CONCURRENT SCHEDULES: QUANTIFYING THE AVERSIVENESS OF NOISE

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Four hens worked under independent multiple concurrent variable-interval schedules with an overlaid aversive stimulus (sound of hens in a poultry shed at 100dBA) activated by the first peck on a key. The sound remained on until a response was made on the other key. The key that activated the sound in each component was varied over a series of conditions. When the sound was activated by the left (or right) key in one component, it was activated by the right (or left) key in the other component. Bias was examined under a range of different variable-interval schedules, and the applicability of the generalized matching law was examined. It was found that the hens' behavior was biased away from the sound independently of the schedule in effect and that this bias could be quantified using a modified version of the generalized matching law. Behavior during the changeover delays was not affected by the presence of the noise or by changes in reinforcement rate, even though the total response measures were. Insensitivity shown during the delay suggests that behavior after the changeover delay may be more appropriate as a measure of preference (or aversiveness) of stimuli than are overall behavior measures.

Key words: concurrent variable-interval schedules, generalized matching law, aversive sounds, behavior during and after changeover delay, key peck, hen

Studies of concurrent schedules of reinforcement have most often been concerned with the effects of variations in the rates of reinforcement. In these situations, the relation between behavior and reinforcement rate is well described by the generalized matching law (Davison & McCarthy, 1988). This relation, when the behavior is measured in terms of responses allocated, is expressed in the following equation:

$$\log(P_1/P_2) = a \log(r_1/r_2) + \log c, \quad (1)$$

where P_1 and P_2 refer to the responses made on the two alternatives, r_1 and r_2 are the number of reinforcements obtained on the two alternatives, and a and c are fitted parameters. Baum (1974, 1979) suggested that a measures the sensitivity of the behavior to changes in reinforcement rate. When a is larger than 1.0 (termed *overmatching*), proportionally more responses have been allocated to the schedules with the richer reinforcement rates than is predicted by an exact match to reinforcement-rate ratios. When a is less than 1.0 (termed *undermatching*), proportionally more responses have been allocated to the schedules with the leaner reinforcement rates than is predicted by an exact

match to the reinforcement-rate ratios. Thus when undermatching is found, it means that the behavior allocation was influenced by the different reinforcement rates but not to the degree that an exact match to the ratios of these rates would predict. Undermatching is a frequent finding in behavior under concurrent schedules with cattle (Matthews & Temple, 1979), pigeons (Hollard & Davison, 1971), rats (Robinson, 1992), and domestic hens (Temple, Scown, & Foster, 1995).

The parameter $\log c$ is said to give a measure of bias due to factors other than different reinforcement rates (Baum, 1979). This measure of bias includes any inherent bias in behavior resulting from variables that are intrinsic to the experiment (such as animal or equipment attributes) as well as any bias resulting from deliberate experimental manipulations of anything other than of the schedules of reinforcement, such as manipulation of reinforcer quality or amount. Separate quantitative measures of the effects of these different sources of bias may be obtained as shown in the following equation:

$$\log(P_1/P_2) = a \log(r_1/r_2) + \log b + \log q, \quad (2)$$

where P_1 and P_2 , r_1 and r_2 , and a are as for Equation 1. $\log b$ is a measure of the bias due to one type of bias (e.g., any inherent bias for one schedule or manipulandum over

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the other), and $\log q$ is a measure of bias due to another type of biaser (e.g., an extrinsic biaser such as differences in reinforcer quality). Thus $\log c$ (Equation 1) is equal to $\log b$ plus $\log q$. Changes in reinforcer delay (Chung & Herrnstein, 1967), quality (Hollard & Davison, 1971), and amount (Todorov, 1973), and aspects of the response, such as force (Hunter & Davison, 1982) and type (McSweeney, 1978; Sumpter, Foster, & Temple, 1995), have been shown to bias behavior (and to change $\log q$).

The degree of bias in behavior under concurrent schedules has also been shown to provide a quantitative measure of animals' preferences among various stimuli. Hollard and Davison (1971), for example, used the generalized matching law to obtain a measure of preference between qualitatively different reinforcers (food vs. brain stimulation) for pigeons. They estimated $\log c$ (Equation 1) only and did not separate the bias due to the different reinforcers from any inherent bias. Matthews and Temple (1979) showed that concurrent schedules could be used to quantify cows' preference for two different feeds. They measured both the inherent bias ($\log b$) and the bias resulting from the feeds ($\log q$). They reported that their data were well described by Equation 2, and that the inherent bias, $\log b$, and the experimentally manipulated bias, $\log q$, appeared to be constant and thus independent of the changes in reinforcement rate.

This methodology has, therefore, proved useful for evaluating preferences for stimuli that animals will respond to obtain (Kilgour, Foster, Temple, Matthews, & Bremner, 1991). There are, however, other stimuli for which it would be useful to obtain measures of preference but for which animals will not work to obtain, such as aversive or unpleasant stimuli.

One way to assess the biasing effects of such stimuli could be to present the stimulus briefly as a consequence of responding maintained by food delivery. This would be possible if the stimulus event was discrete, such as a short electric shock. The biasing effects of electric shock were examined in this way, using dairy cows, but when the shock was paired with responding on one of two concurrent schedules, responding ceased on that schedule (Whittlestone, Mullord, Kilgour, & Cate, 1975). Given the exclusive responding,

the bias due to this stimulus could not be quantified by the generalized matching law (being infinite). Deluty (1976), using rats working under concurrent schedules of food-maintained responding, did not find exclusive responding as long as responses on both levers randomly produced shock. However, when shock production was limited to one lever, the rats responded almost exclusively on the other lever. Thus, it is possible that this procedure could be used to obtain the relative preference for one of two response-produced aversive stimuli. It is clear, however, that such a method can be used only with discrete stimuli.

