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HEARING

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Recent investigations dealing with the analysis of tones and vowels indicate the need of a more or less radical revision of some of the fundamental views of hearing. The most striking results reported during 1913 are probably those of Jaensch (4). This author has devised a unique synthetic method for the study of vowel sounds. He describes his apparatus as a *selenium siren*. The selenium cell is known to be very sensitive to light stimuli. The light to which the cell is exposed is furnished by a projection apparatus. To provide the conditions of a simple sine-wave of measurable vibration rate, a rotating disk with hatched edge is introduced between the source of light and the cell. Combinations of disks and modifications in the hatching provide all manner of complex vibratory stimuli. The cell is connected with a telephone-receiver whose membrane is set in vibration to produce the corresponding sound.

The net result of the investigation is that any disturbance in the regularity of a sine-wave gives a noise, but if the disturbance be sufficiently uniform to maintain an average value without too great a mean variation, a vowel sound is heard. These disturbances may be introduced in different ways. The addition of sine-waves of varying frequencies, which, however, preserve a constant average, changes the tone into a vowel sound. The same effect may be secured with a constant wave-length, by an alteration of phase in short intervals. Even superimposed curves in the ratio of 3 : 4 or 4 : 3 were found to give vowel character to the lower tone, which is at the same time intensified. As Rudolph Koenig first indicated, and recent investigators have clearly demonstrated, the principal vowels are distributed at intervals which approximate

octave distances. The peculiar pitch of a vowel is determined, then, by the average which all the single vibrations must approach. The vowel quality is clearest at a certain mean variation; beyond that it becomes obscured in a more or less undifferentiated noise.

The author concludes that the noise sense is distinct from the tone sense, and that vowels are the specific qualities of noise. He also contends that the sense of noise is genetically prior to the sense of tone, and that Köhler's results, which seemed to show that vowels are qualities of the tone sense, were erroneous. A pure tone, however, which has the vibration-frequency of a certain vowel, will resemble that vowel because of the fact that the tone sense, being more recent in the history of the race, also arouses at the same time more or less of the older and more fundamental noise character of sound. In the case of very low and very high tones, the musical quality and pitch are lost. There remain for these regions noises having the qualities of certain consonants, *m* for the low region and *s* for the high. The author upholds Hermann's "formant" theory together with the conclusion that the vowel sound and the tone upon which it is sung are in large measure independent phenomena. By his synthetic method he finds it possible to vary the vowel with constant pitch, and also to vary the pitch with a constant vowel.

Köhler (6) in a brief communication deals first with some observations on high tones which lead him to believe that the limit of hearing as set for 20,000 vibrations is too low. The *s*-sound is produced at about 8,400 vibrations. *f* appears an octave higher. He regards the latter as a pure tone since it can be eliminated by suitable interference apparatus. With yet higher frequencies, the *f* recedes and a *ch*-sound appears. Interference eliminates this up to 30,000 vibrations. If the octave law holds, we should expect this sound to occur with tones of 34,000 vibrations, at least, and probably vary on upwards so that the limit of hearing would fall between 34,000 and 68,000 vibrations. Confirmation for this view is found in the fact that pathological cases of deafness for high tones also indicate deafness for the consonants *s*, *f* and *ch*.

Although these results are in line with Köhler's well-known theory,¹ they do not seem to be necessarily at variance with Jaensch's contentions, since it is improbable that the interference tubes employed were adjusted with sufficient delicacy to eliminate the adjacent frequencies, which, on the Jaensch theory, are the true producers of the formants in question. It is therefore possible

¹ Cf. this journal, 1911, 8, 96f.

that sounds heard above 20,000 vibration-frequency are no longer tones but noises.

Köhler's second note deals with the theory of clangs. His observations here bring him also into touch with Jaensch, though again unconsciously. He now finds that it is not alone the single partial corresponding to the vibration-frequency of the vowel which contributes to its appearance in a clang, but all the partials of a certain regional valence. Thus he finds that when *a* is sung on a fundamental of 340 vibrations, and all the partials save 1,050—the approximate pitch of *a*—are eliminated, the vowel tends towards *m*, but if 1,360 is permitted to remain, a very good *a* is possible. He concludes that the partials of a clang are relatively weak in a sung vowel. They do not remain side by side as individual components of the clang, but enter into a resultant totality. That which we are able to analyze out of the total clang is not the partial in its full individuality, but rather something left over from the combined totality, and of relative unimportance. In extenuation of these conclusions, a tentative theory is offered of the physiological processes involved. In this the author suggests that the resonators of the basilar membrane are not single fibers, but regional segments corresponding to the different vowel qualities. The intermediate tones between the vowel tones are thus produced by the combined activity of different resonators. A substantiation of these suggestions is sought in the work upon animals, where it has been shown that continued stimulation by certain tones destroys the organs of the cochlea, low tones attacking the tip and high tones the base of the membrane. The amount of destruction, however, has proven too great to be in full accord with the Helmholtz hypothesis. But if the resonators are not numerous, but few in number, this discrepancy is accounted for.

