these formulas. The only exception is the case of the two-electron array $nl^2 \longrightarrow nln'l'$, for which the allowed multiplets have the same relative strengths as the corresponding multiplets of $nln''l \longrightarrow nln'l'$.

[3] It will be convenient to summarize here the spectroscopic terminology which we shall employ:

Level—A set of $2J + 1$ states characterized by a given J value and having the same energy in the absence of an external field.

Term—A set of $(2L + 1)(2S + 1)$ states characterized by a given L and S.

Polyad—A set of terms of the same multiplicity based on the same parent term in the case of the addition of one electron to a parent ion.

Line—Radiation resulting from all transitions between two levels.

Multiplet—Radiation resulting from all transitions between two terms.

Supermultiplet—Radiation resulting from all transitions between two polyads. A more general definition of this term is given in the text.

Transition Array—Radiation resulting from all transitions between two configurations.

Strength—Sum of the absolute squares of the components of electric moment joining the sets of states in question. The intensity of a single line is proportional to the product of the number of atoms in each state of its initial level, the fourth power of its frequency and its strength.

[4] See Russell, *Proc. Nat. Acad. Sci.*, **11**, 324 (1925), and White and Eliason, *Phys. Rev.*, **44**, 753 (1933).

[5] Ufford and Miller, *Phys. Rev.*, **46**, 283 (1934).

THE LOCALIZATION OF PURE TONES

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A person can localize a tone in space primarily because the sound differs at the two ears in intensity, or in phase, or in both. Experimentation[1] shows that, when a tone is led separately to the two ears, the perceived position of the source can be altered at will by varying either the relative intensity or the relative phase. Localization departs from the median plane (the plane dividing the head and perpendicular to the aural axis) toward the side where intensity is greater and/or where phase leads.

If we limit our consideration to the localization of an actual source of tone in the horizontal plane, then the bilateral symmetry of the observer suggests that similar results ought to be obtained on either side; and experiments[2] show that sounds on one side of the observer are practically never mistaken for sounds on the other. Moreover, the placement of the ears is such that, except for the effects of slight irregularities of the head, there are no cues by which the observer can distinguish tones in front from those behind. Hence, it is justifiable, in considering the problem of relative accuracy with which an observer can localize tones of different frequencies, to deal only with localization on one side and not to count front-back reversals of localization as errors. This procedure was followed in the present study.

It has been shown that phase-difference is an effective basis for localization at low tonal frequencies.[3] However, phase-difference becomes equivocal at high frequencies, because there is then more than one position of the sound-source which would give rise to the same binaural difference of phase. The presumption is that localization is built up in experience, and that only univocal bases for localization can become established as effective cues.

Phase-difference provides a univocal basis for the localization of all those tones whose wave-length is so long that the difference in phase does not exceed 360° when the sound-source is shifted from a position directly in front to one directly at the side. On the assumption that the head is a sphere of radius 8.75 cm. the critical frequency can be calculated. To a first approximation the difference in the distance which a sound must travel to reach the two ears is

$$d = 8.75(\sin \theta + \theta)$$

where θ is the angle between the azimuth of the sound and the median plane of the observer. Since, neglecting front-back reversals, we are concerned with only one quadrant, localization ought not to become equivocal until there is more than one position within a single quadrant which would give rise to the same phase-difference at the two ears. In this sense equivocality begins at the frequency whose wave-length is equal to the maximum value of d, or 1520 cycles. As the frequency of a tone increases beyond 1520 cycles, cues for localization become less adequate, because a given phase-difference is associated with more and more positions of the sound-source.

Differences in intensity at the two ears result from the sound-shadow cast by the head. Since this shadow is sharper at high than at low frequencies, greater differences of intensity are available as cues for localization at the high frequencies. Measurements of the difference in intensity at the two ears of tones coming from a source at the side of the observer[4] show that the difference is relatively small for frequencies up to 3000 cycles and that above 3000 cycles it rises rapidly to a maximum of 30 db. Therefore, on the basis of difference in intensity alone, we should expect good localization at high and poor localization at low frequencies.

Since the observer can use either the phase-effect or the intensity-effect in localizing tones, he should be successful in localizing both high and low tones. However, throughout a band of intermediate frequencies, both phase and intensity provide less adequate differences, and in this intermediate region localization should be poorest.

