BEHAVIORAL DISCRIMINATION OF CLICK INTENSITY IN CAT¹

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Avoidance conditioning procedures were used to train cats to discriminate intensity differences between successive clicks. The discriminative behavior was applied in a modified method of adjustment to determine a difference limen (DL) for click intensity. The obtained DLs were consistent within and between subjects, and averaged 4.4 db. This value is greater than previously reported intensity DLs for pure tones in cats.

Neurophysiological studies involving chronic and acute macroelectrode recordings from the auditory pathway have made extensive use of clicks as the form of acoustic stimulation. As a result, there has accumulated during the past 25 yr, an enormous amount of research literature describing the neurological events associated with a click stimulus.

With such a large background of neurological data, a corresponding body of research concerning the behavioral discrimination of clicks might be expected, but this is not the case. With the exception of Zwislocki, Hellman, and Verrillo (1962), who described the effects of pulse repetition, duration, and number on the threshold of audibility, and Saunders and Hertzler (1968), who described the click intensity difference limen (DL) in humans, information concerning the psychophysical parameters of the click is lacking. Because a great proportion of the neurophysiological literature concerning click-evoked activity in the auditory pathway has been derived from the cat, an estimate of the behavioral discrimination of click intensity, in this species, may provide useful information for interpreting the neural events. The present study describes the intensity DL, for a click stimulus of moderate loudness, in the cat.

METHOD

Subjects

One female (J-21) and three male (J-26, 34, 36) adult cats, each weighing about 3.2 kg, served. The external meatus of both ears in all subjects were free of wax occlusions and post-experimental analysis yielded no indica-

tion of middle ear infection. At the start of the experiment, none of the cats had prior experience with the click stimulus. Four months before training began, each cat had electrodes chronically implanted in the left cochlear nucleus and on the dura over the right auditory cortex. During the time that training and testing occurred, all subjects were in excellent health and received no medication for the implant. It is assumed that the presence of these electrodes had little effect on the binaural discrimination of click intensity. The purpose of these implants is described elsewhere (Saunders, 1969).

Stimulus Conditions

The timing controls on a Tektronix 162 waveform generator were set to produce a sawtooth signal every 800 msec. This signal was used to trigger two Tektronix 161 pulse generators. The delay control on one pulse generator was adjusted so that a square wave pulse output occurred 40 msec after the onset of the sawtooth. In a similar manner, an output signal from the second pulse generator was delayed 440 msec. The pulse amplitude from each channel was controlled by attenuators connected in series with each pulse generator. The pulses on each channel were electrically combined in a homemade mixer, amplified by a McKintosh MC-40 amplifier, and converted to clicks with a Jenson Duax

¹This research was supported by NIMH, Public Health service and Higgins funds to Dr. E. G. Wever, Department of Psychology, Princeton University. Reprints may be obtained from the author, Department of Psychology, Monash University, Clayton, Victoria, Australia.

Fig. 1. The apparatus arrangement for producing two independent trains of alternately occurring clicks. The top part of the figure depicts the two forms of stimulus conditions.

8-in. speaker. In this manner, two trains of alternately occurring clicks were produced and their intensity could be independently controlled. The interval between successive clicks was held constant and continually monitored with a Hewlett Packard (5233L) interval counter. Figure 1 illustrates the apparatus arrangement.

A pulse duration was empirically determined from the waveform of the acoustic response and, in large part, depended on the resonant characteristics of the speaker. A Brüel and Kjaer 0.25-in. microphone was located 22 in. below the speaker and the click response detected by the microphone was amplified and displayed on a Tektronix 531 oscilloscope. The pulse duration control on each pulse generator was adjusted until the waveform of the click exhibited a single, high amplitude spike with a minimum number of low amplitude ringing components. The optimal click response for the Jensen speaker occurred at a pulse duration of 0.075 msec. The primary biphasic spike of the click lasted for 0.7 msec and the low amplitude ringing components continued for 2.5 msec. The highest amplitude ringing component was approximately 22 db below the peak-to-peak amplitude of the primary component. The controls on each pulse generator were carefully adjusted so that the waveshape and amplitude of their

respective acoustic responses were identical for similar attenuator settings. The intensity of the click was calibrated by converting the peak-to-peak acoustic response, detected by the microphone, to db re 1 dyne/cm². Free-field calibration was accomplished for 10 positions in the test cage, within the vicinity of the cat's head.

