THE PERCEPTION OF CONSONANCE AND DISSONANCE

BY

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The object of this investigation is first to establish the ranking order of the musical intervals within the octave c′c″ with respect to the degree of consonance, and second, to standardize a measurement of the perception of consonance.*

The term consonance has been variously defined, and has been used to convey several meanings. While in general, it

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has been used with reference to the agreement of simultaneous tones, we find each investigator or theorizer emphasizing some one factor in this complex phenomenon to the exclusion of one or two other factors of similar importance. This diversity of definition results in a corresponding diversity in the ranking order of the common musical intervals as to their degree of consonance. The method in this investigation will, therefore, be: first to determine the factors which enter into the perception of consonance, second, with these factors as a basis, to rank the intervals according to their relative degree of consonance or dissonance, third, to evaluate the ability to perceive consonance in terms of this ranking.

HISTORICAL

A brief resumé of the essential facts bearing most directly on this problem may be presented from the points of view of the theories and definitions of consonance, experimental methods, and ranking of intervals.

Definitions and experimental methods

Pythagoras discovered the regularity of the aliquot division of the vibrating string, and thereby gave a numerical value to the notes of the scale. Since then, the regularity of the vibration frequencies of tones has been known and accepted as a basis of consonance. No thought of the manner in which the mind perceives and distinguishes between consonances and dissonances occurred to the ancient Greeks; the perception was taken for granted. The pleasantness of some intervals and the unpleasantness of others were the only criteria that were present to their minds.

This conception prevailed even up to the time of *Leibnitz* (10) who was the first to call attention of scientists to the fact that the mind did not really analyze or perceive the actual number or the numerical regularity of the vibration frequencies in the intervals. Nevertheless, Leibnitz found no other explanation of this complex phenomenon in consciousness. Therefore, he appealed to the subconscious mind for a solution of the problem and came to the conclusion that the mind unconsciously calculated the ratios of the vibration frequencies.

"Die Musik ist ein verborgenes Rechnen des Geistes, welcher nicht weiss, das es zählt. Denn er tut Vieles mit verwirrten oder unmerklichen Perzeptionen, was er in deutlicher Apperzeption nicht wahrnehmen kann. Die irren, welche meinen, es geschehe nichts in der Seele, dessen sie selbst nicht bewusst sei. Obwohl also die Seele nicht fühlt, dass sie zählt, fühlt sie doch das Ergebnis dieser unmerklichen Zählung, d. h. das aus ihr fliessende Vergnügen bei den Konsonanzen, Missvergnügen bei den Dissonanzen. Denn aus vielen unmerklichen Übereinstimmungen entsteht das Vergnügen."

This unconscious calculation produces a consonant interval when the ratio number does not exceed five. "Wir zählen in der Musik nicht über fünf", says Leibnitz.

Euler (2) agreeing essentially with Leibnitz' explanation, interpreted the feeling of agreeableness of the consonances as due to the ease of perceiving order or coherence in the simpler ratios. He divided the consonances into ten classes, ranking them according to the simplicity of their ratios. Euler was the first scientist to formulate the fundamental law of consonance that "the degree of consonance is in a direct ratio to the magnitude of the common divisor of the vibration frequencies."

Schopenhauer (24) explained the mental processes that accompany the perception of consonances and dissonances in greater detail and regarded music as the highest expression of the divine in the world. It owes its great power to the essential relation which it bears to the human will. Consonances are the result of a rational relation of the vibration frequencies of two notes that can be expressed by small numbers. Their constantly recurring coincidences can be apprehended more readily by consciousness than those whose coincidences are less frequent. The notes, which are the result of this relation, blend. Dissonance is just the reverse of this state, but both consonance and dissonance comprise different degrees, the one shading into the other.

"Music is a means of making rational and irrational relations of numbers comprehensible, not like arithmetic by the help of the concept, but by bringing them to a knowledge which is perfectly, directly and simultaneously sensible. Consonances and dissonances, with their innumerable degrees of difference, portray the movements of the human will in its essential feelings of satisfaction and dissatisfaction."

The distinguishing factor of consonance would accordingly be this feeling of satisfaction portrayed by objectifying the movements of the human will through harmony.

The method of investigation with regard to musical intervals was theoretical, supplemented by but meagre and indeterminate empirical data, up to the time of *Helmholtz* (4), who gave an impetus to experimental investigation through his analysis of sound in the attempt to demonstrate that consonance is dependent upon the coincidences of upper partial tones which result in a relative absence of beats. The important criterion of consonance for Helmholtz is *smoothness*. His definition reads as follows:

"Consonance is a continuous, dissonance, an intermittent sensation of tone. Two consonant tones flow on smoothly, side by side in an undisturbed stream; dissonant tones cut one another up into separate pulses of tone." Consonance is dependent upon "certain determinate ratios between pitch numbers which do not give rise to beats, or only such beats as possess so minimal an intensity as to produce no unpleasant disturbance of the united sound."

On this theory Helmholtz constructed his consonance curve, showing the relative degrees of consonance on the basis of the number of beats possessed by the different intervals as quoted in Table I below.

As early as 1751 *Tartini* (27) called attention to the importance of combination tones, but it was left for Preyer to prepare the way for Krüger's exposition on the influence of difference tones on consonance.

Preyer's (21) experiments with tones, whose overtones and combination tones were excluded, tend to establish the fact that the feeling of pleasantness and unpleasantness of consonances and dissonances is dependent on the overtones and difference tones of the clang.

"The beats of the overtones and combination tones are," says Preyer, "a further criterion, for through them the smoothness of the sensation is destroyed. Yet they do not suffice to explain dissonances, as these occur without beats. The well recognized consonances must give the least combination tones, and the most unpleasant dissonances, the most; the former, the most coincidences, the latter, the least."

Stumpf is the pioneer in the purely psychological field, as he introduces a new point of departure. Stumpf (30) identifies consonance with tonal fusion:

"The sounding together of two tones approaches sometimes more, sometimes less, the impression of unity, and it is apparent that this is more the case, the more consonant the interval is. Even if we recognize the tones as two and separate from one another, yet they form a totality in the sensation, and this totality appears to us as possessing a greater or less degree of unity."

Thus Stumpf postulates "Verschmelzung" as the distinguishing criterion of the degree of consonance. He admits that other criteria exist, but this one factor is the only one necessary in ranking consonances and dissonances. Concerning this factor Stumpf writes as follows:

"Kann der Unterschied konsonanter und dissonanter Töne weder in unbewussten Funktionen noch in den Gefühlen liegen, so wird man ihn in den Tonempfindungen als solchen zu suchen haben, wo ihn denn auch Helmholtz suchte. Da er nun aber nicht in der begleitenden Obertönen und nicht in den Schwebungen liegen kann, so muss er eben in den beiden Tönen selbst liegen, welche wir konsonant oder dissonant nennen. Es ist, soviel ich sehe, nur ein Merkmal, das sich hier arbeitet: die *Verschmelzung* gleichzeitiger Töne."

As a correlate to his psychological theory, Stumpf proposes a physiological basis in his theory of "specific energy" which gives to each fusion its individual character.

Following out the theory that the better the consonance, the better is the fusion, Stumpf applied the technique of experimental psychology. That most consonant intervals are the most difficult to analyze into their constituent elements, is the basis of his method of analysis; and by this method he attempted to rank the intervals. He tested the perception of consonance with Appunn's Tonmesser and with the tones of the pipe organ, varying the quality of tone further by using the different stops of the organ, the observers being requested to record whether they perceived one or two tones, *i.e.*, whether or not the two objective tones served as one subjective. The number of errors for each two-clang constitute a measurement of the degree of consonance of that interval, and determined the ranking order.

Stumpf (29) found no difference between major thirds and sixths, yet he admits that there may be a fine degree of gradation between major and minor thirds and major and minor sixths. All the dissonances are ranked in one group as possessing the same degrees of dissonance, with the observation that the natural seventh, 4:7 may be a slightly better fusion than the other dissonances.

Stumpf (27) lays down the following laws of tonal fusion:

1. Fusion depends on the so-called ratio of vibrations.

2. The degrees of fusion are independent of the tonal region within the tonal range.

3. The degree of fusion is independent of the intensity, whether indeed it be the absolute or relative intensity, so long as the tones remain distinguishable.

4. The degree of fusion is not influenced by the addition of a third or fourth tone.

5. Very minimal deviations of the number of vibrations from the ratio create no perceptible difference in the degree of fusion. If the deviation is increased, the fusion in all pairs of tones, except the lowest degrees, passes into this degree without running through the intermediate degrees, if any. The rapidity of this transition is proportionate to the degree of the initial fusion.

