

MUSIC, MIND, AND BRAIN

The Neuropsychology of Music

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Chapter XII

AFFECTIVE VERSUS ANALYTIC PERCEPTION OF MUSICAL INTERVALS

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INTRODUCTION

When I see an apple, what do I experience? Of course I see it at a certain place in space, and of a certain size - both with respect to my body, and with respect to other things in its environment. But at the same time, I see and experience some of its qualities - its shape, its color, etc. And from these, I may get an imagination of its taste.

This, however, depends on my interest. If I am hungry at the time, I may feel, "Ah, a tasty apple!" But if I am not at all hungry, I might feel, "Oh, just a little apple . . ." In short, the quality of my experience depends on how seeing the apple relates to me personally, or, how I imagine that it relates to me. For instance, even if I were to see a plastic apple, I might still experience seeing what I imagine to be a delicious real apple.

Now, while I might have some particular handicap or personal impression of apples which could alter or distort my experience - for instance, if I were nearly blind, or had once been poisoned with an apple - normally, in our culture at least, ripe apples are more or less relished as tasty, healthful food, and this is quite compatible with the biological fact that for most people, apples are both healthful and tasty. And this fact we understand as being due to our common genetic and physiological heritage.

Now, musical intervals are like apples, in that what we experience when we listen to a musical interval - like what we experience when we see an apple - depends on what kind of interest, motivation, and imagination we bring to the perception.

Meher Baba, the contemporary spiritual author, has described the human mind as having two aspects - the 'inquiring and reflecting' aspect, which pertains to thoughts, and the 'impressive and sympathetic' aspect, which pertains to feelings (Meher Baba, 1955). These are commonly referred to as 'mind and heart' but are, I believe, indissoluble aspects of the

human mind and of human experience - though they may be found in differing balance and harmony in different individuals.

Now, when we hear a musical interval, we certainly can hear its relative pitch-height and size, and we can also hear its physical qualities - its timbre, loudness, consonance, etc. But our whole experience of the interval depends on how we imagine that the interval relates to us personally.

If we are thirsty to hear music, in order to satisfy some emotional need or desire, we may feel, "Ah, what a beautiful chord!" On the other hand, if we were to listen to the same interval as simply a physical sound, with a motive only to analyze or judge its physical properties, we would no doubt have a very different experience, and might think, "Yes, an interval of about four semitones, of complex timbre, . . ." and so on.

The interest of psychophysicists has usually been in this last way of experiencing sounds, as physical sensations. And they have discovered that, excepting various individual variations, limitations, and degrees of sensitivity, most sounds are heard rather the same by most people - and this is understood again to be a reflection of common genetic and neurological heritage.

However, for me and I believe for most of the world, the usual and deepest motive for experiencing music is mainly for the sake of emotional experience. It is important therefore for music psychology and science to consider closely the emotional or affective experience of musical intervals.

If our judgments of the size and pitch of musical intervals are more or less due to our similar neurophysical make-ups, why should not our affective experiences of some intervals be also more or less the same?

RATIOS AND AFFECTS

It is my belief that there exists a particular set of integer-ratio musical intervals which do tend to qualitatively affect our affective imaginations in consistent ways; that is, when we listen to harmonic musical intervals while imagining that they are expressing some feeling, we then tend to agree about what feeling each interval expresses.

On what do I base that conviction?

1. On my own experience as musician and composer;
2. Reading many of the references to qualities of intervals from the Western literature through the centuries;
3. Having experimented for some time with finely tuned intervals;
4. Asking others for their affective impressions of the same intervals;
5. On the results of a pilot experiment which supports the idea that certain musical intervals, even outside of any explicit musical context, tend to effect consistent qualitative changes in the imagination of listeners, when those listeners listen to those sounds as expressions of human personality or feeling.

Some Historical Evidence

1. A second millenium B.C. Babylonian tablet has recently been deciphered which instructs musicians in tuning a diatonic scale by ear, tuning by consonances ($4/3$ fourths). After tuning seven consecutive fourths, the tablet notes, the seventh and first strings will make a dissonant interval (the tritone) (Kilmer, Crocker and Brown, 1976). This establishes that the so-called 'Pythagorean' scale of Boethius and medieval tuning theory was in use at least a millenium before Pythagoras, and that experience of physical consonance has been taken as a basic music principle for at least 3,000 years. In fact, the scale of the Babylonian tablet is the first historical example of what I call a tone-group (see below).