Other stimuli, such as sounds or smells, can be presented for longer periods of time and not just in short bursts. Such stimuli can be continuously present whenever a given schedule of food reinforcement is in effect (in other words, be "overlaid" on the schedule), where presentation is contingent on only the response that produces the schedule. Recently, a range of sounds were used in this way, overlaid on one of a pair of concurrent schedules of food-maintained responding, with domestic hens (McAdie, Foster, Temple, & Matthews, 1993). A sound was turned on by the response that initiated an entry into a particular schedule, and it remained on until a response was made on the other schedule. The sounds included recordings of a piece of music, a train, hens in a commercial poultry shed, a ventilator, and water from a high-pressure hose spraying on concrete. When these different sounds (at the same intensities) were associated with one of two equal concurrent schedules, different-sized biases ($\log q$) resulted. At 100 dBA, $\log q$ (termed *noise bias* by McAdie *et al.*) was largest with the sound of hens in a commercial poultry shed. In addition, for any one sound, the noise bias got larger when the intensity of that sound increased. These bias measures were obtained using only equal variable-interval (VI) schedules; thus, only point estimates of the bias due to each of the sound stimuli could be calculated. McAdie *et al.* did not manipulate reinforcement rate, and therefore it is not known whether these biases would remain constant with changes in rate, as the generalized matching law suggests they should. Thus, further investigation is needed

to determine whether or not the generalized matching law applies to these biasers.

Typically, concurrent-schedule procedures include a changeover delay (COD) that prevents the occurrence of reinforcement for a predetermined period of time whenever an animal changes from one schedule to another (Herrnstein, 1961). This is done to prevent changing schedules from being "accidentally" reinforced and maintained (Herrnstein, 1961). Temple et al. (1995) investigated behavior parametrically under a series of concurrent VI VI schedules and a range of different CODs. They showed that behavior during the COD did not vary with reinforcement-rate changes, in that the values of a (Equation 1) for the response measures during the COD fluctuated around zero (and ranged from -0.12 to 0.16). As a result, measures of behavior in the post-COD period were much more sensitive to reinforcement-rate changes than was overall responding. Temple et al. argued that because responding during the COD was not differentially affected by reinforcement-rate differences, it should be excluded from the measure of the schedules' effects. It is possible that the insensitivity of behavior during the COD might extend to the effects of variables other than reinforcement rate. If so, it might be appropriate to restrict measures of preference or bias to the behavior that occurs after the COD. Although studies of biasers such as reinforcer quality and delay have programmed CODs, none have analyzed behavior during and after the COD separately, so it is not clear if these biasers have differential effects. It might even be expected that when a source of bias is present throughout the COD, as it was in McAdie et al.'s (1993) study, responding both during and after the COD would be affected equally.

The purpose of the present study was twofold. One intention was to investigate the effects of reinforcement-rate changes on the bias produced by a sound stimulus overlaid on one of two concurrent schedules. Thus, it would be possible to determine whether such an overlaid stimulus has a constant biasing effect independent of changes in reinforcement rate (i.e., to see if Equation 2 holds for this type of biaser). The second purpose was to obtain bias estimates from responding both during and after the COD. This would determine whether or not the insensitivity of

responding to reinforcement rate during the COD extends to the effects of such a biaser. The study involved the same hens as McAdie et al.'s (1993) study, as well as the sound that caused the greatest bias—the sound of hens in a commercial poultry shed at 100 dBA. In a series of multiple concurrent VI VI schedules, the reinforcement rates available on each key and the key and color associated with the presentation of sound were systematically varied.

METHOD

Subjects

Four White International hens, numbered 11, 13, 14 and 15 and aged approximately 36 months, were used. They were maintained at $80\% \pm 5\%$ of their free-feeding body weights by daily weighing and appropriately calculated postexperimental feeding of commercial laying pellets. Water was freely available in their individual home cages, and grit was supplied weekly. These hens had had 1 year's experience with concurrent VI VI schedules with various sounds overlaid on one of the two schedules (McAdie et al., 1993).

Apparatus

The particle-board experimental chamber measured 57 cm by 42 cm by 54 cm internally. The floor consisted of a metal grid enclosed in an open steel tray (2 cm high). Situated on one of the walls of the chamber were four circular Perspex response keys, only two of which were active during the experiment. The active response keys were 3 cm in diameter, 10 cm apart, and 38.5 cm above the grid floor. When operative, these keys were lit from behind via 1-W bulbs with red or green covers. A force greater than 0.1 N was required on the response keys before a peck was effective. The food magazine was situated halfway between the two response keys, 9 cm from the grid floor. During reinforcement, the keylights were extinguished, the food magazine was lit by a 1-W white light, and the hopper was raised to allow access to wheat for 3 s. The magazine light and keylights provided the only source of illumination in the chamber.

The experimental chamber was enclosed in a sound-attenuating box made of particle board and lined with polystyrene (4 cm

thick). The external measurements of this chamber were 100 cm by 78 cm by 65 cm. The sound-attenuating box stood on a steel frame (33 cm high), with wooden blocks (2 cm high) and rubber pads (1 cm high) positioned under each outside corner in an attempt to eliminate any vibration from the concrete floor. Both the chamber and the outer box were reached through hinged walls.

An Onkyo® TA-RW400/200 cassette tape deck was used to relay the auditory stimulus, which took the form of a taped recording of hens in a commercial poultry shed during cleaning with a mechanical sweeper (range of frequencies 3800 to 6700 Hz, mean frequency 5560 Hz) and had previously been used by McAdie *et al.* (1993). The taped stimulus was transmitted into the experimental chamber via two circular Pro-series® speakers (25 W, 4 Ω , dual cone, 4 in. diameter) placed separately 5 cm from the outer edges of the response panel, 15 cm above the grid floor. A number of holes were drilled to facilitate sound transmission. A public address TOA-430M solid-state mixed-power amplifier, with a power output maximum of 45 W rms and frequency response of ± 3 dBA over the range of 50 to 15000 Hz, was used to amplify the auditory stimulus.

The sound level was checked at least twice each experimental day with an Amplaid® SLM 13 decibel meter and was adjusted if required. A microphone attached to the meter was placed in the center of the chamber, 33 cm from the grid floor, and the dBA level was measured with the chamber door closed. The intensity of the sound stimulus was set at 100 (± 1) dBA. Background noise levels taken from within the chamber were measured at approximately 50 dBA.

Solid-state logic-control equipment located in an adjacent corridor controlled the experimental events.

Procedure

No training was necessary, because the birds had a previous history of responding under this procedure, and the hens were placed directly into the first experimental condition. At the start of each session, both keylights were lit red for 10 min (termed a component), then both were lit green for 10 min, then red again for 10 min, and then

green again for 10 min. There were no black-outs between changes of keylight color. Each component was in effect for 10 min; thus, the total session was 40 min long.

