microwave pulses is roughly determined by the sum of squares of harmonic amplitudes for a train of pulses between 8000 and 12,000 pps, yields curves (for pulses of constant peak power) of the dependence of loudness (and thresholds of sensation) on pulse duration (Figure 4). The character of these curves is fully in accord with data reported by *Frey* [1962], *Frey and Messenger* [1973], and *Guy et al.* [1975].

The observation of beat frequencies during simultaneous presentation of RF and AF signals indicates that RF hearing is transduced at linear or quasi-linear levels of the nervous system, which agrees well with the thermoacoustic hypothesis. However, longer pulse widths that increased the mean power level produced increases in loudness that rose more rapidly than predicted by the thermoacoustic model. Moreover, the suppression of the acoustic response to a 5000-pps train of RF pulses by a 10-kHz AF signal, which was down by at least 20 dB, is at variance with the thermoacoustic model.

The smooth threshold curves above 8000 pps and the qualitative invariance of acoustic sensations as subjects' heads were immersed in water are at odds with the thesis that altering the acoustic resonant properties of the head (by immersion) would alter the perceptual quality of the RF signal. Further, because the human head is resonant at 0.8 GHz, which should be associated with a "hot spot" in its center, partial immersion in water should dampen its resonance, reduce its rate of absorption, and yield a loudness function different from that observed by us.

It is possible that the differing sensation induced by RF pulses of width greater than 50 μs can be explained by the thermoacoustic model, if not borne of other sources of sensory activation (e.g., by the teeth). Further study is needed to clarify the lower pitch and the external referencing of sound associated with longer pulses.

In summary, our data indicate that additional psychophysical studies of RF hearing are needed. The thermoacoustic model, while very promising and doubtless correct for higher peak densities and shorter pulses of irradiation, is inadequate to explain a number of pecularities of auditory sensation observed by us near threshold levels. Further development is in order.

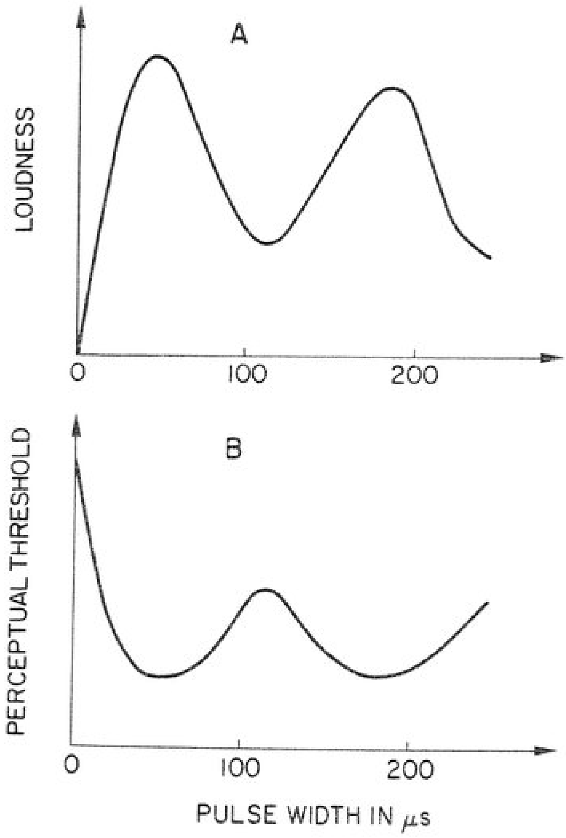

Fig. 4. A: Loudness of an RF signal as a function of pulse width. B: Threshold of detection of an RF signal as a function of pulse width. Pulses of constant amplitude recurred at 2000 pps.

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REFERENCES

Chou, C. K., A. W. Guy, and R. Galambos (1977), Characteristics of microwave-induced cochlear microphonics, *Radio Sci.*, *12*(6S), 221-228.

Constant, P. C. (1967), Hearing EM waves, in *Digest of the 7th International Conference on Medical and Biological Engineering*, p. 349, Roy. Swedish Acad. Eng. Sci., Stockholm.

Foster, K. R., and E. D. Finch (1974), Microwave hearing: Evidence for thermoacoustic auditory stimulation by pulsed microwaves, *Science*, *185*, 256-258.

Frey, A. H. (1961), Auditory system response to modulated electromagnetic energy, *Aerosp. Med.*, *32*, 1140-1142.

Frey, A. H. (1962), Human auditory system response to modulated electromagnetic energy, *J. Appl. Physiol.*, *17*, 689-692.

Frey, A. H. (1963), Some effects on humans of UHF irradiation, *Am. J. Med. Electron.*, *2*, 28-31.

Frey, A. H., A. Fraser, E. Siefert, and T. Brish (1968), A coaxial pathway for recording from the cat brain stem during illumination with UHF energy, *Physiol. Behav.*, *3*, 363-364.

Frey, A. H., and R. Messenger (1973), Human perception of illumination with pulsed ultra-high-frequency electromagnetic energy, *Science*, *181*, 356-358.

Guy, A.W., C. K. Chou, J. C. Linn, and D. Christensen (1975), Microwave induced acoustic effects in mammalian auditory systems and physical materials, *Ann. N. Y. Acad. Sci.*, *247*, 194-218.