2. The first Western medieval reference to the ($5/4$) just major third called it more sweet or 'suave' than the then-traditional ($81/64$) Pythagorean third (Gut, 1976). Helmholtz (1862), who devoted the final but often overlooked chapter of his monumental book on the experience of music to the differences in feeling of just, Pythagorean, and equal-tempered tuning systems, wrote

The later interpreters of Greek musical theory have mostly advanced the opinion that the differences in tunings which the Greeks called 'colorings' (chroai) were merely speculative and never came into practical use . . . But it seems to me that this opinion could never have been entertained or advanced by modern theorists, if any of them had actually attempted to form these various tonal modes and to compare them by ear.

It is not at all difficult to distinguish the difference of a comma ($81/80$ or 1.25%) in the intonation of the different degrees of the scale, when well-known melodies are performed in different 'colorings', and every musician with whom I have made the experiment has immediately heard the difference.

Melodic passages with the Pythagorean thirds have a strained and restless effect, while the just thirds make the same passages quiet and soft. (Helmholtz, 1862, p. 407-408).

Note the agreement of Helmholtz' nineteenth century subjects with the medieval manuscript cited by Gut. The small (enharmonic) pitch differences in the just and Pythagorean variants of the intervals of the Western scale have been all but forgotten since the establishment of the compromise system of equal temperament. At the same time, belief in innate connections between intervals and affects has been replaced with widespread skepticism. However, the apparently systematic connection of interval affect with interval ratio referred to here by Helmholtz is a most interesting phenomenon.

3. Again, Boomsalter and Creel (1963), repeating Helmholtz' experiments with melodies, found that musicians almost always hear such small (enharmonic) pitch shifts as differences of 'color', i.e. timbre or feeling, rather than as pitch differences - unless they are specifically asked to list for pitch shifts.

My Own Work

My experiments have shown me that the way such small pitch differences among integer-ratio intervals are experienced depends on what listeners imagine they are hearing. An extremely small change in pitch of a complex tone will give rise to a distinct impression of vowel shift when listeners are asked to imagine a vowel sound in the tone. When I ask listeners to imagine that they are hearing musical expressions of personality or of feeling, they hear small differences in tuning of a musical interval as distinct differences in feeling or expression. Moreover, in a pilot experiment (Makeig and Evans, 1979), the feeling experienced for each interval, or more exactly, the qualitative effect of each of several intervals on the imaginations of listeners seemed to be significantly consistent among listeners. The method of projective imagination has rarely been consciously used in psychoacoustic research, but deserves to be more so.

Sensitivity to Ratios

Listening for the feeling of an interval instead of for its size dramatically increases one's sensitivity of feeling to small tuning differences, especially for many integer ratio intervals and their mistunings. As Erv Wilson, the tuning theorist, recently remarked*, the more in tune an (integer-ratio) interval is, the more one wants to hear it in tune. This has been the spontaneous remark of several musicians to whom I have demonstrated the affective results of tuning variations of musical intervals.

However, intervals which are exactly tuned to integer-ratios take on, as Wilson notes, a (beat-free) 'glassy' quality which sounds unlike ordinary music. It is not the feeling quality of the integer-ratio intervals which sounds 'un-natural', but the physical sound-texture. This would seem to indicate that the musical feeling quality of an interval is separate in experience from its physical consonance, pitch register, or timbral quality. This fact is the basis of the practice of musical transposition. Although variations in register, timbre, or sound-texture certainly can alter the overall feeling experienced, there is yet some quality of an interval by which musicians recognize and identify it (as noted, for example, by Siegel and Siegel, 1977).

Modern experiments to define the feeling associated with various intervals have generally not been successful (Maher, 1979). However, the

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technique of projective imagination, combined with multi-dimensional scaling of responses appears to be a most promising technique for objective study of this phenomenon.

Recent Evidence for Parallel Affective and Analytic Perception

That the feeling of a musical interval may be a separate experience from the experience of the pitch-height of the tones of the interval and may even be mediated by different neural information processing has been suggested by the psychoacoustician Evans (1978) on the basis of recent neurological and psychoacoustic evidence. Evans suggests that recognition of musical intervals is based on periodicity ('time') information, whereas pitch-height and physical consonance is most likely supplied mainly by 'place' information. Goldstein (1978) points out that the accuracy of pitch judgments is greater than would seem to be physiologically possible using either place or time information, but is within the range of expectation if both kinds of information are in fact used in some integrated manner. Both de Boer (1976) and Evans (1976) have commented that lack of attention to the 'subjective' experience of the various psychoacoustic phenomena associated with 'pitch' has created confusion in the field, for not all experiences of pitch share a common subjective or objective nature. A similar confusion is seen in aesthetic research which attempts to measure aesthetic experience with a one-dimensional measure ('preference'), rather than analyzing the significant dimensions on independent ranges of variability in the experience.