During all components VI schedules were in effect on both keys. All VI schedules were comprised of 15 intervals in random order from arithmetic progressions of the form $j + kx$, where $k = 2j$ and $x = 0, 1, 2, \dots, 14$. The values of j were chosen to produce the appropriate mean interval in each schedule. The VI schedule pairs were chosen so that the programmed overall reinforcement rates remained constant. The schedules were independent in that the arrangement of a reinforcer for one response was not affected by the availability of a reinforcer for a response on the other schedule. In all conditions there was a 2-s COD, which ensured that the hen responded on a given schedule or key for at least 2 s before reinforcement became available. The VI schedules for one component stopped timing during the other component.

In Condition 1, no sound was present and the VI schedules were programmed at VI 60 s on the left key and VI 180 s on the right key. In Condition 2, the sound stimulus (hens in a commercial poultry farm) was relayed into the experimental box when the left key in the red component or the right key in the green component was pecked. The noise remained on until there was a peck on the right key in the red component or the left key in the green component (i.e., until the subject changed over to the other key). When the component changed from red to green or vice versa, if the sound had been off in the previous component it came on, or if the sound had been on in the previous component it was turned off. The same schedules as in Condition 1 were in effect.

Over the next 10 conditions, the schedules in effect and the key that activated the sound stimulus in each component were varied systematically. The reinforcement-rate ratios and the key associated with noise were varied to generate five pairs of data points, such that for one point of each pair the sound was associated with the red-left key and the green-right key and for the other point the sound was associated with the red-right key and the green-left key. These conditions are presented in detail in Table 1.

Experimental sessions were conducted dai-

Table 1

The side associated with the noise in the red and green components in each condition and the schedule in effect on the left and right keys. The schedule labeled VI 55 was actually VI 55.38.

Condition No.	Key associated with the noise		VI (s)	
	Red	Green	Left	Right
1 ^a			60	180
2	right	left	60	180
3	left	right	60	180
4	left	right	180	60
5	right	left	180	60
6	right	left	90	90
7	left	right	90	90
8 ^a			240	55
9	right	left	240	55
10	left	right	240	55
11	left	right	55	240
12	right	left	55	240

^a No-noise conditions.

ly. Determination of stability in each experimental condition was based on two criteria. First, the median of the relative response rates in the last five sessions could not differ by more than .05 from the median of the previous five sessions in both the red and green components. This had to occur a total of five, not necessarily consecutive, times. This criterion is frequently used in concurrent-schedule research (e.g., Hollard & Davison, 1971). Second, daily graphs of the proportion of responses made to the left key in each component had to be judged stable for each hen through visual inspection by two or more laboratory members before conditions were changed. Both criteria had to be met in each component.

For both the red and green components, dependent measures included number of pecks to the left and right keys, seconds spent working on the left and right keys, and number of reinforcements collected on the left and right keys. The number of post-COD responses to the left and right keys in each component and the total number of changeovers (COs) made in each component were also recorded. The interchangeover intervals were calculated from these data.

RESULTS

The mean raw data from the last 5 days of each condition for each hen are shown in the

Appendix. All of the derived measures shown below are based on data summed across the last five sessions for each bird. All ratios represent the left-key measure over the right-key measure. Figure 1 shows the logarithms of the left:right ratios of the number of responses and time allocated as functions of the logarithms of the ratios of the number of reinforcements obtained for the two no-noise conditions (Conditions 1 and 8). Response- and time-allocation data were similar for each hen. All but one of the lines had slopes shallower than 1.0; the exception was the line fit to the red time data for Hen 15.

In Conditions 1 and 8, there were no experimentally arranged biasers for either component; therefore, $\log q$ should be zero, and the intercepts are measures of $\log b$ (Equation 2). If there was no inherent bias in these data, then the lines should fall together and pass through the origin. Any separation of the lines reflects a tendency for that bird to respond differentially in the two components. There were two potential uncontrolled or inherent sources of bias contributing to the measures of $\log b$ in each component. The first was an overall tendency to respond more to one key or the other (overall side bias), as can be seen for the data of Hens 13 and 14. The second potential source of inherent bias resulted from a tendency to respond more on one side than the other in one component than in the other, termed here *component bias*, which is most marked for the data from Hens 11 and 15. The overall side bias can be estimated from the midpoint between the two intercepts for each pair of lines, and the size of the component bias is the distance from this midpoint to each line. Thus $\log b$, for one component, can be estimated from the overall side bias plus the component bias and, for the other component, from the overall side bias minus the component bias. The component bias estimates for response and time data are shown in Tables 2 and 3. In general, they were small (ranging from 0.010 to -0.101, with a negative bias indicating more responding to the left key in the green component than to the left key in the red component).

The left panel of Figure 2 shows the logarithmic left:right response ratios as a function of the obtained logarithmic reinforcement measures from the conditions in which noise

Fig. 1. The logarithms of the ratios (left:right) of the numbers of responses made on (left panel) and time allocated to (right panel) the two keys as functions of the logarithms of the obtained reinforcement-rate ratios (left: right) on the two keys for the two no-noise conditions for each hen. The solid lines and circles represent data from the red component. The dashed lines and crosses represent data from the green component. The dotted lines indicate exact matching.

Table 2

Slopes and intercepts, percentage of variance accounted for (% VAC), and standard error (SE) of the lines fitted to the logarithms of the means of the last 5 days of the response ratios from each condition. Estimates of component bias, combined noise and component bias, and noise bias alone are also given. Negative component biases indicate more responding to the left key in the green component than to the left key in the red component in the no-noise conditions.

						Estimates of bias		
Hen		Slope	Intercept	% VAC	SE	Component	Combined	Noise
Noise associated with the right key in the red component								
11	red	0.65	0.13	87	0.14	-0.065	0.11	0.18
	green	0.77	-0.09	91	0.13			
13	red	0.74	0.12	93	0.11	-0.027	0.07	0.10
	green	0.62	-0.02	92	0.10			
14	red	0.50	0.14	82	0.12	0.010	0.16	0.15
	green	0.56	-0.17	99	0.03			
15	red	0.86	-0.03	79	0.22	-0.101	0.04	0.14
	green	0.72	-0.11	73	0.24			
Noise associated with the left key in the red component								
11	red	0.75	-0.09	74	0.24	-0.065	0.09	0.03
	green	0.80	0.08	91	0.13			
13	red	0.55	0.02	93	0.08	-0.027	0.02	0.01 ^a
	green	0.46	0.05	68	0.16			
14	red	0.50	-0.11	80	0.14	0.010	0.13	0.14
	green	0.53	0.15	82	0.11			
15	red	0.61	-0.20	62	0.24	-0.101	0.15	0.05
	green	0.81	0.09	66	0.31			

^a Bias towards the key associated with the noise.

