Four Parameters of Information Processing in the Cochlea

The present report is an investigation of cochlear potentials using signal transients to a precisely defined, informationally relevant, four-dimensional elementary signal or acoustical wave packet.

Materials and methods. The elementary signal[1] of the structural information theory of sound[2] is a transient impulse or wave packet, which is based on a special relation between 4 signal parameters[3]: f_o, the signal midfrequency; t_o, the signal midperiod; Δf, the signal bandwidth; and Δt, the signal duration. These 4 signal parameters are considered to have 4 different units of measurement[3]. The smallest elementary signal is defined by the bounding conditions: $\Delta f \cdot \Delta t = f_o \cdot t_o = {}^1/_2$, or $s(t) = e^{-(t-t_o)^2} \cdot e^{i2\pi f_o t}$ and is shown in Figure 1.

The signal can be generated electronically by passing a rectangular wave of duration t_o through a bandpass filter set at one half octave around the midfrequency f_o such that $f_o \cdot t_o = {}^1/_2$[4]. The appropriate Δf and Δt are also obtained thereby, i.e., $\Delta f \cdot \Delta t = {}^1/_2$, as the amplitude modulation due to the nonideal cutoff characteristics of the filter approaches a Gaussian waveshape ($e^{-(t-t_o)^2}$) at a one half octave setting around the f_o. The Δf defines 2 standard deviations in f units, with f_o the mid or average frequency. Similarly, the Δt defines 2 standard deviations in t units, with t_o the mid or average period. A frequency-amplitude plot of the signal is also of Gaussian form. Elementary signals of different f_os defined by the bounding conditions stated above always appear as in Figure 1 given a variable time base. I now turn to the cochlear potentials studied.

It is believed that the cochlear microphonic (CM) – *ana.c.* potential – follows closely the waveshape of the carrier of the acoustical stimulus throughout the length of the cochlea, except when the stimulus is composed of many frequencies, when a dispersion of the frequency components occurs according to a semi-response specificity of the 4 cochlear turns of the guinea-pig. In the experiments reported here using four-dimensional signals, the CM recorded follows not only the shape of the carrier or midfrequency (f_o) of the signal, but also the bandwidth (Δf) components. There is no distortion of the wave packet shape represented in Figure 1, and there is no spatial dispersion of the Δf components. This leads us to believe that the f_o and Δf components of a signal are registered differently in the cochlea, permitting the waveshape of an elementary signal to remain unaltered under a spatial dispersion of the f_o components of the signal.

The summating potential (SP) – *a d.c.* response to an *a.c.* acoustical stimulus – is presently considered to be the sum of various components, but predominately a negative and a positive component is emphasized. The polarity to stimuli of long (1 msec +) duration and high intensity is usually negative, but under certain circumstances, e.g., with stimuli of low intensity, the polarity is positive[5]. The experiments reported here use stimuli of short duration (2 msec ($f_o = 1$ kHz) and less). There is no agreement on the rise time of the SP[6]. It has been estimated, for example, that the latency of the negative SP is less than ${}^1/_2$ a wave length and less than 100 μsec[5]. The SP is thought to follow the envelope or amplitude modulating component of a long duration acoustical stimulus. In the experiments reported here with short duration stimuli, the SP follows less closely the stimulus envelope. More noticeable is that the SP components are of constant duration, even when the Δt components of the signal are diminished at higher frequencies (because of the $f_o \cdot t_o = \Delta f \cdot \Delta t = {}^1/_2$ relation).

The elementary signals were led through a preamplifier to an ALTEC 808-8A driver which was connected by closed coupling to the auditory canal of the subjects (guinea-pigs) anesthetized with Dial in Urethane (0.25 cc/kg). Differential electrodes – teflon coated nichrome steel of 50 μm o.d. – were differentially implanted in the SV and ST of the first turn of the cochlea and at least one other turn. The signal recorded, averaged and displayed was thus the difference potential SV-ST[6]. The SP was elicited by a signal of the appropriate Gaussian modulating envelope using a non-phase locked carrier of the appropriate f_o.

Results and discussion. The result obtained in the case of the CM (Figure 2) is that: 1. apart from some distortion – in this instance at low (1–2 kHz) frequencies – the CM waveshape elicited is preserved at different f_os. This effect is not due to the middle ear transfer characteristics – the volume velocity versus SPL function decreases at a rate of only 6 db/octave, and we used signals of only ${}^1/_2$ octave bandwidth around the center frequency. 2. The duration of the CM is almost constant at different f_os, whereas the signal used decreases progressively in duration as the f_o is increased (from $\Delta t = 2$ msec at 1 kHz to $\Delta t = 0.2$ msec at 10 kHz, see white line marker in Figure).