6. Fusion remains and retains its degree when both tones do not affect the same ear.

7. Fusion remains in the mere representation of the imagination.

8. If we proceed above the octave, the same degrees of fusion recur with the ratio of vibrations increased one or more octaves. m : n 2x as m : n if m is less than n and x equals a small whole number.

Faist (3), following out Stumpf's method literally, attempted to verify these laws of fusion, in experiments on the pipe organ with the use of its different stops. In a preliminary experiment he employed what he termed "the direct method", *i.e.,* "the method of serial rank, in distinction from the indirect method used by Stumpf. This method involves the ranking of the intervals directly, keeping the whole series in mind and giving them their relative rank. The result of Faist's experiments tended to verify all of the laws postulated by Stumpf, except the third. He found that the relative intensity of the components of the interval did influence the perception of fusion.

Both *Meyer* (14) and *Stumpf* (34) have also attempted to measure consonance by means of reaction time. The consonances were always distinguished from the dissonances but this method showed no consistency in the ranking of the other intervals, and it was rejected by Meyer as unreliable. Meyer also investigated the effect of variations in intensity, and found that the less consonant the intervals are, the greater is the difficulty of recognizing them in their minimal intensity, and that the relative loss of intensity of higher tones synchronous with lower tones has no perceptible influence within the octave. As to the effect of presenting one tone to each ear, for the purpose of excluding the difference tones, Meyer affirms that this exclusion results in a loss of ability to rank the more difficult intervals, although consonances are readily distinguished from dissonances.

Buch (1) criticizes Stumpf for neglecting to regulate the conditions of his experiments. He thinks it unlikely that experiments made with the organ of the "Domkirche in Halle" could be carefully enough regulated to be trustworthy. Accordingly, Buch constructed a special instrument, using the organ, by means of which he regulated the intensity, duration, and pitch of the intervals. His experiments were made with, and without analysis. He makes a distinction between making a judgment from the point of view of analysis and that of synthesis. He developed a twofold ranking of the intervals, one on the basis of fusion, and the other on the basis of smoothness.

Lipps' (11) explanation of consonance is based on the rhythmic coincidences of the tonal series. The rhythmic coincidences have their correlate in the psychic processes. For our immediate consciousness, consonance appears as an agreement in unity, or, as Lipps expresses it, "eine Zusammengehörigkeit, eine einheitlichkeit". Furthermore, it is an agreement that gives rise to a feeling of satisfaction. "Consonanz ist ein Verhältnis zwischen Tönen in dessen Natur es liegt, Befriedigung zu erzeugen." The most perfect consonance does not give rise to the most satisfaction as it is "empty and monotonous."

Meinong and Witasek (8) introduced the method of "paired comparisons" in determining the ranking of the intervals, as played on the tones of the violin. They state their conclusion briefly as follows:

" . . . zwei Töne um so mehr verschmelzen, (a) je näher ihnen der Klang steht, auf den als Partialtöne bezogen werden können, (b) je grösserer Zahlenwert dem Verhältnis ihrer Schwingungzahlen zukommt."

Their results are interpreted in terms of the Ebbinghaus theory of hearing. Their experiments demonstrate that the method of paired comparisons may be used to good advantage in the testing of the perception of the degree of consonance and the ranking of the intervals. Meyer has questioned the reliability of their results because of the inaccuracy of the violin as to pitch.

Using the method of "paired comparisons" with the tones of Appunn's Tonmesser, tuned to the accuracy of 1 v.d., *Pear* (19) determined the ranking of the intervals in degree of consonance. The observers recorded the intervals compared as equal, plus, minus, or doubtful in preference, and the ranking order was computed on the basis of the number of "votes" given each interval. He considered fusion, analyzability, pleasantness and unpleasantness, and association, the factors which might enter into the perception of consonance. These factors were explained and illustrated for the observer, and he was instructed to make his judgment on the basis of fusion."

Wundt's explanation (41) shows that consonance is dependent on the confluence of various factors. There are four criteria that are more or less essential conditions of this phenomenon, namely: (1) Purity, the number of primary difference-tones of different orders, which combine to give the consonant chords a distinct or individual character; (2) uniformity, the uniform relation of the intervals to the compass of the scale; (3) the discrimination of consonance by the recognition of the tonal elements, dependent on the direct and indirect relation of clangs; (4) the fusion of tones into a "clang unity" through the dominance of one of the tonal elements—the one which arouses the most intensive associations.

Wundt explains dissonance as a "diffuse tonal fusion." The diffuse nature of dissonance arises, on the one hand, from the physiological condition of tone absorption; on the other, psychologically, through the distinct differentiation of tones arising from the compounding of the interfering difference-tones. Consonance is, therefore, an act of the apperceptive faculty of mind, which synthesizes the tones into a unity. The attention concentrates on the tonal element that carries with it the strongest associations, and brings all the related phenomena to a focus with the same.

Krueger (8) adopts the first criterion of Wundt as the explanation of consonance and dissonance. A two-clang always possesses five difference-tones. The pitch of each is determined by the formula h-l, 2h-l, 3h-l, etc. These difference-tones are related to every other simultaneous tone in the clang exactly in the same manner as the simultaneous primary tones. Thus, coincidences, beats, intermediate tones result from these difference-tones, and influence our perception of consonance. The best consonances are those that are characterized by the absence of distinct difference-tones. Dissonances are the result of difference-tones in the two-clang which interfere with one another. The degree of dissonance depends on the number of these interfering difference-tones.

Krueger (6) bases his theory on empirical data. His method of experimentation had for its object the determination of the number and pitch of the difference-tones present in the various intervals. In order to exclude the overtones, he used the tuning forks. The observer was requested to record the number of difference-tones in each interval, and to identify the pitch of each on a Tonmesser.

Stumpf (29) has criticized Krueger's results as not showing sufficient consistency to substantiate his theory. As another proof against the theory he states that consonance and dissonance are perceived even when the tones composing the two-clang are presented one to each ear, thereby excluding the possibility of difference-tones.

To sum up the historical review, we have gathered the data into a table by different authorities and methods, showing the order of consonances and dissonances:

This historical summary shows that the factors emphasized in the course of investigating this complex phenomenon have been: the feeling of satisfaction, agreement of tones, smoothness, fusion, and purity, with slight variants of these. We recognize the fact throughout that the order of the intervals tends to correspond to the simplicity of the ratios, expressing this mathematical relationship. That the feeling of satisfaction, or the feeling of pleasantness, is too variable and general a factor to be used as a constant criterion, is evidenced by the fact that it has not entered as a determining factor in any of the experimental investigations.

The most fundamental factor in ranking consonance and dissonance may be termed *blending,* the tendency of tones to merge into a composite tone that shows a more or less distinct agreement of constituent parts in so far as they are perceived

RANKING OF INTERVALS TABLE I—*Historical order of consonances and dissonances*

Authors	*Date*	*Instrument*	*Method*	*Criteria*	1:2 $c' c''$	2:3 $c' g'$	3:4 $c' f'$	4:5 $c' e'$	3:5 $c' a'$	5:6 $c' e'^b$	5:8 $c' a'^b$	5:7 $c' g'^b$	9:5 $c' b'^b$	9:8 $c' d'$	15:8 $c' b'$	15:16 $c' d'^b$
Franco of Cologne	12th cent.		Theoretical	Pleasantness	1	2	2	3	4	3	4	5	5	5	5	5
Euler	1739		Mathematical	Pleasantness	1	2	3	4	5	6	7	8	9	10	11	12
Helmholtz	1863	Various	Coincidences of upper partials Beats	Smoothness	1	2	3	5	4	6	7	8	9	8	10	11
Stumpf	1883	Pipe organ (Different stops)	Analysis	Fusion	1	2	3	5	4	6	7	8	9	8	10	11
Faist	1897	Pipe organ (Different stops)	1) Direct 2) Analysis	Fusion Fusion	1	2	3	4	4	4	4	5	5	5	5	5
Meinong and Witasek	1897	Violin	Paired comparisons	Fusion	1	2	3	5	6	9	4	7	8	10		
Lipps	1899		Theoretical	Rhythmic coincidences	1	2	3	4	5	6	7	8	9	10	11	12
Buch	1900	Pipe organ Tonmesser	Analysis	Fusion Smoothness	1	2	3	3	3	4	4	4		5	6	
Krueger	1903	Tuning forks	Analysis	Purity	1	2	3	4	3	6	5	5	4	7		
Pear	1911	Tonmesser	Paired comparisons	Fusion	1	2	3	4	5	7	6		8	9	10	11

*The mathematical ratios are in some cases only approximate, *e. g.* the ratios for $c'g'^b$ and $c'b'^b$, 5:7 and 9:5. The ratios differing slightly for the different authorities.

as members. This term has been used by some authorities as synonymous with consonance and to express the agreement of tones. The recurrent similarities of which the early scientists spoke and which Schopenhauer and Lipps have emphasized might also be classed under the category of blending. Preyer, Wundt, and Krueger have emphasized the importance of purity as a criterion and it has proved to be a specific mark of the agreement of the component tones.

