DETECTION OF BRIEF TONES IN NOISE BY RATS¹

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Two rats were trained to detect brief 8000-Hz tones centered in a one-third octave band of noise. The procedure was analogous to the yes-no method of human psychophysics in that one response was defined as correct and reinforced if the tone were present in the noise, and another response was correct and reinforced if the tone were absent. The percentage of correct responses was determined principally by the energy in the tone for the range of durations studied (75 to 600 msec): if the tone's duration were halved, for example, its power had to be doubled to keep the percentage of correct responses about the same. The ratio of the energy in the tone to the power per cycle of the noise needed to maintain 75% correct responses was about 36 db for one animal and 41 db for the other. Although the two responses were similar, and their consequences equal, biases in responding were sometimes observed.

The purpose of the present study is to present further evidence that the "yes-no" procedure commonly employed with human subjects can be used to study the hearing of animals. This procedure is used to show that rats can detect brief tones in noise, and that detection depends upon the energy in the tone—the product of its power and duration—at least for durations ranging from 75 to 600 msec.

The yes-no procedure presents one stimulus to the subject who then must respond in one of two ways (for example, "Yes, I detect it", or "No, I do not detect it", with human subjects). This method is not the preferred one for studying human sensory processes because, unless the consequences of each type of response are equated, biases easily arise in responding, and these may distort the estimate of the subject's sensitivity. With animal subjects, the reinforcing and punishing consequences of a response can be explicitly specified, and therefore the consequences of each type of response

can be equated exactly. In the present experiment, the "yes" response was pressing one key in the experimental chamber, and the "no" response was pressing another. A correct response, whether on one key or the other, was reinforced by a burst of electrical stimulation to the rat's brain, and an incorrect response produced a brief period in which no responses were effective.

The yes-no procedure has been used by a number of other investigators of animal sensory processes, but the consequences of each type of response have not always been made equal. Hack (1963), for example, reinforced correct "yes" responses but not correct "no" responses, and Clack (1966) punished incorrect "no" responses but not incorrect "yes" responses. Two studies have equated the consequences of each type of response with monkeys (Mishkin and Weiskrantz, 1959; Symmes, 1965). In these experiments, however, there was only one measured response, so that either responding or withholding a response was reinforced if correct. Blough (1958) suggested that there may be an advantage in requiring two responses rather than one because extraneous variables that sometimes determine whether or not an animal responds will then affect each response equally. In the present procedure, two similar responses were required of a rat, and the consequences were symmetrical. These two properties of the design presumably minimize biases in the yes-no procedure.

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METHOD

Subjects

Two male albino rats of the Charles River CD strain served. They were implanted, under anesthesia from pentobarbital sodium solution (Nembutal), with bipolar stainless steel electrodes (Plastic Products MS 303) aimed at the region of the posterior hypothalamus. The electrodes were fastened to the skull with stainless steel screws and dental cement. After the experiment the animals were sacrificed, and perfused with saline and neutral-buffered formalin solutions. The brains were washed in water, dehydrated in solutions of alcohol, embedded in celloidin, sectioned, and stained. Electrode tips were localized, with the aid of König and Klippel's (1963) stereotaxic atlas, in the following areas: Rat X1, *fasciculus medialis prosencephali*; Rat Y2, *nucleus ventromedialis (hypothalami)*, *pars medialis*.

Apparatus

The experimental compartment had Plexiglas side and rear walls, an aluminum front wall, and a grid floor. Its internal dimensions were 13 in. long, 9.5 in. wide, and 19.5 in. high (0.33 by 0.24 by 0.49 m). Two circular keys were mounted on the front panel; their centers were 135 mm apart, 40 mm above the floor, and 50 mm from each side. A response that opened the switch of either key could be reinforced. A central light was also mounted on the front panel with its center 100 mm above the floor. When this panel light was on, the animal could turn on the auditory stimulus by breaking a beam of light that shone across the rear of the chamber and focused on a photocell 40 mm above the floor.

The experimental compartment, which had no ceiling, was placed inside a sound-attenuating chamber. A speaker (University model 4401) was suspended from the ceiling of this chamber directly above the light beam. The noise stimulus, which was the same throughout the experiment, was a one-third octave band centered at 8000 Hz. It was obtained by passing the output of a Grason-Stadler noise generator (model 901) through a Bruel and Kjaer band-pass filter (model 1612). The noise spectrum was flat in this region. The nominal bandwidth of the filter at the 3-db points was 1830 Hz. The tone that was sometimes added to the noise was an 8000-Hz sinusoid produced

by a Wavetek function generator (model 111), and filtered by the band-pass filter. Both the noise and the tone plus noise were gated by a Scientific Prototype switch (model 4042-J) with an exponential rise and decay of about 12 msec. The level per cycle of the noise at the light beam was about 34 db *re* 2×10^{-4} microbar. The durations of the auditory stimuli were either 600, 300, 150, or 75 msec. They were controlled by a Hunter timer and measured with a Hewlett Packard electronic counter (model 5223L).

