INSTINCTIVE MUSIC

BY SYDNEY E. INGRAHAM

Plates 24, 25

IN recent years a very fine piece of work has been carried on by Mr. Albert Brand and Professor Arthur A. Allen of Cornell University, and their associates, in photographing the songs of wild birds. A few years ago Mr. Brand published in 'The Auk' (52: 40–52, 1935) an article entitled 'A Method for the Intensive Study of Bird Song,' in which he described how he counted the frequencies of the notes on his sound films in order to determine their pitch. At the time he wanted to find out the range of pitch in bird notes, and he gave tables showing the highest frequencies in thirty-five different songs. He also showed some interesting graphs of the songs, but in these he had recorded the pitch only rather roughly with reference to our own musical scale, and without considering the length of notes and stops. As we are by no means certain that birds sing according to our musical scale, it occurred to me that it would be worth while, from the point of view of musical theory, to make some microscopic transcriptions of a few of the more musical bird songs, with the pitch, the relative intervals, the rhythm and the dynamics shown to the eye precisely as they were sung, without any, or at least without too much reference to our own system of instrumental tuning and musical notation.

Mr. Brand has also published two books entitled, 'Songs of Wild Birds' and 'More Songs of Wild Birds' which contain in their cover-flaps sets of small victrola records made from his sound films. He very generously gave me permission to transcribe songs from these records by any method that I could devise, and kindly sent me a set of his original films, with samples of the songs of about a dozen birds. Lately I have received another box-full, with fourteen different songs. Of course, only a few can be reproduced here.

I set to work, not at first on the films, but on one of the victrola records, because the songs of the records were longer and musically more nearly complete. My time unit for counting on the victrola record was 1/100th of a second. Calculating according to the speed of the victrola turntable, I had radial lines traced on the record, dividing the circle into, roughly, seventy-seven small segments, each with a musical time value of 1/100th of a second. On the films my unit was 1/96th of a second, because there are very convenient sprocket-holes cut close together along the edges of all sound films, and it is easily calculated from the speed of exposure that the space from one sprocket-hole to the next on a 35-millimeter film has a time value of 1/96th of a second. Before beginning, I examined the sound films sent me by Mr. Brand and I could tell at once that in some respects the films were much richer material than the victrola records—there was more recording of overtones, especially in the songs of the larger birds. As the overtones determine the quality of the tone of a note, there was more *Klangfarbe,* as the Germans call it, on the films. A perfect scientific guide to bird song ought to contain microphotographs showing characteristic sound waves of certain bird notes with their overtones, then we could take a long look at the throaty quality of the note of the Yellow-billed Cuckoo, or at the wheezy tone of the Black-throated Blue Warbler. And possibly, in the future, if someone were to make a specialized study of the sound films of birds and other animals, new instruments might be devised with special overtone combinations which would add all kinds of amusing natural effects to our orchestras.

The development of sound photography is so recent that relatively few intensive transcriptions of sound films have yet been made. If I seem to stress the significance of the overtones in the following study, I may have been influenced partly by the mere use of a powerful microscope on sound film, because one cannot look at the rhythmical and complex patterns of sound waves, week after week, month after month, without a growing conviction that there must be still a great deal to be learned musically as well as scientifically about overtones; they are the chief revelation of this new branch of extra-sensory technique. Under the microscope one can see that they are not always produced quite simultaneously with the fundamental. It often happens that their number is likely to increase as the sound of the fundamental is dying away, and this slight lag in time may account for our subjective awareness of them, not only as haphazard tonal combinations, but in their true order as a natural musical scale, in relation to each other.

EXPLANATION OF THE CHARTS

Although the frequency numbers of musical intervals advance geometrically, doubling with every octave, we are used to even-sized octaves, so I chose semi-logarithmic paper for my charts. The lines on this paper are not evenly spaced; they are ruled gradually closer and closer together as they rise, in such a way that the distance between 2 and 4 is the same as the distance between 3 and 6, 4 and 8, etc., so that the space up and down represents an even and constant rise in pitch as we seem to sense it, with equal spaces for each higher octave.

The reason why we are used to even-sized octaves is quite curious and revealing for it goes to the root of music. Our musical perception of the ratios of sound waves controls our sense of pitch and is connected also with the automatic capacity for modulation or transposition that we seem to share with birds, a capacity for shifting the tonality of one or more intervals so that the harmony centers upon a new keynote. The best explanation would seem to be, with reservations, the Weber-Fechner law, a famous psychological generalization, first stated by Weber, and later developed by Fechner. "In comparing objects," said Weber, "it is clear that we perceive not the actual difference between the two objects, but the ratio of this difference to the magnitudes of the two objects compared." If the stimuli from external objects are increasing in geometrical progression, the psychological series increase only in arithmetic progression. And when we have two series corresponding point by point, the one geometric and the other arithmetic, the mathematical relationship between the two must be a ratio or logarithmic one. Fechner developed this idea and formulated it as an equation.

