was continuously available in individual home cages.

Apparatus

Two standard two-key pigeon chambers were used (Grason-Stadler E1184J). The operanda were two translucent keys 10.2 cm apart and 20.4 cm from the floor. The minimum force required to operate a key was 0.05 N. Stimuli were projected to the right key by a rear-mounted multiple-stimulus projector. The left key was illuminated by a 15-W lamp. White noise at 78 dB was sometimes presented through speakers located behind the keys. Ambient noise level in each chamber with the exhaust fan running was about 70 dB. The light intensity on the main key (right key) was measured with a light-dependent resistor taped to the key. Without a dark stimulus projected onto the white key, the intensity was 95 lux; with a stimulus projected, the intensity was 75 lux. Each chamber was sound attenuated and located in a room adjacent to the controlling equipment. Reinforcement was 5-sec presentation of grain in a magazine halfway between and 15.3 cm below the keys.

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Procedure

Sessions were usually conducted seven days a week, each session lasting approximately 40 min.

Preliminary training. The subjects were trained by successive approximations in a special chamber to feed from a magazine and then to peck a key. After a period in which every response was reinforced, series of variable-interval (VI) schedules were introduced. In the first VI training session, the first response occurring after an average of 4 sec since the previous reinforcement (VI 4-sec) produced food. In the second and third sessions, reinforcement was scheduled on an average of once every 15 sec (VI 15-sec) and once every 30 sec (VI 30-sec) respectively. In the fourth and fifth sessions, reinforcements were scheduled once every minute on average (VI 1-min).

Concurrent training. Beginning with the sixth session, the subjects were divided into two experimental groups for 33 sessions. Group $\bar{E}$ (no extinction; B_1 to B_4) was studied in one chamber where two components were successively available on the main (right) key. The stimuli correlated with the two components were a black cross on a white key ($C + \bar{N}$) and a white key plus white noise ($\bar{C} + N$). Schedules of reinforcement in each component were VI 2-min and VI 4-min respectively.

Group E (extinction; B_5 to B_8) used a second chamber where three components were available on the main key according to a recycled mixed sequence of 18, composed of all six combinations of three stimuli. The stimuli correlated with the three components were a black circle on a white key ($C + \bar{N}$), a white key plus white noise ($\bar{C} + N$), and a white key alone ($\bar{C} + \bar{N}$). Schedules of reinforcement associated with each component were VI 2-min, VI 4-min, and extinction respectively. The VI schedules used were based on the distributions of intervals described by Fleshler and Hoffman (1962).

In both chambers, a peck on the left key, the changeover or CO key (Findley, 1958), switched components. The CO key was illuminated during all concurrent training and subsequent testing, except that following each peck on the CO key, the light behind the key went out and the key was inoperative for 3 sec to prevent bursts of pecking that might have resulted in inequalities of stimulus presentations. A changeover delay (COD; Herrnstein, 1961)

specified a minimum delay of 3 sec between a peck on the CO key and the availability of reinforcement for a peck on the main key during all concurrent training and subsequent testing.

Different forms were presented on the main keys in the two chambers because identical forms were not available. The forms chosen (cross and circle) comprised approximately equal dark areas. To prevent the exposure of group $\bar{E}$ to extinction, birds were always placed in and removed from the chambers while the schedules were running. Session duration was approximately 40 min.

Compound testing. The day following the final training session all subjects were given a compound test. During this test four components were available, according to mixed sequences. For group $\bar{E}$, the components were a black cross on a white key ($C + \bar{N}$), a white key plus white noise ($\bar{C} + N$), a white key alone ($\bar{C} + \bar{N}$), and a compound of a black cross and white noise ($C + N$).

For group E, the components were a black circle on a white key ($C + \bar{N}$), a white key plus white noise ($\bar{C} + N$), a white key alone ($\bar{C} + \bar{N}$), and a compound of a black circle on a white key plus white noise ($C + N$). Each test lasted 30 min and was preceded by a 10-min warmup involving normal concurrent schedule training. Reinforcement was available for the first 15 min of the compound test in those components ($C + \bar{N}$; $\bar{C} + N$) in which it was available during concurrent training.