Table 3

Slopes and intercepts, percentage of variance accounted for (% VAC), and standard error (SE) of the lines fitted to the logarithms of the means of the last 5 days of the time ratios from each condition. Estimates of component bias, combined noise and component bias, and noise bias alone are also given. Negative component biases indicate more responding to the left key in the green component than to the left key in the red component in the no-noise conditions.

						Estimates of bias		
Hen		Slope	Intercept	% VAC	SE	Component	Combined	Noise
Noise associated with the right key in the red component								
11	red	0.77	0.19	90	0.14	−0.064	0.16	0.22
	green	0.85	−0.14	94	0.12			
13	red	0.88	0.18	96	0.10	−0.004	0.11	0.11
	green	0.57	−0.03	96	0.06			
14	red	0.74	0.08	74	0.22	0.004	0.15	0.15
	green	0.84	−0.21	98	0.07			
15	red	0.83	0.06	89	0.15	−0.052	0.07	0.12
	green	0.79	−0.07	90	0.15			
Noise associated with the left key in the red component								
11	red	0.84	−0.13	70	0.30	−0.064	0.15	0.09
	green	0.81	0.16	92	0.12			
13	red	0.67	−0.01	94	0.09	−0.004	0.06	0.06
	green	0.60	0.11	87	0.12			
14	red	0.55	−0.10	93	0.09	0.004	0.09	0.09
	green	0.58	0.08	73	0.15			
15	red	0.63	−0.16	74	0.20	−0.052	0.11	0.06
	green	0.77	0.06	89	0.15

Fig. 2. The logarithms of the ratios (left:right) of the numbers of responses made on the two keys as functions of the logarithms of the obtained reinforcement-rate ratios (left:right) on the two keys for each condition for each hen. The left panel shows data from the conditions in which noise was associated with the right key in the red component (Conditions 2, 5, 6, 9, and 12). The right panel shows data from the conditions in which noise was associated with the left key in the red component (Conditions 3, 4, 7, 10, and 11). The solid lines and circles represent data from the red component. The dashed lines and crosses represent data from the green component.

was associated with the right key in the red component and the left key in the green component (Conditions 2, 5, 6, 9, 12) and the right panel shows data from the conditions in which noise was associated with the left key in the red component and the right key in the green component (Conditions 3, 4, 7, 10, 11). The lines generally fit the data well. That the sound biased the behavior is shown by the data in the red component being above those from the green component in the left panel and by the reverse in the right panel of Figure 2. All the lines have slopes less than 1.0, ranging from 0.50 to 0.86 for the red-component data and from 0.46 to 0.81 for the green-component data.

The intercepts of the fitted lines give estimates of the bias, $\log c$ (Equation 1) which combines the effects of inherent and extrinsic biasers ($\log b$ and $\log q$, Equation 2). The midpoint between the intercepts of each pair of lines shown in Figure 2 indicates the degree and direction of any overall inherent side bias in responding in these conditions. These are generally similar to the overall side biases shown in Figure 1; for example, Hen 13's data show a small bias in responding towards the left key throughout the experiment. This overall side bias is part of the inherent bias measured by $\log b$ (Equation 2).

The distances between the midpoint and the intercepts are given in Table 2 and give measures of the bias resulting from the presence of the noise combined with any component bias. Thus, the actual magnitude of the effect of the sound cannot be established without taking into account the component bias (Figure 1 and Table 2). The component bias for each hen was then removed from the combined noise and component bias measure to give estimates of the bias due to the noise alone ($\log q$). As shown in Table 2, these noise biases ranged from 0.10 to 0.18 when noise was associated with the right key in the red component, and between 0.01 towards the noise, for Hen 13 only, to 0.14 away from the noise when the noise was associated with the left key in the red component.

The data in Figure 3 are for time-allocation ratios. All of the lines have slopes less than 1.00; for the red-component data they range from 0.55 to 0.88, and for the green-component data they range from 0.57 to 0.85. For most hens there was a clear separation of the

lines from the red and green components for both sets of conditions. Typically there was more separation of the lines for the time measures than for the response measures.

The estimates of bias in the time-allocation data from the red and green components were calculated as for the response data and are shown in Table 3. The component biases for the time data calculated from the no-noise conditions (Conditions 1 and 8) are also shown in Table 3. As with the response data, component biases were small, with 3 hens tending to spend more time responding on the left key in the green component than the left key in the red component and 1 (Hen 14) spending more time responding on the right key in the green component than on the right key in the red component. The estimates of the combined noise and component bias and the noise bias alone for the time data are all similar to the values found for the response data. The estimates of noise bias ranged from 0.06 to 0.22 away from the noise.

Figure 4 shows the logarithms of the ratios of the responses made on the two keys in each component during and after the COD as functions of the logarithms of the left:right ratios of the number of reinforcements obtained on the two keys for each condition involving noise. The post-COD data follow patterns similar to, but steeper than, those for the same bird's total-response data (Table 4). The lines generally fit these data well (with variances accounted for ranging from 66% to 99%). The lines fit to the response-ratio data during the COD have slopes around 0.0, ranging from -0.19 to 0.10 (Table 5). The variances accounted for by these lines are very low because of the shallow slopes. In these cases the standard error is a better estimate of the degree of fit; these are generally similar to, or smaller than, those for the response, time, and post-COD data.

Table 6 gives the slopes and intercepts of the lines joining the data from the two no-noise conditions (1 and 8) during and after the COD and the estimates of component bias. The slopes are similar to those from the equivalent data in Tables 4 and 5. The component biases based on these data (half the distance between the intercepts) are also given in Tables 4 and 5 for ease of comparison. There are no consistent differences between

Fig. 3. Plotting conventions are the same as in Figure 2 and are for time-allocation data.

