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Several years ago the writer suggested that harmonic analysis of sound together with the rigid extension of Helmholtzian resonance theories has led us astray in the field of auditory phenomena, particularly from the point of view of the psychologist.[1]

The point of view presented here is that the psychological aspects of hearing can be referred to differences in the wave pattern or characteristics of the stimulus as it strikes the ear. In other words, a study of the sound wave for the purposes of explaining auditory phenomena will not rest upon analysis by an application of the Fourier theorem or by an Henrici Analyser or other instrument which attempts to break up a compound or complex wave into a hypothetical physical condition in which there are a number of independent systems of vibratory movement, but will rest solely upon a gross study of the sound wave itself. The evidence for this position will be reviewed.

For many years when two or more tones were sounded together giving rise to the hearing of beats, intertones, and combination tones — in other words, tones not originally present in the component sounds — explanations had been given for the hearing of these new tones based upon the asmetry of the tympanum, damping effects of the ossicles of the middle ear, variations in tone of the tenser tympani and stapedius muscles, the asmetry and damping effects of the fenestra ovalis, peculiar modes of functioning of other structures of the inner ear, cortical phenomena, and even some mysterious subjective phenomenon.

Such explanations have been rather completely ruled out. Almost a quarter of a century ago Schafer[2] reported the hearing of difference tones by subjects who had previously lost the ear drum. Further evidence has come repeatedly from individuals with middle ear deafness who have reported hearing combination tones through bone conduction. Finally, the classical experiment of Wever and Bray[3] subsequently verified by other experimenters,[4] has shown that the ear is fairly faithful in communicating the wave form of the stimulus to the cochlear nerve and to parts of the auditory tract.

In consequence of such researches it is necessary for us more ac-

[1] Root, Alfred R., Auditory Persistence, Sommation and Fusion in Successive Impulse-Periods. *Psychol. Rev.*, 1928, 35, 507–514.

[2] *Passow u Schafer'sche Beitr.*, 1913, 6, 207.

[3] Wever, E. G., and Bray, C. W., The Nature of Acoustic Response, *J. Exper. Psychol.*, 1930, 13, 373–387.

[4] Cf., Elmqvist, B. Sjostrom, Wever och Bray's Forsok, *Hospital Stidende,* 1933, 76, 11–12.

Hughson, W., Crowe, S. J., and Howe, H. A., Physiology of the Ear, *Acts Ptholaryngol.,* 1934, 20, 9–23.

curately to discover the exact wave form of the stimulus striking the tympanum. When that is done most of the difficulties in explaining sounds, and the quality of sound heard, disappear. We know, for example, that if the displacement from two simple vibratory movements are permitted to fuse and we vary the initial phase differences of those displacements, the resultant sounds are differently perceived. Furthermore when such displacements are photographed from a high-grade Cathode-Ray Oscillograph, appreciable differences in the wave form are observed. Harmonic analysis in a situation of this type would reveal two simple vibratory systems of frequencies.

We know also that if we take two frequencies and keep the same initial phase differences and vary their respective amplitudes, the resulting compound wave form will show vast differences, and that the perception of those sounds will vary considerably.

Evidence that traditional acoustical methods do not suffice in psycho-physical studies of sound are found in the following well known researches. Fletcher[5] took a complex sound with a fundamental frequency of 128 cycles. The tone was then run through a series of electrical filters which had cut out successively frequencies of the order of 128, 256, 512, etc., cycles. The sound was then led through a phone to an observer. The observer, after the lower frequencies had been filtered out, still reported a pitch approximately 128 cycles. Scripture[6] interpreted those findings by saying that the recurrence of any pattern of sound waves itself gives rise to the hearing of a tone whose pitch is that of the frequency of recurrence of the pattern. Essentially the same principle has been reported in the work of Dennert,[7] Hermann,[8] Max Meyer,[9] Schaefer and Abraham,[10] in their investigations of the so-called interruption tone. Researches of the above character could have been greatly simplified had care been taken and facilities available for discovering the character of the wave form as it struck the observer's ear.