Whatever the explanation, it is obvious that musically we do perceive not the actual frequency difference between two sound waves, but the ratio of the two frequencies. Here are two frequency intervals, 200–100, 774–387; we hear them both as octaves, the second pitched considerably higher than the first. Both are in the ratio of 2 to 1. A musical interval, then, is a ratio, so that the two words can be used here synonymously.

Semi-logarithmic paper is ratio paper and if we choose it for this work we are deliberately reproducing an automatic process of our sense of hearing and arranging the frequencies of bird song so that we see them on the graphs as we hear them, in a diminishing perspective of pitch. The original charts that I made are rather large. Unfortunately, when they are photographed for reproduction and reduced, the fine lines and close figures printed on the semi-logarithmic paper tend to disappear, so I have marked on the right-hand margins the diminishing intervals of the frequencies in thousands. But because we are so accustomed to the regular musical symbols, I have drawn on the left margins sections of our musical staff to scale, with large notes representing the common chord and showing the positions of C6 and C7 in our tuning. The diminishing ratios of the physical scale and the equal ratios of our own scale can then be easily compared. C7 is the last note on the piano; it is two octaves above the high C of a light soprano. In bird song it is a note of medium pitch and it occurs frequently.

On the graphs every frequency number is plotted just as the bird sang it, and it will be seen that there are a great many random notes in the songs that do not fit into any musical pattern. But occasionally a bird seems to be aiming deliberately at a musical ratio, and in that case I have drawn pencil lines on the graphs to show the position of some of the basic intervals, such as octaves, fifths or thirds, which belong both to the series of overtones and to our muscial scale, and the eye can then easily judge whether the bird is singing them in tune or not. The tuning of pure overtones is very simple,

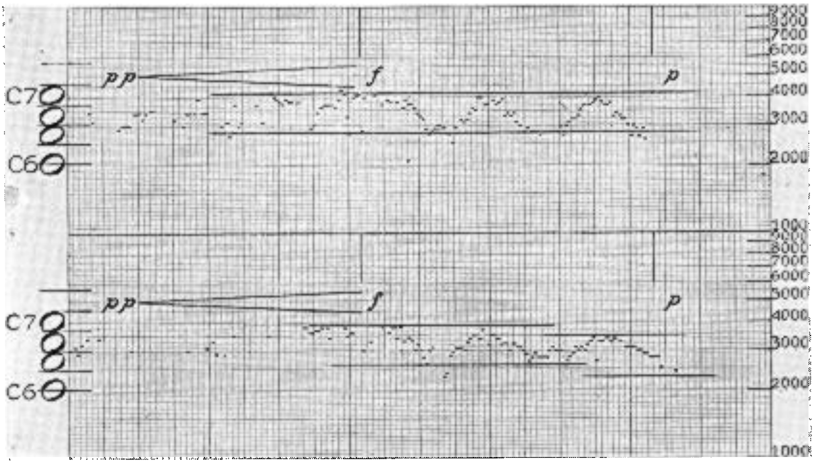


FIG. 1.—SONG OF THE VEERY

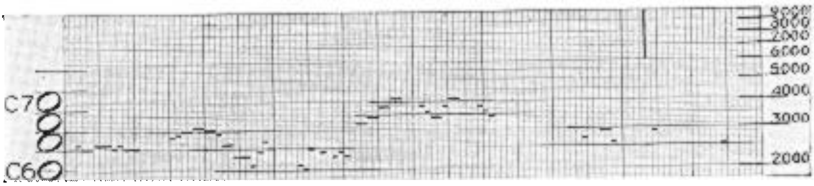


FIG. 2.—SONG OF THE OLIVE-BACKED THRUSH

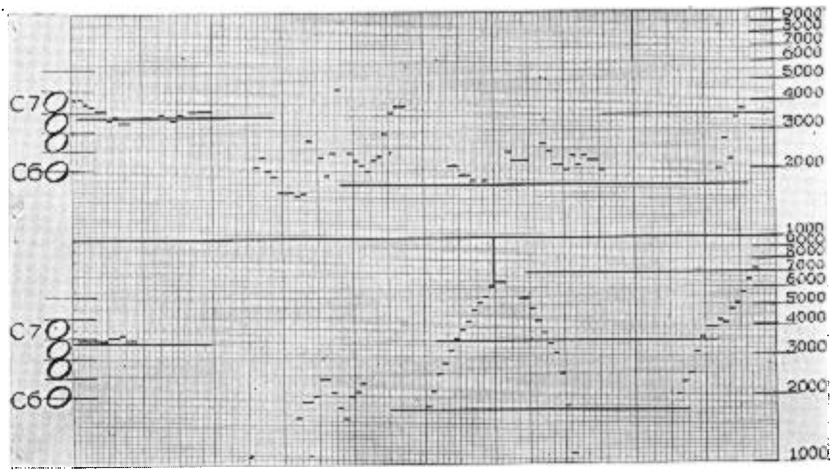


FIG. 3.—SONG OF THE BROWN THRASHER

in contrast to the complexities of our own logarithmic tuning. If we assume 2000 frequencies as a base note in a bird song, the octave, as in our scale, will be 4000. The pure fifth will be 3000. The notes of the common chord will be 2000, 2500, 3000 and 4000 and they can be very easily picked out by eye on the semi-logarithmic paper.