Evans' theory of the dual nature of pitch seems in accord with the phenomenology of experience of small pitch variations. When we hear a singer sing a note 'flat', we mainly experience a note that feels 'sour', rather than experiencing (or before experiencing) the same note as being 'too low'. Musicians may feel that their most immediate experience is of the note being 'too low'. However, the reaction-time experiments of Balzano (1978) show that even advanced music students know that a minor third for example is 'some kind of third' before they know that it is a minor third (or 'flat' third). Similarly Siegel and Siegel (1977) showed that musicians have extreme difficulty in judging whether a fixed out-of-tune interval is too sharp or too flat. This fact is common knowledge among musicians who must tune their own instruments, and find it easier to do so by varying the pitch steadily until the quality of the interval is recognized most clearly.

Kunst-Wilson and Zajonc (1980) have found that under certain circumstances, persons exposed to brief flashes of random octagon shapes can better recognize which shapes they have seen before by asking themselves, "Do I seem to like this shape?" than by asking the more analytic question, "Do I recognize this shape?" This is only one of several memory experiments referred to by Kunst-Wilson and Zajonc which show that access to prior experience may be more direct through attention to affective association than through conscious analytical inquiry. The following analogy shows, I believe, the value of using affective as well as analytical abilities in a process of on-going perception.

Imagine two kinds of speedometer displays. In one, the speed of the

vehicle is displayed on the front window of the vehicle in numerical form. In the second, speed is shown by tinting part or all of the window with a color whose wavelength (i.e. hue) is proportional (or inversely proportional) to the speed of the vehicle. It is possible that this second display would be much more useful in high-speed maneuvering, where attention to the displayed information in the first example, would tend to interfere with attention to rapidly changing details of the environment. The hue-coded speedometer might come to be experienced by the driver (or pilot) much like an affective sense or feeling of the speed of the vehicle, without interfering with his or her attention to the world outside the vehicle.

I do not mean to imply by these arguments that the major function of affective experience is to increase perceptual efficiency. Through feelings, we are able not only to better know ourselves, but also to better know and be able to identify with others. Through affective experience of art and music, we are able to deepen our knowledge through feeling, not only of the artist or composer, but also of ourselves and our relationships to others. I believe that such experience is for most people the primary and deepest appeal of music (see Meyers, 1927).

The Left-Right Dichotomy

The much-explored differentiation in function between the right and left hemispheres (in 'normal' right handers) may possibly be characterized as a differentiation between sequential, rapidly varying perception and cognition, and 'held', more slowly changing, global spatial and affective processes (Pribram, 1978; Smith and Tallal, 1980; Polzella et al., 1977). In particular, results of many of the dichotic pitch recognition experiments show a small right-ear (left hemisphere) advantage for trained musicians (especially on more difficult tasks (Shannon, 1980). 'Non-musicians' usually show no such ear advantage, or more commonly show a left-ear advantage.

However, the idea that musicians experience music more with their left brain while non-musicians experience music more with their right brain has recently been shown to be unrealistic. Gordon (1978) found a right-hemisphere advantage for musicians in a major chord recognition task. Moreover, recently Sidtis (1980) has claimed that the right hemisphere is specialized for complex pitch perception, as opposed to pure tone frequency following. Most interestingly, Shannon found that hearing a harmonic (simultaneous) octave in the right ear allowed musicians to respond quicker, "Not an octave!", whereas heard with the left ear they responded quicker, "Yes, an octave!" This suggests there is more than one way to recognize an octave, and that each side of the brain may work on the task differently, perhaps according to different modes of listening which may be concurrent.

It is plausible that some 'left-right' polarization might be found for 'affective' and 'analytic' aspects of pitch perception as well. Interval quality (and timbre) might be better perceived using the right hemisphere, whereas rapid and accurate pitch-trajectory tracking might be better performed using the left hemisphere. In a recent review, Brust (1980) refers to evidence that this may be the case. However, to my knowledge, no experiment has specifically inquired into how 'affective' listening alters the left-right balance, and to what extent.

The Experience of Musical Consonance

Terhardt (1977) has pointed out the difference between the experience of physical consonance based on sensation of roughness at 'places' on the basilar membrane, and the experience of consonance of musical intervals (in Western tonal music at least) which seems to be based on the same principle of 'harmonic template matching' which is apparently used by the nervous system in deriving fundamental pitch from a complex harmonic or inharmonic sound.

Beament (1977) has suggested in some detail how presence of periodicity within the auditory nervous system at submultiples of spectral frequencies generates an array of subharmonics which could be used by the nervous system for recognition of integer-ratio musical intervals. The often-noted presence of a range of subharmonic periodicities for each of a range of harmonics of a normally harmonic musical sound implies the existence within the nervous system of a harmonic/subharmonic network of activity, which in the case of integer-ratio musical intervals becomes an interrelated array of information.