Baley (1) reports some interesting results which may be correlated with Köhler's theoretical suggestions. This investigator finds that several tones, differing by small but equal vibration-frequency, when simultaneously sounded, have a tendency to flow together into a single resultant tone, whose pitch is that of the arithmetic mean of the several tones. This tendency is so strong that, in the middle region of the scale, even ten tones embracing an interval of a half-tone may be thus united into one mean tone. The phenomenon occurs after a shock which lasts for a short time, and is dependent to some extent upon the position of the head. Yet even in unfavorable positions, the number of discriminable

tones is less than the actual number sounded. With the addition of tones on either side of a small interval, the impurity of the interval is not increased, although an unpleasant effect, due to the noisy and confused character of the complex sound, is experienced.

Révész (13), whose experiments with v. Liebermann were reported last year,¹ has since published a brochure in which the general bearings of his distinction of tonal quality and pitch upon music are given. Certain of his conclusions are in accord with Jaensch's views, since he finds the vowel series to be independent of both pitch and quality. v. Liebermann, who is deaf for quality in certain regions of the scale, still recognized without difficulty the vowels of this region, while another observer, who was quite deaf for tones above c^3 , could still detect the vowels which occur at these pitches. He, therefore, also refutes Köhler's original view that vowel quality is the single characteristic of tones, and concludes that the tonal series is made up of three subsidiary series, namely, pitch, musical- and vowel-quality. Regarding "absolute pitch," he finds two distinct phenomena: absolute pitch in the true sense, and absolute quality. The first is acquired, the second is apparently innate, yet the first is found without the second, the second never without the first.

In his study of the musical interval, he finds both pitch and quality to be involved. Distance alone does not determine the interval, because the same interval in different regions of the scale gives an impression of different distances. In addition to pitch-distance there must also be a quality-distance, which he terms a "segment." Equal segments are not always equal intervals, because the segment remains the same when its qualities extend beyond the range of an octave. In successive tones the appearance of the interval is the foundation of melody. With simultaneous tones—harmony—pitch rather than quality is the more important factor, as the phenomenon of "orthosymphony" has shown.

The painstaking experiments of v. Maltzew (9) deal with the reliability of judging successive intervals in the high and low regions of the scale. The common musical intervals were employed, and for the higher register they fell between c^3 and c^6 . All were within the octave range, and were judged both as ascending and descending steps. Errors in judgment were found to increase progressively with increased pitch. Consonant intervals were judged with more reliability than dissonant intervals, except in

¹ Cf. this journal, 1913, 10, 107f.

the case of seconds, the larger intervals being less reliable and the errors more widely distributed than the smaller. Two kinds of error were prominent: (1) the confusion of neighboring intervals, which is most frequent when the interval is small; (2) the confusion of intervals having a similar degree of consonance.

A consideration of the parts played by fusion and distance in the judgments led to the conclusion that neither can be offered in explanation of the results. If it were chiefly a matter of either or both, there should be no marked difference in judging ascending and descending intervals, yet the latter are much less reliable than the former. The author infers, therefore, a qualitative individuality of musical steps, a content of interval which is not referable either to fusion or distance. This "Schritt- oder Übergangserlebnis" is in many ways identical with Révész's concept of the "segment." Marked tendencies were noted to substitute smaller for larger intervals, and familiar or frequent for unfamiliar or infrequent intervals. There was also discovered in the higher region a normal "false-hearing," which occasions confusion among common intervals such as the octave and major sixth. The reason is that the higher tone is heard at a lower pitch than it actually possesses. A perseverative tendency is also operative at times, which occasions the recurrence not only of certain tones, but also of certain intervals. In the lower region of the scale the errors were found to be of a similar nature, although the presence of overtones often added to the difficulty of making reliable judgments.