Two patterns of clicks were employed (see Fig. 1). The first was a series of constant intensity clicks (−30 db re 1 dyne/cm²) that always occurred in the testing environment. This condition was referred to as the background stimulus. The second pattern was the discriminative stimulus (DS) and occurred when the intensity of alternate clicks were increased. The louder of the clicks was designated C_1 while the other, of constant intensity, was C_2 . The DS consisted of 18 pairs of C_1 and C_2 and lasted 14.4 sec. The onset of the DS was controlled by a set of relay contacts that switched the output from one pulse generator through a third attenuator (see Fig. 1). This attenuator was initially adjusted to increase the pulse amplitude and hence the click intensity by 20 db. As the subject performed the discrimination task, the intensity difference (ΔI), in db, between C_1 and C_2 was systematically varied by changing the levels on the third attenuator. Careful calibration of the acoustic responses insured that click intensity

was equal for DS or background stimulus conditions when all three attenuators were set to equal levels. The relay controlling the DS was operated by a solid state (Digi-Bits) logic circuit that timed the DS duration, administered shock reinforcement, and recorded the number of correct and incorrect responses.

A Grason-Stadler shock generator (E6070B) was used to administer a scrambled shock reinforcer to the footpads of the cat as it stood on a gridfloor in the test cage. The intensity of the shock was empirically adjusted to the minimal level necessary to maintain avoidance behavior. This intensity never exceeded 2.0 ma. A conditioned reinforcer (red light) was located in the test cage and was always paired with the occurrence of shock.

Training Procedures

The procedures used to define the DL for click intensity were derived from the modified method of adjustment originally described by Békésy (1947). The Békésy method requires a subject continually to adjust stimulus conditions in order to track a sensory threshold over time. The present methods restructured the continuous threshold tracking procedure to a fixed trial procedure. The various phases for training the subjects to respond in the presence of the DS, and the application of this response to an intensity discrimination task, were adapted from methods originally described by Clack and Herman (1963).

All training and testing took place within a sound-proof booth. The cats performed the discrimination task in a wire mesh cage 20 in. by 7 in. by 14 in. (508 mm by 178 mm by 356 mm). The floor of the cage consisted of a series of horizontal brass rods 0.25-in. (6.3 mm) diameter and separated by 0.5 in. (13 mm). The grid floor was independent of the cage frame and rested on a pivot point that allowed it to rock 0.25 in. (6.3 mm) when depressed at either end. A tilt of the floor momentarily opened a set of switch contacts and constituted the response for a given situation. In the first phase, each cat was trained to avoid shock by making a tilt response within 14.4 sec after the onset of the DS. Failure to respond within this period of time resulted in a pairing of DS and shock which continued until the cat caused the floor to rock. The specific nature of the response for both avoidance and escape behaviors was movement over the pivot point

of the tilting grid floor. Due to the narrowness of the cage, the response, on successive trials, was effected by the cat as it moved either forward or backward over the pivot point. As avoidance performance improved, the nature of the tilt response changed. Extraneous motor activities gradually extinguished until the cat sat over the pivot point and made the response by simply leaning far enough forward or backward to rock the floor. The tilt floor procedure introduced a behavioral restraint that maintained the position of the auditory receptors within a controlled stimulus field. Typical measures of click intensity about the cat's head yielded a range no greater than 2.1 db. The specific nature of the rocking behavior, the apparatus employed, and the advantages it offers for auditory experiments have been detailed elsewhere (Saunders, 1968). The inter-trial interval (ITI) during Phase 1 was held constant at 50 sec and the cats were trained in daily, 30-trial sessions. Throughout training, the acoustic difference between C_1 and C_2 was fixed at 20 db. Phase 1 continued until each subject exhibited a performance criterion of two consecutive sessions with at least 90% avoidance responses. When criterion was achieved, the second phase began.