Goldstein (1976) has suggested that the periodicity information may be

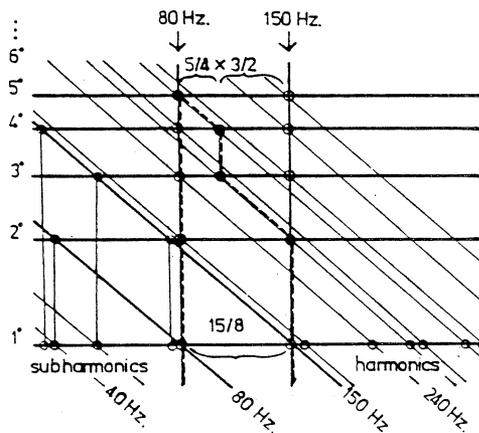


Fig. 1. Schematic tonotopic planar array capable of factoring ratios into their lowest prime factors, (also capable of signalling fundamental frequency of a complex harmonic or near-harmonic tone). Oblique stripes represent spectrum - here, fundamental frequencies of two tones (80 and 150 Hz.) related by the interval (frequency ratio) $15/8$. Horizontal thick lines represent successive harmonics (here 1-5 only). Vertical lines 'collect' harmonics of a single frequency. Information about the higher tone's frequency spreads out along the vertical lines wherever an oblique frequency stripe intersects a harmonic line. One most direct path from the higher to lower tone is shown in dotted lines. The prime factors of the ratio are determined by the number of vertices of such a direct path which occur on each harmonic stripe.

translated at the brainstem level into a central tonotopic or 'place' representation of pitch. Figure 1 shows how such a central tonotopic tract might hypothetically be arranged so as to signal (1) fundamental frequency, and (2) the component prime factors of an interval which approximates an integer-ratio interval.

The harmonic lattice of fifths and thirds recently illustrated by Longuet-Higgins (1978) has been used to plot musical tuning systems since the time of Mersenne. Now, if harmonic intervals were represented at some stage in the nervous system within some such a tonal harmonic array, and if our emotional nervous system were connected in some orderly way to such a neurological representation, we might expect that the structure of our affective experience of intervals which are in or are close to integer-ratios might be similar to the underlying structure of pitch relations among the intervals themselves.

Neurologically, this is mere speculation. However, psychologically this does seem to be the case. It is remarkable that the theory of ratio-interval affect which I shall outline in this paper, though seemingly far from the concerns of psychoacousticians and auditory neurologists seems very much in harmony with latest trends in the theory of pitch perception.

Both Evans (1978) and de Boer (1976) have pointed out that in psychoacoustic tests of frequency discrimination more than one kind of experiential cue is normally used by subjects, for residue pitch and fine frequency discriminations particularly. While this even seems to be the case in isolated psychoacoustic experiments, affective perception is much more important in the process of normal music listening, in which the stream of sonic events is much too dense and complex to be 'understandable' without use of affective perception. Although some highly trained musicians may claim to follow musical activity purely 'analytically', experiments such as Balzano's (1978; this volume) show that they do not in fact do so.

In any case, highly analytical listening is not a possibility for that large majority of music lovers whose analytical abilities to label, retain, and identify musical pitch and time relationships are undeveloped, and, as beginning music theory teachers know, are often surprisingly poor. For example there have been unpublished reports of many untrained listeners being unable to recognize major and minor triads as 'different'. Yet the affective difference between major and minor triads is one of the principal means used by composers to manipulate the feeling of popular songs and melodies. Its efficacy is indirectly attested by the extreme commercial success of such music.

A really valuable science of music must, I believe, include a detailed understanding of the experience of music which I have been calling affective experience. Helmholtz (1862, p.410-411) himself ended his book on music with the request that others in the future take up and carry on the study of musical affects which he had begun. With the availability of present computer synthesis, multidimensional scaling, and psychoacoustic measurement techniques the time for such study seems to have come.

Definition of Affective Quality

I define the affective quality of a musical interval to be its consistent tendency to qualitatively influence the imagination of listeners particularly, but not limited to the imagination of personal feeling.

The physical variable which I propose to isolate is pitch ratio. To do this, I assume all other physical parameters - timbre, dynamics, register, rhythm - are:

1. made musically normative
2. held constant, and
3. made as affectively neutral as possible.

I am therefore isolating only a small part of the affective experience of music itself. However, I believe that this modest approach accurately reflects the state of current knowledge, or I might say, of current ignorance of the subject of musical affect in general. I further believe that intensive study of one aspect of musical affect may be of greater use than the method (widespread in the music education literature) of studying the affective experience of recordings of excerpts of various complex musical performances. Furthermore, the affects of individual musical intervals and harmonies is not at all an inconsequential subject, since harmonies and consonances play such an important structural and affective role in Western tonal music.