As to the timing of the charts: In the transcriptions from the victrola record, I plotted 1/100th of a second to each small square printed on the paper, except in the case of the Veery's song, which was so long that I used only half a square for each unit. Strong vertical lines drawn downward from the top of the charts mark the lapse of each second. In the case of transcriptions made from sound films, I plotted 1/96th of a second to each small square of the paper. I corrected this error of four per cent in pitch, not by changing all the frequency figures, but by changing the relative position of the note C as marked on the left-hand margin of the charts. On all the charts the lapse of a second is clearly shown by the strong downward line from the top, and that is the simplest time measure for the eye to follow.

At first, I had wondered whether I might not use our own musical notation as a frame work, but for various reasons I found it quite impractical. The tuning of our well-tempered scale is a matter of tedious calculations. Each rise of a semitone represents a ratio of 1.05946. In order to find a fifth, for instance, which is seven semitones higher than a given tonic, the frequency number of that tonic must be multiplied by $(1.05946)^7$. Then the spacing up and down on the musical staff does not correspond accurately to a constant rise in pitch; a half space represents here a whole tone, there a semitone.

VEERY

This song of the Veery (Pl. 24, fig. 1) is both simple and complex. There is a very simple musical phrase—like five-finger exercises played on a harp—which is repeated four times, but never exactly in the same way. On this victrola record, the beginning of the first phrase is interrupted and blotted out by a Robin's call, but by looking at the charts one can see that the three other repetitions all begin in the same way, with a soft tremolo, very irregular, teetering and pianissimo, that rises crescendo to a flatted fourth before it touches the loud pure fifth which is the dominating interval of the song. This introduction is half of the song; it takes one second, the whole two seconds. It is curious that there is usually no record of an introductory tremolo for the wildness and delicacy of such a gradual crescendo must add to the beauty of the Veery's song.

The second half of the song is the sort of thing we are more familiar with, and yet it is disappointing for it seems short and incomplete. There is the waving, curling musical line typical of the Veery, a slurring upward and downward between fifths, but we usually expect four or five downward shifts. Here we see only two or three waves at the end of each phrase, with either one downward modulation of about a whole tone, or none at all.

The pitch of these fifths is usually 3900 over 2600 sharpening to 4000 over 2700, and modulating to 3500 over 2300 frequencies. However disappointing, the record at least makes it clear that a bird can have a musical ear, for there is no mistaking the Veery's intention, the pure fifths are repeated over and over again in the second half of each phrase. The interval is not a mere accident, as it might perhaps seem to be in the more irregular song of the Bobolink. Curiously enough, the flatted fourth is also repeated at the same point in each call, as if it were a habit. But the fifth is in tune and obviously forms the basic pattern of the song. Nor is it mere chance that there is a tendency to shift the pitch of the interval downward. The pattern of the Veery's song has been recorded by countless ornithologists in the field and there is always a tendency to downward modulation. Mathews writes it so.

Here is very good evidence to show that birds apprehend the relative pitch of sound waves according to their *ratios*, just as we do, and consequently share our instinctive faculty for making changes of tonality. In the article in 'The Auk,' to which I have already referred, Mr. Brand made a study of the Winter Wren's song, which is very brilliant and dazzling, and delivered at great speed. "Because of the great number of notes," he wrote, "in the Winter Wren's song (113 in all), it has been necessary to divide the graph in half. . . . Here an interesting phenomenon will be noticed at once. The second half of the song is almost an exact repetition of the first half, except that it is a couple of notes higher. This is exactly what is heard, although some observers have guessed that the second half was a full octave higher than the first." Perhaps individual Winter Wrens make different transpositions.

I have the sound film of a Hermit Thrush's song. I have not yet had time to transcribe it, but I know from ear that it can be defined as a series of modulations—very rapid inverted arpeggios, with long pauses between, each phrase introduced by a single note, long drawn out, on a different pitch, striking the tonic, as it were, of the new chord in the new key—a piling up of overtones on shifting fundamentals.

Olive-backed Thrush

(From the victrola record)

It would seem that the Olive-backed Thrush is singing arpeggios which contain not only the notes of our common chord (the fourth, fifth, sixth and eighth partials), but also the seventh partial, omitted in our music. This chart (Pl. 24, fig. 2) is the first of four sheets recording a song with five different phrases. They are all somewhat similar, variations of arpeggios, climbing to a rather uncertain octave, but the first is the clearest. The frequencies were not easy to read on the victrola record. In America the thrushes, the Wood Thrush, the Hermit and the Olive-backed, all sing variations of arpeggios based on the common chord.