The magnitude of the tone was specified by the dimensionless quantity, E/N_0 —the ratio of the energy in the tone to the power per cycle of the noise. This quantity is often used in detection experiments with humans. A quantity proportional to the energy in the tone was obtained by measuring the voltage of the tone across the speaker (with a Ballantine voltmeter, model 300), squaring the voltage, and multiplying it by the duration of the tone in seconds. A quantity proportional to the power per cycle of the noise was obtained by measuring the voltage of the noise across the speaker, squaring it, and dividing by the equivalent rectangular bandwidth of the noise (assumed to be 2000 Hz on the basis of the filter's specifications). The constant of proportionality cancelled out when the ratio, E/N_0 , was found; the decibel value of the ratio is $10 \log (E/N_0)$. The acoustic level of the tone, measured by a General Radio sound-level meter (model 1551-B), varied by 2 db in different regions of the light beam.

Procedure

The events in a trial. The animal was trained to turn the auditory stimulus on by breaking the light beam. This response turned off the panel light, lit both keys, and produced at random either noise alone or tone plus noise with probability of 0.5 (scheduled by a Scientific Prototype probability generator, model 4020-J). At first, a response on either key was reinforced with brain stimulation, but after a few sessions the rat had to press the right-hand key if the tone were present in the noise and the left-hand key if the noise alone were present. These responses may therefore be called "correct". "Incorrect" responses on either key produced a 5-sec timeout during which the panel light was off and an interruption of the light beam did not produce the auditory stim-

ulus. During this preliminary training both the auditory stimulus and the keylights remained on for the duration of a trial (5 sec) or until the animal responded, whichever occurred first. During determination of the psychometric functions, however, the tone always went off before the animal responded. If the animal did not respond within 5 sec, then it had to turn the auditory stimulus on again, but in fact this happened only about once per 1000 trials.

Psychometric functions. The psychometric functions reported here were obtained after 22 sessions by Rat X1 and after five sessions by Rat Y2. For most of the preliminary work with Rat X1 the tone was added to the noise in accordance with a Gellermann series. But after thousands of rapidly recurring trials, sequential dependencies within the series allowed the animal to make about 60% correct responses even when the tone was turned off an effect also reported by Terman (1970). The psychometric functions reported here were therefore obtained with the tone added to the noise in a random sequence determined, without restriction, by the probability generator.

One psychometric function, at a particular duration, was obtained per session. Each session began with 600 preliminary trials with the largest energy-to-noise ratio. The next 200 observations were recorded to obtain an estimate of detection at that level. Then, without interrupting the session, the level of the tone was reduced by 3 db and the next 200 trials recorded, and so on. (Occasionally, more than 200 trials were recorded owing to the experimenter's momentary absence.) Five psychometric functions were obtained: first for 600 msec, and then for 300 msec, 150 msec, and 75 msec in that order, and finally for 600 msec again.

Brain stimulation. The reinforcer was a 0.5-sec train of rectangular pulses of alternating polarity with a pulse width of 0.2 msec and a repetition rate of 100 per sec. They were delivered by a constant current source, with a peak current of 0.20 mA for Rat X1 and 0.24 mA for Rat Y2. Previous work on visual and auditory discrimination (Terman and Kling, 1968; Terman, 1968) suggests that electrical stimulation in the area of the posterior hypothalamus does not produce different discriminative performance from reinforcement with food.

RESULTS

Figure 1 shows the psychometric functions of both rats for each stimulus duration. The ordinate shows the percentage of trials on which a response was correct, and the abscissa shows the energy in the tone relative to the power per cycle of the noise. Each point is based on at least 200 observations, and the line joins the medians. For Rat X1 the percentage of correct responses rises from near-chance to near-perfect detection over the 18-db range of E/N_0 . The slope of Rat Y2's function is shallower and rises to 85% correct at the highest energy level studied. The decibel level of E/N_0 needed to maintain 75% correct responses is about 36 for Rat X1 and 41 for Rat Y2.

The filled circles in Fig. 1 show a second psychometric function for 600 msec obtained after the functions for each duration were collected. It was obtained to determine whether there had been any systematic change during the preceding four experimental sessions. There were no clear systematic differences on these two days. As another precaution, we disconnected the 8000-Hz source on the next day and gave each animal 600 trials in which only noise of 600-msec duration was presented. The animals were still rewarded on those occasions on which they pressed the "correct" key as determined by the program, even though the stimulus was always noise. Under these conditions Rat X1 made 49.7% correct responses and Rat Y2 made 51.2% correct.