The psychological literature particularly has been amiss on this point and has led to gross speculation. The experiments on beating tones using two tuning fork sounds have not yielded consistent results. The evidence now indicates that variations in amplitude and complexity, and phase differences of the sounds used, made for variations in the compound pattern.

We have conducted research for several years which indicates rather definitely that most everything that we perceive is referable to the sound wave of the stimulus. The following is a description of the apparatus used. A light passes through a wave pattern on a negative photographic plate having a known wave form. An interrupter disc operated by a constant speed motor passes in front of

[5] *Cf., Speech and Hearing.* 1928.
[6] *Ztsch. f. Sinnesphysiol.,* 1927, 58, 195–208.
[7] *Arch. f. Ohrenheilkunde.* 1887. 24, 181.
[8] *Arch. f. d. ges. Physiol.,* 1894, 56, 490–493.
[9] *Zsch. f. Psychol.,* 1896, 11, 210–214.
[10] *Arch. f. d. ges. Physiol.,* 1894, 56, 490–493.

the photographic plate thus varying the amplitude of the beam of light according to the wave form on the plate. The lens system maintaining approximately parallel rays conducts the beam to a photocell attached to an amplifier. The variations in light are converted into electrical impulses exciting a diaphragm in a telephone receiver which is located in a sound booth. The output of the system has been checked and its fidelity in reproducing the wave form on the photographic plate has been checked with a Cathode-Ray Oscillograph.

Through such an apparatus known wave forms of sound can be produced and compared with one another and the tones heard from such sounds can be checked with features of the stimulus.

The exciter lamp as light source is of the regular commercial movie variety. The interrupter disc is so constructed that its slots can be varied from one-tenth of a millimeter to three millimeters in width and are a distance apart equal to the width of the wave on the photographic plate. The disc is geared so that the light source is interrupted 180 times per second, thus always giving a fundamental tone of 180 cycles. The current generated in the photocell is led to a two stage transformer-coupled amplifier having a gain of approximately 50 decibels. The output from the amplifier operates a pair of Baldwin head phones. The gain of the amplifier is "flat" within two decibels from 30 to 5,000 cycles per second. Above and below these limits amplification falls off very rapidly being practically zero at 10 and 10,000 cycles. The plate voltage is derived from a self-contained power supply operating from the 110 Volt A.C. mains. The voltage remains constant at 88.5 volts despite severe fluctuations in line voltage through the use of an argon-filled regulator tube. The filament voltage is supplied by a standard six-volt storage battery. The exciter lamp is of the regular 7.5 volt concentrated filament type used in theatre sound equipment. The photocell is a Westinghouse, Type SK-60. The anode voltage of 88.5 volts is supplied by the power supply contained in the amplifier. The response of the Baldwin phones is very faithful except in the region of 1,000 cycles due to the diaphragmatic resonance. Direct current from the last amplifier tube is kept out of the phones by a resistance-condenser filter so that distortion due to strains on the diaphragm are eliminated.

Using this apparatus the principles published seven years ago[11] find complete verification.

It may be said that the regular although not necessarily consecutive recurrence of a displacement gives rise to the sensation of tone corresponding to its particular period. This is true with such displacements beginning with zero pressure or whether they are superimposed upon other displacements. In terms of sound waves therefore, a characteristic which is part of a complex wave is, within certain limits, capable of giving rise to sensation of a new tone. This

[11] Root, A. R. *Op. Cit.*

fact has always had acceptance so far as simple tones are concerned and it makes consistent our knowledge with reference to combination tones. We know that beats are periodic variations in amplitude and as such may be treated as another type of displacement which is adequate in stimulating the sensation of the cycle beat tone. When we examine a complex wave form or complex displacement we may treat each characteristic as a unique displacement whose recurrence under certain conditions gives rise to the hearing of a different and unique tone. Its period has empirically been derived in terms of the distance between its highest peak and the next adjacent peak. If, therefore, we have a wave form with two characteristics, and no more than two characteristics, the observer hears three tones. If we call those peaks of characteristics A and B and the recurrence of those characteristics in the succeeding wave A', B', the periods effective for the hearing of the three tones are calculated from the distances A-B, B-A', A-A'.