Fig. 4. Plotting conventions are the same as in Figure 2. The solid lines and unfilled circles represent the red-component post-COD data. The dashed lines and filled circles represent the green-component post-COD data. The solid lines and filled squares represent the red-component during-COD data. The dashed lines and filled squares represent the green-component during-COD data.

Table 4

Slopes and intercepts, percentage of variance accounted for (% VAC), and standard error (SE) of the lines fitted to the logarithms of the means of the last 5 days of the post-COD response ratios from each condition. Estimates of component bias, combined noise and component bias, and noise bias alone are also given. Negative component biases indicate more responding to the left key in the green component than to the left key in the red component in the no-noise conditions.

Hen		Slope	Intercept	% VAC	SE	Estimates of bias		
						Component	Combined	Noise
Noise associated with the right key in the red component								
11	red	1.11	0.21	86	0.26	−0.092	0.19	0.28
	green	1.31	−0.16	88	0.27			
13	red	1.36	0.11	97	0.12	−0.029	0.17	0.20
	green	1.03	−0.06	94	0.14			
14	red	0.95	0.19	93	0.13	−0.010	0.22	0.23
	green	0.95	−0.24	99	0.05			
15	red	1.25	0.09	83	0.29	−0.110	0.10	0.21
	green	1.04	−0.11	80	0.29			
Noise associated with the left key in the red component								
11	red	1.16	−0.18	68	0.42	−0.092	0.16	0.07
	green	1.29	0.13	90	0.22			
13	red	0.96	−0.06	90	0.18	−0.029	0.04	0.01
	green	0.81	0.02	68	0.29			
14	red	0.81	−0.20	91	0.14	−0.010	0.23	0.22
	green	0.90	0.26	89	0.14			
15	red	0.89	−0.18	69	0.31	−0.110	0.19	0.08
	green	1.12	0.20	66	0.42			

Table 5

Slopes and intercepts, percentage of variance accounted for (% VAC), and standard error (SE) of the lines fitted to the logarithms of the means of the last 5 days of the response ratios during the COD from each condition. Estimates of component bias, combined noise and component bias, and noise bias alone are also given. Negative component biases indicate more responding to the left key in the green component than to the left key in the red component in the no-noise conditions.

Hen		Slope	Intercept	% VAC	SE	Estimates of bias		
						Component	Combined	Noise
Noise associated with the right key in the red component								
11	red	-0.07	0.04	0	0.13	0.014	0.03 ^a	0.04 ^a
	green	-0.06	0.10	6	0.06			
13	red	-0.19	0.08	74	0.06	0.008	0.05 ^a	0.06 ^a
	green	-0.06	0.17	7	0.06			
14	red	-0.05	0.09	0	0.07	0.024	0.07	0.05
	green	-0.02	-0.04	0	0.07			
15	red	0.10	-0.18	0	0.13	-0.052	0.05 ^a	0.00
	green	0.04	-0.09	0	0.07			
Noise associated with the left key in the red component								
11	red	-0.09	0.10	4	0.09	0.014	0.03 ^a	0.02 ^a
	green	-0.01	0.05	0	0.07			
13	red	-0.10	0.16	11	0.09	0.008	0.02 ^a	0.01 ^a
	green	-0.07	0.13	0	0.08			
14	red	0.02	0.04	0	0.06	0.024	0.03 ^a	0.01 ^a
	green	0.01	-0.01	0	0.08			
15	red	-0.03	-0.16	0	0.07	-0.052	0.05	0.00
	green	0.05	-0.06	0	0.15			

^a Bias towards the key associated with the noise.

Table 6

Slopes and intercepts of the lines joining the logarithms of the means of the last 5 days of the left:right response ratios made during and after the COD for each component (red and green) in the no-noise conditions. Estimates of component bias present during and after the COD are also shown. Negative component biases indicate more responding to the left key in the green component than to the left key in the red component.

Hen	Red		Green		Component bias
	Slope	Intercept	Slope	Intercept	
After COD					
11	1.429	-0.144	1.132	0.039	-0.092
13	0.857	0.018	1.040	0.075	-0.029
14	0.899	0.066	0.813	0.086	-0.010
15	1.400	-0.177	1.148	0.042	-0.110
During COD					
11	-0.117	0.057	-0.020	0.029	0.014
13	-0.230	0.147	-0.206	0.131	0.008
14	-0.063	0.125	-0.003	0.078	0.024
15	0.197	-0.145	0.320	-0.041	-0.052

these component biases and the component biases for the overall response data (Table 2).

Estimates of noise bias were derived for during- and after-COD data as described previously. In general, the post-COD data (Table 4) resulted in greater noise biases than did the overall response, time, or during-COD response data (Table 5). Noise bias estimates based on the during-COD data were small, ranging from 0.06 towards the noise to 0.05 away from it, with five of the eight estimates being towards the noise.

Figure 5 shows the mean number of changeovers made in the last five sessions of each condition for each hen. For a given pair of schedules when sound was present in a session (all conditions except 1 and 8), the changeover rate depended on whether the sound was associated with the richer or the leaner schedule. Figure 5 shows that for each schedule pair, more changeovers were made when noise was paired with the rich schedule than when noise was paired with the lean schedule. This was true for 27 of the 32 cases for the individual data. When no sound was present (Conditions 1 and 8), there were fewer COs when the more disparate schedules were in effect (Condition 8), and there was no general tendency for greater numbers of COs to be made in one component than the other. Whether sound was associated with the

Fig. 5. The arithmetic average of the number of changeovers made in the last five sessions of each condition for each hen. The open circles represent data from the red component, and the crosses represent data from the green component.

left key in the red component and the right key in the green component (Conditions 3, 4, 7, 10, and 11) or vice versa (Conditions 2, 5, 6, 9, and 12), the number of COs decreased as the schedules became more disparate, with equal-schedule CO data (Conditions 6 and 7) for the most part showing more COs than the unequal schedule pairs.

Twice during the experiment a no-noise condition preceded a noise condition without a schedule change (Conditions 1 and 2 and 8 and 9). This allowed the effect of sound on number of COs to be directly examined. In both cases when sound was added to the lean schedule but not the rich, there were decreases in the number of COs made in that component (Figure 5). When the sound was added to the rich schedule, the number of COs made in that component increased.