When the energy in the tone was constant, the percentage of correct responses was virtually independent of the tone's duration. This can be seen in Fig. 2, where the abscissa shows the duration of the stimulus and the parameter is the relative energy in the tone. On these coordinates an animal detecting the energy in the tone would show a constant percentage of correct responses for a constant energy-level of the tone, regardless of duration. The data for both animals fit that description to a first approximation, as shown by the solid lines that connect points representing tones of constant energy, although there is a tendency for Rat X1 to achieve a higher percentage of correct responses at 75 msec than at other durations of the same energy.

Still another aspect of the data is shown in Fig. 2 by the dashed lines that join three sets of points representing tones of constant power.

Fig. 1. Percentage of correct responses as a function of the relative energy in the tone for each animal at each stimulus duration. The filled circles show a replication of the function for 600 msec after the other durations were obtained. Each point is based on at least 200 observations. The line joins the medians.

Fig. 2. Percentage of correct responses as a function of the duration of the stimulus with the relative energy in the tone as a parameter. The solid lines join points representing tones of equal energy, and the dashed lines join three of the sets of points that correspond to tones of equal power.

For a given energy, the power in the tone varies inversely with its duration. Here it can be seen that the detectability of a tone of constant power increases with the tone's duration, at least from 75 to 600 msec. (For the sake of clarity we have joined points only for the three most widely separated values.)

Despite the symmetry of the consequences of the two responses, and despite the similarity of the nature of each response, biases were sometimes observed for one response over the other. One way of illustrating this is shown in Fig. 3 where the extent to which a rat favored one key over the other is shown as a function of the relative energy in the tone. The ordinate shows the ratio of the percentage of times the right-hand key was pressed to the percentage of times the tone was presented. A ratio of one represents no preference for one response over the other; ratios greater than one represent a bias in favor of the right key, and ratios less than one represent a bias in favor of the left key. We have plotted this "position preference" as a ratio rather than as the simple percentage of responses to the right or left key because the probability generator rarely presented the tone exactly 50% of the trials. (The mean percentage of trials on which the tone was presented was 49.50 for the 64 points that constitute the psychometric functions. The standard deviation of these percentages was 3.85, where the standard deviation on the basis of the binomial formula for 200 observations with $p = 0.5$ is 3.54.)

These points show that position preferences increased as the signal level decreased. Rat X1 preferred, on the whole, the left key and Rat Y2 the right key. The spread of the points at low levels shows that the preferences were unstable from day to day: sometimes when the tone was barely detectable there would be no preference for either key, and sometimes there would be a substantial one. Position preferences were more pronounced at low stimulus levels partly because more errors were made at low levels, and an animal can exhibit a preference for one key over the other only when it is making errors. If an animal were to make no errors, then the percentage of times it went to each key would be governed by the percentage of times the tone was presented.

Another way of illustrating biases for one key over the other is to plot the percentage of "hits" (the percentage of trials on which the

right-hand key was pressed when the tone was present) against the percentage of "false alarms" (the percentage of trials on which the right-hand key was pressed when the noise alone was present). Figure 4 shows two such plots for each animal; these plots are for the two sessions in which the duration was 600 msec, and conveniently illustrate the extremes of the biases obtained. Each point is for a different energy value of the tone and is based on at least 200 observations. The points lie between the upper left-hand corner, which corresponds to 100% correct, and the major diagonal, which corresponds to 50% correct. Points that lie along the minor diagonal represent no bias in the sense that the two possible kinds of error, false alarms and misses (pressing the left-hand key when the tone was present), are equally likely. If bias is defined as a tendency to make one kind of error rather than another, then a constant bias can be seen independently of detectability as a constant angular departure from the minor diagonal. The dashed line, for example, illustrates a bias of misses over false alarms of 5:1.

Figure 4 shows that on the first occasion, Rat X1 favored the left key and so made fewer false alarms than misses. On the second run this bias was virtually abolished. Rat Y2 showed little bias until the tone became difficult to detect, when the bias went in opposite directions on the two days illustrated.

DISCUSSION

The principal shortcoming of the yes-no procedure for studying human sensory processes is the bias in responding that easily develops with the method. Figures 3 and 4 show that the present rats had biases, even though both responses were similar, and even though the consequences of each were symmetrical. Our definition of bias (an unequal number of false alarms and misses) means that bias is exhibited by pressing one key more than the other, especially when errors are frequent. This definition is intuitively reasonable when reinforcement is equally probable at each key.

No simple description of the nature of the biases illustrated in Fig. 4 occurs to us. If the points followed a straight line from the upper-left corner to the major diagonal, as they did in Terman's (1970) study of the rat's differential threshold for sound pressure, then false

Fig. 3. The ratio of the percentage of times the right-hand key was pressed to the percentage of times the tone was presented as a function of the relative energy in the tone. Ratios greater than one indicate a position preference for the right-hand key, and ratios less than one a position preference for the left-hand key.