BROWN THRASHER

(Variable amplitude film)

This fragment (Pl. 24, fig. 3) is not nearly long enough to give the complicated rhythmic repetitions for which the Thrasher is famous. The notes are slurred and look quite irregular, although one can discover a wavering tendency to pitch some of them around a tonic of 1750, with an octave of 3500 and with once a rise to a second octave of roughly 7000, a very high pitch, showing the wide range of the Thrasher's music.

By far the most interesting notes in this record are the very long slurs at the end. The one which goes both up and down is remarkable because it is an almost perfect example of an arithmetic scale or slide, that is to say, a scale in which the pitch rises by even arithmetic increases in even time. This slur is the best proof of an arithmetic scale in bird song that I have so far found among these few examples. When many more transcriptions have been made, we shall be able to tell better whether it is a mere accident or not.

Though a great many birds, for instance, the Screech Owl, the woodpeckers, even the Robin, sing small fragments of a scale, it so happened that none was recorded on this material that I was studying, so I paid particular attention instead to the slides, of which there were many, for it is a fact that slurs and slides are much more common in bird song and in primitive music than the long tone ladder with regular steps, as we know it in our music.

No one understands exactly how changes of pitch are made in a bird's throat, but it would seem that a gradual and continuous slide can be made almost automatically, but at different rates of increase, a matter perhaps of degrees of energy of muscular contraction. The slides recorded on my charts have different curves and lines, showing that the increase of frequencies can approximate an arithmetic progression in its timing, or a geometric progression, like that of our own scale in which the frequencies double in even time, or an even more rapid and explosive rate of speed, as in the Chestnut-sided Warbler's song. From the point of view of musical theory, the arithmetic slide is particularly interesting because it provides a natural framework with even timing for the physical scale of overtones.

The slur at the very end of the Thrasher's song covers slightly over two octaves, from 1750 to 7000, but unfortunately it is not perfectly smooth, there is a hitch in the middle. It has, however, one important characteristic of the arithmetic scale: the higher octave took the Thrasher twice as long to sing as the lower octave. If this slur were automatically 'interrupted,' that is to say, divided into separate, evenly timed notes, the upper octave would have twice as many notes as the lower.

White-throated Sparrow

(Variable amplitude film)

Four notes on a monotone, to the rhythm of 'Sam Peabody' (Pl. 25, fig. 4). Though so simple, this record is very interesting. Under the microscope the monotonous notes reveal an effect of alternating dynamics very delicately varied and controlled. The notes are long drawn out and the pitch is held very steadily, which is most unusual for a bird—such deviations as there are may be due to fractional errors in my counting. In the first note there are four alternations between *ff* and *mp*, in the second note the underlining of the accent shows as a slur, like a little upward push, rising to a longer *ff* which only dies away at the end of the note. The last two notes each have three alternations from *f* to *p*.

It is clear that in this case the wavering, floating, tenuous quality of a Whitethroat's note is not a wavering from pitch, it is a matter of very subtle variations in dynamics, like the vibrato on a violin, with the accented note treated quite differently from the three others. The tempo is very slow; the pitch 4000 frequencies, that is, very close to C7, two octaves higher than the high C of a light soprano.

Song Sparrow

(Variable density film)

The transcription (Pl. 25, fig. 5) covers about two seconds and a half of the opening of a Song Sparrow's song. The three staccato notes to begin with seem very familiar, and yet it is a surprise to learn that each one of them lasts only 1/66th of a second, and that the pauses between are five times as long as the notes themselves. To our ears, owing to the reverberations, there would hardly seem to be any pauses for silence, but the effect of the three notes would be very staccato.

The long interrupted note coming after the three opening ones was still more of a surprise. At first I was inclined to call it a trill, because it looked like one, but the speed of the beats was so extraordinarily rapid, and their succession so perfectly rhythmic and regular, as if produced automatically, that I have come to think that is must be one of those odd fricative or

