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A. AMPLITUDE VARIABILITY OF N_1; COMPARISON WITH THE MODEL

As we previously reported (1), a probability model for the thresholds of peripheral auditory neurons, based on a two-population hypothesis, predicts a response variability function of the sort shown in Fig. XIII-1. We also reported that experimental agreement with this predicted function had been obtained over the range of the sensitive population, but that in the higher intensity range we obtained ambiguous results. Two additional experiments confirm this early report. The data are given in Fig. XIII-2. The range of the sensitive population is approximately -100 db to -60 db, as determined from the intensity function (1, 2). Variability is seen to be minimal at the ends of this range and maximal at about the center, as the model requires. The asymmetry in the function over this interval can be accounted for by assuming population overlap in the neighborhood of -60 db.

L. S. Frishkopf

References

1. Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., Oct. 15, 1954, pp. 87-94.

2. Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., Oct. 15, 1953, pp. 45-50.
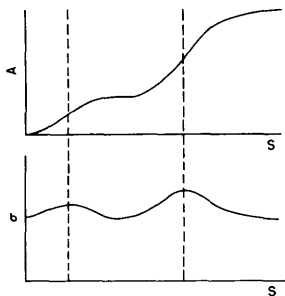
Fig. XIII-1

(a) A two-population intensity function, for disjoint population; (b) a corresponding variability function σ (S) of the kind predicted by the model.
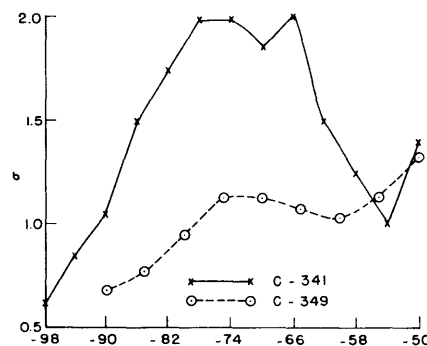

Fig. XIII-2

Variability as a function of stimulus intensity, for two experimental animals, over the range of the sensitive population.

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B. EVOKED RESPONSES TO CLICKS IN RELATION TO ON-GOING CORTICAL ACTIVITY

We have been studying, in anesthetized cats (dial-urethane), the interaction between on-going electrical activity recorded at the cortex and the specific cortical response evoked by an acoustic click presented once every four seconds.

For this purpose we have constructed:

1. A four-channel timing and gating circuit. This apparatus — working in conjunction with four oscilloscope channels and two sweep generators — provides two slow traces (300 msec) triggered approximately 250 msec before the click-stimulus and two fast traces (75 msec) triggered just before the click.

Since these times are adjustable, we can present a "long look" at the on-going activity, trigger our click stimulus at any chosen time in this long interval, and then observe the evoked response on both the slow and fast time bases. Two slow and two fast channels are available.

In addition, each channel is gated so that a short portion at the start and end of each trace records no signal; the scope input is grounded at these times. This reference line represents zero potential difference between our recording electrodes for frequencies within the passband of our physiological amplifiers (0.5 cps - 5 kc/sec), although not for other frequencies.

Figure XIII-3 presents a simplified timing diagram of two of the four channels. The fast sweep (e), 50-msec gate (f), and stimulus pulse (g) are all timed from the delayed trigger (d). We have explored activity after the evoked response (e.g., repetitive responses) by moving this trigger back to a point near the start of the slow sweep. However, in the present experiments, since we were interested in activity preceding the evoked response, the time relations were as shown in Fig. XIII-3.

2. A four-channel mixer. By mixing some of the electrical pulse delivered to the earphone with the physiological signals, we can mark the time of click stimulation on each of the four oscilloscope traces. (See Figs. XIII-4(a) and (b).)

Figures XIII-4(a) and (b) show potentials recorded from a monopolar electrode placed on the surface of the middle ectosylvian (in auditory area I). We have arbitrarily chosen the peak-to-peak amplitudes a_2 and a_3 as measures of evoked response amplitude.

We have confined our preliminary analyses to correlations between total on-going activity and evoked response amplitudes. As the measure of total on-going activity, we have selected the sum of the absolute instantaneous amplitudes (measured from our "zero potential" reference line) at 15-msec intervals before the start of the evoked response. Pearson correlation coefficients (r) were computed between this total activity measure (T) and both a_2 and a_3.

Results under three experimental conditions are summarized in Table I.