Table 7 gives the average interchangeover interval for each schedule, component and bird for each condition. Within each condition, interchangeover intervals were generally shorter when noise was associated with a particular schedule than when it was not, regardless of the reinforcement rate on that schedule. The difference between interchangeover intervals with and without sound was greater for the rich than for the lean schedules. In addition, the interchangeover intervals were almost always greater for the richer schedule of each schedule pair (regardless of the presence or absence of the sound) (94 of 96 possible cases). To illustrate the effect of sound on the interchangeover interval more clearly, the differences between the interchangeover intervals for Conditions 1 and 2 and for Conditions 8 and 9 are presented in Figure 6. Positive numbers show that the interchangeover interval increased, and negative ones indicate that the interchangeover interval decreased when the sound was added. It is clear that in all cases when the sound was added to the lean schedule of the pair, the interchangeover interval on the rich schedule increased. The interchangeover interval on the lean schedule to which the noise was added decreased for 3 hens and increased slightly for Hen 15. When the sound was added to the rich schedule of the pair, the interchangeover interval on that schedule decreased for all subjects and both pairs of conditions. The interchangeover interval on the lean schedule did not change consistently.

DISCUSSION

This study provides the first demonstration of bias due to an overlaid aversive stimulus over a range of reinforcement rates. Hen behavior under concurrent schedules was consistently biased away from the sound. The

Table 7

The mean interchangeover interval (in seconds) for each hen and condition from the last five sessions.

Hen	Condi- tion	VI		Red		Green	
		Left	Right	Left	Right	Left	Right
11	1	60	180	8.5	3.0	9.3	3.4
13				9.8	3.4	12.7	3.8
14				7.7	5.4	7.9	4.8
15				10.3	3.8	8.9	4.0
11	2	60	180	14.1	2.9 ^a	7.0 ^a	3.4
13				21.7	3.7	10.5	6.3
14				9.2	3.3	7.4	4.2
15				14.1	4.4	8.3	4.5
11	3	60	180	11.2 ^a	3.0	13.4	3.1 ^a
13				9.0	3.2	11.3	3.2
14				7.3	4.5	10.1	4.1
15				9.1	5.1	16.6	5.3
11	4	180	60	3.3 ^a	12.3	4.4	5.4 ^a
13				3.7	8.3	5.2	6.8
14				4.1	12.8	4.8	10.3
15				4.1	7.6	5.2	5.4
11	5	180	60	5.9	6.9 ^a	3.7 ^a	12.8
13				4.1	6.9	4.6	9.5
14				3.2	11.3	3.4	13.5
15				5.1	6.7	4.3	7.9
11	6	90	90	7.3	3.7 ^a	4.6 ^a	5.3
13				5.6	4.2	5.2	7.0
14				5.0	4.6	3.8	8.4
15				8.2	5.4	5.3	6.8
11	7	90	90	4.3 ^a	4.3	6.4	3.4 ^a
13				4.1	5.2	5.1	4.3
14				5.2	5.9	7.1	5.3
15				6.3	10.1	7.6	6.9
11	8	240	55	5.1	23.0	4.8	12.4
13				3.7	7.9	3.8	8.2
14				4.3	9.3	4.8	12.2
15				4.7	30.6	5.3	16.8
11	9	240	55	5.7	16.4 ^a	4.2 ^a	25.9
13				3.3	7.1	3.6	8.5
14				5.4	8.0	3.8	22.7
15				5.7	22.6	5.5	35.4
11	10	240	55	4.1 ^a	25.1	5.5	14.5 ^a
13				3.7	10.1	3.9	7.3
14				8.0	20.0	17.1	15.5
15				6.5	35.5	5.9	22.6
11	11	55	240	5.7 ^a	6.1	11.0	3.5 ^a
13				4.8	2.7	5.2	2.1
14				6.5	4.5	9.5	4.3
15				8.5	7.5	17.6	5.7
11	12	55	240	10.4	3.3 ^a	7.5 ^a	4.1
13				8.5	2.5	8.3	3.6
14				14.2	4.7	12.7	7.0
15				17.0	6.1	14.6	1.5

^a The key associated with noise in each component, if there was one.

Fig. 6. The top panel shows the average interchangeover intervals for each hen for the same schedules from Condition 2 (noise) minus the same data from Condition 1 (no noise). The bottom panel shows Condition 9 (noise) data minus Condition 8 (no-noise) data. The circles and squares represent data from the rich and lean schedules, respectively. The filled and unfilled symbols represent data from the schedules paired with no noise and noise, respectively.

generalized matching law provides a means of quantifying this noise bias by allowing the removal of the inherent bias (the combined overall side bias and component bias; $\log b$, Equation 2), estimated from the fitted lines, from the total bias ($\log c$ in Equation 1) to obtain estimates of noise bias only ($\log q$ in Equation 2). The data are generally well described by straight lines, suggesting that all the biases remained constant as the reinforcement rates were varied. This is similar to the finding of a constant bias resulting from different types of reinforcers (Hollard & Davison, 1971; Matthews & Temple, 1979).

The degree of noise bias found in the response measures varied across hens and was comparable to the biases found for the same hens and the same sound using equal schedules only (McAdie et al., 1993). The degree of biases found is also similar to that reported

for cows' preferences for crushed barley over meatmeal (Foster, Temple, Robertson, Nair, & Poling, 1996), much bigger than that reported for cows' preferences for crushed barley over dairymeal (Matthews & Temple, 1979), and less than that reported for pigeons' preferences for wheat over electrical stimulation of the brain (Hollard & Davison, 1971). In the studies just cited, measures of bias from response and time data were very similar. This was also true for the current data. Tables 2 (response measures) and 3 (time measures) show that the estimates of bias away from the noise were between 0.03 and 0.22, suggesting that working without the sound was between 1.1 and 1.7 times more preferable to working in its presence for 3 of the 4 subjects. Hen 13 was the exception, with one of her two noise bias estimates based on total response data showing a very slight (0.01) bias toward the noise. This hen generally had small biases, and it is not clear if this was truly a bias towards the noise or a result of measurement error.

One important feature of the current procedure was that the biasing effects of the noise were demonstrated within the session. Thus when the behavior was biased away from the noise, it was clearly biased away from one key in the red component and from the other key in the green component. The components differed only in the key that was associated with the noise. Thus the procedure provided a convincing demonstration that the noise was responsible for the bias in the hens' behavior.