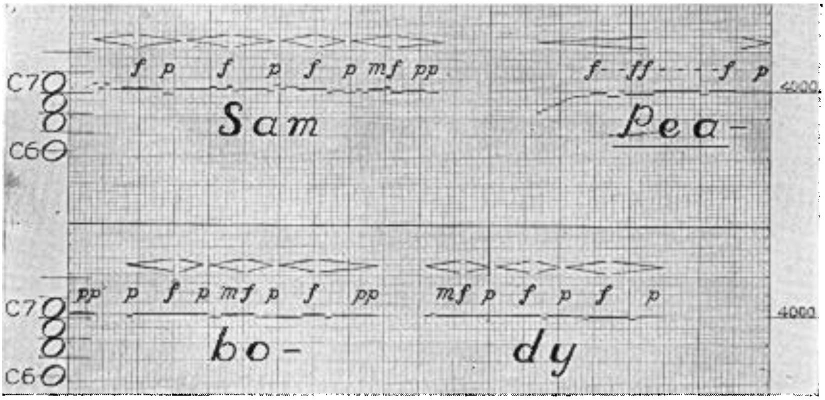


FIG. 4.—SONG OF THE WHITE-THROATED SPARROW

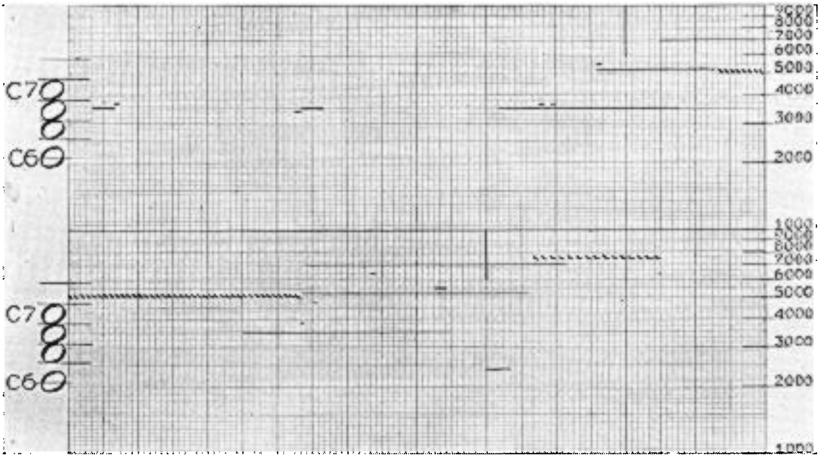


FIG. 5.—SONG OF THE SONG SPARROW

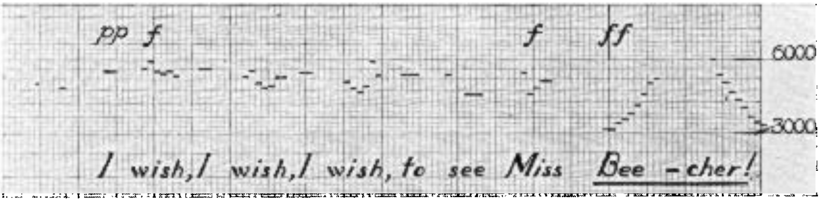


FIG. 6.—SONG OF THE CHESTNUT-SIDED WARBLER

wheezy notes of which we hear such a variety in bird songs, a sound with something like a *z* or an *r* in it, and yet not quite either. A trill at that speed, one hundred beats to a second, would hardly sound like an ordinary trill. The pitch was around 5000. The whole note or trill actually consisted of about forty-eight beats, or tiny separated notes, and each of these beats was made up of a group of about thirty-five vibrations, with the first ten waves distinctly higher in pitch than the rest; how much higher it was difficult for me to tell, because my time unit of one hundredth of a second was not fine enough for the necessary measurement.

The last note on the record was another interrupted one, but with beats not quite so rapid. What would be the difference in effect to our ears, I cannot say.

Mr. Brand was also surprised at the speed of bird notes. He recorded that "many of the notes in the Song Sparrow's song and in the songs of many other species are of incredibly short duration, so short that they could not possibly be heard by the human ear except in combination with the preceding or following notes." He also found "the abrupt and lightning quick changes of pitch" in the Winter Wren's song most astonishing. One might fancy that the whole tempo of bird life were speedier than our own, and the little birds speedier than the big birds. In flight-songs the rhythm of the music may be set to the beat of the wings and we know now how extraordinarily rapid that may be.

Chestnut-sided Warbler

(Variable density film)

It is amusing to see how closely and exactly this microscopic record (Pl. 25, fig. 6) fits the catch phrase, 'I wish, I wish, I wish to see Miss *Beecher!*' except that we should normally need three or four seconds to say it, whereas Miss Beecher's lively little friend takes scarcely more than one second.

The song is much more like an emphatic sentence made up of words than it is like a phrase of abstract music. The rhythm, of course, is very familiar, actually that of iambic blank verse, rising with force and intention to a climax. Harmonious intervals are lacking, but there are complex inflections, ending with the characteristic, explosive little slur up and down.

It may be noticed on the chart that the slurring makes a concave upward curve. This means that the speed of increase of pitch is even greater than geometric, for our own logarithmic scale would show as a straight line on this semi-log paper. The slow arithmetic scale, as in the Thrasher's song, shows as a convex upward slur.

OUR OWN MUSICAL INSTINCT AND THE PHYSICAL SCALE

I am not considering here the tempo, the rhythm or the dynamics of bird song, different and fascinating as these are, or the slurring and trilling, but simply the question of musical intervals. I must apologize to 'The Auk' for seeming to stray away from the subject of ornithology, but can only say that my original purpose was rather general. I wanted to study bird song and musical instinct from the point of view of theory, and then look back again at our own music from out-of-doors, so to speak. Our music is based upon a scale which we never hear in Nature. How can this be? There is a wide gap between the very simplest form of our musical art and that of birds.