Table I

	Condition A (N = 49)		Condition B (N = 50)		Condition C (N = 50)	
	a_2	a_3	a_2	a_3	a_2	a_3
$\bar{m}$ (μv)	620	800	450	710	370	660
σ (μv)	92	88	170	260	130	250
r	-0.42	-0.43	-0.01	-0.04	-0.47	-0.49

Condition A: Deeply anesthetized cat (C-353) in which the low-frequency components of on-going activity were small. Passband, 0.5 cps to 5 kc/sec.

Condition B: Lightly anesthetized cat (C-354) with large low-frequency components of on-going activity. Passband, 0.5 cps to 5 kc/sec.

Condition C: The same 50 responses as in B except that the passband was 8 cps to 5 kc/sec. Most of the low-frequency components are attenuated.

N is the sample size; $\bar{m}$ is the mean amplitude; σ is the standard deviation; and r is the correlation between response amplitude and on-going activity. For a_2 and a_3, see text.

In Condition A, the low-frequency components of the on-going activity have been largely eliminated by deeply anesthetizing the animal and the correlations are significant ($p < 0.01$). In Condition B, these components are present and the correlations are essentially zero, while the identical activity, when filtered as in Condition C, shows highly significant correlations ($p < 0.01$). We may infer that the high-frequency on-going activity, as defined by the passbands of our amplifiers, is negatively correlated with the amplitude of the cortical response evoked by a click. Of note are the comparable correlations under Conditions A and C for both amplitude measures.

We hope to define, by further study, the actual cortical elements involved in this interaction.

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C. ANALOG CORRELATOR FOR ELECTROENCEPHALOGRAPHY

1. Measurements of Correlator Accuracy

A program was begun to determine the accuracy of the analog correlator (1, 2). Emphasis was placed on determination of the characteristics of the multiplier because it is the critical element of the system. The measurements made thus far have been concerned primarily with the accuracy with which a sinusoid can be squared. Because in normal operation of the correlator the multiplier is followed by an integrator, the multiplier output was filtered in the tests so that only the average value was observed. The differential input of a Tektronix Model-512 oscilloscope was used for null methods,
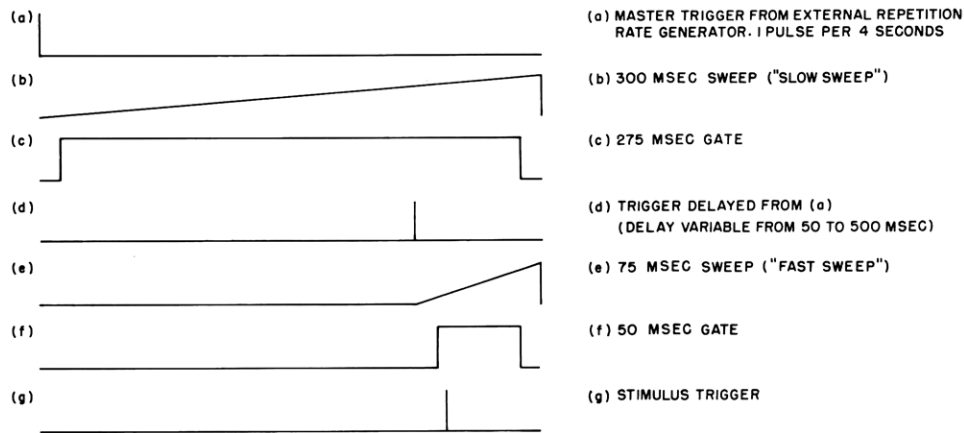
(a)

(b)   (b) 300 MSEC SWEEP ("SLOW SWEEP")

(c)   (c) 275 MSEC GATE

(d)   (d) TRIGGER DELAYED FROM (a)
         (DELAY VARIABLE FROM 50 TO 500 MSEC)

(e)   (e) 75 MSEC SWEEP ("FAST SWEEP")

(f)   (f) 50 MSEC GATE

(g)   (g) STIMULUS TRIGGER

Fig. XIII-3

Simplified timing diagram of one fast and one slow oscilloscope channel.

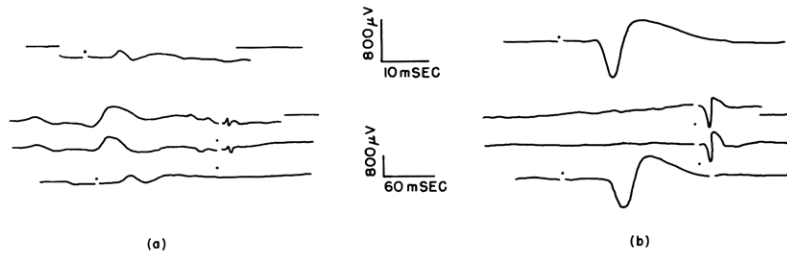800 μV   10 mSEC

800 μV   60 mSEC

(a)   (b)

Fig. XIII-4

(a) Selected oscillogram showing much on-going activity with small evoked response. Polarity: negative up.