Authorities agree with respect to the ranking of the octave and the fifth, first, and second, respectively; but, for the remaining intervals, we find disagreements due to the quality of tone, to the variation of the method of investigation, and to the variation in the basis of judgment.

It may never become possible to arrive at absolute agreement in the order of ranking, but it is plain from this brief historical survey that much may be gained in that direction by a clearer conception in regard to the nature of consonance, the analysis of conditions, and specific definition of terms for the purpose of experimental control. This will be the object of our next part.

ANALYSIS AND RANKING OF INTERVALS

The following series of experiments are the result of two years of investigation in the psychological laboratory of the State University of Iowa, extending from the fall of 1911 to the fall of 1913.

Preliminary Study of Apparatus

In a preliminary series of experiments, the reed organ, the pipe organ, blown bottles, the dichord, tuning forks, and the piano were tested with reference to their adaptability and efficiency in producing tones for an accurate measurement of the perception of consonance. Ten experienced observers were given the test, here designated as Series A, and were requested to give introspections with regard to the quality of tone. The recommendations which follow are based on this ranking and the introspections of the observers.

The reed organ was supplied with a set of accurately tuned reeds, even temperament. The pipe organ pipes were of the open wooden type, producing a soft mellow tone. These were tuned to correspond to a set of forks tuned in just intonation, or forks of even temperament as the case required. The "blown bottles" were selected instead of the Stern tone-variators on account of their being more easily manipulated, *i.e.*, it was possible to have a complete series tuned permanently. This apparatus consisted of ordinary bottles of cylindrical shape, which, when empty, gave approximately the tone of c′, 256 v.d. They were tuned in just intonation by filling with paraffin. The mouthpieces were firmly attached to the bottles. The organ pipes and the "blown bottles" were energized by compressed air under constant pressure.

The dichord (Spearman's) was strung with a heavy piano string (wound wire), and was sounded by stroking with a cello bow. The wound string responds more readily, and the heavy cello bow eliminated the harsh and grating overtones and noises incident to the use of the ordinary wire string and the lighter bow of the violin. To avoid changes in the quality of the tone, the dichord was played in a uniform manner, care being taken to stroke the string evenly near the bridge.

In the early experiment, the forks were sounded mechanically before carefully attuned Helmholtz resonators, but later by a free movement of the hand. In the most successful mechanical devices, the handles of the forks were firmly mounted in rubber casings before the resonators, and were struck by means of hammers, mounted on steel springs. Wooden, cork, rubber and the regular felt piano hammers were tested, and the piano hammer was selected as producing the clearest tone. But, in spite of precautions, the thud incident to striking the fork, proved a distraction and caused impurities and, therefore, presentation by hand proved to be the best method.

The nine intervals, c′c″, c′e′, c′f′, c′g′, c′d′, c′e′, c′a′, c′b′♭, c′d′, were studied as sounded by each of these three instruments in two extensive series, (1) by the method of paired comparisons, and (2) by Stumpf's method of direct analysis; *i.e.*, in the former series, relative consonance was judged for successive pairs upon each of the factors which may constitute consonance, and in the latter a direct judgment was based on fusion alone.

The reed organ was finally rejected because the tone was somewhat harsh and difficulty was experienced in securing a uniform timbre of the tone throughout the octave. The dichord was found impracticable as, beside showing variations in quality with slight variations of pressure and adjustment in bowing, it requires a change of the bridge for each note and is difficult to manipulate. The blown bottles, while producing a clear tone, presented difficulties in regulation. *Sylvester* (37) demonstrated that the pitch of a blown bottle is very difficult to control but we found that variations in the relative intensity of sound and the timbre were far more difficult to control. The inevitable difference in timbre made the tones stand apart in the two-clang in such a way as to be prohibitive.

The instruments available for the test were found to be the piano, the tuning forks, and the pipe organ.

The test of consonance with a rich quality of tone can be given more expeditiously by the piano than by the dichord. The piano offers an advantage in its availability and in the perfection it has reached as a musical instrument. It also has the advantage of being familiar and agreeable. Most of the sources of error, which may arise in the use of the piano, can be effectively guarded against. As three strings are sounded for each tone, each of these must be accurately tuned so that no beats arise in the single tone. The same end may be gained by damping two of the strings, thus leaving only one to vibrate. An accurate piano tuner can, however, eliminate the beats that are present in the single tones of the ordinary piano. To eliminate many of the impurities that may arise from resonance, the soft pedal should be used continuously in the test.

The organ pipes present the difficulty of regulating the wind pressure so as to keep it constant. As with the blown bottle, the variations in intensity and in the adjustment of lips causes considerable variations in the pitch. Uniformity of pressure and accurate adjustment is accomplished in the regular pipe organ by a rather complex mechanism, which it is difficult to improve upon in the laboratory. It is, therefore, best to use a good organ where access to one can be had. The pipe organ of the Methodist Episcopal Church of Iowa City which we used. is a modern two-manual organ, which was in good condition. The most favorable stop for this experiment was found to be the "stopped diapason" which gives a tone intermediate in richness between the rich tones of the piano and the pure tone of the tuning fork. The tones of the organ are, however, not so clear-cut as the piano and tuning fork tones. Therefore, the observer has not the same certainty in his judgments of the organ tones as of the piano or tuning fork tones. Simultaneity in sounding the tones was regulated by opening and closing the stop after the keys of the interval had been pressed down.

The tuning forks are the most reliable in both pitch and timbre. If presented by hand, in a uniform manner, they give clear and distinct tones, which are especially well adapted for a test of consonance. The tuning forks used in these tests were accurately tuned to the tempered scale. The frequencies as recorded on the tonoscope registered: c′—258.6, d′♭—274, d′—290, e′♭ — 308, e′ — 326, f′ — 246, g′♭ — 364, g′ — 387, a′♭ — 410.14, a′ — 435.9, b′♭ — 460.8. b′ — 487.8, c″ — 517.2. Precautions were taken to secure pure tones by sounding the forks in a uniform manner before tuned Helmholtz resonators. The twelve resonators were mounted on the rim of a wheel and the c′ set on the center so that by giving a turn to the wheel any one of these in the rim could be swung into position horizontally to the right of the c′.

In the preliminary experimentation on the quality of the tone, two general facts were fairly well demonstrated. First, it was shown that the ranking of consonance will vary slightly for different qualities of tone. This is expressed quantitatively in later experiments. Second, when by the use of two sets of tuning forks, the just intonation was compared with the tempered intonation, no difference in ranking of the intervals large enough to affect the order resulted from the difference in temperament. This conclusion agrees with Faist's (3) statement with regard to minimal variations in vibration frequencies.

Criteria of consonance and dissonance

It is clear from the historical survey, and it was demonstrated in the preliminary experiments, that the fundamental reason for the great divergence in the ranking by experts and the consequent disparagement of the ranking of consonance and dissonance has been due to the failure to take common ground in the definition of these terms. Our first step was, therefore, to put the various claims of factors involved to a test in a long and painstaking series of analytical tests in which the various possible factors of criteria were isolated and discussed critically under control. This preliminary inquiry resulted in the recognition of the following factors:

For consonance:

1. Blending—a seeming to belong together, to agree.
2. Smoothness—relative freedom from beats.
3. Fusion—a tendency to merge into a single tone, unanalyzable.
4. Purity—resultant analagous to pure tone. (See Wundt.)*

For dissonance:

1. Disagreement—incompatibility.
2. Roughness—harshness, unevenness or intermittence.
3. Disparateness—separateness or seeming to stand apart—analyzable, "twoness".
4. Richness—resultant analogous to rich tone.

In terms of these factors we may then define consonance as follows: *When the two tones of a two-clang tend to blend or fuse and produce a relatively smooth and pure resultant, they are said to be consonant.* Dissonance is the reciprocal of this. "Agreeableness" which has played an important rôle in the popular conception and in the theory is here conspicuous by its absence. The perception of consonance as above defined there-

* Restfulness—a feeling of completeness, finality or satisfaction, with its opposite disquietude—a feeling of incompleteness, needing to be resolved, was first adopted as a fifth criterion, but it soon developed that it must be dropped as it is a variable criterion directly due to progression and association, which must be excluded.

fore becomes a cognitive act of discrimination rather than a mere feeling of agreeableness.

Method of procedure

The above definition, with its analysis into blending, smoothness, fusion and purity displayed on a chart, was read and discussed, giving all of the observers a consistent understanding of the definition.

The observers were instructed to judge each "two-clang" as an aesthetic object by itself, without respect to the effect of progression, meaning, association, or mood, and to make their judgments on each of the above given criteria in turn in separate series of experiments for each of the four criteria.

