

#### XIV. COMMUNICATIONS BIOPHYSICS

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#### A. RESPONSES AT THE AUDITORY CORTEX TO REPETITIVE ACOUSTIC STIMULI

Synchronous neural activity has been recorded from the whole auditory nerve in response to repeated stimuli presented at rates up to 2000 per second. However, cortical activity, recorded by gross electrodes, exhibits no visually detectable primary responses to individual stimuli at relatively low rates (approximately 100 per second), for several reasons:

1. As the repetition rate increases, the amplitude of response decreases (Fig. XIV-1).
2. The duration of the cortical response results in overlapping and interference of responses at the higher repetition rates.
3. As the responses become smaller, it becomes more difficult to detect them visually, since they are imbedded in ongoing activity. Although it is feasible to reduce the ongoing activity by the use of anesthesia, its possible effects upon the "following" of the evoked cortical responses necessitates the study of unanesthetized animals.

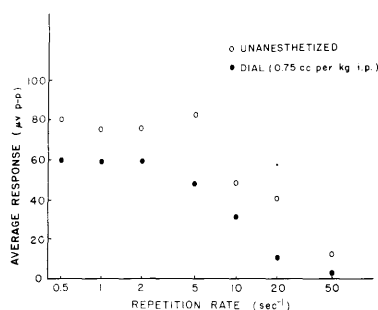


Fig. XIV-1. Peak-to-peak amplitudes of average responses from unanesthetized and anesthetized cats plotted against repetition rates for click stimuli. Steady-state responses are averaged for more than 2 minutes for each point. Intensity level of clicks, -62 db re 1 volt across the phone. (Cat 427: active electrode near posterior ectosylvian sulcus; indifferent lead on headholder.)

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CLICK RATE

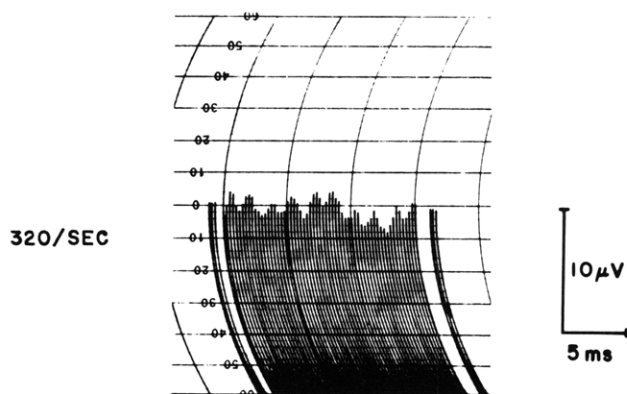
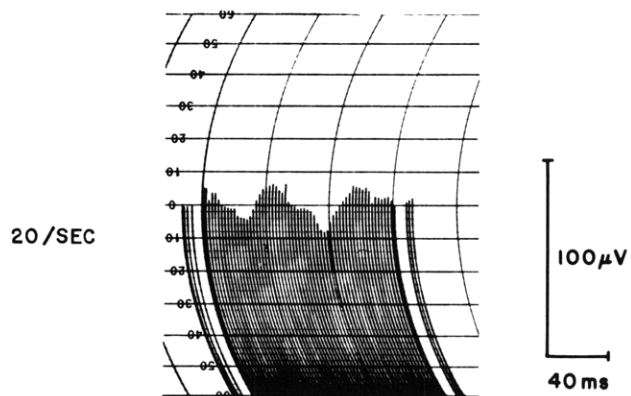
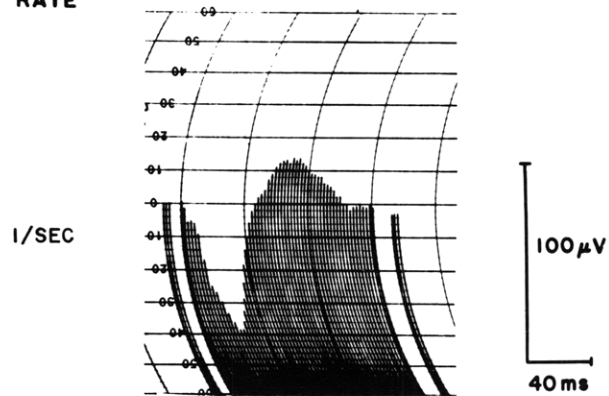


Fig. XIV-2. Averaged cortical responses from unanesthetized cat to clicks at different repetition rates. Stimulus intensity level, -62 db re 1 volt across phone. (Cat 430: active electrode near posterior ectosylvian sulcus; indifferent lead on headholder.)