Kemp's investigation (5) dealt mainly with direct observations on simultaneous clangs, produced by the tonometer, in comparing groups of two and three with reference to their degree of fusion. The experience of fusion is defined as a characteristic, unanalyzable content. As secondary features are noted the unity of the experience and the incomplete analysis of the clangs involved. The main result of these experiments is the distinction of four principal characteristics which contribute to the experience of consonance, each of which possesses its own peculiar features. These are: fusion, sensory agreeableness (*sinnliche Wohlklang*), sensory conformity (*sinnliche Zusammenpassen*) and harmonic conformity (*harmonische Zusammenpassen*). It was possible for the observers to differentiate these and to establish differences in the order of musical intervals when their judgments were based upon these different points of view. The following table indicates these differences of order, the highest degrees being given first:—

Fusion	Sensory Agreeableness	Sensory Conformity	Harmonic Conformity
{ Fifth } { Fourth }	Major Third and Major Sixth	{ Fifth } { Major Third and } { Major Sixth }	{ Fifth and } { Major Third }
Major Third	Fifth		{ Major Sixth and } { Minor Third }
{ Sixths and } { Minor Third }	Fourth Minor Sixth and Minor Third	{ Fourth } { Minor Third and } { Minor Sixth }	{ Fourth and } { Minor Sixth }

The complexity of the experience of consonance is further indicated by the following table, in which the Roman numerals, I., II., III., measure corresponding degrees:

	Fusion	Sens. Agr.	Sens. Conf.	Harm. Conf.
Fifth.....	I.	II.	I.	I.
Fourth.....	I.	III.	III.	III.
Major Third.....	II.	I.	I.	I.
Minor Third.....	III.	III.	III.	II.
Major Sixth.....	III.	I.	I.	I.
Minor Sixth.....	III.	III.	III.	III.

Experiments were then performed to compare the fusion value of two-tone and three-tone chords, and especially to test Külpe's law, that with equal degrees of fusion among the intervals of a chord, a higher total fusion is obtained when the more highly fused interval is lowest in the chord. Stumpf has contended that the fusion of an interval is not affected by the addition of a third tone. The difference between these authorities is adjusted, and both laws are found to be valid. Stumpf's law appears to be applicable to an "ideal" fusion, and its operation is approximated when the observer abstracts from the added tone. The effect of the third tone is, however, in accordance with Külpe's law when the abstraction is incomplete. With the attention directed to sensory agreeableness rather than to pure fusion, a change in the effect was always found when the third tone was added, irrespective of complete or incomplete abstraction, but the change was not the same as that which occurs when pure fusion is the standard of judgment. Since an added tone does not necessarily alter the fusion of an interval, but does, under the same conditions, invariably change its character of agreeableness, the conclusion is reached that feeling is not referable to the sensory components, as such. Stumpf's opinion that the agreeableness of chords is to be reckoned among the sensory feelings, is therefore questioned.

Waiblinger (18), in a brief article, elaborates a previous pronouncement that the constructive elements of modern European

music are the *fifth* and *major third*. In the major triad, *c-e-g*, the "tonic effect" is noted in the tendency of both *e* and *g* towards *c*. In the minor triad, *c-eb-g*, *g* again tends towards *c*, but also towards *eb*. This is held to account for the incomplete satisfaction, or "minor effect" in music. Both the scale and its various triads are then analyzed with respect to these "convergent" and "divergent" tendencies. It is found that in the major scale there occur four convergent and three divergent chords, while in the minor scale two are convergent and five divergent. Taken together, and eliminating identical triads, there appear to be four convergent and eight divergent three-tone chords. An attempt is then made to show that musical effects, both melodic and harmonic, are resolvable into these tendencies occasioned by the tonic effect. The analyses are somewhat difficult to follow, since they are expressed throughout in terms of the letters of the scale, rather than by a numerical notation to indicate the relationships involved.

Krüger (7) in a brief abstract summarizes his well-known theory of consonance, and criticizes some of the objections to it which have been raised by Lipps and Stumpf. "The fundamental phenomenon of all dissonance consists in the existence of a *mistuned unisone* at the bottom of the total acoustic complex." The chief objections to the theory are declared to rest upon the neglect of associative factors, which play a large part in the concrete perception of tonal combinations. The immediate perception of consonance and dissonance is not independent of absolute pitch. Psychologically speaking, consonance and dissonance seem to have originated within the limits of the human voice.

K. L. Schaefer (14) has reported five cases in which combination-tones were perceived after loss of the drum or middle ear apparatus. Difference-tones of every order and pitch, even the very low tones, can apparently be heard in the absence of the ear drum. In the author's opinion the seat of difference-tones is the oval window. Peterson (11), however, referring to Clemens Schaefer's conclusion (1910) that combination-tones may arise in the fluid of the inner ear, calls attention to the fact that he had reached this same conclusion and had published results in its support in 1907. He also notes that his experimental results have demonstrated that subjective combination-tones do not appear after the fundamentals, but simultaneously with them.