The final 15 min of the compound test was conducted in extinction. The CO key operated during the compound test as it had during concurrent training.

RESULTS

Three behavioral measures were used: number of responses in a stimulus, time spent in the presence of that stimulus, and the absolute rate of responding (obtained by dividing responses to the stimulus by time spent in the presence of that stimulus) during that stimulus.

Table 1 shows the number of responses, time spent, and response rates in each stimulus, averaged over the last five days of concurrent training. At termination of training, all subjects, with the possible exception of B_2 , discriminated between components on the main key. All emitted a greater number of responses, and

Table 1

Average number of responses, time spent (sec), and response rate (resp/min) in each stimulus during the last five days of training. Average responses on the CO key are also shown.

Measure	Schedule	Stimulus	Group $\bar{E}$				Group E			
			B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
Response	VI 2-min	$C + \bar{N}$	1483.8	532.8	1291.4	1069.6	2194.8	2172.6	2241.8	3041.0
	VI 4-min	$\bar{C} + N$	780.6	500.4	807.4	694.0	795.4	943.4	579.0	730.2
	EXT	$\bar{C} + \bar{N}$					144.2	396.4	318.6	359.0
COs	—	—	309.4	265.4	346.6	235.6	175.8	290.8	213.8	141.8
Time	VI 2-min	$C + \bar{N}$	1428.2	1441.4	1313.6	1383.6	1304.0	1119.6	1180.2	1519.6
	VI 4-min	$\bar{C} + N$	922.0	909.2	1038.6	968.2	555.2	631.6	689.4	447.8
	EXT	$\bar{C} + \bar{N}$					448.0	543.2	421.0	379.0
Rate	VI 2-min	$C + \bar{N}$	62.0	22.1	58.8	46.5	96.7	116.7	113.7	118.9
	VI 4-min	$\bar{C} + N$	50.8	32.9	46.5	42.9	85.7	89.5	48.7	98.8
	EXT	$\bar{C} + \bar{N}$					20.2	43.7	44.7	56.7

spent more time in the VI 2-min than the VI 4-min component. For group E, the number of responses, time spent, and absolute rate of response were lowest in the extinction component.

One of the group $\bar{E}$ subjects (B_2), emitted similar numbers of responses during the VI 2-min and VI 4-min components, but clearly discriminated in terms of time spent in each. This is reflected in a lower rate of response

Fig. 1. Number of responses, time spent, and absolute rate of responding in each stimulus during the compound test. Results are shown for each subject trained with an extinction component (group E). The number of effective COs is shown below the response data for each subject.

Fig. 2. Number of responses, time spent, and absolute rate of responding in each stimulus during the compound test. Results are shown for each subject trained without an extinction component (group $\bar{E}$). The number of effective COs is shown below the response data for each subject.

during the VI 2-min component. All other birds gave highest rates of response in the VI 2-min component and lowest rates in VI 4-min (group $\bar{E}$) or EXT (group E) components.

As there was no systematic difference between behavior in the first and second halves of the compound test, only the combined results are presented. Figures 1 and 2 present the compound-test results, showing the number of responses emitted, time spent in each stimulus, and absolute rate of responding for each subject. Of principal interest is the comparison between values for the compound stimulus ($C + N$) and the reinforced training stimuli ($C + \bar{N}$) and ($\bar{C} + N$). Figure 1 shows that for each bird in group E, time spent and responses emitted in $C + N$ were greater than in the other stimuli. Three birds showed a higher rate of responding in $C + N$ than in the other stimuli, but for one bird (B_5), response rate in $C + N$ was between $C + \bar{N}$ and $\bar{C} + N$. In terms of responses and time spent in stimuli, birds in group E demonstrated a preference for $C + N$ over the other stimuli.