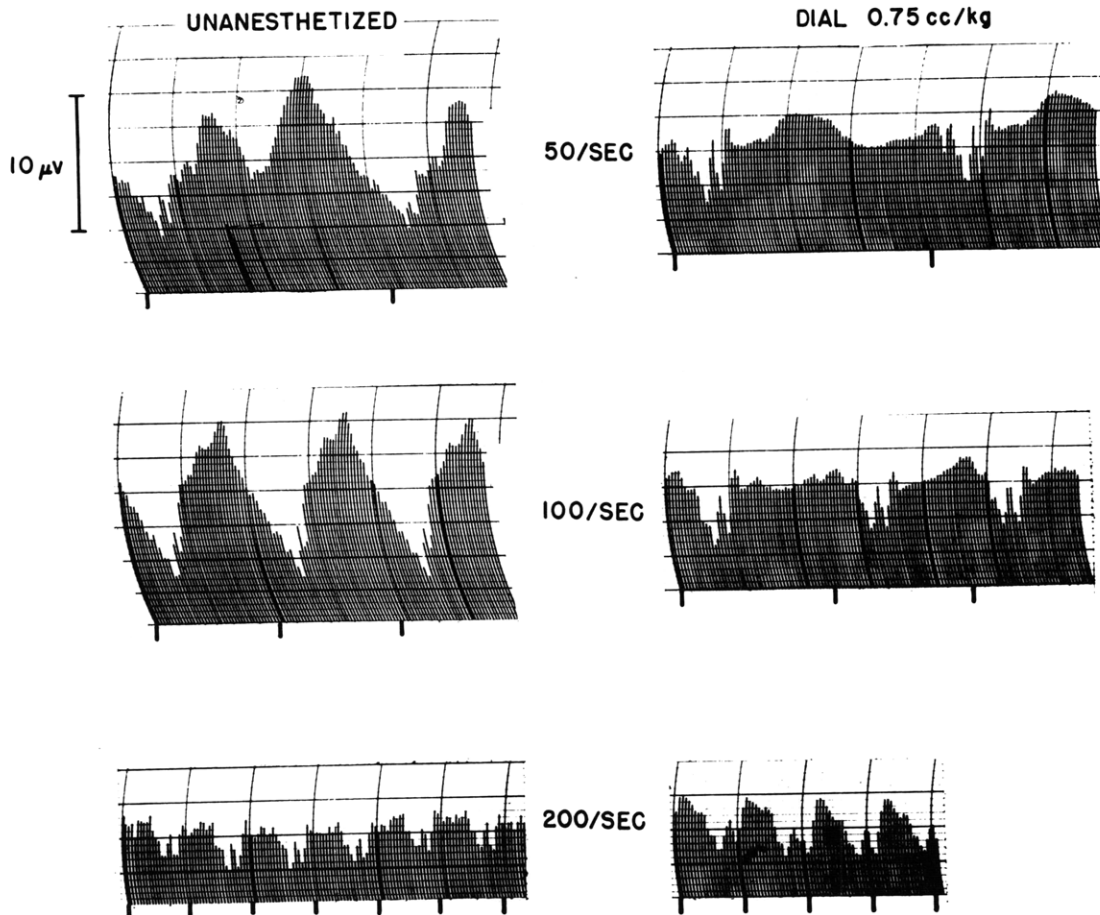


Fig. XIV-3. Averaged cortical responses to clicks delivered at various repetition rates under unanesthetized and anesthetized conditions. Markers under each record indicate the time at which clicks were presented. Stimulus intensity level, -62 db re 1 volt across phone. (Cat 427: active electrode near posterior ectosylvian sulcus; indifferent lead on headholder.)

