ANIMAL PSYCHOPHYSICS: IMPROVEMENTS IN THE TRACKING METHOD¹

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It is difficult to maintain stimulus control in animal psychophysical studies using the tracking method. Loss of stimulus control is characterized by wandering thresholds and responses in the absence of the stimulus. Rats were trained to make a variable number of licking responses to turn on an auditory stimulus. A response on a lever in the presence of the stimulus was reinforced with food. Two procedures were added to improve stimulus control. First, lever responses in the absence of the stimulus raised the intensity of the stimulus at the next presentation; second, rate of reinforcement in the threshold region was maintained at about the same level as that in the suprathreshold region by reducing the number of licking responses required to turn on the stimulus. Using these two procedures, stimulus control was improved and maintained and reliable auditory intensity thresholds were obtained.

Various modifications of the tracking method, originally developed by Békésy (1947), have been widely used in animal psychophysical studies (Alder and Dalland, 1959; Blough, 1958; Gourevitch and Hack, 1966; Harrison, Abelson, and Fisher, 1960; Stebbins, Green, and Miller, 1966). The essentials of the method are as follows. A food-deprived organism is trained to respond on two manipulanda. Responses on one (A) turn on a stimulus. In the presence of the stimulus, a response on the second (B) is reinforced by food, turns off the stimulus, and initiates the intertrial interval. Responding on A may be arranged on an interval or ratio schedule. For measuring an absolute sensory threshold, each time a response on B is reinforced, the intensity of the stimulus on the next trial is decreased by a predetermined amount. If the animal fails to respond on B when the stimulus is on, the intensity of the stimulus on the next trial is increased by the same predetermined amount. If the animal remains under stimulus control it will maintain the stimulus in the threshold region.

The two responses may be incorporated in a single manipulandum, as used by Békésy

(1947) and Stebbins (1966). The essential difficulty with this method is that the animal can receive reinforcement either by remaining under stimulus control and responding appropriately or by coming under the control of the nonstimulus characteristics of the procedure (that is, being controlled by the schedule aspects of the procedure). In the simple case considered here, if the animal responds on A and occasionally switches to B, some responses on B will be reinforced because they will coincide with the stimulus being on, even if it is subthreshold.

The development of schedule control is encouraged by two factors. The fact that reinforcements may be obtained in the absence of stimulus control may drive the intensity of the stimulus progressively down until it is below the threshold value. Even if a few opportunities for reinforcement were missed and the stimulus intensity thereby increased, these increases may be insufficient to bring the stimulus back to suprathreshold values. Hence, the animal is working under conditions in which there is, effectively, no longer a stimulus present, requiring that reinforcement be obtained by working under control of the schedule. Secondly, in the threshold region, approximately half the stimuli will be subthreshold. This will effectively double the intertrial interval (or ratio), halve the rate of reinforcement, and, as we have found, weaken stimulus control.

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To overcome these difficulties, the basic procedure is usually elaborated to minimize schedule control while maximizing stimulus control. However, if conditions are made very unfavorable to obtaining reinforcement in the absence of the stimulus, responding in the threshold region may be disrupted (for example, the animal may simply cease responding). Some compromise procedure is usually found in which stimulus control can be maintained for either periods in a session or for some sessions, and results obtained in these periods or sessions are used for estimating threshold.

We are investigating the absolute auditory intensity threshold to bands of noise in the albino rat using the tracking method. The essential procedure outlined in the first paragraph of this paper was used, with standard procedures added to minimize schedule control and maximize stimulus control. In these additional procedures, a response on manipulandum B in the absence of a stimulus produced a timeout and reset the ratio counter (operated by responses on A). The stimulus was presented for only 2 sec. By these methods we have been able to measure thresholds, but a number of sessions have not been usable because stimulus control was judged to be unreliable. This results in wasted time because only a fraction of the data is used for threshold measurement. The difficulty of maintaining stimulus control in animal psychophysics is frequently referred to in the literature (for example, Blough, 1958; Elliott, 1967; Moody, Beecher, and Stebbins, 1974; Stebbins, 1970) and is certainly not unique to our experiments.

To overcome these difficulties we have improved the tracking procedure first by making the failure of stimulus control change the procedure to one favoring stimulus control; in this way, loss of stimulus control is self correcting. Second, the reinforcement density was maintained in the suprathreshold and threshold regions.

METHOD

Subjects

Three albino rats, 24 months old, had been used in prior threshold studies. Body weight was maintained at approximately 80% of free-feeding weight by limiting food intake.