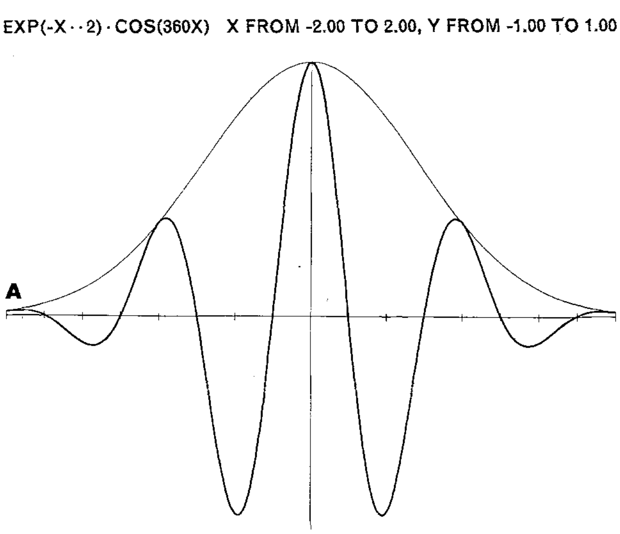

Fig. 1. Elementary signal defined by the bounding conditions $\Delta f \cdot \Delta t = f_0 \cdot t_0 = 1/2$. In the time domain, the signal is $s(t) = e^{-(t-t_o)^2} \cdot e^{i2\pi f_o t}$; in the frequency domain, the signal is $s(f) = e^{-\pi^2(f-f_o)^2} \cdot e^{i2\pi t_o f}$. Given a variable time base, the signal is of this form at different f_os.

[1] D. Gabor, J. Instn. elect. Engrs *93*, 429 (1946).

[2] T. W. Barrett, T.-I.-T. J. Life Sci. *1*, 129 (1971). J. Sound Vibration *20*, 407 (1972); *25*, 638 (1972). – Acustica *27*, 44 (1972); *27*, 90 (1972); *29*, 65 (1973). – J. Acoust. Soc. Am. *54*, 1092 (1973).

[3] T. W. Barrett, J. Acoust. Soc. Am. *54*, 1092 (1973).

[4] A. R. Tunturi, Am. J. Physiol. *181*, 630 (1955).

[5] H. Davis, B. H. Deatherage, D. H. Eldredge and C. A. Smith, Am. J. Physiol. *195*, 251 (1958).

[6] I. Tasaki, H. Davis and J. P. Legouix, J. Acoust. Soc. Am. *24*, 502 (1952).