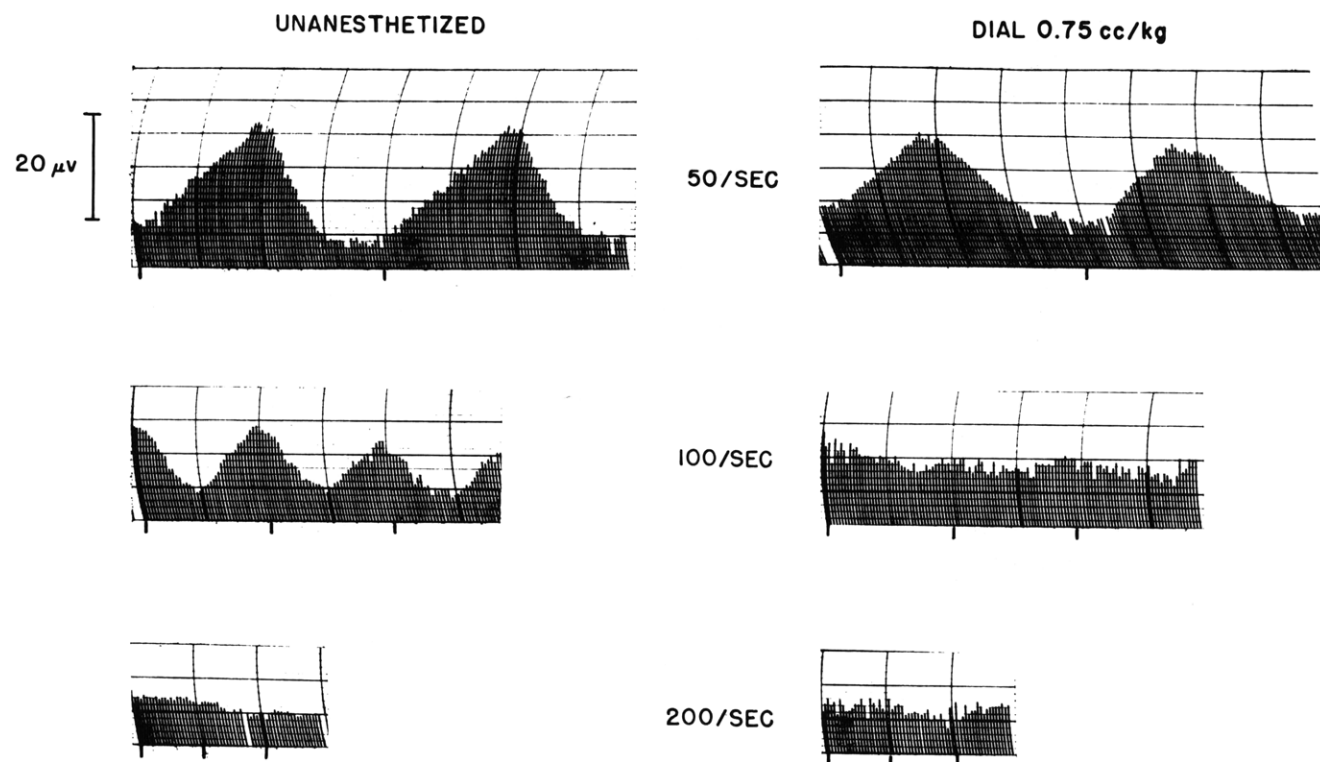


Fig. XIV-4. Averaged cortical responses to repeated bursts of noise as recorded by concentric electrodes. Stimulus intensity, -75 db re 1 volt rms across phone. (Cat 449: electrodes in middle ectosylvian gyrus.)

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In the present study, we have used both anesthetized and unanesthetized (encéphale isolé) cats. Responses were recorded on magnetic tape and processed by an electronic average-response computer (1, 2). By these means small responses are detectable in the presence of large ongoing activity.

Stimuli were delivered monaurally by a type PDR-10 earphone at intensity levels at which the auditory system is undoubtedly mechanically linear.