The experiment was made "with knowledge", and was conducted on the plan of an informal seminar, allowing a discussion of each judgment, but each observer recording his own final judgment. The intervals were sounded simultaneously, with a duration of approximately two seconds, and were repeated as often as requested by any observer—sometimes as many as fifteen or twenty times.

In determining the constant factors that enter into the perception of consonance and the ranking of the musical intervals, one must rely on the introspection and judgment of experienced observers of different types. For this experiment, therefore, eight observers were carefully selected on the basis of their training and fitness for the work.*

Even with the definition of consonance and the control of procedure here adopted, there remain many points of doubt and individual differences in opinion among observers as to the order of consonances. Since it was necessary to arrive at one

* They were the following: Professor C. E. Seashore, Assistant Professor Mabel C. Williams, Professor Edward Schaub, and Professor Robert Fullerton, Dr. Alma D. Schaub, Dr. Thomas Vance, Mr. Hazelette and the writer. Professors Seashore, E. Schaub, and Williams and Fullerton were members of the faculty, the last named being the head of the Department of Vocal Music. Dr. Thomas F. Vance was an advanced student in Psychology; Dr. Alma Devries Schaub had taken her Ph.D. in Psychology; and Mr. Hazelette was a graduate student in Physics and an experienced flute player.

particular order which might be considered a norm, the observers adopted the plan of sitting together in the experiment, proceeding very slowly, and discussing all cases of doubt or difficulty, analyzing the situation, varying the conditions of stimulation, and refining observations. This proved a very great advantage since each of the eight observers, of different types of training, offered to one another criticisms and suggestions for points of view and in this way distinctions were developed and errors of observation were eradicated which might otherwise have passed unnoticed.

Statement of results

As a group of trained observers, we found no difficulty in four-fifths of the sixty-six cases of paired comparisons at the beginning, and, after discussion, the differences of opinion centered about a still smaller number of the cases. Since each observer recorded for himself, we secured eight individual sets of ranking, although all of these were materially modified by the enlightment which came through mutual criticism and the repetition of trials. The record showed for each observer the ranking of the intervals for piano, tuning-fork, and pipe organ, and on each of the four factors, blending, smoothness, fusion, and purity separately. This series we may designate as *Series B.* The results will be stated in Table III after the results of the final test, *Series C,* have been stated in Table II.

It was the original intention to accept the average of these records (Table III) as a norm, but the discussion and mutual criticism was so stimulating and interesting that all the observers agreed to sit again and continue by the same method until all should agree and a unanimous verdict could be handed in as in the case of a jury. This was done with the piano and tuning-forks separately in what is here designated as Experiment Series C. The pipe organ was left out to shorten the labor, in view of the fact that the observers were of one mind that the piano and the tuning-forks were the best instruments available for the rich tones and the pure tones respectively.

The final returns in this series (C) are condensed in Table II, where the record is kept for piano and organ for each of the eleven intervals on blending, smoothness, fusion, and purity in terms of the number of times a given interval was preferred. Since there were twelve intervals, the one that was preferred to every other would have a record of 11, meaning that it was preferred to eleven other intervals, the next one would be preferred to ten other intervals, etc. The actual rank is, therefore, approximately the inverse order of these numbers as is indicated by the Roman numerals.

The intervals are given in this table in the order in which they rank for the piano in the average.

It is manifestly out of the question to combine the ranking on fusion with the ranking of the other three criteria since the former results in a peculiar classification of its own. The other three criteria, however, seem to work together, prove mutually supplementary, and result in a fairly similar order of ranking. (See Table II). These are, therefore, brought together through the average in the last column of Table II, (Fig. 8), which may be regarded as the goal of the experiments in this Part on the order of ranking.

The data of this table are illustrated in Figures 1-8, which are self-explanatory and will aid materially in the interpretation of the table.

Table II is the principal table of facts to be considered here, but Table III is inserted for two purposes: (1) to furnish the tentative data for the pipe organ tones, and (2) to show to what extent the order of rank in Series C deviates from that of Series B (Table II).

The rank for the organ tone stated in Table III would probably not have changed very much if this tone quality had been carried through Series C as was done with the piano and tuning-forks. The change of relative rank for the piano and the tuning-forks from Series B to Series C may be seen by a comparison of these two tables, those in Table III representing the average of independent judgments of the eight observers and Table II the unanimous verdict reached later by the same observers.

While there are normal variations in the figures which denote

Interval		*Blending*		*Smoothness*		*Fusion*		*Purity*		*Total* {Blending Smoothness Purity}	
$c'c''$	P.	11	I	11	I	11	I	11	I	11.0	I
	F.	11	I	11	I	11	I	11	I	11.0	I
$c'g'$	P.	10	II	9	III	8	V	9	II	9.3	II
	F.	10	II	9	III	6	III	10	II	9.7	II
$c'a'$	P.	6	VI	10	II	3	VIII	7	IV	7.7	III
	F.	7	VI	10	II	2	VII	8	III	8.3	III
$c'e'$	P.	9	III	7	V	6	V	5	V	7.0	IV
	F.	8	IV	7	IV	7	IV	5	V	6.7	V
$c'f'$	P.	7	V	6	VI	5	VI	8	III	7.0	V
	F.	9	III	7	IV	7	IV	5	V	7.0	IV
$c'a'^{b}$	P.	5	VII	8	IV	3	VII	5	V	6.0	VI
	F.	6	VI	7	IV	3	VI	6	IV	6.3	VI
$c'e'^{b}$	P.	8	IV	5	VII	8	IV	2	VIII	5.0	VII
	F.	5	VII	3	VII	7	IV	3	VI	3.7	VII
$c'g'^{b}$	P.	4	VIII	4	VIII	4	VII	3	VII	3.7	VIII
	F.	4	VIII	5	V	4	V	3	VII	4.0	VIII
$c'b'^{b}$	P.	3	IX	3	IX	1	IX	4	VI	3.3	IX
	F.	3	IX	4	VI	1	VIII	3	VII	3.3	IX
$c'd'$	P.	2	X	1	XI	9	III	2	VIII	1.7	X
	F.	2	X	1	IX	8	III	1	IX	1.3	XI
$c'b'$	P.	1	XI	2	X	0	X	1	IX	1.3	XI
	F.	1	XI	2	VIII	0	IX	2	VIII	1.7	X
$c'd'^{b}$	P.	0	XII	0	XII	10	II	0	XI	0.0	XII
	F.	0	XII	0	X	10	II	0	X	0.0	XII

TABLE III—*Rank of consonances and dissonances (Series B)*

		Blending		*Smoothness*		*Fusion*		*Purity*		*Total* {Blending, Smoothness, Purity}	
		av.	m. v.	av.	m. v.	av.	m. v.	av.	m. v.	av.	m. v.
	P.	10.9	.2	11.0	.0	10.5	.7	11.0	.0	10.9	.2
c' c''	F.	11.0	.0	11.0	.0	11.0	.0	11.0	.0	11.0	.0
	O.	11.0	.0	11.0	.0	10.8	.3	11.0	.0	10.9	.1
c' g'	P.	9.0	1.0	9.0	1.0	5.6	.9	9.3	.9	8.2	.9
	F.	9.9	.2	9.4	.5	6.3	1.6	9.6	.5	8.8	.7
	O.	9.6	.6	9.4	.8	6.6	.9	9.3	.6	8.7	.7
c' a'	P.	6.8	.5	7.5	.8	3.0	.5	7.3	.6	6.2	.6
	F.	6.0	.7	7.1	.7	2.8	.8	7.5	1.0	5.9	.8
	O.	6.0	1.0	6.8	1.3	2.8	.6	7.0	1.0	5.7	.7
c' e'	P.	8.8	.6	7.5	1.1	7.1	.4	7.3	.9	7.7	.8
	F.	8.4	.5	7.5	.6	7.0	1.0	7.0	1.0	7.5	.8
	O.	9.0	.3	7.1	1.2	6.5	1.3	8.0	.8	7.7	.9
c' f'	P.	7.6	1.0	6.8	.8	4.9	.7	7.4	1.3	6.8	.9
	F.	7.9	.2	6.0	.8	6.0	.3	6.5	.8	6.6	.5
	O.	7.9	.5	7.3	1.1	5.1	.7	6.9	.9	6.8	.8
$c'\ a'^{b}$	P.	6.1	1.2	6.5	1.0	3.1	.7	6.4	1.3	5.5	1.0
	F.	5.5	.8	6.5	.9	2.8	.4	6.6	.8	5.4	.7
	O.	4.6	.5	5.3	.9	3.1	.7	5.9	.4	4.7	.6
$c'\ e'^{b}$	P.	6.1	.4	4.8	1.0	6.1	1.4	4.1	.7	5.4	.8
	F.	5.9	.2	2.5	.8	7.5	.6	4.3	.6	5.1	.6
	O.	6.9	.4	5.0	.8	7.0	1.0	4.4	1.0	5.8	.8
$c'\ g'^{b}$	P.	4.0	.0	4.1	.2	3.5	.8	4.3	.9	3.9	.5
	F.	4.9	.7	4.4	.9	4.1	.7	3.8	.4	4.8	.7
	O.	4.8	.8	4.8	.6	4.1	.9	4.0	.4	4.5	.7
$c'\ b'^{b}$	P.	2.6	.5	2.9	.2	1.0	.0	3.6	1.3	2.5	.5
	F.	3.0	.0	3.8	1.9	1.0	.0	3.8	1.2	2.9	.8
	O.	3.0	.3	3.1	.9	1.6	.6	3.6	1.7	3.8	1.1
c' d'	P.	2.4	.7	1.4	.5	6.9	1.7	2.0	.3	3.2	.8
	F.	1.9	.2	1.0	.0	7.0	.5	1.0	.0	1.4	.2
	O.	1.3	.4	1.3	.4	8.1	.7	1.3	.4	3.0	.6
c' b'	P.	.6	.3	1.5	.5	.3	.0	1.0	.0	.9	.1
	F.	1.1	.2	2.0	.3	.0	.0	2.1	.2	1.3	.2
	O.	2.0	.3	1.8	.6	.3	.2	2.8	1.5	1.7	.3
$c'\ d'^{b}$	P.	.0	.0	.0	.0	9.8	.4	0.0	.0	2.5	.1
	F.	.0	.0	.1	.1	9.8	.4	.1	.1	2.5	.2
	O.	.0	.0	.0	.0	9.3	1.0	.0	.0	2.3	.3