In Phase 2, a trial light (white) and non-discrimination trials were introduced. A discrimination trial occurred whenever the light was paired with the DS. The non-discrimination trial occurred when the light was paired with the background stimulus for 14.4 sec. The trial light thus served to distinguish discrimination and non-discrimination trials from the background stimulus. The two types of trials were presented in a random sequence and during a session each occurred approximately 50% of the time. During Phase 2, the inter-trial interval was shortened to 20 sec and the number of trials in a session was increased to 60 (30 discrimination, 30 non-discrimination). Subjects were trained to respond differentially to the two trial conditions. The cat could avoid shock by responding in the presence of the DS on a discrimination trial (correct avoidance) and by not responding during a non-discrimination trial. Conversely, failure to respond on a discrimination trial, within 14.4 sec, resulted in a pairing of DS and shock until a response occurred. A tilt during a non-discrimination trial was followed by a 0.5-sec shock and termination of the trial (false posi-

tive). The training in this phase progressed in daily sessions until each subject exhibited a performance criterion of two consecutive sessions of at least 90% correct avoidance responses and less than 10% false positive responses. When this level of differential performance was achieved the next phase was introduced.

The sequences in Phase 3 were identical to those described in Phase 2, except that stimulus conditions were systematically modified and the reinforcement schedule was altered for threshold level performance. Whenever the cat responded correctly during a discrimination trial, the acoustic difference between C_1 and C_2 was reduced by 2.0 db on the next discrimination trial. A non-avoidance response resulted in a 2.0-db increase in ΔI on the next discrimination trial. The difference between C_1 and C_2 remained unchanged if a false positive response occurred. In this way, the cat effectively tracked its discrimination threshold over a number of trials.

To control performance in the threshold region, the reinforcement schedule was modified so that the subjects would not be shocked for subliminal conditions. This was accomplished by using a procedure similar to that employed by Clack and Herman (1963). Reinforcement was placed on a ratio schedule such that three successive non-avoidance trials had to occur before a shock was delivered. The shock contingency, however, was structured so that each correct avoidance response subtracted one from the sum of non-avoidance trials needed to complete the 3:1 ratio. Thus, any sequence of three non-avoidance responses that increased ΔI by 6.0 db would result in

Fig. 2. The acquisition rate in all four subjects.

Fig. 3. The differential threshold for consecutive threshold tracking sessions.

the administration of shock for all subsequent incorrect behaviors at higher levels of ΔI . During a tracking session, the ratio always began from the lowest level of ΔI . The conditioned reinforcer (red light) continued to indicate incorrect responses while the shock was off, and helped to retard extinction when the animal performed at threshold.

Threshold sessions typically lasted 50 trials or about 25 to 35 min. The testing in Phase 3 continued until each subject exhibited a stable DL for 10 consecutive sessions.

RESULTS

Figure 2 illustrates the rate at which all subjects acquired the avoidance behavior. These results show that an average of 11 sessions or 330 trials was necessary before criterion performance for Phase 1 was achieved. As avoidance performance improved, the motor activity used to rock the grid floor systematically changed. When avoidance training was completed, the cat sat over the pivot point and tilted the floor by shifting its weight either forward or backward very quickly. The development of this behavior followed the same

progression as that described by Saunders (1968). Although response latency was not systematically recorded, there appeared to be a substantial number of trials where the latency was at least 10 sec. Long latency responses were observed throughout Phase 2 and 3.

Criterion performance for the second phase was quickly achieved, often within several training sessions. The ease with which the cats learned to respond on only discrimination trials was rather surprising. It appeared that once the avoidance behavior to the DS was firmly established, little, if any, stimulus generalization occurred to the trial light.

Unfortunately, the rapid acquisition of differential performance in Phase 2 was not reflected in the ability to track stable thresholds in the third phase. Figure 3 shows the average DL for all subjects on consecutive threshold sessions. These data indicate that stable threshold performance was not achieved until after Session 13. The exponential nature of the data plotted in Fig. 3 indicate that the cats quickly acclimated to the conditions of threshold tracking. However, sophisticated discrimination performance required a considerable degree of practice.

Figure 4 illustrates the performance of one cat during a typical threshold session. The ordinate shows the intensity difference (ΔI) and the abscissa represents consecutive discrimination trials. Every threshold session began with ΔI at 20 db and each track could be characterized by a series of correct discriminations early in the session.