McAdie et al. (1993) and the current experiment found that when no noise was present for either key, there were small differences between the biases shown in the red and green components. The keys were physically the same in both components and were, as far as possible, the same color within a component. However, the hens responded relatively more to one key in one component than they did to the same key in the other component. This has been termed here the component bias and has been considered to be part of the inherent bias ($\log b$, Equation 2). Such biases are similar to the slight changes in bias across replicated conditions reported, for example, by Matthews (1983). In addition to the component bias, a tendency to respond more to the left than to the

right key independent of key color (i.e., a position bias, termed here overall side bias) was also found in the present results. This bias is also considered to be part of the inherent bias.

Undermatching is a common finding in studies of concurrent-schedule behavior (Davison & McCarthy, 1988; Robinson, 1992). The degree of undermatching found here is similar to that reported for other studies using hens as subjects (e.g., a values from 0.37 to 1.01 for response data and from 0.36 to 1.05 for time data, Sumpter, 1993; a values from 0.64 to 0.98 for response data and from 0.59 to 1.00 for time data, Scown, 1983). In addition, the degree of undermatching here was similar for the noise and no-noise conditions, suggesting that undermatching was not a function of the addition of the biaser.

In spite of the presence of the sound, behavior during the COD showed very small noise biases, with five of the eight estimates being slightly towards the noise. Thus, the post-COD response data gave necessarily more extreme noise bias measures than did the overall response data. Other studies of bias (e.g., Hollard & Davison, 1971; Matthews & Temple, 1979) have not recorded responding during and after the COD separately, so comparative data are not available. However, Temple *et al.* (1995) showed that responding during the COD was remarkably insensitive to changes in reinforcement rate (a values ranging from -0.12 to 0.16). In this study, overall responding generally undermatched reinforcement rate (a values around 0.90), and the post-COD data overmatched (a values around 1.30). Although the current data generally showed a slightly greater degree of undermatching for overall responding (Table 2) than the Temple *et al.* study did, the behavior during the COD in the present study showed a similar degree of insensitivity to reinforcement-rate changes (a values ranging from -0.19 to 0.10). Thus, there was an insensitivity to the scheduled parameters (including the noise) during the COD period. It is possible, as Herrnstein (1961) originally suggested, that the COD separates the schedules such that responses during the COD are "neutral" and are not under the control of either schedule. Because strong preferences for the richer of two schedules and biases against the schedule associated with noise

stimuli were not reflected in the during-COD data, it may be that post-COD data give the "better" estimate of bias. This suggestion requires further study with other types of stimuli.

It is also possible that sound could punish the response that produced it. Even though the changeover response started the sound, McAdie (1991) found that responding during the COD did not appear to decrease when a sound was introduced, suggesting that the noise had not functioned as a punisher of those responses. However, with this procedure, there is only a response contingency for the first of a series of responses on a particular side key. Therefore, the schedule of punishment would be very intermittent and likely to attenuate any suppressive effects that response-contingent noise might have. Thus, effects might be seen not in the COD responding but in the rate of changing over between schedules, because a CO response into the schedule associated with the sound could be punished by its onset. McAdie (1991) examined the numbers of COs with equal VI schedules, and found that there was no consistent tendency for them to be lower in conditions in which noise was present than in those without it. In that study, CO responses did not appear to be reduced by the onset of a sound.

In general, equal concurrent schedules generate higher rates of changing over than unequal schedules do (Baum, 1974; Sumpter *et al.*, 1995). This can be seen in the present study when the overall rates of COs are compared for equal and unequal schedule conditions with sound present on the same key. The rate of changing over has also been found to decrease as the scheduled reinforcement rates get more disparate (Baum, 1974; Sumpter *et al.*, 1995). This was generally true here as well, for the conditions without sound (Conditions 1 and 8, Figure 5). It is also clear in the present data that when the sound was associated with the richer of a particular pair of schedules, the rate of changing over for that schedule pair was higher than when the sound was associated with the leaner schedule of the same pair. In the two conditions that followed a no-noise condition (Condition 2 compared with 1 and 9 with 8), the COs increased somewhat when the noise was added to the rich schedule and decreased

markedly when the sound was added to the lean schedule of the pair. It is possible that the addition of the sound (an aversive stimulus) to the rich schedule reduced the value of that schedule, thus making the rich and lean schedules less disparate and resulting in increased COs. In the same way, when added to the lean schedule, noise might increase disparity between the schedules and result in decreased COs. In this respect, adding noise could have functioned in the same way as adjusting scheduled reinforcement rates, and this was reflected in the changed changeover rates. Although McAdie's (1991) CO data were not highly orderly, 4 of the 6 hens (including 3 of the current hens, 13 being the exception) showed constant decreases in the number of COs made as noise intensity increased over three conditions. This would be predicted if increased intensity decreased the value of the schedule. These CO decreases also correlated with increases in noise bias.

Changeover responses and interchange-over intervals can vary independently. For example, number of COs can remain constant while interchangeover intervals become longer on one schedule and shorter on the other. Similarly, number of changeovers might vary while the interchangeover interval remains constant on one schedule and either increases or decreases on the other. In the present data, when sound was associated with the richer schedule of the pair, time to leave that schedule was shorter than when sound was not associated with either schedule (Table 7 and Figure 6). Under the same conditions, time to leave the lean schedule was not affected (Figure 6). These changes were accompanied by small but consistent increases in CO rates (Figure 5). Similarly, 3 subjects left the leaner schedule slightly sooner (Hen 15 very slightly later) when sound was associated with it than when there was no sound associated with either schedule. Under the same conditions, they stayed for much longer periods of time on the rich schedule (Figure 6). These changes were associated with large decreases in CO rates (Figure 5). Thus, superimposing sound on a schedule generally reduced the time an animal worked on that schedule, not only over the whole session but also between each changeover. The effect of the sound on interchangeover interval on both schedules and on CO rate was depen-

dent on the relative reinforcement rate of the schedule that was associated with the sound. Thus it appears that the presence of the sound has effects similar to changes in the relative value of the schedules. Other studies of biasers of concurrent-schedule performance have not reported interchangeover times; thus, it is not clear whether this pattern is unique to aversive biasers or whether the reverse would be found with positive biasers.