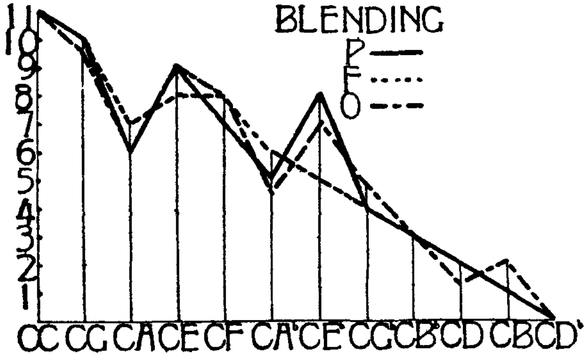

FIG. 1. Blending, for piano, forks, and organ respectively.

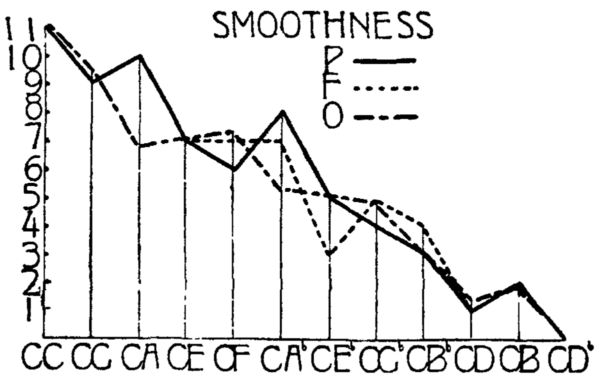

FIG. 2. Smoothness, for the three instruments.

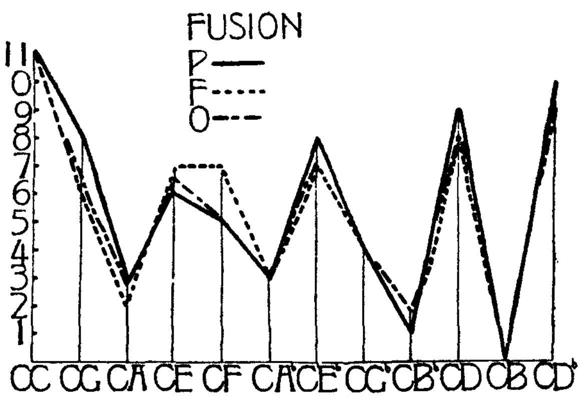

FIG. 3. Fusion, for the three instruments.

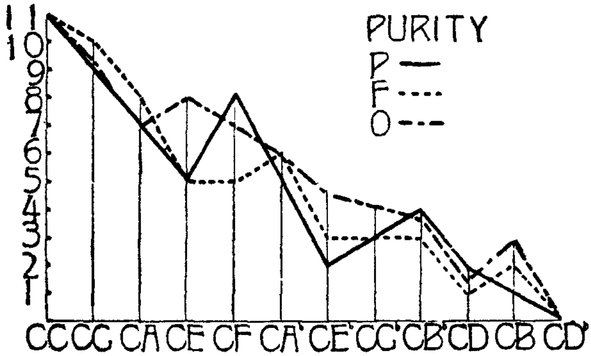

FIG. 4. Purity, for the three instruments.

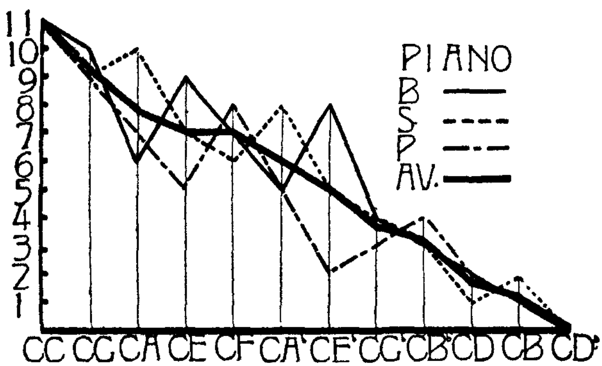

FIG. 5. Blending, smoothness, and purity, with the composite (Av.) from these for the piano.

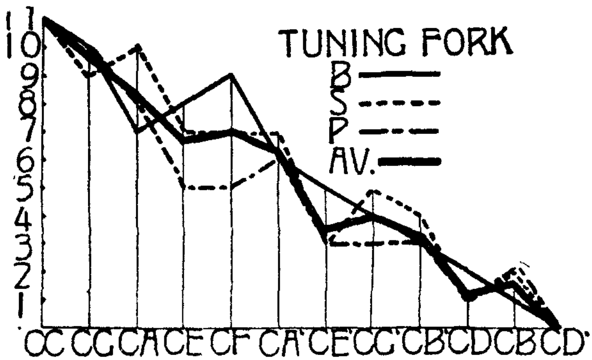

FIG. 6. Blending, smoothness, and purity, with the composite from these for the tuning forks.

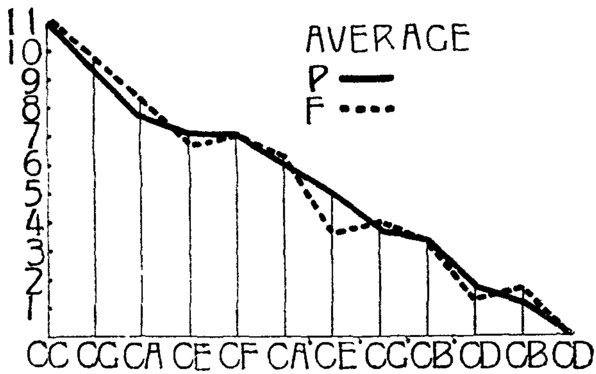

FIG. 7. Comparison curves for piano and tuning forks.

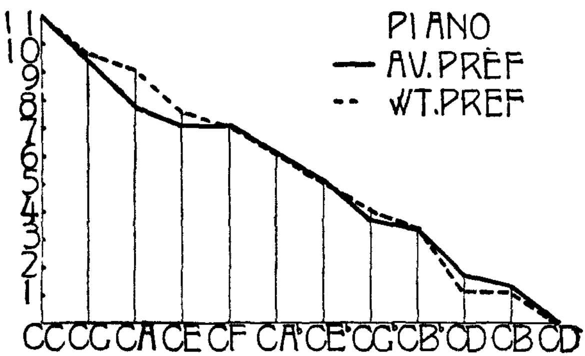

FIG. 8. Comparison of the average preference and the weighted average preference for the piano.

the number of preferences, few of these are enough to alter the order of rank. The nature of the change and the quantitative difference may readily be seen by comparing corresponding figures in the two tables.

The mean variation of the preferences in Series B is given in Table III in order to convey some idea of the variability in individual decisions by different observers. The mean variation may also be regarded as showing, to some extent, the relative difficulty of different intervals.