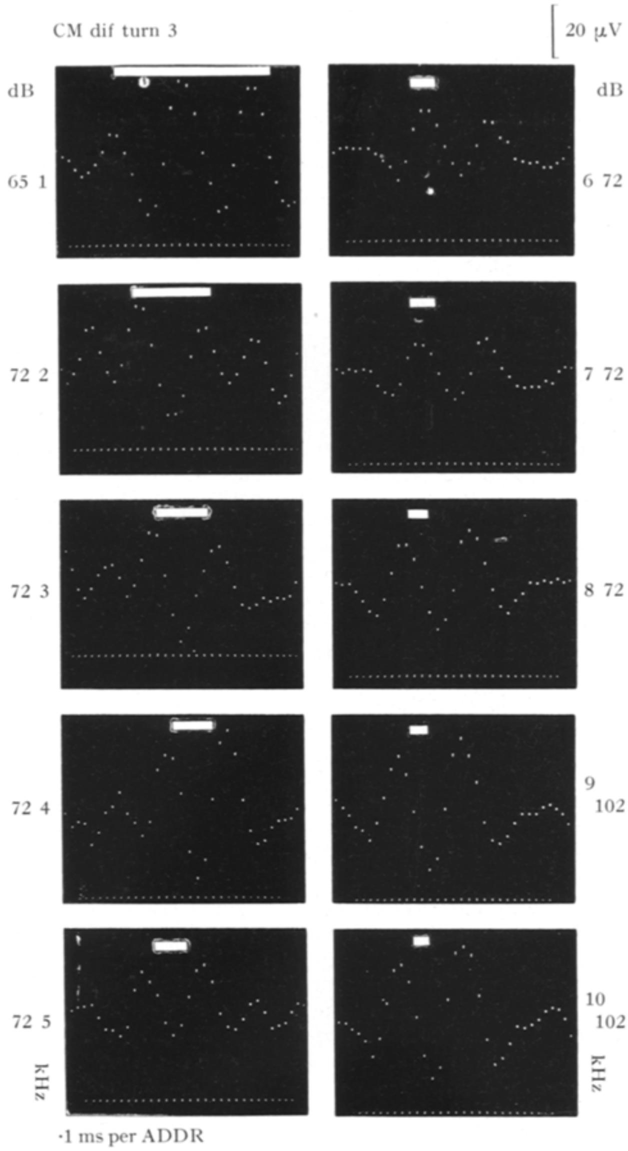

Fig. 2. Averaged cochlear microphonics (CM) recorded in the 3rd turn by the differential electrode (SV–ST) technique. The Δt of the elementary signal used is shown as a white bar in each photograph. The f_0s are given in kHz and the sound pressure levels are given in dB *re* 20 µPa. Notice that particularly at high frequencies the CMs are of far longer duration than the Δt of the stimulus indicated by the white bar. Average of 60 responses.

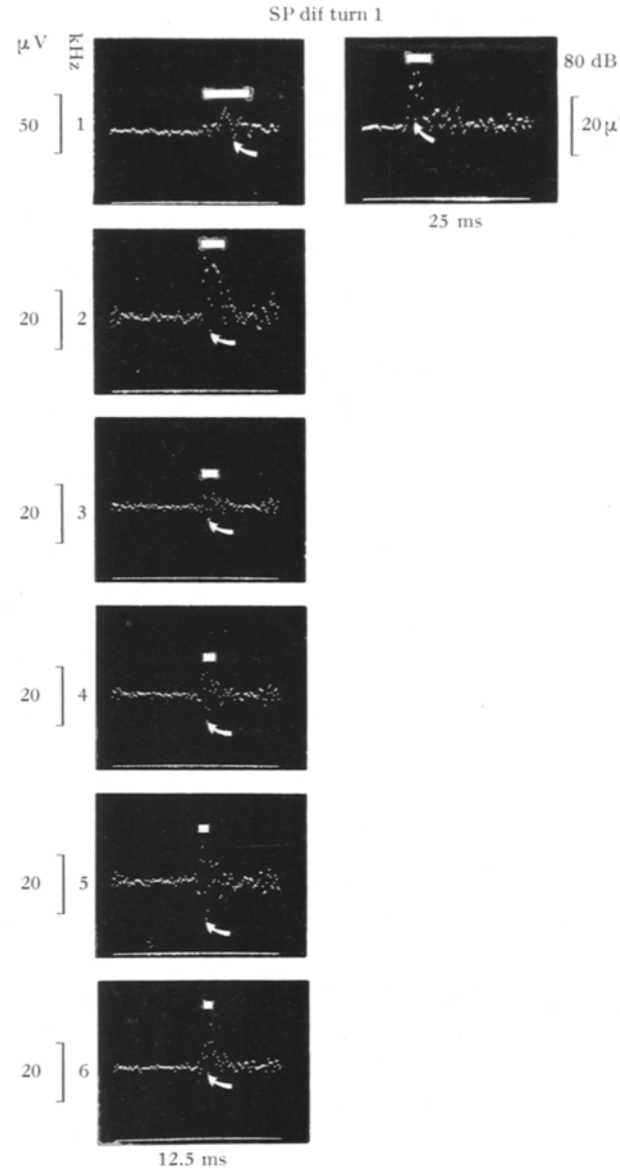

Fig. 3. Averaged summating potentials (SP) recorded in the first turn by the differential electrode (SV–ST) technique. The Δt of the elementary signal used is shown as a white bar in each photograph. The f_0s are given in kHz and the sound pressure levels are given in dB *re* 20 µPa. The white arrow indicates the negative dip in the SP which reaches a maximum at $f_0 = 5$ kHz. Average of 60 responses.

In the case of the SP, the result (Figure 3) is that 1. a negative SP of very short duration (see arrow in Figure) is maximum for an optimum ($f_o = 5$ kHz in Figure), i.e., the negative SP is distributed in the cochlea according to the signal f_o; 2. the duration of the positive and negative SP – like the CM – is constant even when the Δt components of the signal are diminished at high frequencies.

Zusammenfassung. Es wurden die mikrophonische Potentiale und Summierungspotentiale der Ohrschnecke mit elementar-akustischen Signalen (Wellenpaketen) untersucht. Offenbar wird zu einem Gesamtbild der Ohrschneckenpotentiale eine Vier-Parameter-Analyse der akustischen Signale benötigt.

T.W. BARRETT

Department of Physiology and Biophysics, University of Tennessee Center for the Health Sciences, 894, Union Avenue, Memphis (Tennessee 38163, USA),
13 May 1974.