Figure XIV-2 shows electronically computed responses to clicks at rates of 1, 20, and 320 per second. The responses at the highest repetition rate are apparently not of cortical origin but result from spread from remote regions. These responses disappear when the recording electrodes are concentric: one electrode is 2 mm deep in the cortex, while the other is the sleeve resting on the surface of the cortex.

Figure XIV-3 shows responses recorded by a monopolar electrode to clicks delivered at rates of 50, 100, and 200 per second. Since the time scale has been expanded, the waveforms of the responses are more clearly outlined. At 200 clicks per second only activity of short duration remains in responses from both unanesthetized and anesthetized preparations. It is this type of activity, locked to the stimulus, that constitutes the responses to the 320 per second clicks shown in Fig. XIV-2; the concentric electrodes do not record this activity. In unanesthetized cats, but not in cats under Dial anesthesia, the concentric electrodes record synchronous activity in response to 100 clicks per second.

Similar results are obtained when bursts of noise, rather than clicks, are used as stimuli (Fig. XIV-4). With the concentric electrodes, synchronous responses are recorded when the stimuli are delivered at rates up to 200 per second in the unanesthetized animal, but only up to 100 per second in the anesthetized cat.

It is possible that at different stimulus intensities, the limits of synchronous following would occur at different repetition rates; however, the present experiments are confined to approximately 30 db above the threshold of the cat's electric responses. It should be noted that following, as recorded by gross electrodes, deals with averaged responses from many neurons. Such records do not necessarily imply that single units would follow at these rates.

In summary, at low intensity levels the auditory cortex of unanesthetized cats appears to follow stimulation by clicks and bursts of noise up to rates of 200 per second.

M. H. Goldstein, Jr., N. Y. S. Kiang

#### References

1. J. S. Barlow and M. A. B. Brazier, Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., April 15, 1955, p. 79.
2. J. S. Barlow and R. M. Brown, Technical Report 300, Research Laboratory of Electronics, M.I.T., July 14, 1955.

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B. A VERSATILE STIMULUS PROGRAMMING DEVICE

A wide-range time-delay generator for electrophysiological and psychoacoustic experimentation was designed and built. The device enables the experimenter to control the temporal spacing and the duration of stimuli. In each of these ranges the delay can be varied over a decade by means of a continuous control. In addition, the stimulus programming device will — after the occurrence of a prescribed delay — either initiate or terminate a stimulus the first time a reference waveform passes through a given amplitude in a given direction.

The stimulus programming device is composed of four "building blocks" that can be interconnected in whatever combinations the experimenter desires. One combination is shown in Fig. XIV-5. With the switch in the other position, the device must be externally triggered at the beginning of each cycle. When the equipment is first turned on, or after the cycle has been interrupted for any reason, points F, G, and H (and therefore K) will be at a dc potential of less than 150 volts, with the result that the initial-pulse generator initiates a rundown in delay generator I. Thereafter, unless operation