Trace 1: Evoked response to click approximately 70 db above cat's "threshold." Trace 2: Same response as in trace 1 with longer record showing prior activity. Trace 3: Same response as in trace 2 but filtered at 8 cps highpass. Trace 4: Same response as in trace 1 but filtered at 8 cps highpass.

The time of click stimulation is indicated by the pulse which precedes the evoked response on each trace.

Upper calibration, fast traces; lower calibration, slow traces.

(b) Selected oscillogram showing little on-going activity with large evoked response. (The legend is the same as that of Fig. XIII-4(a).)

and the filtered multiplier output was compared with a dc voltage obtained from battery sources. The amplitude of the inputs to the multiplier was varied simultaneously from the maximum allowable value, approximately 1 volt rms, over a 20-db range in steps of 5 db. Input sinusoids of frequencies from 100 to 1000 cps were used in the tests. The accuracy of the measurements has not been established definitely; preliminary results are not completely consistent, but the error seems to be a few per cent at most. Further tests are needed for precise quantitative evaluation. The dependence of the accuracy of the correlator on the balance of the circuits must also be determined.

A commercially available analog-computer component, the MU Duplex Multiplier (manufactured by George A. Philbrick Researches, Inc.) was tested under the same conditions. A comparable maximum error was observed, and the multiplier balance appeared less sensitive than that of the correlator multiplier.

Further tests must be made to evaluate both multipliers for correlator use. The drift tests performed indicate a 24-hour drift of less than 0.015 volt for each multiplier if it is first thoroughly warmed up. Other tests that will be made include determination of the effect of adding an uncorrelated signal such as noise to one input of the multiplier. A procedure is being formulated for the evaluation and testing of correlators.

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References

1. Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., Jan. 15, 1953, pp. 47-49.
2. Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., Jan. 15, 1954, pp. 71-72.

2. Correlation Studies of Brain Potentials

Some pilot correlograms were run with the analog correlator for electroencephalography. Most of these were analyses of electroencephalograms of patients, including autocorrelations of recordings from various parts of the head and crosscorrelations between them. These preliminary studies give evidence for a long-persisting periodic oscillation with unexpected stability of phase. (In the case of one patient, correlation was carried out to a delay of 13.5 sec, and the correlation was still detectable at this long delay time.) That activity of a rhythmic nature is usually prominent in the electroencephalogram has been recognized for many years and the Walter toposcope (1) gives partial information about the phase relations.

Several studies of these periodic oscillations in man are in progress, including the effect on them of rhythmic sensory stimulation by a stroboscope and by peripheral nerve stimulation. The effect of sleep was also recorded.

These studies were paralleled by recordings from animals. These included chronic

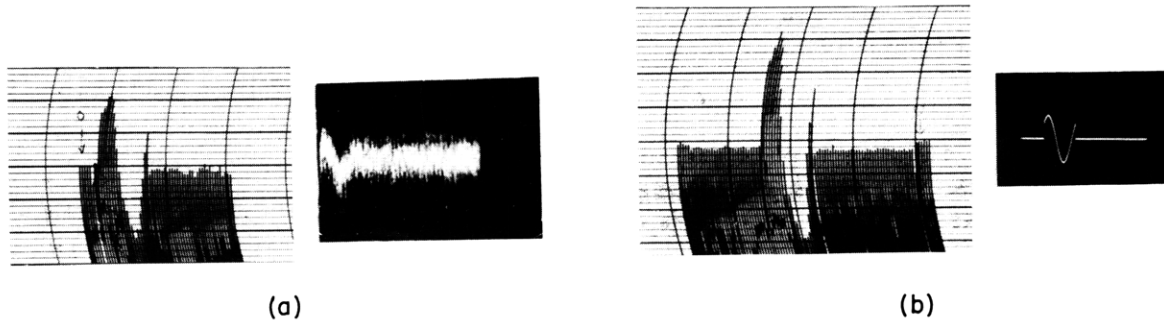(a)   (b)