In order to test this deduction we performed an experiment on a platform elevated 9 feet above the roof of the Biological Laboratories of Harvard University. Tones were generated by a loud speaker attached to the end of a 12 ft. arm which was free to rotate in a horizontal plane around the observer. The absence of vertical surfaces at the level of the observer eliminated the possibility of errors due to reflected sound. The tones were presented at each of 13 positions, 15° apart, on the right side of the observer.

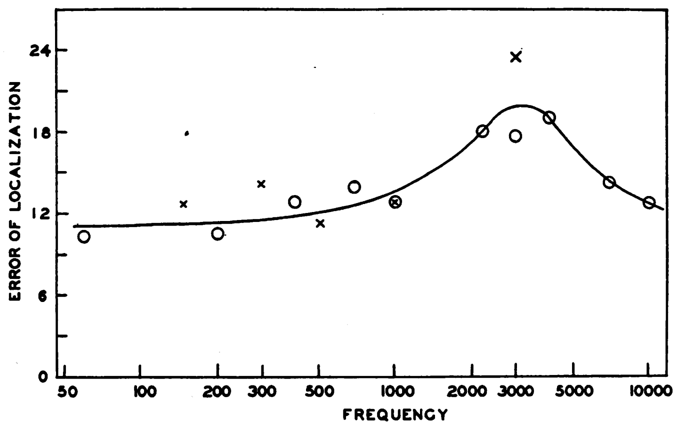

FIGURE 1

Dependence of localization on frequency. The ordinate represents the average of the errors in degrees made by both observers. The crosses are for the shorter series of judgments made in 1933. The circles represent the results obtained in 1934. Note the region of poor localization around 3000 cycles.

The results of the experiment are shown graphically in figure 1. Each circle represents the average of the errors made by both of the two observers. Each observer made 10 observations with the tone at each of the 13 positions at every frequency. The crosses represent some preliminary observations. In computing the errors of localization we took the difference between the reported position of the sound and either the actual position or the corresponding position in the other quadrant. Thus, if the tone was at 30° from the median front position, the localization was regarded as correct if the observer reported either 30° or 150°.

It is clear from figure 1 that the accuracy of localization of all tones below 1000 cycles is approximately the same as that of tones above 7000 cycles, whereas the localization of tones between 2000 and 4000 cycles is relatively poor. This finding is precisely what is anticipated by our previous considerations; although it contradicts the previous general belief[5] regarding the impossibility of localizing high tones.

These results point definitely to a dual mechanism for the angular localization of tones in the horizontal plane. Phase-differences are the primary basis for the localization of low tones, whereas high tones are localized principally by reason of differences in intensity at the two ears. In the intermediate region around 3000 cycles, where the differences in intensity are relatively small and where phase-differences are equivocal, the observer localizes tones with the least accuracy.

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[1] O. C. Trimble, *Psychol. Rev.*, **35**, 515–523 (1928).

[2] A. H. Pierce, *Studies in Auditory and Visual Space Perception*, New York, 1901, p. 52.

[3] H. M. Halverson, *Amer. J. Psychol.*, **38**, 97–106 (1927).

[4] J. C. Steinberg and W. B. Snow, *Bell System Tech. J.*, **13**, 247–260 (1934).

[5] H. M. Halverson, op. cit.

ACETYL CHOLINE AND CHROMATOPHORES

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A few years ago I published a brief note on the effects of acetyl choline on chromatophores (Parker, 1931). The results detailed in this note, considering the remarkable properties of this material, were in no way startling and were obtained by using only a relatively concentrated solution of the substance (1 part in 1000). After injecting this concentration into Fundulus the fishes darkened slightly, that is, their melanophore pigment became dispersed and in most cases they died. It was clear that this concentration was near the lethal limits for Fundulus. Since then I have learned of the work of Loewi and Navratil (1926), Engelhart and Loewi (1930), Matthes (1930) and Gollwitzer-Meier and Bingel (1933) all of whom have pointed out the destructive effect of blood on acetyl choline and the success with which this destruction can be overcome by the use of physostigmine. Since my first publication Wunder (1931) has reported very briefly on what appeared to be an essentially negative action of acetyl choline on the chromatophores of Rhodeus, and Smith and Smith (1934) have noted no positive effects from this substance when injected into Scorpaena. I therefore resolved to test the matter anew and to employ physostigmine as a protective agent.

Physostigmine itself has been shown to have an effect on melanophores