As one might have expected, I found by these charts that the birds were occasionally singing intervals in simple arithmetic ratios, and occasionally transposing them. Then I found the long slide in the Thrasher's song where the change of frequencies was an arithmetic progression, the numbers increasing evenly and in even time. What deductions can one draw from these simple facts?

One day, out of idle curiosity, when I was just beginning this work, I drew the graph of an arithmetic scale on semi-logarithmic paper and was interested to discover that at regular intervals on this slide appeared a series of musical intervals which looked extremely familiar in their order, as if they must have some basic musical significance, first the octave, then the fifth, then the notes of the common chord, plus the seventh, till a succession of eight intervals was reached very similar to our old 'natural' diatonic scale of seven intervals. For several weeks, actually, I told myself that the birds must be singing 'arithmetic' intervals before I discovered that I had stumbled unawares upon the theoretic framework of those very overtones that I had been looking at with such interest through the microscope, and that their proper nomenclature was the series of overtones, or Helmholtz Order of Harmonic Partials. They were indeed fundamental to all music and to the science of acoustics, being based upon the law of the reinforcement of sound. According to this law, higher-pitched sound waves often occur automatically as exact multiples of a fundamental, and they produce resonance by reinforcing and intensifying the fundamental, whereas multiple sound waves which do not fit each other are out of tune, so that the haphazard currents produce either impure tones or silence.

When I first began this study I had no preconceived idea as to what I should find. I thought, conventionally, that the octave scale, possibly the well-tempered scale of Bach, was the basis of our music. I have now come to a different conclusion: I think both birds and human beings are instinctively sensitive to the natural or physical scale of overtones, created automatically in any vibrating column of air according to the law of resonance. And I think we are directly sensitive, musically, to the ratios of this same law of resonance and reinforcement, whether they apply only to multiple vibrations from a single source, or to all patterns of sound waves that meet and mingle in the air and fit and flow together—like the perfect playing of the Flonzaley quartet. An octave is still an octave to our ears when it is played by two instruments.

Recent researches by the Bell Telephone Company show that the human ear is built on the lines of an extremely complex, very minute grand piano, with 24,000 vibrating fibers for strings stretched across the basilar membrane, the shorter fibers more taut, the bass fibers looser. Each fiber vibrates more strongly to a sound wave of its own frequency, according to the law of resonance, and missing overtones or missing fundamentals can be created automatically by the irregular shape of the ear drum.

Some of the lower animals have ears even more complex in some respects than ours, but the number of vibrating fibers is usually less. Birds have only 3000; otherwise their mechanism is similar to ours and is explained by what is called the 'resonance theory of hearing.' If we accept the resonance theory, it seems natural to assume that the basis of instinctive music must be the physical scale of overtones, created automatically according to the law of resonance.

The term instinctive music, of course, covers much more than merely bird song. It has been noted by the psychologists that we ourselves use musical intervals in our speech, especially in exclamations. Octaves, fifths, fourths, major thirds and minor thirds, we speak and cry them all to express various shades of feeling, but with the same sort of vagueness and inaccuracy that is heard in the songs of birds, the ratios so wrapped around in ambiguous slurs and slides and random waverings that only a few people such as actors and natural mimics can consciously control them. These inflections are probably based on the overtones, and it is entirely possible that we use the seventh partial, for instance, to express some perfectly familiar and unmistakable shade of feeling, just as instinctively and without being any more aware of what we are doing than is the Olive-backed Thrush.

Having plotted them on a graph, I knew that the overtones in their regular order formed a kind of natural musical scale, and it occurred to me that it might be worth while, for a better understanding of the essential difference between our art music and bird song, to make a comparison between the characteristics of this scale and those of our own two scales, the diatonic and the chromatic.

The physical scale is an "infinitely variable" series, and contains, theoretically, all the possible notes that are in harmonic relationship to one fundamental and consequently in pure intonation. Defined according to frequency numbers, it is an arithmetic series in which the number of the fundamental is the same as the unit of increase. If the fundamental is 1, the series is 1, 2, 3, 4, 5, 6, 7, etc., ad infinitum, the familiar a, b, c of mathematics. If the fundamental is 32, as roughly for the key of C, the unit of increase is also 32 and we arrive at 256 frequencies for middle C.

Defined according to relative wave lengths or frequency timing, the physical scale becomes a quite different series of diminishing ratios:

$$1,\ \frac{1}{2},\ \frac{1}{3},\ \frac{1}{4},\ \frac{1}{5},\ \frac{1}{6},\ \frac{1}{7},\ \frac{1}{8},\ \frac{1}{9},\ \frac{1}{10},\ \frac{1}{11},\ \frac{1}{12},\ \frac{1}{13},\ \text{etc.}$$

Through our sense of hearing it is evident that we perceive this series not according to the first definition, as an arithmetic series of equal increases, but as a succession of musical intervals diminishing with a diminishing difference. This may be explained either by the second definition, or according to the Weber-Fechner law, closely related to it.