Fig. XIII-5

Detection of a sine wave in noise. (a) Crosscorrelation of a repetitive pulse with
a single cycle of a 200-cps sine wave in noise of the same rms amplitude (insert).
Gate width, 0.2 msec; $\Delta\tau$ = 0.25 msec; integration time, 8 sec; number of sam-
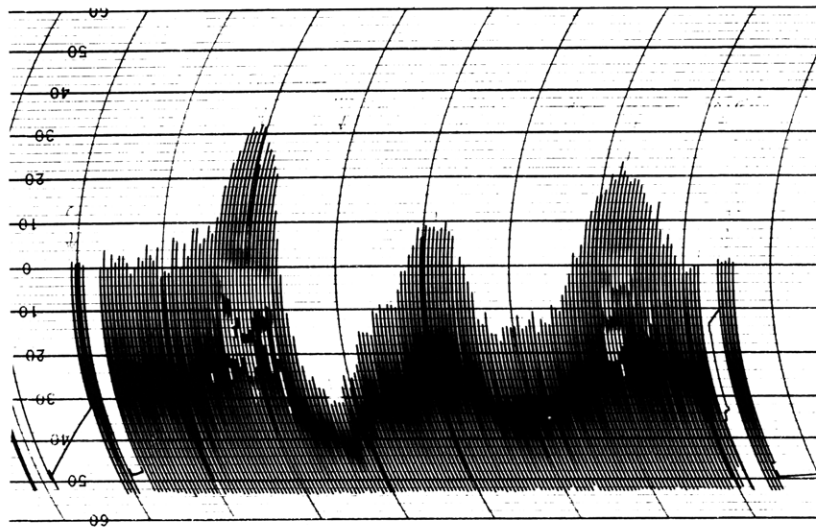ples, 160. (b) The same crosscorrelation, but without added noise.

Fig. XIII-6

Crosscorrelation of cortical response with flash. Flash rate, 1 per second; number
of responses, 45; $\Delta\tau$ = 2.5 msec. Parieto-occipital recording. The first 4 pen
excursions on the left and the last 5 on the right give the zero of the system. The
correlogram shows that the first major deflection that is time-locked to the stimu-
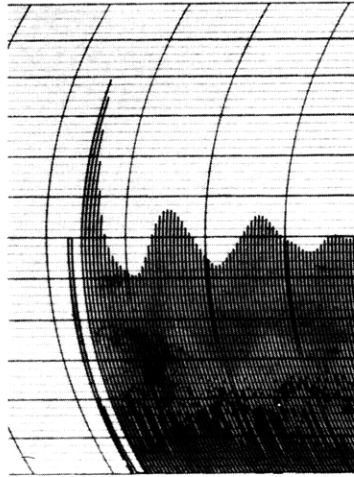lus is occipital-positive and of long latency (91 msec).

Fig. XIII-7

Autocorrelation of the spontaneous activity recorded from area I of the auditory cortex of an anesthetized cat ($\Delta\tau$ = 10 msec; integration time, 20 sec).

experiments in which permanent electrodes were implanted in cats, enabling recordings to be taken without anesthesia and studies to be made of the action on this activity of various drugs that influence the central nervous system. Others were acute experiments involving opening the skull and recordings made directly from the brain's surface. This technique, which enables intracerebral recordings to be made, has the disadvantage of introducing the variables of surgical shock, anesthetic level, and the disturbance of metabolic exchange.

Utilizing the principle of crosscorrelation of a time series with a repetitive unit impulse function, a special circuit for the correlator system was developed for the detection of responses in brain potentials evoked by experimental sensory stimuli. In effect, this circuit enables the correlator to compute the average response. In addition to the gain in signal-to-noise ratio that occurs with correlation methods in general, this principle of crosscorrelation of brain potentials with sensory stimuli possesses the added advantage of preserving in the correlation process the average waveform of the evoked response. A description of this circuit, which replaces the multiplier unit of the correlator for the detection of these responses, will appear in the technical report on the correlator system that is in preparation. The preservation of the waveform obtained with this circuit is indicated in Fig. XIII-5, a crosscorrelation of a repetitive brief pulse with a synchronously occurring burst of a sine wave in noise.

The circuit was also used for crosscorrelation of cortical potentials with sensory stimuli in recordings both of patients and of animals. Figure XIII-6, a crosscorrelation in man, illustrates this. The repetitive, rhythmic, average potentials (of about 9-cps frequency) set up by the brief flash (35 μsec in duration) are revealed by this process. Here these potentials are quite striking, whereas in the recording from an ink-writing oscillograph run simultaneously, only the first wave of the response was detectable. Similar results have been obtained in an unanesthetized cat.

Figure XIII-7 is an example of the autocorrelation of a recording from area I of the auditory cortex of an anesthetized cat.

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Reference

1. W. G. Walter and H. W. Shipton, A toposcopic display system applied to neurophysiology, J. Brit. I.R.E. 11, 260 (1951).