One further step should be taken: a group of trained observers should proceed as in Series B and C above, except that only one decision should be rendered for the three criteria on the following basis: *Give the decision on blending alone if the degree of blending is perceptibly different; if not, make the decision on smoothness; and, if there is no difference in either smoothness or blending, base the decision on purity.*

That procedure has the merit of basing the decision on a single criterion—the appropriate one in each case—instead of striking an average of three. The ranking by this method may possibly modify the order denoted by the average in Table II.

To what extent there is likelihood of any effect upon the order of rank by this step may be judged upon analyses of the basis of the decision for each part of intervals as recorded in Series C. In this series the group worked for a unanimous verdict on what constituted the deciding criterion, just as it worked for a unanimous verdict on the order. The final decisions of the group are contained in Table IV.

TABLE IV—*Basis of judgment for individual pairs*

	$c'g'^b$	$c'd'^b$	$c'f'$	$c'd'$	$c'e'$	$c'e'^b$	$c'g'$	$c'c''$	$c'a'^b$	$c'b'$	$c'a'$
$c'd'^b$	s										
$c'f'$	b	s									
$c'd'$	s	s	s								
$c'e'$	b	s	p	s							
$c'e'^b$	b	s	p	s	p						
$c'g'$	b	s	b	s	s	s					
$c'c''$	b	s	b	s	p	p	b				
$c'a'^b$	s	s	b	s	b	s	b	b			
$c'b'$	b	s	b	b	b	b	b	b	b		
$c'a'$	s	s	s	s	s	s	b	b	s	b	
$c'b'^b$	b	s	b	s	b	b	b	b	s	b	s

b—blending; p—purity; s—smoothness. The order of the intervals in this table is the order used in giving the test.

Table IV shows that thirty-one of the pairs are determined primarily by the factor of blending, thirty-one primarily by the factor of smoothness, and only in four pairs does purity enter in as the determining factor. In the comparisons of the dissonant intervals $c'd'$ and $c'd'^b$ with the remaining intervals the element of roughness is the characteristic that determines the judgment in every case, except in the pair $c'b'$ and $c'd'$. $c'c''$ and $c'a'$ depend primarily upon the criterion of blending. In the comparison with $c'e'$ and $c'c''$, purity enters as the deciding factor. In comparison of $c'a'$ with these two intervals, smoothness gives c'a' the first place. The ranking of c'a' is largely determined by the criterion of smoothness. However, in the judgments of the pairs c'a' and c'b', and c'a' and $c'b'^{b}$, blending becomes the criterion. c'e' is determined by blending in its comparisons with $c'b'^{b}$, c'f', $c'a'^{b}$, c'b', $c'b'^{b}$. In the judgment of the difference of major and minor thirds, purity is the most distinct element which gives c'e' the better rank. c'f' in all cases not mentioned above, except in the case of $c'e'^{b}$, is judged on the blending factor. In the case of $c'e'^{b}$ the purity of the two intervals determine their rank, as c'f' ranks II in purity while $c'e'^{b}$ ranks III. The minor sixth ranked above the minor third on account of its relatively greater degree of smoothness. In all other cases, not mentioned above, the minor third is judged on the basis of blending. c'b' is judged on its lack of the factor of blending in all cases, except in its comparison with $c'd'^{b}$. In the two dissonances c'b' c'd', there is difficulty in deciding on account of their apparent difference in character. Both are extremely dissonant, c'b' ranking lower in blending and c'd', on the other hand, ranking perceptibly lower in smoothness. As the blending is the more important factor, c'd' is given the first place. In the pair $c'b'^{b}$ and $c'a'^{b}$, there is a minimal difference in blending, but $c'a'^{b}$ is perceptibly smoother than $c'g'^{b}$. In the intervals $c'g'^{b}$ and $c'b'^{b}$ blending determines the judgment. In some cases, such as c'c'' and c'a', all three criteria coöperate. The superior ability to perceive consonance consists in selecting the factor which most influences the ranking.

Turning then to the specific question before us, we may estimate, on the basis of data in Table IV, what the probable effect would be of a single decision according to the above directions as compared with an average decision for these three criteria.

The analysis is reduced to final figures in Table V in which "average preference" is taken from the last column in Table II for piano and tuning forks respectively;—B., S. and P. denote the number of times the judgment was based upon the factor of blending, smoothness, and purity respectively, for each interval when compared with other intervals according to the exhibit in Table IV.

"Weighted preference" is calculated by weighting the average in accordance with the number of decisions based on each of these factors. Thus, turning to Table IV, we see that for the interval $c'g'$ the decision may be reached seven times on blending, and four times on smoothness, while purity need not be considered; the preference rank for blending is 10 and for smoothness 9. For this interval, we accordingly get $7 \text{x} 10 + 4 \text{x} 9 \div 11 = 9.6$ as the weighted average.

Section A, of table V (Fig. 8) is based on the piano quality but as a rough approximation we have used the same weighting for tuning forks, Section B of Table V.

TABLE V.—*Comparison of weighted and average preferences*

Int.	Av. Pref.	Order	Wt. Pref.	Order	B.	S.	P.
			A. For Piano				
$c' c''$	11.0	I	11.0	I	6	2	2
$c' g'$	9.3	II	9.6	II	7	4	
$c' a'$	7.7	III	9.0	III	3	8	
$c' e'$	7.0	IV	7.5	IV	5	4	2
$c' f'$	7.0	V	6.9	V	7	3	1
$c' a'^{b}$	6.0	VI	5.9	VI	5	6	
$c' e'^{b}$	5.0	VII	5.0	VII	3	5	3
$c' g'^{b}$	3.7	VIII	4.0	VIII	7	4	
$c' b'^{b}$	3.3	IX	3.0	IX	7	4	
$c' d'$	1.7	X	1.1	X	1	10	
$c' b'$	1.3	XI	1.1	XI	10	1	
$c' d'^{b}$	0.0	XII	0.0	XII		11	
			B. For Tuning Fork				
$c' c''$	11.0	I	11.0	I			
$c' g'$	9.7	II	9.6	II			
$c' a'$	8.3	III	8.3	III			
$c' e'$	6.7	V	8.0	V			
$c' f'$	7.0	IV	8.1	IV			
$c' a'^{b}$	6.3	VI	6.5	VI			
$c' e'^{b}$	3.7	VIII	3.5	VIII			
$c' g'^{b}$	4.0	VII	4.4	VII			
$c' b'^{b}$	3.3	IX	3.4	IX			
$c' d'$	1.3	XI	1.1	X			
$c' b'$	1.7	X	1.1	XI			
$c' d'^{b}$	0.0	XII	0.0	XII			

It is rather surprising that for the piano the weighting does not alter the order found for the mere average. For the purpose of a tentative working norm with the piano, tempered scale, (when the decision is made on one of the three factors directed as above, namely: if possible, on blending; if not, on smoothness; and if not on either of these two, on purity), the order in which the intervals are given in Tables II, III, and V may be regarded as the standard order from the best consonance to the worst dissonance, as expressed in Fig. 9.

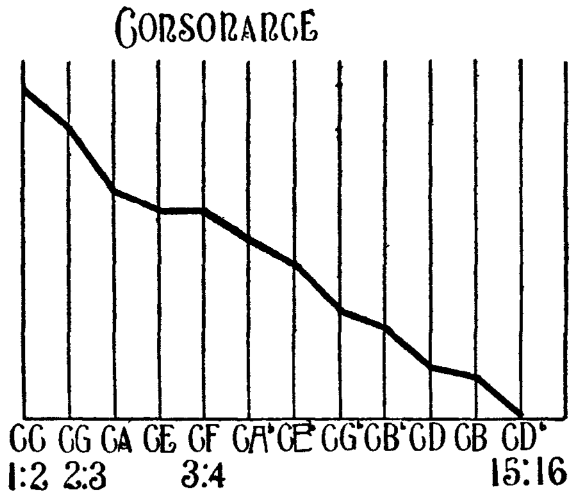

FIG. 9. Norm: the order of consonance-dissonance for the piano.

A rough approximation to the relative degree of certainty in the preference of one interval to another is shown by the numbers which denote the number of times an interval is preferred. This is true both for great differences, *e.g.*, c′c″ and c′d′, as well as for adjacent intervals, *e.g.*, c′c″ and c′g′. The irregularities in the curve, of course, mean just such differences; thus, in Fig. 9 the difference between the consonance of c′c″ and c′g′ is decidedly larger than the difference between c′e′ and c′f′.

Since the primary object of this investigation was to standardize the measurement of the sense of consonance, the main object of the present section of the work was to secure a norm which might be considered a conventional standard for such purposes. All this work on ranking is, therefore, merely accessory to the main object of this investigation. For this reason, the detailed discussion of the introspections and the theoretical interpretation of the empirical records may perhaps best be deferred for a more elaborate investigation.

We have here, at least, a tentative norm established for the first time after recognition of the principal factors isolated under experimental control. Later refinements of experiments may make minor changes in the order, but we have made progress by developing a working principle—the recognition of specific criteria.