THE BASIS OF THE WESTERN HARMONIC SYSTEM

If, as I have suggested, the structure of our affective experience of harmonic musical intervals is based on the structure of the pitch relationships among the harmonic intervals - what is this common structure? I take as my musical example common-practice Western tonal music with octave equivalence.

The Hierarchy of Harmonic Contexts

The Western tonal harmonic system may be modelled as a self-embedded hierarchy of harmonic contexts, namely the central tonic, the tonic-fifth duality, the triad, the 5-tone or pentatonic scale, the 7-tone or diatonic scale, and the 12-tone chromatic scale system (see Fig. 2). These six harmonic contexts are the most basic reference contexts used in Western tonal music.

Tone-Groups

Now, what is their common structure? Each of these contexts (excepting the triad) can be modelled as strings of consecutive fifths - that is, as nearly $3/2$ pitch ratios. But all of them have an important additional property. Each of the strings of fifths comes very close to forming a circle of fifths. That is, the interval from the last tone to the first tone of each

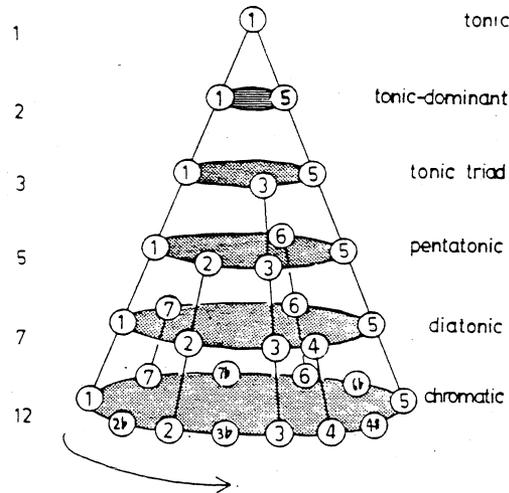


Fig. 2. The six hierarchical harmonic contexts of common-practice Western tonal music. In each figure of this article, the numbers within the tone-circles refer to degrees of the major diatonic scale, possibly modified by sharps or flats.

string of fifths is in each case almost itself another fifth (see Fig. 3).

Here 'almost' a fifth means in particular that the difference between this closing interval and a perfect ($3/2$) fifth is an interval which is not larger than any interval occurring between any two tones of that level in the hierarchy. Such near-circles of a single generating interval I call one-dimensional TONE-GROUPS, and in particular, CONSISTENT tone-groups.

One dimensional tone-groups can unambiguously be considered to be one-dimensional cyclic groups by identifying each tone with all of its octaves. Members of a tone-group are then often said to be 'pitch-classes' or 'chromas', under the assumption of 'octave-equivalence' (see Balzano, 1978, Shepard, in press)*.

The triad, however, (either major or minor) cannot be modelled satisfactorily as a one-dimensional tone-group. It can, however, be modelled as a two-dimensional tone-group generated by a $3/2$ fifth and a $5/4$ just major third. It turns out that consistent two-dimensional tone-groups, generated by the same two intervals, can model each of the six hierarchical levels very well. The structure of a two-dimensional tone-group can best be pictured in three dimensions as a torus or doughnut.

* Topologist Michael Freedman has given me the following mathematical definition - tone-groups are the fundamental domains of approximate quotient groups of finitely-generated rational or real commutative free groups modulo the octave.

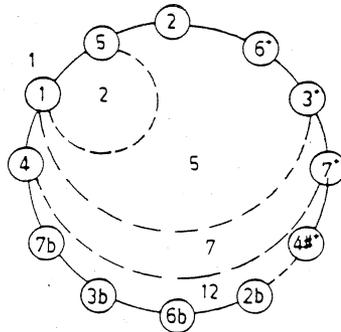


Fig. 3. Near-circles of fifths forming consistent one-dimensional (Pythagorean) tone-groups (under octave equivalence). The closing 'near-fifths' are shown using dashed lines.

Figure 4 shows a still larger, so-called enharmonic, 53-tone consistent tone-group of perfect fifths and just thirds*. It contains both the one-dimensional (so-called Pythagorean), and the two-dimensional, (so-called just), tone-group hierarchies. In a two-dimensional tone-group, there are several closing intervals, each almost equal to one or the other of the generating intervals.