McAdie et al. (1993) found that with equal concurrent schedules, the degree of bias changed with the dBA. Further clarification of the effect of sound on behavior would be obtained by changing the dBA and then varying the reinforcement rates. If sensitivity remained constant while bias changed, this would add further support to the generalized matching law and its prediction that bias and reinforcement-rate parameters can vary independently. If sensitivity changed with the bias, then this would suggest that the two parameters are not independent.

The present experiment shows that behavior can be biased away from an aversive stimulus that is overlaid on a schedule and not simply a consequence of each response. It shows that this bias can be quantified by the generalized matching law. These findings begin to address the measurement of animals' preference for or against such things as "noisy" environments. Thus the present methodology could be useful for investigation of issues concerning the welfare and housing of animals.

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APPENDIX

The subject, condition, the number of pecks made to the left and right schedules (PL and PR), time spent in the left and right schedules (TL and TR), and reinforcements obtained on the left and right schedules (RFL and RFR) for both the red and green components are shown. The left and right responses made after the COD (PCL and PCR, respectively) in the red and green components are also shown, along with the numbers of changeovers (CO) made in the red (R) and green (G) components. The means of the last 5 days' data from each condition, for each hen, are shown.

Hen	Con- di- tion	Red						Green						Red		Green		CO	
		PL	PR	TL	TR	RFL	RFR	PL	PR	TL	TR	RFL	RFR	PCL	PCR	PCL	PCR	R	G
11	1	558	257	850	303	19	6	583	258	846	309	17	6	423	112	429	111	100	91
11	2	672	197	950	193	19	6	636	283	785	377	17	6	572	51	418	76	67	113
11	3	708	204	901	241	20	7	693	173	935	219	17	5	587	76	579	56	81	70
11	4	219	643	241	905	5	17	359	527	519	637	7	19	82	537	170	333	74	118
11	5	329	334	521	605	6	17	193	478	257	892	6	17	164	207	72	401	88	70
11	6	485	310	761	379	13	12	378	425	539	628	11	12	311	171	163	261	104	119
11	7	394	447	549	547	11	12	408	318	723	381	13	11	178	259	210	142	128	112
11	8	126	607	207	932	4	19	201	593	320	822	4	21	47	545	92	494	41	66
11	9	181	525	295	847	4	19	95	506	158	984	4	20	83	433	33	454	52	38
11	10	134	603	159	972	4	20	178	513	317	832	5	18	57	556	84	439	39	57
11	11	414	389	555	596	17	5	477	189	872	277	19	5	236	265	344	85	98	79
11	12	591	229	868	277	19	5	515	289	744	409	21	5	439	109	345	148	84	99
13	1	352	195	857	294	18	6	359	153	889	265	17	6	237	91	269	70	87	70
13	2	420	97	979	169	16	5	342	131	723	432	17	6	373	41	246	64	45	69
13	3	510	207	852	299	19	6	486	165	898	257	17	6	373	81	376	66	95	79
13	4	173	351	360	798	5	16	195	305	498	654	7	18	69	274	95	221	97	96
13	5	162	302	429	721	6	18	135	306	380	773	6	18	55	223	57	246	105	82
13	6	261	205	662	497	12	12	216	227	491	663	11	12	142	108	116	164	117	95
13	7	261	261	509	647	12	13	300	243	625	536	12	12	121	162	168	143	124	124
13	8	194	322	363	786	4	20	190	299	370	788	5	19	73	261	77	237	99	96
13	9	187	334	370	782	5	18	173	394	342	816	4	20	64	262	65	333	111	96
13	10	163	336	305	843	4	20	204	340	404	757	5	18	63	285	84	271	83	104
13	11	368	223	742	421	17	5	327	214	832	341	18	4	184	106	163	95	153	161
13	12	447	183	889	264	17	5	391	189	805	349	20	5	315	65	274	99	105	97
14	1	608	319	679	475	16	7	565	290	715	437	18	6	401	153	374	130	88	91
14	2	528	248	843	301	19	6	413	342	733	421	17	6	335	80	249	144	91	99
14	3	500	372	712	437	17	6	673	264	820	331	17	6	278	170	534	103	98	81
14	4	236	445	275	864	5	19	247	398	363	787	6	17	95	328	136	258	68	76
14	5	279	444	252	890	6	18	174	512	231	918	6	19	123	315	77	404	79	68
14	6	464	395	597	551	13	13	235	394	361	798	10	12	217	157	105	229	121	95
14	7	404	438	539	609	11	13	431	275	664	491	13	11	185	259	260	127	104	93
14	8	245	366	360	783	4	19	181	288	326	829	4	18	81	254	73	198	84	68
14	9	260	314	462	682	4	19	100	333	166	982	4	18	107	214	36	274	85	43
14	10	93	351	326	815	4	16	126	105	612	554	5	11	40	293	91	73	41	36
14	11	382	275	681	470	17	4	449	174	796	357	19	5	215	126	337	65	105	84
14	12	419	142	858	281	16	6	279	182	748	411	15	4	316	64	179	94	60	59
15	1	370	172	839	312	19	5	400	181	796	358	18	6	271	63	257	69	82	89
15	2	347	127	875	271	17	6	336	228	743	407	19	6	264	47	207	101	62	90
15	3	354	194	755	389	18	6	390	93	868	276	18	6	258	77	321	35	77	52
15	4	203	355	402	750	6	18	363	225	571	592	7	15	94	209	187	87	98	110
15	5	226	287	499	653	6	16	223	316	406	744	6	18	117	144	103	179	98	94
15	6	251	205	691	457	13	10	210	305	506	647	10	14	184	94	125	180	85	96
15	7	149	285	442	705	11	11	217	214	605	544	12	12	95	196	154	117	70	79
15	8	41	325	151	986	4	19	93	282	277	872	5	18	21	286	53	216	32	52
15	9	50	294	231	913	4	17	41	324	154	985	4	20	26	247	19	295	40	28
15	10	52	337	175	959	4	19	61	318	238	911	4	17	32	309	34	278	27	40
15	11	198	203	609	537	18	5	287	98	864	280	19	4	149	122	248	51	72	49
15	12	235	99	839	300	19	5	239	128	799	350	18	5	203	44	194	69	49	55