MEASUREMENTS OF THE PERCEPTION OF CONSONANCE AS A MUSICAL TALENT

Having determined the constant factors of consonance, the ranking order of the intervals, and the method and apparatus adapted to this test, the writer will in this section, give an account of measurements made under the above prescribed conditions. These measurements were made with three ends in view: first, to secure measurements of individual abilities; second, to establish a norm; and third, to test this measurement under controlled conditions.

Apparatus

The intervals of the octave c′c″ were presented by the method of paired comparison, being played on a piano accurately tuned in the tempered scale. The tones were sounded with moderate loudness, the soft pedal being applied continuously during the test. Each two-clang was sounded with a duration of approximately 2 seconds, with an interval of 1 second between the members of each "pair", and 4 seconds between each repetition. Every pair was sounded at least twice, more frequently three or four times, and in the more difficult comparisons a relatively greater number of times.

Definition and illustration of criteria

Special precautions were taken to impress the fact that mere agreeableness is not the basis of the decision. It was pointed out that a dissonance may be very agreeable for some musical purposes and that the rich musical body of the two-clang, such as the major third, may be the most agreeable and still not the most consonant. It was made clear that the test is a cognitive act of discrimination as opposed to the traditional affective test employed in music.

A placard bearing the definition of consonance was placed before the class, reading as follows:

Consonance is:

(1) *Blending,* a seeming to agree, to belong together.

(2) *Smoothness,* relative freedom from beats.

(3) *Purity,* thinness of tone, absence of richness.

The conductor of the test then explained tersely and concretely how the experiment would proceed, how to record, and how to apply the above-defined criteria in arriving at a decision. The 66 trials, which constitute one complete set, were made in one hour. The intervals used to illustrate the above criteria were sounded in a different octave from the one used in the test. Both the negative and positive aspects of the criteria, *i.e.,* consonance and relative absence of consonance were presented. Thus, without naming the intervals, c'c''—c'b' and c'e'—c'b' were given to illustrate blending, the first interval in each pair bringing out the positive, the second, the negative aspect of blending. As illustrations of smoothness, the pairs c'b'—c'd' and c'a'—$c'e'^{\flat}$ were played. In both of these pairs judgment is best based on smoothness, the first presenting a large difference, the second a small difference. The element of roughness in the minor third is scarcely perceptible, but it is the deciding factor in the comparison of these two intervals, as the major sixth undoubtedly owes its higher rank to its greater degree of smoothness in this pair. c'c''—$c'e'^{\flat}$ were selected to illustrate tonal purity. The octave is a relatively pure interval, while the minor third is rich in quality. In order to give a still clearer conception of purity, a criterion somewhat vague in the mind of the average observer, a tuning-fork was sounded before an attuned Helmholtz resonator, which gave a clear pure tone; and this was compared with the rich tone of the piano and violin and with two-clangs. The observers were finally instructed to make their judgments on each pair with respect to the three criteria in the order named and illustrated; namely, giving first preference to blending, second to smoothness, and third to purity. In all cases where they found blending to be the decisive factor, they were instructed to judge on this criterion. In case they were unable to decide on the basis of blending, they should take the second criterion into account; and, if smoothness was not decisive, the test of purity should be applied. In a large portion of the cases the three criteria coöperated and agreed.

Since the sequence of intervals is a factor that cannot be overlooked, a fixed order of comparisons, which distributed the consonances and dissonances fairly was adopted, as given in Table VI. The body of this table contains three sets of information:

TABLE VI—*The order of trials, the correct preference and the schedule of demerits*

	$c' g'^{b}$	$c' d'^{b}$	$c' f'$	$c' d'$	$c' e'$	$c' e'^{b}$	$c' g'$	$c' a'^{b}$	$c' b'$	$c' a'$	
$c' d'^{b}$	1 1 4										
$c' f'$	2 2 3	3 2 7									
$c' d'$	22 1 2	4 2 2	5 1 5								
$c' e'$	23 2 4	24 2 8	6 2 1	7 2 6							
$c' e'^{b}$	39 2 1	25 2 5	26 1 2	8 2 3	9 1 3						
$c' g'$	40 2 6	41 2 10	27 2 3	28 2 3	10 2 2	11 2 5					
$c' c''$	52 2 7	42 2 11	43 2 4	29 2 9	30 2 3	12 2 6	13 2 1				
$c' a'^{b}$	53 2 2	54 2 6	44 1 1	45 2 4	31 1 2	32 2 1	14 1 4	15 1 5			
$c' b'$	61 1 3	55 2 1	56 1 6	46 1 1	47 1 7	33 1 4	34 1 9	16 1 10	17 1 5		
$c' a'$	62 2 5	63 2 9	57 2 2	58 2 7	48 2 1	49 2 4	35 1 1	36 1 2	18 2 3	19 2 8	
$c' b'^{b}$	66 1 1	64 2 3	65 1 4	59 2 1	60 1 5	50 1 2	51 1 7	37 1 8	38 1 3	20 2 2	21 1 6

For each block the top number denotes the order of the trial; the first number below denotes whether the first (top heading) or the second (side heading) is the better; the third number denotes the number of demerits assigned.

In each square the *first* figure denotes the order of trials, the *second* the correct preference, and the *third* the amount of demerits (to be explained later), in case of error in the preference.

The sequence of trials is the conventional order in a series of paired comparisons: each two-clang is named by reading the name at the top and the name at the side in two columns that intersect and form a given square. The two-clang given at the top of a column was always sounded first and the one at the side second. The observer was required to express his preference 1 or 2 according as he preferred the first or the second.

The evaluation of the record is based on the ranking of the intervals established in the preceding part, Table II.

The weighting of demerits

In order to arrive at a method of grading the records, an arbitrary scale of demerits was established. The amount of the demerit for each incorrect judgment was computed on the deviation from the norm. One unit of demerit was given for each step of deviation from the norm. Thus, the observer, in his judgment of the pair c′c″-c′g′ signified by recording 2 that the latter interval is the better consonance, he was given a demerit of 1, as c′g′ is in rank removed 1 step from c′c″. If, on the other hand, in his judgment of the pair c′c″-c′e′♭, he records his choice as 2, thereby placing the minor third as a better consonance than the octave, the error is more significant, and he is given a demerit of 5. The greatest possible demerit for any one judgment is 11 as in the pair c′c″-c′d′♭.

If every answer should be wrong there would be 286 demerits according to Table VI. But this cannot happen because in the long run fifty per cent. of the judgments would be correct by chance, since there are only two possibilities in each case. This reduces the maximum number of probable demerits to 143, which would be the number for one who had *no ability* to appreciate differences in consonance and dissonance and depended entirely upon chance. Such demerit, therefore, is equivalent to 100 ÷ 143, or seven-tenths of one per cent. The records may then be stated in terms of per cent. of success in conforming to the norm by deducting .7 per cent. from 100 per cent. for each demerit earned. While this weighting is somewhat arbitrary, it does approximate justice to the situation because it is approximately proportional to the magnitude of the error in each case.

Since it would complicate matters to require the observer to follow the order of Table VI in recording, the records were kept in straight columns, the first three containing twenty records each and the fourth six,—one column being left blank between each of these to give space for the marking of error and demerit.

This test was first made on the students in the elementary psychology class in the University of Iowa for the class of '12-'13. After this research had been completed the department furnished similar records for the '13-'14 class; the following year Miss Nesta Williams furnished the records for the '14-'15 class; and Mrs. Esther Allen Gaw contributed the records for the class of '15-'16. Since the publication of the original document has been delayed it is possible to incorporate this large mass of data which have been gathered through the very generous coöperation of the members of the department of Psychology, into one group making 1045 cases.

The norm established.—The general distribution of these cases is shown in Fig. 10, which is based on a number of cases

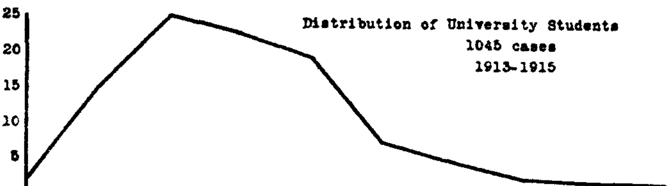

FIG. 10.

sufficiently large taken as a norm. In other words, this curve serves two purposes: it shows how abilities in this act vary and distribute themselves; and it may serve as a norm in terms of which any future record may be interpreted.

Bearing on the order of ranking—The data contained in Part

II bear in themselves a basis for the ranking of intervals which may serve at least as a basis for the criticism of the norm established before. The records for the class of '12-'13 are tabulated to show the total number of preferences for each interval. These are shown in Table VII. In the first column the intervals are given in the order accepted as a norm. (Fig. 9, Table V). The second column contains the per cent. of cases in which each interval was preferred over all with which it was compared. From this the rank of the intervals is indicated in column 3 which shows the deviation of this empirical ranking from the norm.