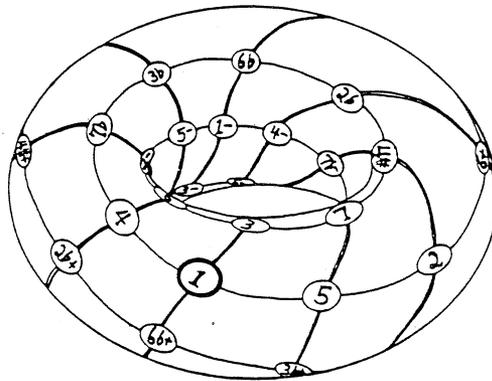


Fig. 4. Extended-just 53-tone tone-group as a web-of-fifths-and-thirds formed into a torus by identifying tones separated in pitch by schismas (0.1%) and emmas (0.3%). This tone-group contains all the smaller tone-groups belonging to both the Pythagorean and the just tone-group hierarchies (Makeig, 1979a).

* The schisma (about 0.1%) is the difference between five octaves and eight fifths plus a just third. I have coined the word 'emma' for the difference (about 0.3%) between an octave and five fifths less six just thirds.

Now, I believe, we have modelled the harmonic basis of the Western tonal musical system as a hierarchy of self-embedded consistent one- or two-dimensional tone-groups. It turns out, most significantly, that these are the only such hierarchies generated by the intervals $3/2$ and $5/4$. Note also that tone-groups generated by $3/2$ and $5/4$ could in another sense be said to be generated by the whole set of intervals $2/1$, $3/2$, $4/3$, $5/4$ and $6/5$ - by octave and group inversion. That is, these are the only consistent tone-group hierarchies generated by compounds of frequency ratios occurring among the first six linear harmonics of a harmonic complex tone.

Further, the basic chords (major, minor, sevenths) and modes (major, minor Dorian, etc.) found in Western music in fact correspond to the different placements of the fundamental domains of the basic tone-groups within the lattice of octaves, fifths and thirds.

The Tonal Harmonic Lattice

Now both of these hierarchies of tone-groups can be represented as hierarchies of the successive consistent sub-groups of the infinite lattice of intervals composed of octaves, perfect fifths and just thirds, which Longuet-Higgins (1978) has recently illustrated following earlier tuning theorists. Longuet-Higgins argues convincingly that diatonic scales and keys are in fact compact subsets of the harmonic lattice, and he discusses the compromises effected by equal temperament. However, he neglects the affective distinctions created by the fine distinctions in tuning which result as one goes farther and farther out from the tonic in the lattice. That is to say, he discusses only the diatonic and chromatic levels in the tone-group hierarchy in relation to the lattice, and neglects the enharmonic.

The two enharmonically equivalent sub-systems of intervals (Pythagorean and just), with respect to a common tonic, generate chromatic (12-

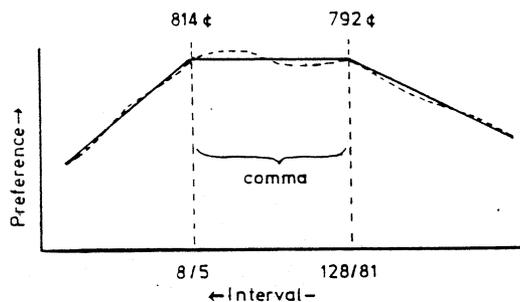


Fig. 5. Relative percent of 'in tune' judgments (labelled 'preference') for various sizes of minor sixths, as a function of frequency ratio. The dotted line shows the actual data, the solid line Tanner's interpretation of the data. Note boundaries of zone of highest preference, the just ($8/5$) and Pythagorean ($128/81$) minor sixths. (From Tanner, 1972).

tones to the octave) scale-systems whose tones differ by only a comma (1.25%). Equal-tempered tuning evolved as a compromise chromatic system, whose tones all lie within the commatic (1.25%) zones bounded by the respective tones of the Pythagorean and just chromatic tone-groups. Tanner (1972) reported that musicians strongly tended to describe as 'in-tune' those thirds and sixths whose ratios were within the commatic zone defined by the Pythagorean and just thirds and sixths respectively, and to describe as 'out-of-tune' thirds and sixths whose frequency ratios did not fall within these so called 'zones of tolerance' (see Fig. 5).

This phenomenon exemplifies the role of a lower (finer) level of the tone-group hierarchy defining pitch categories which are then used in categorical perception of actual musical pitch relations at a higher (grosser) level in the hierarchy. For instance Siegel and Siegel (1977) found that musicians described as 'in tune' those fourths, fifths and tritones whose frequency ratios were within 20 cents (1.25%) of the respective simplest harmonic (3/2) fifth and (4/3) fourth. (Their tolerance for tritones, an interval that has no simple ratio interpretation, was somewhat larger.) The results of Siegel and Siegel were limited by their use of only five different tunings for each interval. Tanner's results showed that, for several degrees of the musical scale, the 'in-tune' zone is actually a comma (1.25%) wide, rather than two commas, as suggested by Siegel and Siegel's results. Tanner (1972, 1976) calls this the zone of 'identification by tolerance.'