Meyer (10) considers Bocci's recent demand that more attention be given to the morphological peculiarities of the organ of Corti

in devising theories of hearing, and objects to the imputation that his theory is open to this criticism. In reply, he maintains that his theory, together with those of Bonnier and ter Kuile are the only ones truly founded upon morphological facts. The three may be regarded as essentially one theory, since all are based upon the ideas of Johannes Müller. After reviewing the contributions of Bonnier and ter Kuile, the author describes his own method of procedure, and defends the use of the mathematical analysis, which he has found to suit the facts of the case better than does the Fourier analysis. The next problem was to apply this method to the mechanical processes of the organs involved. It was found to be applicable to an inelastic, bendable rod, to one end of which a transverse wave-motion is conducted. In conclusion, he propounds nineteen questions and answers concerning the morphological peculiarities of the cochlear organs. Among the points taken up are several dealing with the arch of Corti. This arch, it is maintained, affords a skeletal support which adds strength to the membranous tissues. Furthermore, the widened membrane at the apex of the cochlea provides a greater stimulable area for increased intensities than would be otherwise possible. In accordance with the resonance theory, however, we should expect an opposite distribution of fibers. The advantage of a long canal is to furnish a greater capacity of analysis. Animals having a short canal probably distinguish only high and low tones. A canal without windows would still afford a seat of hearing; the addition of windows simply adds to the sensitivity of the organ.

Peterson (12) in a second article reviews the present situation with regard to conflicting theories of hearing, and concludes that the facts seem to demand a resonance theory of the type indicated by Helmholtz. Three specific objections to the Helmholtz theory are then considered. First, as to the intensity relations of combination-tones, it has been found that difference-tones are sometimes more intensive than their fundamentals. This, he believes, may be readily explained when the difference-tones in question occur at a pitch which is more frequently heard than that of the fundamental. Furthermore, two or more difference-tones often coincide to strengthen each other. The difference-tones which fall between the fundamentals are weak, because the lower fundamental, which is known to acquire increased intensity, obscures them. Second, as to the obliteration of tones by lower loud tones, this he finds to be very slight when the tones are conducted directly through the

skull. He therefore concludes that the interference ordinarily observed is largely physical, and external to the cochlea. Third, the perception of the direction of sound by means of phase-differences is referred to "some cortical region" which may take note "of a slight disparity in phase, so to speak, of the neural impulses from the two ears."

Goebel (3) reports experiments upon the prepared ear of a hen under microscopic examination. His results indicate that the acoustic activity of the fowl's cochlea is similar to that of the maculæ in mammals, and seems to present a link between the human maculæ and cochlea. The direct cause of stimulation in all such organs is to be sought in the transformation and displacement of a membrane (*Deckhaut*). Thus, the underlying hair-cells are stimulated. The inner papillæ of the basal membrane (*Grundhaut*), in which the hair cells are embedded, serve for high tones, and the outer ones for low tones. In addition, the cochlear region is in general more sensitive to medium and high tones, and the macular region to low tones.

Beyer (2) reports observations on patients with defects of the middle ear, and finds that even the lowest tones may be heard in the absence of the drum and ossicles, including the stirrup-plate. The intactness of the labyrinthine membranes is apparently the only absolute condition for the proper functioning of the cochlea. The middle-ear apparatus is regarded as a mechanism for subtle regulation of the labyrinthine water column. Schulze (15) supports the view that the ossicles vibrate with the fluid of the cochlear canal as a fixed or incompressible body, because the linear dimensions of the bones are so small, when compared with the wave-lengths of the more usually heard tones, and, furthermore, because the vibration-frequencies of the bones are so much greater than those of the highest tones. Kutvirt (8) investigated 198 new-born babes, mostly within ten minutes to twenty-four hours after birth. He estimates that three-fourths of the new-born react to sound within twenty-four hours. Acuity or weakness of hearing he finds to be in relation to the length and difficulty of birth.

Waetzmänn's book (17) is said to give a careful review of the resonance theories of hearing, with special reference to the views of Helmholtz. It is chiefly the physical problems which are dealt with.

Urban's (16) audiometer, which may be mentioned in conclusion, has already been described by Seashore in this journal.¹

¹ Cf. this journal, 1914, 11, p. 20.

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¹ For my references to the articles of Beyer, Kutvirt, Schaefer, Schulze, and Waetzmann, I am indebted to the review notices of H. Beyer and W. Kohler in the *Zsch. f. Psychol.*, 1913, 66, 290-293, and of H. Keller in the *Arch. f. d. ges. Psychol.*, 1913, 28, 129-130.