Apparatus

A wire-mesh cage contained a drinking tube (attached to a drinkometer), a response lever, and a liquid food dispenser attached to one wall. Water was not delivered through the drinking tube, licking of the tube being simply one of the responses used in the procedure. The licking of a drinking tube was used because the low noise involved in licking was thought to interfere less with the auditory stimulus than would the click of a lever. The wire-mesh cage was placed in an aluminum chamber with a sound attenuation of approximately 40 dB. Placed in this chamber, and facing one wall was a loudspeaker (University, Sphericon) through which the stimulus could be presented. The speaker faced the wall to encourage production of a diffuse sound (noise band) throughout the chamber by reflections from the walls. A houselight was mounted above the wire-mesh cage. The aluminum chamber was placed in a separate room from the control and recording equipment.

The sound system consisted of a noise generator (Gerbrands, 901A), electronic switch (Gerbrands, 329C), a microvolter (General Radio, 1346), a variable bandpass filter (#5500), a wide band amplifier (DC10A), and a programmable recording attenuator (Gerbrands, E3262A). The output of the attenuator (which was connected to the speaker) was continually monitored by a cathode ray oscilloscope. The stimulus consisted of a noise band dropping off 10 dB per octave from the center frequency. Noise bands rather than tones were used for two reasons. First, the lack of standing waves makes calibration of the sound field easier than when tones are used. Second, when a chamber with reflecting walls is used, a diffuse sound field is produced that varies little in intensity from place to place in the animal's enclosure.

The intensity of the sound in the animal chamber (with the attenuator set at zero attenuation) was measured with a Brüel and Kjaer 0.25-in. microphone (Type 4136). The calibration of the microphone was checked from time to time using a Brüel and Kjaer pistonphone. The microphone was placed in the vicinity of the drinking tube for intensity measurements, but it was found that due to the reflections from the walls of the chamber the sound was of essentially equal intensity in

all parts of the animal enclosure. With this system, it was found that noise bands centered on frequencies between 2.5 kHz and 40 kHz could be obtained at intensities of at least 60 dB (reference 20 $\mu\text{N}/\text{m}^2$; with the attenuator set to zero attenuation).

Procedure

The basic schedule on which the animals were studied was derived from a number of prior experiments aimed at finding a procedure suitable for measuring intensity thresholds. Licking the drinking tube (response A) turned on the stimulus on a variable ratio (typically 15 to 1). The stimulus remained on for a limited-hold period of 2 sec. A response on the lever (response B) during this period was reinforced by access to 0.2 cc of a 1:2 mixture of condensed milk and water. A response on the lever in the absence of the stimulus reset the ratio counter to zero and introduced a timeout of 20 sec. During the timeout the houselight was extinguished. Responses during the timeout did not advance the ratio counter and were without any other consequences. A response on the lever in the presence of the stimulus operated the attenuator and decreased the intensity of the following stimulus by 5 dB. A failure to respond on the lever in the presence of the stimulus operated the attenuator and raised the next presentation of the stimulus by 5 dB. These operations of the attenuator were used in estimating the threshold.

The loss of stimulus control in this procedure is characterized by the occurrence of lever presses in the absence of the stimulus. It is these responses that were used in the self-correcting procedure, the attenuator being operated and the stimulus intensity raised 5 dB by these responses. Thus, the occurrence of extra responses brought the stimulus back to suprathreshold values, making conditions favorable for the maintenance of stimulus control. Since the animal occasionally makes a lever response in the absence of the stimulus, even between presentations of suprathreshold values of the stimulus, only every second lever press in the absence of the stimulus raised the attenuator by 5 dB. Increases in the intensity of the signal produced by these lever presses (which were dependent on schedule control) were distinguished from increases produced by a failure to respond when the stimulus was on,

and they were not used for threshold estimation. The rate of reinforcement in the threshold region was maintained at approximately that in the suprathreshold region as follows. If the animal failed to respond in the presence of the stimulus, the normal variable-ratio schedule was changed to a VR 2. Thus, a missed stimulus was almost immediately followed by a second stimulus, 5 dB higher than the one just missed.

Relay programming equipment (Grason-Stadler) was used. The animals were studied in daily sessions of 40 reinforcements each. At the beginning of each session, the attenuator was set to zero and the intensity of the signal checked. In this way, the animal was exposed to suprathreshold stimuli for the first few trials of the session until it had stepped the attenuator down to the threshold region. This also favored the maintenance of stimulus control.