The Weber law is usually stated in this way: If the stimuli are increasing in geometrical progression, the sensations increase only arithmetically, in other words the sensations lag behind the stimuli. But in the case of the physical scale, the stimuli, the frequency numbers of the notes, are *not* advancing geometrically; it so happens that they are advancing evenly and precisely as an arithmetic progression. If we still assume that the relation of stimulus and sensation is logarithmic and apply Fechner's equation, then we find that the overtones must be visualized as a diminishing series according to Gunter's logarithmic scale:

The spacing of the lines on semi-logarithmic paper is according to this very Gunter's logarithmic scale, so the paper is therefore perfectly adapted to the plotting of overtone scales.

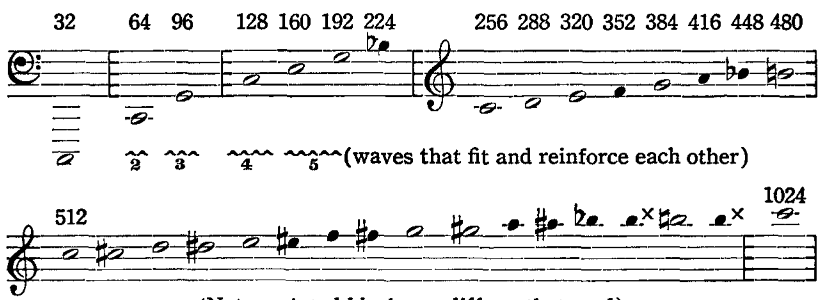
So far as I know, Gunter's logarithmic scale has never before been used in connection with musical theory, but I believe it may serve to emphasize the main characteristics of the physical scale, and in so doing clear up certain misconceptions as to our sense of pitch, which is logarithmic, and our instinct for pure intonation, which is connected with an arithmetic series of frequencies. It shows that the two can be easily reconciled.

Now as to the relationship between our present musical scales and this foundation of instinctive music that we share with the birds and lower animals. The pre-Bach diatonic scale, with its original tuning, *do re mi fa sol la si do*, was a scale of uneven intervals in pure intonation, closely related to the fourth octave of overtones, as may be seen by glancing at a table of comparative frequency numbers. *Do re mi sol si do* are identical in both scales, *fa* and *la* were obtained by inversion from upper C but every interval can be found among the lower partials. One could hardly look for better evidence than this to prove that our musical instinct is sensitive to the physical scale, for music anticipated science by 2500 years in its discovery and utilization of practically the first four octaves of overtones. The Pythagorean scale is essentially a fragment of the physical scale, but not perfect and complete, for the seventh partial and its derivatives are conspicuous by their absence.

On the other hand, the well-tempered scale with its complex fractions is a product of higher mathematics, and the birds do not use it because they can make changes of tonality instinctively. It corresponds to our logarithmic sense of pitch, but it does not entirely satisfy our sense of harmony and pure intonation, for these follow the law of resonance which requires that musical intervals, to be perfectly in tune, must be exact multiples of their fundamental.

Order of Harmonic Partials or Series of Overtones

With 32 frequencies as arithmetic increase, in the key of C



(Notes printed black are differently tuned)

SCALES

Arithmetic		*Old Diatonic*			*Tempered*	
ratio	in 8ths	ratio			or logarithmic	
	256		C	256	C	256
					C ♯	271.2
9/8	288	9/8	D	288	D	287.3
					D ♯	304.4
10/0	320	5/4	E	320	E	322.5
		4/3	F	341 1/3	F	341.7
11/8	352					

SCALES—*Continued*

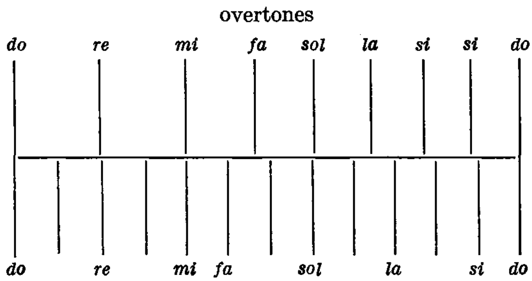
Arithmetic		*Old Diatonic*			*Tempered*	
ratio	in 8ths	ratio			or logarithmic	
					F ♯	362
12/8	384	3/2	G	384	G	383.6
					G ♯	406.4
13/8	416	5/3	A			
		5/3	A	426 1/3	A	430.5
14/8	448					
					A ♯	456.1
15/8	480	15/8	B	480	B	483.2
16/8	512	16/8	C	512	C	512

An automatic capacity for modulation or transposition is one of the most significant manifestations of our musical instinct. We can sing a tune not merely in one key, or merely in twelve keys, but at any desired pitch within our vocal range, and this without any mental effort. No doubt the faculty is connected with our subconscious perception of the ratios of overtones, which are constantly being piled up at lightning speed on rapidly shifting fundamentals. If we had to make changes of tonality rationally, calculating frequency ratios by mental arithmetic, we would find the process quite lengthy and tedious.