Higher and Lower Octaves

If the restriction of formal octave equivalence is dropped from our model then each tone-group can be modelled as a doughnut or circle containing and contained in concentric doughnuts or circles of tones at higher and lower octaves. This gives rise to an inherently five-dimensional model which is similar to that proposed by Roger Shepard (1978). These five dimensions are built up of two dimensions (for circles of thirds), plus two

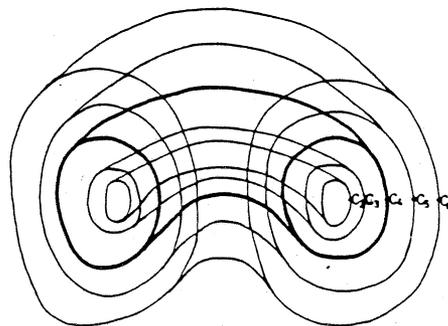


Fig. 6. Cross-section of a five-dimensional model of extended-just harmonic pitch relationships, collapsed into three dimensions. Only one tone (C4) and its higher and lower octaves are shown.

more (for a circle of fifths), plus one more (for higher and lower octaves). They can be modelled in three dimensions as in Fig. 6.

Shepard generates the same structure as the cross-product of a circle of fifths and a circle of rising chromatic semitone steps. While he overlooks the possibility of the psychological existence of enharmonic varieties of the twelve chromatic scale-steps, his five-dimensional 'double helix of musical pitch' model is structurally homologous to the spatial representation I propose here.

Group Theories of Perception

It seems to me that the tone-group model, and the group structure generated by physical harmonic relationships which it represents, must be an important clue to the understanding of our ability to perceive and experience tonal musical pitch relations - and must be at least part of the reason that Western tonal music has been so long-lived, and is being so well assimilated in other places in the world today.

Note also that its structure seems similar to the systematic and hierarchical structures of:

1. phoneme features in speech,
2. opponent color processes in vision,
3. Western musical meter (which also is built of nested hierarchic cycles, e.g. periods, measures, beats, half-beats, etc.).

An example of group theory in modelling of perception is given by Ermentrout and Cowan (1979), who show that the geometry of visual hallucination patterns can be explained using a group-theoretic model based on known principles of feature detection in the human visual system. In fact, the theories of tone-groups and interval affect developed in this paper are quite similar to the Ermentrout and Cowan work in that both theories model a range of percepts using group theories whose generating elements are primary logarithmic transforms of sensory input to the nervous system (real log frequency transforms in the case of pitch, complex log spatial transforms in the case of vision).

Jairazbhoy (1971) has hypothesized that the evolution of North Indian raga scales is based on cultural evolution of stable Pythagorean tone-groups. Jairazbhoy dismisses the possibility of just or other extended-just ratios forming the basis of scalar structures, but his rejection of this possibility does not seem to be based on personal experience. That the extended-just tone-group is the basis of Indian music and music theory, as well as being the basis for ancient Chinese, Greek and Arabic music theories, is the claim of Daniélou (1978). His historical evidence for this claim is apparently quite debatable (see Bake, 1957 for review). But the theory is essentially a psychoacoustic or psychoaesthetic theory, and should not be judged on the basis of references in historical music theory.

Other closed, symmetric representations of perceptual ranges have been catalogued by Roger Shepard (1978, 1979), who terms them 'perceptual manifolds'. A recent major and accessible synthesis of more general topological thinking applied to dynamic biological processes is Winfree (1980).

THE THEORY OF INTERVAL AFFECT

The tone-group model for tonal music raises the question whether harmonic perception as well as interval affect might be modelled using a similar structure. The basis for such a model has in fact been proposed for the affective perception of intervals used in classical Indian and other world musics by the French world-music theorist Alain Daniélou (1978).

In essence, according to Daniélou's theory, any musical interval which is composed of a sum or difference of one or a few finely-tuned (2/1) octaves, (3/2) fifths and (5/4) thirds - outside of any particular musical context, but considering the lower tone to be a fixed tonic - has an affective quality which can be modelled, likewise, as the sum or difference of the basic qualities of its constituent upwards and downwards octaves, fifths and thirds. This holds not only at the first six levels of the tone-group hierarchy, but for larger tone-group levels, each composed of sums and differences of (2/1) octaves, (3/2) fifths and (5/4) thirds, out to the 53-tone tone-group which I call the extended-just. This implies that the affective qualities of the octave, fifth and third are distinct or conceptually orthogonal.