It is apparent that there are certain limitations under which these facts are true and that is the relative amplitude of displacement which makes for the masking of a characteristic of small relative amplitude by a characteristic of relatively large amplitude. To sum up this point, it is variations in displacement and amplitude that determine pitch in hearing. That is true both in simple and complex sounds.

The acceptance of the above principle has been hampered by our elementary studies in simple tones. When an elastic body, which vibrates in a simple pendular motion, is displaced we have observed a regular and successive recurrence of that motion or period. When the sound waves from two such simple vibrating bodies fuse we have assumed, because the compound wave can be analysed into its two simple components, and there is regular and consecutive recurrence of those two frequencies in the compound wave. We know that the compound wave form does not exhibit such consecutively recurring displacement. We have shown definitely that the sensation of a continuous tone in a clang is not dependent upon the consecutive recurrence of its period. Large gaps may occur before a period is again repeated. For example, the sensation of a continuous tone of the order of 900 cycles occurs even though the period of 1/900 of a second recurs only at the rate of 100 times per second. The greater the rate of recurrence of a given period, the louder is the tone. This is in accord with what we know concerning resonance. This fact does not run contrary to resonance theories of hearing. If selected resonance does take place on the basilar membrane, it suggests that damping in the cochlea is not as great as it has been supposed. This, however, is a mooted point and is irrelevant in our present discussion.

Further researches are going forward to discover masking effects of one characteristic of the wave by another to determine the thresholds of relative amplitude of characteristics of the complex wave for hearing.

Another group of researches has been concerned with auditory fusion where consecutive wave form varies. This follows the lead of Metfessel[12] who coined the term "sonance" to represent auditory qualities which depend upon variations of consecutive sound waves. Metfessel, nine years ago, pointed out that the vibrate in a singer's voice added a richness or liveliness to an otherwise constant pitch. Subsequently, Tiffin experimented to determine the nature of vibrate yielding various perceptual effects.

We know that the character of voice and instrumental sounds varies with the wave form and that training studies are now under way, under the direction of Seashore of Iowa, which set-up a standard wave form for the singer to produce, and that where the singer has finally reproduced the desired wave form, there is a desired quality in perception.

We have experimentally produced a pattern of sound waves each wave length or period of which has been slightly shorter and, in some cases the reverse, than the preceding one, thus producing what the singer knows as a slide. If such a pattern is of short duration, even with a range as great as two octaves, the observer reports a sound which has a more or less definite pitch located in the middle of the range but with a character wholly different from a tone of that perceived note. The human voice illustrates such patterns very well. Usually in the utterance of a single syllable, we phonate them in sliding fashion and unless the slide is pronounced both in range and duration the syllable by itself is rarely perceived as a definite slide but is allocated to a rather definite pitch on the musical scale, but with a character quite unique. We have begun researches in such patterns of a voice inflection to determine their various perceptual effects and, if possible, to set up standards in the training of speech since intonation is a part of language.

In this paper is presented evidence to support Seashore's dictum, that everything we hear is referable to the sound wave and that the pattern of configuration of the wave are series of waves, affords the basis for psychophysical studies in sound.

UTILIZATION OF SOME FARM WASTES

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In considering the utilization of any waste material for the manufacture of new products it is of importance to study some factors connected with the waste material as well as those of the products themselves. What are the possible uses of the products? What are the markets for them? Can they compete in price with others already available? Can entirely new uses and applications for them be found? Is it possible to make them in large enough

[12] *Psychol. Rev.*, 1926, 33, 459–466.