Fig. 4. Percentage of hits *versus* percentage of false alarms for the two psychometric functions obtained with 600-msec stimuli. Each point is based on at least 200 observations and is for one energy-value of the tone. The minor diagonal is the locus of points with equal misses and false alarms; the dashed line is the locus of points with misses and false alarms standing in a constant ratio of 5:1.

alarms and misses would always stand in a constant ratio. The points for the first session of Rat X1 are almost parallel to the ordinate, and so represent a tendency to keep the proportion of false alarms constant. This is like satisfying the Neyman-Pearson objective of statistical design (*cf.* Green and Swets, 1966, p. 23 *ff.*).

On the second run of Rat Y2 the bias became greater as the tone became more difficult to detect. Hence, the increased position preference at low energy levels for this run, shown in Fig. 3, is not solely the result of a constant bias contributing more to position preference as errors increased, but is the result, in addition, of a bias that became greater as the tone became less detectable. This effect, and its consequent position preference, is not inconsistent with the notion that the rat maximizes the probability of reinforcement per response, or the density of reinforcements per session. A detected tone, for example, is a discriminative stimulus for the reinforcement of pressing the right-hand key, and an animal that distributed its responses according to the discriminative stimuli would thereby maximize the density of reinforcements. In other words, bias would reduce the density of reinforcements per session. At the other extreme, if the tone were never presented, but responses to each key were rein-

forced randomly and equally, then the distribution of responses between the keys would have no effect on the density of reinforcements per session. Under these conditions biases are perhaps to be expected, despite the symmetry of the experiment. At intermediate levels of detectability both processes presumably combine to produce intermediate degrees of bias.

We have described the detection-behavior of the rats by the quantity "per cent correct responses," even though biases occurred in responding. Signal detection theory has suggested dimensions, like d' , that measure sensitivity independent of bias, but we have eschewed their use here because we have no evidence on the theoretical relationships implied by them. A measure of sensitivity independent of assumptions about the distribution of sensory events can be obtained from the yes-no method. Green and Swets (1966) proved that the area under the receiver operating characteristic is such a measure. But obtaining this curve, which shows how hits and false alarms covary for a constant stimulus level, requires the manipulation of response bias. Our own objective was to minimize bias in an effort to obtain an equally good measure of sensitivity, namely, the percentage of correct responses from an unbiased animal. We were not altogether successful in achieving this aim, and we

assume that the biases obtained will depress the percentage of correct responses.

The effects of bias on percentage correct can be determined if a bias-free estimate of sensitivity is available. Suppose that d' is such a measure, and suppose the ratio of misses to false alarms is 5:1, which is about the upper limit of bias observed in the present experiment, as illustrated by the dashed line in Fig. 4. Calculation shows that percentage correct is depressed at most by 4% with this degree of bias. For example, if 70% correct is obtained with an equal number of false alarms and misses (30% of each), then $d' = 1.05$ according to Elliott's table in Swets (1964). If a subject's sensitivity remained unchanged at $d' = 1.05$ but his misses exceeded false alarms by a little over 5:1, then tables of d' show that this is achieved by 43% hits and 89% correct rejections (or 57% misses and 11% false alarms) yielding 66% correct responses, a decline of 4%. The effect of bias on per cent correct is greatest at intermediate levels of detectability and diminishes to zero at the limiting cases of 100% and 50% correct. On the assumption that sensitivity can be measured by d' , then, the bias in the present experiment depressed per cent correct by a small amount.

Given this reservation, the psychometric functions for both animals are considerably less steep than comparable ones for humans detecting brief tones (Green and Swets, 1966, Fig. 7-5). The functions have about the same slope, however, as the example reported by Gourevitch and Hack (1966) of a rat detecting a tone of 1.2-sec duration. The power of the tone relative to the power per cycle of the noise needed to maintain 75% correct responses at 600 msec is about 40 db for Rat X1 and 43 db for Rat Y2. These values exceed the average value of about 35 db, determined by a tracking method, found by Gourevitch (1965) for rats detecting an 8000-Hz tone of indefinite duration in wideband noise.

The range of durations, from 75 to 600 msec, over which the energy of the tone seemed to govern detection for the present rats extends to somewhat longer durations than those found by Clack (1966) for the monkey, or Green, Birdsall, and Tanner (1957) for humans. Nevertheless, Green *et al.* did find that

detection of tones of constant power improved up to 3 sec, but at a lesser rate than in the region where detection varied with energy. We could not extend our durations much beyond 600 msec without introducing additional contingencies, because the rats would then respond before the stimulus was switched off. Nor could we reduce the durations below 75 msec with the available equipment. Both extensions would determine the temporal limits for which energy is the effective stimulus.

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