On primitive stringed instruments the player could make changes of key instinctively, by sliding his fingers up and down till they found the pitch required by his ear. But when complex instruments like the harpsichord and the clavichord were designed, with immovable keys, the number of fixed notes required for any real freedom of transposition of the pure diatonic scale would have been very large, for the intervals did not fit each other. The instrument presented the difficulty, and the difficulty was solved by changing not the instrument but the scale—a new scale was introduced based on mathematical theory, a logarithmic scale of equal ratios, dividing each octave into twelve equal musical intervals called semitones. The frequency numbers of these semitones advance by gradually bigger and bigger leaps, doubling with every octave, like compound interest doubling in twelve years.

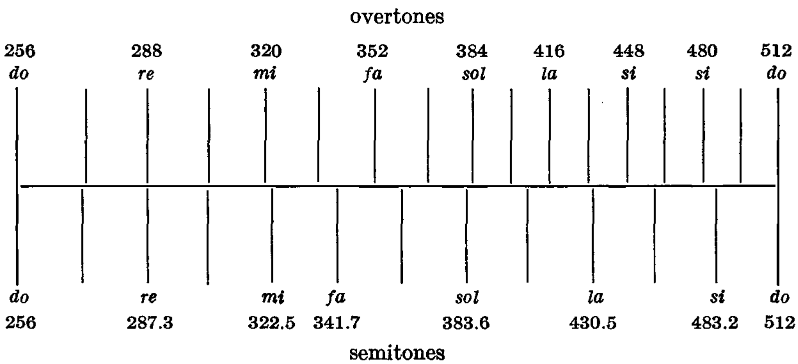
Of course, logarithmic equal-interval scales could be devised according to any number, 7, 10, 53, any number to the octave, and one could foretell of all of them that they would be partly out of tune, and that their equal intervals would seem to us to have harmonic significance only in so far as they happened to approximate overtone intervals. No doubt the number twelve was chosen because it gave the best fit, very good in the lower half of the octave, not so good in the upper. The old diatonic scale was differently tuned to fit into the new mold, and could now be repeated slightly

Overtones measured by their Ratios fitted to Logarithms in Twelfths



Ratios of fourth octave of overtones, in arithmetic eighths, assuming four inches as wave-length of fundamental.

Ratios of fifth octave of overtones, in arithmetic sixteenths, assuming eight inches as wave-length of fundamental.



out of tune anywhere up and down a ladder of continuous equal semitones, covering six or seven octaves. If a modern inventor were faced with this same problem of transposition, he might perhaps be able to solve it mechanically, and then we could imagine the natural scale liberated from its present shackles.

No doubt a scale of equal intervals has certain aesthetic qualities that a scale of diminishing intervals could never exactly reproduce. It appeals, perhaps, to an artistic instinct of a more general order, the instinct for equal measurements, as in formal design or metrical verse. Yet it is not the whole of music,—it never was; beautiful music was written, too, before the eighteenth century.

Possibly with the further development of research in sound photography, musicians may become more and more interested in overtones and instinctive music, and may at last wish that they could hear the natural scale in all its purity and judge for themselves as to its musical possibilities.

One can imagine an instrument on which the compromise, the fusion of two incompatible scales, would be made mechanically instead of theoretically by ambiguous tuning, etc., something like the piano or the electric organ, but with a double logarithmic keyboard, on which could be played both the well-tempered and the natural overtone scale, the latter fitted if possible with an automatic device which would enable the player to raise or lower the pitch of the whole keyboard to any transposition required. If the overtone scale has true musical significance, we should then hear an instrument with harmonic possibilities far greater than those of the piano. Logical lines of harmonic or melodic progression could be developed continuously up and down the whole keyboard instead of being limited by the convention of repeating, identical octaves. Each octave would repeat the notes of the next lower octave, but with additional finer intervals between. Octave scales in pure intonation could be played from any note but no two would be exactly identical.

To the ear, the finer intervals would merge, no doubt, into a continuous slide. But experiments have shown that the ear is capable of making amazingly fine adjustments, sometimes quite unconsciously. For instance, good violin players and singers can adjust themselves with the piano to the well-tempered scale, but when they are unaccompanied they instinctively revert to pure intonation. This proves what we might well expect, that pure overtone intervals are the line of least resistance to our musical instinct, for they have been our heritage for millions of years. In every sound that we hear, in every tone, we subconsciously analyze their permutations and combinations.

A double keyboard would not be so very impractical, for many of the notes are almost identical and the greater scale would include the lesser. Of course, the new keyboard would have to be more complicated, with thinner keys in increasing rows in the upper registers.

But this is a flight of fancy, an outgrowth of a very simple idea, namely, that the intervals of the lower overtones are to be heard in the songs of birds, sung and repeated and transposed deliberately. Of course, the theory of a physical basis to music is not in the least new or original.

I do not believe that birds have any scale or musical system of their own; I think they are quite innocent of any such artificial scheme, but yet are sensitive in much the same way as we are to the laws of Nature, not only through the mechanism of their ears but with all their being.

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