RESULTS AND DISCUSSION

The three animals used in this experiment had given the least satisfactory performance in prior threshold experiments with a larger group of animals. Any improvements in behavior produced by the added procedures should be readily detectable by using such animals. The effect of introducing the self-correcting and constant-reinforcement-rate procedures on the performance of RT 25 is shown in Figure 1. This animal had been used for about one year before these procedures were introduced and only about 10% of the sessions had proved suitable for obtaining thresholds.

The performance of RT 25 on the second day after the self-correcting procedure was introduced is shown in Figure 1A. Stimulus control was maintained at the beginning of the session until the attenuator was reduced by about 43 dB. At this point, loss of stimulus control is apparent, the attenuator varying over a wide range during the session ("threshold wandering", Blough, 1958) with the animal giving many lever presses (indicated by a dot on the record) in the absence of the stimulus. A threshold cannot be calculated from such a record.

The twelfth session is shown in Figure 1B. The number of lever presses in the absence of stimuli has decreased and the number of stim-

Fig. 1. Attenuator records of RT 25 selected to show changes in behavior during the course of the experiment. A. Second session. The intensity of the stimulus covered a wide range of values and virtually all the increases in intensity of the stimulus were due to lever presses in the absence of the stimulus. B. Twelfth session. The intensity varied over a narrower range and there was an increase in the number of intensity increases produced by the animal not responding during the presentation of the stimulus. C. Twenty-fourth session. Note the stable value of the threshold and the small number of intensity increases produced by responding on the lever in the absence of the stimulus. Dots on the record indicate increases in intensity produced by lever presses in the absence of the stimulus. The time scale is 4 min.

uli not responded to has increased. The level of the attenuator wandered less than in the second session, and a threshold was calculated from this record. While performance was improved in comparison with the second session, such behavior is of marginal value in calculating thresholds.

Performance of the animal on the twenty-fourth session is shown in Figure 1C. The threshold is stable and the record shows less variability than that shown by Gourevitch (1970, his Figure 12) for a comparable threshold procedure.

Animal RT 27 showed a greater improvement than RT 25, and RT 26 showed less improvement, but even the behavior of the latter animal was suitable for calculating thresholds.

A second way of showing improvement in threshold behavior is shown in Figure 2. This figure shows the progressive increase in the number of stimuli not responded to (the data used in calculating thresholds) over sessions. RT 27 showed a large increase in these stimuli

on the ninth session after the self-correcting procedure was introduced. RT 25 shows a steady increase of these stimuli after the tenth session. RT 26 shows a slower increase than the other two animals after about the tenth session.

A third way of showing improvement in stimulus control is shown in Figure 3. Plotted in this figure are the number of lever presses in the absence of the stimulus for each session for a typical rat (RT 25). RT 25 shows a steady decline in the number of these responses. All these data clearly show that the two procedures added to the basic threshold schedule improve and maintain stimulus control in the threshold region. Furthermore, the addition of these procedures renders many more sessions useful for the calculation of thresholds.

The absolute intensity threshold functions generated by the three animals are shown in Figure 4. Results from two of Gourevitch's rats are also plotted in the figure for comparison. The maximum sensitivity of RT 25 is within 5 dB of the maximum sensitivity of the

Fig. 2. The number of stimulus presentations not responded to as a function of sessions for RT 25, RT 26, and RT 27.

least sensitive of the functions obtained by Gourevitch (1970, his Figure 14). RT 26 is within 3 dB of the most sensitive of the Gourevitch animals. Measurements were not made above 40 kHz, so the most sensitive point of RT 26 was not obtained. Thresholds were re-measured at five points (see Figure 4). Four of the re-measured thresholds were within 1 dB of the original measurements. One was within 3.5 dB and one was within 2 dB of the originals.

The threshold function for RT 27 suggests that this animal has a hearing defect. This animal generated extremely reliable thresholds, an example of a record is shown in Figure 5, and there is no reason for thinking that the function is the product of faulty performance on the threshold schedule. Stimulus control was clearly demonstrated in this animal by increasing the signal by 20 dB approximately one quarter of the way through the

session. The animal's behavior changed appropriately.