Figure 2 shows that for three birds in group $\bar{E}$, responses emitted in $C + N$ were nearly equal with either $C + \bar{N}$ or $\bar{C} + N$. Only in one case (B_1) did responses in $C + N$ exceed the next highest value by more than a few responses, and this difference was small compared to those typical of birds in group E. Three birds spent nearly equal time in $C + N$ and $C + \bar{N}$, the other (B_3) spending time in $C + N$ halfway between that spent in $C + \bar{N}$ and $\bar{C} + N$. Response rates generally showed little differentiation. Two birds had their highest rates of response in $C + N$, but only in one case (B_1) was there much difference between the two highest rates. Figure 2 also shows that group E birds did not distinguish between $\bar{C} + N$ and $\bar{C} + \bar{N}$ on any measure.

Comparison between absolute values in Figures 1 and 2 shows that for $C + N$, $\bar{C} + N$, and $C + \bar{N}$ the number of responses emitted and the rate of response were always higher in group E than in group $\bar{E}$. A similar trend is seen in the training data (Table 1), although

there is overlap of group ranges of both responses and rates in the case of $\bar{C} + N$.

DISCUSSION

There was a clear difference between the two groups in the preference displayed for the compound stimulus, as indicated by the numbers of responses emitted in each stimulus. If summation is defined as greater responding in the compound stimulus than in the component stimuli, it was shown by all group E birds, and to a lesser extent by one bird in group $\bar{E}$. The same result was obtained from the time measure, although two of the birds in group E showed only a marginal preference for the compound. Neither group showed systematic differentiation of response rates during the compound test.

These results demonstrate a summation effect in concurrent schedules paralleling that observed in multiple schedules, suggesting a single phenomenon encompassing both classes of schedule. Moreover, the results provide some support for the observation that summation requires the presence of an extinction component during training (Weiss, 1971). The typical result following training without an extinction component has been characterized as "averaging", responding in the compound being intermediate between that occurring in the two components (e.g., Weiss, 1971). The present result was quite different from this; in general, birds in group $\bar{E}$ treated the compound like $C + \bar{N}$, and treated $\bar{C} + \bar{N}$ like $\bar{C} + N$. In short, their behavior seemed little affected by the presence or absence of white noise. Discrimination training for group $\bar{E}$ used two pairs of redundant relevant cues, so that the two components could be distinguished on the basis of either pair alone; presence *versus* absence of key stimulus, or presence *versus* absence of white noise. Training for group E, on the other hand, involved three components, which could not be distinguished on the basis of either key stimulus or noise alone. Results of the compound test suggest that group $\bar{E}$ subjects distinguished the two components solely on the basis of the presence or absence of the key stimulus, and did not attend to the auditory cue. Such a result might well have been predicted from other experiments with pigeons in which key stimuli have been found

to "overshadow" redundantly available auditory stimuli (cf. Miles and Jenkins, 1973). However, the fact that the visual stimulus was correlated with the higher rate of reinforcement may also have been important.

Our final point concerns the greater absolute values in group E than in group $\bar{E}$ during the compound test. This result is inconsistent with a particular explanation of summation proposed by Meltzer and Masaki (1972). They suggested that extinction during the absence of both auditory and visual cues ($\bar{C} + \bar{N}$) leads to both elements ($\bar{C}$ and $\bar{N}$) acquiring "inhibitory" properties. This leads to reduction of responding when either inhibitory element is part of a compound stimulus, as in $\bar{C} + N$ or $C + \bar{N}$; when no inhibitory elements are present, as in the compound $C + N$, responding is elevated by the loss of inhibitory influence, and summation results. If this explanation were correct, response values in $\bar{C} + N$ and $C + \bar{N}$ would be lower in group E than in group $\bar{E}$, since the latter group received no extinction training with $\bar{C} + \bar{N}$. The obtained result was quite the opposite to this, indicating that Meltzer and Masaki's theory has little value as an explanation for summation in the present experiment.

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