Threshold level performance was indicated when the acoustic changes were relatively stable after many discrimination trials. The ses-

Fig. 4. A typical threshold track for one subject. The DL performance for all subjects is shown in the upper right-hand corner.

sion described in Fig. 4 indicates that J-26 reached threshold on the ninth discrimination trial. For the remaining 27 trials, its performance maintained ΔI within a 6.0-db range. The actual threshold for any session was determined from the mean intensity difference settings for the last 15 discrimination trials. Thus, the performance of J-26 produced a DL of 4.7 db. A threshold could be reliably predicted after as few as 12 to 18 discrimination trials. All subjects were capable of producing a DL track within 10 min and two exhibited reliable performance with the inter-trial interval as short as 9.0 sec.

The false positive (fp) responses that occurred during this particular threshold session are indicated in Fig. 4. These behaviors were observed only while the subject was performing in the region of threshold. The number of false positives on any threshold session rarely exceeded 1% of the total non-discrimination trials.

In the upper right-hand corner of Fig. 4 can be seen the average threshold performance for the last 12 sessions. The standard deviation (SD) is also shown. The DL within and between subjects exhibited considerable consistency.

Figure 5 shows the performance for all subjects when the percentage of correct responses, on all discrimination trials during the last 14 sessions, were plotted against each intensity difference level. The percentage of correct

Fig. 5. The DL determined from the percentage correct discriminations for all subjects.

responses increases rapidly between 2.0 and 8.0 db. For intensity differences at or greater than 10.0 db, performance never fell below the 90% level. Of the 127 trials at 2.0 db, only two correct discriminations were recorded. When the results are plotted in this fashion, the interval of uncertainty is clearly defined between 2.0 and 10.0 db. The differential threshold can be determined from Fig. 5 by noting the intensity difference that would cause the cats to respond on 50% of the discrimination trials. An extrapolation of ΔI from the 50% correct response level yields a DL of 4.4 db. This threshold compares favorably with the DLs computed for individual subjects during the last 12 threshold sessions.

DISCUSSION

In part, the small number of studies concerned with the psychophysics of click stimuli may stem from difficulties in determining the parameters of this cue. The present methods for specifying and calibrating the click are not presumed to represent a "perfect" procedure. It may be that a "standardized" click is impossible to specify. However, the techniques employed do provide a convenient guideline for specifying the click output from any transducer.

The behavioral procedures have proven successful for training cats to track a DL for click intensity. The reliability of the threshold measures within and between subjects suggest that the results represent a close approximation to the intensity DL for these stimulus conditions. However, it must be noted that the "yes-no" situation has been criticized on the grounds that it introduces a response bias that may obscure the "true" sensory threshold (Blough, 1966). Although it is likely that some level of response bias was operating in the present situation, the weight of this argument is reduced by the occurrence of false positive responses. A response bias would have elevated the threshold so that the cats were always responding to above threshold levels of the DS. Such a bias would reduce uncertainty over stimulus conditions and preclude the occurrence of false positive responses. The data, however, show that the cats did make false positive responses and that these behaviors occurred only at threshold levels of ΔI . Thus, the occurrence of false positive responses, al-

though infrequent, diminished the influence of a response bias and provided additional evidence that the cats were performing near or at their sensory threshold.

The average DL of 4.4 db, obtained at a loudness level of -30 db re 1 dyne/cm², is considerably greater than the noise DL (Miller, 1947) or 1.0 kHz DL (Riesz, 1929) in the human subject, at similar sensation levels. Saunders and Hertzler (1968) reported that the click intensity DL for human subjects, at a sensation level only 5.0 db less than that used in the present study, was 2.9 db. These authors also noted that the intensity DL for click stimuli, in the human, appears to be less sensitive than the intensity discrimination of either pure tones or noise. The click DL in cat, similarly, is greater than previously reported pure tone intensity DLs in this species (Dworkin, 1935, Rabb and Ades, 1946, Rosenzweig, 1946). Saunders and Hertzler (1968) noted that the transient nature of the click give it qualities that are considerably different from noise or pure tone stimuli. In particular, the sharp onset and offset of the click, has definite properties and the undesirable nature of these transients has been recognized and controlled for in many auditory experiments by the use of onset generators designed to eliminate this artifact. It appears that the click intensity DL is greater than the intensity DL for pure tones or noise and that this relationship also holds true for the cat. Moreover, previous data show that the ability of cats to discriminate pure tone intensity is less than that of man for similar stimuli. The present results extend this observation to the intensity discrimination of clicks.

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Received 9 January 1969.