TABLE VII—*The rank of the intervals in the 1913 class test*

	% of choices	Rank of choices
c′ c″	12.4	2
c′ g′	10.0	5
c′ a′	11.8	3
c′ e′	13.1	1
c′ f′	9.6	6 or 7
c′ a′^{b}	9.6	6 or 7
c′ e′^{b}	10.5	4
c′ g′^{b}	9.8	8
c′ b′^{b}	6.5	9
c′ d′	3.8	10
c′ b′	2.1	11
c′ d′^{b}	1.8	12

A glance at this table shows rather satisfactory agreement between the standard order and the empirical order. The orders VIII, IX, X, XI, and XII are the same in both cases, and with these may be counted VI and VII which happen to tie. The deviations occur, therefore, in the first five intervals, chiefly, *i.e.*, in the consonances; and it will be observed that these deviations are due mainly to the fact that the major third is unduly preferred in the empirical rankings. This can be accounted for by the fact that the factor of agreeableness had not been eliminated satisfactorily in the test of this first year. The musical value of the third as compared with the octave must have influenced the students to some extent so that there was a large number of cases in which the major third was preferred to the octave and the fifth. The dropping of the major third in rank will of course raise the octave and the fifth and secure closer agreement with the norm. The same principle is perhaps also operative in tending to throw the middle range somewhat higher than the norm. The intervals $c'e'^b$ and $c'g'^b$ and $c'b'^b$ are rich musical intervals which may have been favored slightly on the same fallacy as that which threw the third off.

It will probably be found that this sort of error was eliminated by more rigid instructions on this point, emphasizing the fact that the preference is an intellectual judgment rather than an appreciation of musical value in the terms of agreeableness.

With this one exception then, the empirical results on the whole tend to confirm the order established in the norm.

The class of '12-13 was required to fill out a questionnaire on musical training in the form given by Professor Seashore in the report of the Committee on "The Standardization of Pitch Discrimination" (25). This questionnaire is designed to secure a measure of general musical ability, musical training, musical environment, and the expression of musical feelings. For the present purposes, the members of the group were ranked on musical training. The Spearman co-efficient R between this musical training and the record for the consonance test is only $R = .02$, which is very remarkable in view of the fact that one should ordinarily expect those who had had musical training to do better than those who had had none. This absence of correlation is of the greatest significance for the value of this test in that it tends to show that it is fairly independent of training and will, therefore, have diagnostic value.

The correlation between perception of consonance and ability to perform, *i.e.*, to sing or play in music is based upon the same questionnaire returns, gave the Spearman coefficient of $R = .06$ which again is an indication of the effect that the perception of consonance is quite independent of training because it would be fair to assume that the degree of correlation would easily be covered up by the principle of selection by which those who have a good ear for consonance would be likely to acquire musical training.

The correlation between pitch discrimination and the perception of consonance by the Pearson product-moments method was found to be $r = .18$. This is not so large a correlation as one should really expect and it may be that this is due partly to the fact that pitch discrimination is an immediate sensory experience, whereas the perception of consonance as here tested involves a complex judgment.

The Pearson coefficient for the correlation for consonance and tonal memory is .34 which speaks for the close relationship of these two factors.

Evaluation of the method.—Roughly, the goal of this series of experiments has been reached; we have found a norm for the order of consonances and dissonances and a norm for the distribution of abilities among university students. Both of the fields here opened up must be worked more fully and the two problems are quite distinct. In connection with these experiments, much material has been collected and much is inherent in the records themselves which would throw light on the validity and interpretation of these norms as well as upon the technique of measurement.

But some place must be set for the division of labor; and, since Mrs. Esther Allen Gaw and others have taken up the experimental work in the laboratory from the point at which it was left by the writer in 1914 and propose to carry the analysis of this measurement into finer details, this report must come to a close with the apology that it is only preliminary.

Recommendations Toward a Standard Test

The method of procedure that has been followed, as stated above, can be recommended in giving a test in the perception of consonance, but it is necessary to emphasize certain precautions that must be followed.

In giving the interval, the experimenter must exercise care in the striking of the two keys so as to make the tones equally strong, for the factor of intensity plays a rôle in consonance. The experimenter should practise the combinations and order of pairs until he can play them with ease and without hesitation in an approximately uniform manner.

As has been pointed out by *Seashore* (25), "the tone most favorable for accurate results" is one of moderate intensity, "the just perfectly, clearly perceptible tone." "It is ordinarily purer than a stronger tone and favors concentration." This precaution in the measurement of pitch discrimination applies as well to the measurement of the perception of consonance. The piano tone is rich and tends to develop many impurities when sounded loudly. These are partially at least if not wholly eliminated through the use of the soft pedal.

Uniformity of duration is important, as the sounding of one tone or note of the two-clang longer than the other proves a distraction and disturbs the observer in his discrimination. It also gives him a clue as to the interval played and changes the nature of the test. The longer duration of one note of the pair tends to change the character of the interval as this note takes a dominant place in the perception, and thus influences the judgment.

The two clangs within the pair should be presented in rapid succession with a constant interval of 1 second, as discrimination of successive stimuli involves the element of memory. A brief interval, therefore, presents the best condition for comparison as "the curve for tonal memory shows that the accuracy of memory falls off very rapidly, immediately after the first second of the interval." (25). A longer interval is necessary between the pairs to eliminate the influence of progression of intervals. Each pair should stand distinctly by itself as a stimulus for comparison and should have no reference to the preceding or succeeding pair. An interval of four seconds accomplishes this end.

The order of presentation of the pairs should be definitely determined by the preparation of a key in which the consonances and dissonances are distributed throughout. This order should also distribute the easy and difficult comparisons, so that the test will be somewhat uniform in difficulty of discrimination throughout sections of the whole test. Such an order prevents undue fatigue at any one point in the test as it conforms in some measure to the double fatigue order, which is a rule of of experimentation in psychological tests. The order also prevents the succession of two-clangs in a definite harmonic series, which must be avoided in the test.

The key given above Table VI was prepared with these precautions in mind, and is well adapted to the measurement of the perception of consonance. If the pairs are to be given in the reverse order, a different key should be made and given separately. The order should not be reversed in the repetitions, as this causes confusion and leads to mistakes in recording.

It has been noted how the element of fatigue may, to some extent, be obviated by the arrangement of the order of presentation. A test of this nature is naturally interesting if conducted in the correct manner, and elicits a continuous conscious effort, which becomes fatiguing if prolonged beyond the endurance of those tested. As has been pointed out by Seashore (25), this fatigue is not a fatigue of the sensory process, but it arises from the concentration of the attention. The attention tends to fluctuate and become distracted when engaged in continuous concentration for any length of time. This is more the case, the greater the conscious effort needed to make an intelligent choice or judgment. The perception of consonance requires this concentration to a very great degree, as it is relatively complex in its nature and requires a keen discrimination and constant application to perceive differences. In this respect, it differs from the mere sensory tests which involve only one factor. As an additional precaution against ennui, or to prevent fatigue, a rest is allowed after each group of ten trials. This divides the one hour recitation time during which the test is given, into three periods, of which the last two, when the element of fatigue is liable to be prevalent, are somewhat shorter than the first period. This tends to equalize the conscious effort, and prevents incorrect judgments due to fatigue.

What has been stated above applies to the sustaining of the attention. In order to secure the attention of the observer, a further precaution is taken in securing the right attitude toward the test, that will stimulate the conscientious application. The experimenter, in giving a class test, must have the energetic and enthusiastic coöperation of all participants. This cannot be overemphasized as an important factor in the measurement of the perception of consonance, which requires such a careful and discriminating application of attention to the details involved.

Summary of Conclusions

Among the conclusions reached in this study the following are prominent:

1. The historical failure to reach an agreement in regard to the rank of consonance and dissonance is due largely to a disagreement as to what constitutes consonance.

2. The perception of consonance is a cognitive process, involving the factors of blending, smoothness, and purity.

3. The order of the ranking of the intervals varies for different qualities of tone. The order has been established for tuning forks, piano, and pipe organ.

4. The uniformity of the distribution curves for different classes tends to show that the factors of the test can be controlled so as to make it well adapted as a class test.

5. A system of weighting errors has been established.

6. The distribution of grades reveals a very great diversity in this capacity among normal observers.

7. The perception of consonance is elemental in a secondary sense in so far as it is based rather on the elemental capacities for pitch discrimination and tonal memory than on acquired musical ability or training.

8. The test in itself is not an adequate measure of musical capacity, but forms one of a series including pitch discrimination, tonal memory, sense of rhythm, tonal imagery, etc. that may be advantageously used for this purpose.

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