Effect upon auditory interval discrimination by perturbations in the nanosecond region¹

IRWIN POLLACK, MENTAL HEALTH RESEARCH INSTITUTE, UNIVERSITY OF MICHIGAN, Ann Arbor, Mich. 48104

A temporal uncertainty, or jitter, of less than 200 nsec in the intervals of an auditory pulse train significantly raises the interval (pitch) discrimination threshold. The results suggest a preneural, i.e., cochlear, analysis for high frequency auditory pulse trains.

The sensitivity of the auditory system to the temporal properties of auditory signals is truly remarkable. We accept, without a flinch, that a skilled listener can discriminate nearly a 1 Hz change in a 1000 Hz tone (Harris, 1952). Yet, when the same result is rephrased to reflect that a skilled listener can detect a 1 μ sec change in a signal with a period of 1 msec, our interest is reawakened. Similarly, binaural temporal disparities in the low μ sec region are detectable for lateralization (Mills, 1958). For, we might ask, exactly how does a system consisting of individual neural units which operate in the msec region (Kiang, 1965) preserve temporal information in the μ sec region? With respect to lateralization, temporal disparity detectors have been identified in the superior olivary nucleus which respond to small temporal differences (Galambos, Schwartzkopff, & Rupert, 1957; and Moushegian & Rupert, 1962). The present study is concerned with the limits of temporal resolution for interval discrimination. Specifically, the present paper seeks to examine the effect of sub-microsecond perturbations on the limits of interval discrimination. A portion of the data has been incorporated within a more extensive set of measurements of interval sensitivity of auditory pulse trains (Pollack, 1968).

Method. Pulse trains were generated by a Digital Equipment Corporation PDP-8 computer. The unit of temporal control for the interval between successive pulses was one quarter of the basic computer cycle of 1.5 μ sec, i.e., to 3/8 μ sec. The temporal uncertainty, or jitter, of the computer is considered by the manufacturer to be less than 0.02% of the basic computer cycle. Pulse trains were generated either with no additional jitter, or with plus or minus one 3/8 μ sec temporal unit introduced upon one half of the intervals. The latter operation results in an average jitter, or variability, of 3/16 μ sec or 187 nsec. Since an equal number of plus and minus changes was

Fig. 1. Auditory interval discrimination for trains of pulses as a function of the number of successive inter-pulse intervals. The ordinate of Figs. 1 and 2 represents the change in the center inter-pulse interval, IPI_c , required for 50% correct discrimination in a four-interval forced choice test. The parameter is the average temporal jitter imposed upon each inter-pulse interval.

Fig. 2. Auditory interval discrimination for trains of pulses as a function of the duration of the inter-pulse interval.

made, the mean interval was independent of jitter. Brief (10 μ sec) monopolar pulses were smoothed by Koss PRO-4 earphones and adjusted by the listener to a comfortable listening level.

In a given observational sequence, four pulse trains were presented to the listener. The task of the S was to detect which one of the four sequences was different from the other three. The average inter-pulse interval (IPI) of one of the sequences was made longer than the others. The size of the IPI difference was changed by an adaptable stimulus programming procedure of variable step size (Taylor & Creelman, 1967). The procedure converged upon the IPI difference required for 50% correct discrimination in a four-interval forced choice (4IFC) test. This difference will be called the threshold. Sixteen university music students served as experimental Ss. Each contributed at least two thresholds per experimental condition. Averages are based upon geometric means across listeners.

Results. The results are summarized in Figs. 1 and 2. In both figures, the ordinate is the average threshold difference in the inter-pulse interval. Superior discrimination is associated with lower thresholds. Under selected conditions, interval discrimination of 1 μ sec and lower is obtained. In the tests of Fig. 1, the center, or mean, inter-pulse interval was about 0.5 msec and the joint role of jitter and the number of inter-pulse intervals was sought. Significant threshold differences (by the binomial sign test) between 187 nsec and 0 jitter are obtained only for larger numbers of intervals. The slope of the initial portion of the curve is drawn at -1.3, but a direct inverse relation of -1.0 is reasonable, especially for the jittered data. In the tests of Fig. 2, each pulse train was 128 intervals long and the joint role of jitter and the mean inter-pulse interval was sought. Significant threshold differences between 187 nsec and 0 jitter are obtained only for the shorter inter-pulse intervals.

In partial summary, differences in the mean interval between successive pulses of the order of 1 μ sec are detectable by skilled listeners. Perturbations of the mean interval of the order of 200 nsec significantly increase the interval difference threshold for long trains of short inter-pulse intervals.

Discussion. If we are inclined still to think of auditory analysis of high frequency pulse trains in the temporal domain, the problem is compounded by the observation that the frequency discrimination threshold is not modified if the frequency change is introduced over a 10-sec period (Sergeant & Harris, 1962). Since there are 10^4 cycles of a 1000 Hz tone in a 10-sec period, the temporal change between successive cycles is in the *pico*second range! Obviously, the auditory nervous system cannot be called upon to monitor temporal changes in this region. Rather, present-day auditory theory suggests that the relevant operations involve a spatial transformation performed by the preneural cochlear system (Von Békésy, 1960, 1967), followed by successive sharpening operations in the auditory neural system (Katsuki, 1961).

REFERENCES

- GALAMBOS, R., SCHWARTZKOPFF, J., & RUPERT, A. Microelectrode study of superior olivary nuclei. *Amer. J. Psychol.*, 1959, 197, 527-536.
- HARRIS, J. D. Pitch discrimination. *J. Acoust. Soc. Amer.*, 1952, 24, 750-755.
- KATSUKI, Y. Neural mechanism of auditory sensation in cats. In W. Rosenblith (Ed.), *Sensory communication*. Cambridge, MIT Press, 1961. Pp. 561-583.
- KIANG, N. *Discharge of patterns of single fibers in the cat's auditory nerve*. MIT Research Mono. 35, Cambridge: MIT Press, 1965.
- MILLS, A. W. On the minimum audible angle. *J. Acoust. Soc. Amer.*, 1958, 30, 237-246.
- MOUSHEGIAN, G., & RUPERT, A. Binaural interaction in the superior-olivary complex of cat. *J. Acoust. Soc. Amer.*, 1962, 34, 1988.
- POLLACK, I. Discrimination of mean temporal interval within jittered auditory pulse trains. *J. Acoust. Soc. Amer.*, 1968, 43, in press.
- SERGEANT, R. L., & HARRIS, J. D. Sensitivity to unidirectional frequency modulation. *J. Acoust. Soc. Amer.*, 1962, 34, 1625-1628.
- TAYLOR, M., & CREELMAN, D. PEST: Efficient estimates on probability functions. *J. Acoust. Soc. Amer.*, 1967, 41, 782-787.
- VON BEKESY, G. *Experiments in hearing*. New York: McGraw-Hill, 1960.
- VON BEKESY, G. *Sensory inhibition*. Princeton: Princeton University Press, 1967.

NOTE

1. This research was supported by Grant GB 2894 of the National Sciences Foundation. The computer program was written by Mr. Peter Headly. Interface equipment was designed by Mr. Eugene Maas. Data processing was performed by Mr. Wen Chao Hsieh and Mrs. Diane Ray was responsible for scheduling the experimental tests.