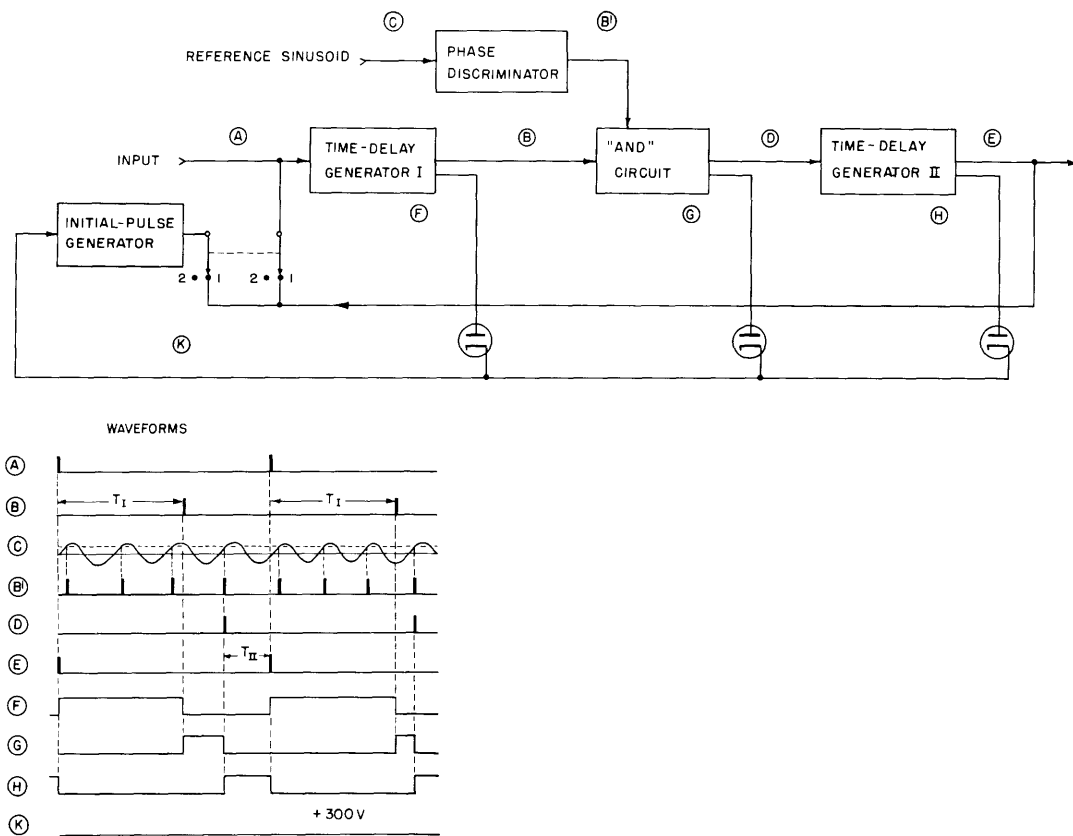


Fig. XIV-5. Block diagram of stimulus programming device.

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is interrupted, either F, G, or H will be at a potential of greater than 150 volts, and the initial-pulse generator will be effectively disconnected from the circuit. The "AND" circuit stores the information that the delay generated by the first time-delay generator has occurred until the reference sinusoid reaches the desired phase, and then triggers delay generator II. The output of the second delay generator re-initiates the cycle. (The outputs of the time-delay generator and the "AND" circuit are identical, so that either could have been used to trigger the second delay unit.) As many delay generators and phase discriminators as desired may be included in the loop, and both pulse and gate outputs are available.

The time-delay generator has 11 coarse ranges, with each range providing a decade of variation of output duration. Fine control is accomplished by means of a variable dc control voltage, which may be located many feet from the equipment. The time-delay generator is linear to higher than  $\pm 0.2$  per cent over the entire range, and exhibits less than 0.05 per cent jitter. A 10 per cent change in heater voltage produces a 0.1 per cent change in output duration. A 10 per cent change in plate-supply voltage also produces a 0.1 per cent change in output duration, but in the opposite direction, thereby making the performance of the delay generator extremely insensitive to line-voltage variations. The input of the delay unit must be greater than 10 volts in magnitude and have a rise time of less than 2  $\mu$ sec. A cathode-coupled phantastron is used to generate the time delays. Since the phantastron rise time is a function of the delay length, the output of the phantastron is used to trigger a Schmitt circuit whose output is differentiated, clipped, and shaped, and then fed to a cathode follower to provide uniform, low-impedance output pulses.

The phase discriminator has a flat response from 0.25 cps to 20 kc. The reference signal is first amplified 30 times in an ac amplifier, with 40 db of negative feedback and negligible phase shift over the operating range. By means of an attenuator, the output of the amplifier is set to 100 volts peak-to-peak, and this signal is impressed on one input of a difference amplifier. A control voltage on the other grid of the difference amplifier makes it possible to select any 5-volt "slice" of the 100-volt signal and amplify it at the plate of the difference amplifier. This amplified horizontal "slice" of the reference voltage is used to trigger a Schmitt circuit whose output is differentiated and used as an input of the "AND" circuit. The linearity of the circuit is better than  $\pm 1$  per cent over the entire range, and jitter is negligible. Short-term dc drift is minimized by putting both halves of the difference amplifier in the same envelope. Long-term drift is not troublesome, since neon indicators allow quick calibration without the use of meters or additional equipment.

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