Our data are based on noise bands falling off 10 dB per octave either side of the center frequency, whereas the data of Gourevitch are based on pure tones. One effect of using noise bands is to lower the threshold at a given frequency in regions of the function where the change of sensitivity is greater than 10 dB per octave. The change of sensitivity between 32 kHz and 40 kHz is greater than 20 dB per octave, as is the change between 40 kHz and 50 kHz. Thus, the thresholds at 32 kHz and 50 kHz would be expected to be lower than those for pure tones. The differences in sensitivity at the lower frequencies between RT 25 and RT 26 and Gourevitch's data may be due to strain differences or to a greater sensitivity to noise than to pure tones. The differences in threshold below about 28 kHz between our animals and those measured by

Fig. 3. The number of lever presses in the absence of the stimulus as a function of sessions (RT 25).

Fig. 4. Absolute intensity thresholds to bands of noise as a function of the center frequency of the noise band. The noise bands fell off approximately 10 dB per octave from the center frequency (measured fall-off in the animal's chamber). Thresholds were measured twice at some frequencies and these results are indicated by the appropriate symbols above or below the line. Data from two of Gourevitch's animals are shown in dashed lines and indicated by G. Gourevitch measured thresholds using pure tones.

Table 1

Day-to-day variability in thresholds (dB SPL) of one rat (RT 26). Thresholds are listed in the order measured.

Session	Frequency					
	16 kHz	32 kHz	4 kHz	8 kHz	40 kHz	1.5 kHz
1	12.16	8.65	18.34	17.02	7.34	26.82
2	9.99	9.37	17.77	15.7	4.12	26.99
3		7.25	13.67	12.0	6.53	27.06
4			19.34

Fig. 5. Attenuator record of RT 27, eleventh session. At the beginning of the session the stimulus was decreased 20 dB from its normal value. At the arrow, it was restored to its normal value. The behavior of the animal changed appropriately. Dots indicate increases in intensity of the stimulus produced by lever presses in the absence of the stimulus.

Gourevitch cannot be due to unwanted harmonics in the lower-frequency signals. The sound produced in the animal's enclosure by the bands of noise was investigated using a Brüel and Kjaer condenser microphone, the output of which was fed through a filter having a 24 dB per octave bandwidth. No spurious upper frequencies were found. We were also unable to detect any artifacts in our signal that were correlated with the onset of the stimulus.

The day-to-day variability of thresholds for a typical rat (RT 26) is given in Table 1. This variability is similar to that shown by Gourevitch (1970, his Figure 13).

These data show that reliable thresholds can be generated by the schedule investigated in this experiment and that stimulus control is maintained over many sessions of testing.

REFERENCES

- Adler, H. E. and Dalland, J. I. Spectral thresholds in the starling (*Sturnus vulgaris*). *Journal of Comparative and Physiological Psychology*, 1959, **52**, 438-445.
- Békésy, G. V. A new audiometer. *Acta Otolaryngologica*, 1947, **35**, 411-422.
- Blough, D. S. A method for obtaining psychophysical thresholds in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1958, **1**, 31-44.
- Elliott, D. N. Effect of peripheral lesions on acuity and discrimination in animals. In A. B. Graham (Ed.), *Sensoryneural hearing processes and disorders*. Boston: Little, Brown and Company, 1967. Pp. 179-189.
- Gourevitch, G. and Hack, M. H. Audibility in the rat. *Journal of Comparative and Physiological Psychology*, 1966, **62**, 289-291.
- Gourevitch, G. Detectability of tones in quiet and in noise by rats and monkeys. In W. C. Stebbins (Ed.), *Animal psychophysics*. New York: Appleton-Century-Crofts, 1970. Pp. 41-66.
- Harrison, J. M., Abelson, R., and Fisher, G. Some relations between the auditory system of the medulla and auditory-stimulus functions. *Journal of the Experimental Analysis of Behavior*, 1960, **3**, 207-220.
- Moody, D. B., Beecher, M. D., and Stebbins, W. C. Behavioral methods in auditory research. In C. Smith and J. Vernon (Eds.), *Handbook of auditory and vestibular research methods*. Springfield, Ill.; Charles C Thomas, 1974. *In press*.
- Stebbins, W. C. Auditory reaction time and the derivation of equal loudness contours for the monkey. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 135-146.
- Stebbins, W. C. Studies of hearing and hearing loss in the monkey. In W. C. Stebbins (Ed.), *Animal psychophysics*. New York: Appleton-Century-Crofts, 1970. Pp. 41-66.
- Stebbins, W. C., Green, S., and Miller, F. L. Auditory sensitivity of the monkey. *Science*, 1966, **153**, 1646-1647.

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