Figure 7 shows the 53-tone extended-just 'doughnut' (large tones) un-

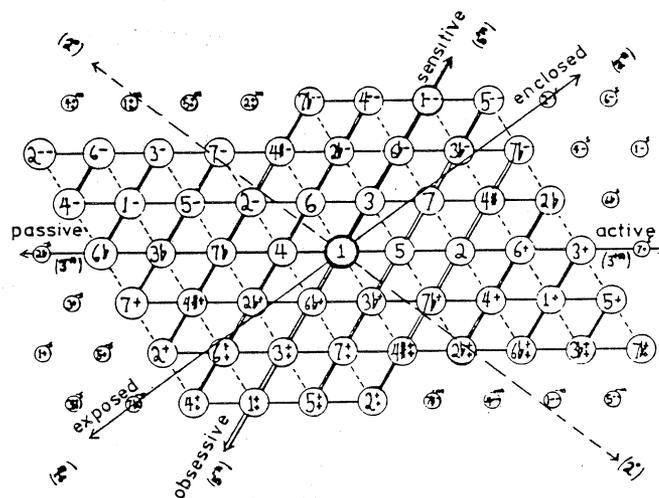


Fig. 7. The tonal lattice of fifths and thirds (assuming octave equivalence), showing the three affective axes of the theory of interval affect (Daniélou, 1967; Makeig, 1979). The central tone is the tonic. Fifths ascend left to right. Just major thirds ascend lower-left to upper-right. Relative distances of tones from the affective axes reflect the relative powers of 2, 3 and 5 in the integer ratio by which each tone is related to the tonic. In this chart each tone is considered to lie in the octave above the tonic. (From Makeig, 1979).

rolled onto a flat surface. Each interval is named according to its upper note, and is thought of as being smaller than an octave. The three 'affective axes' are also drawn on the figure.

For example, the $15/8$ just major seventh (the interval from the tonic 1 up to 7 in figure 7), composed of a perfect $(3/2)$ fifth (1 up to 5) and a just major $(5/4)$ third (5 up to 7) - has both the 'sweet, suave, sensitive' quality of the third and also the 'dynamic, active' quality of the fifth. Furthermore, $15/8$ has a 'rooted, potent, enclosed' feeling which is the peculiar quality of downward octaves $(1/2)$.

Interval Affect and the Semantic Differential

Note that Figure 7 gives one-word descriptions of the poles of the three affective axes. These simple verbal labels are intended for intuitive interpretation only. I would like to note, however, an apparent parallel between these three dimensions and the three principal dimensions of verbal affective meaning discovered by Osgood et al., (1957).

Specifically, the dimension labelled 'active-passive' (corresponding to positive and negative powers of 3 in ratio) is similar to the semantic differential, 'active-passive' axis. The dimension which I label 'enclosed-exposed' (corresponding to negative and positive powers of 2 in an interval ratio) parallels Osgood's potent-impotent dimension. Finally, the dimension which I label as 'sensitive-obsessive' (corresponding to positive and negative powers of 5 in an interval ratio) parallels Osgood's good-bad dimension.

Osgood (1971) has noted that he began his semantic differential studies thinking he was measuring attitudes, but later felt he was really measuring underlying dimensions of affect. However, Osgood did not go on to rephrase his original scales in terms of purely affective markers. For example, his scale, 'good-bad', has both conceptual (judgmental or 'evaluative' in Osgood's terminology), and also affective connotations.

It is my tentative conclusion, based on intimate experience with the qualities of the intervals, that the three dimensions of interval affect actually represent the purely affective dimensions underlying Osgood's semantic differential results. However, the individual conceptual interpretations which different individuals give to the different dimensions may depend on the person, and their experience. The semantic differential hypothesis may be tested, I believe, by modelling both the semantic differential space and the interval affect space, using multi-dimensional scaling of verbal responses to intervals, in a paradigm which allows free use of projective imagination (imagining that the interval represents affective characteristics of some person's moods or feelings)*.

* The possibility of collecting parallel physiological data for this experiment is suggested by Chapman's evoked potential experiments with the semantic differential (Chapman, 1980).

Objections to the Theory

Those readers who are familiar with the sound of the abovementioned major seventh only in its tempered form may not be able to associate with it the adjectives I have proposed. But note that the tempered major seventh is a whole one-eighth of a semitone higher than the just major (15/8) seventh. And such small differences in pitch can make big differences in affective perception, even (as Helmholtz also noted) in the perception of melodies. While this fact may surprise many modern musicians. in this matter (as again Helmholtz also clearly stated) only persons with personal experience have a basis for judgment. (Some subjective experience is available through the sound examples accompanying this volume.)

Here I feel I should state my view that a certain proportion of recent music psychology literature has been written by persons who attempt to make far-reaching conclusions from limited experiments, without ever having bothered to try to experience critically for themselves the musical phenomena they are writing about. I would say that those who question the idea of 'the beauty of just intervals' without ever having actually listened musically for that beauty under the guidance of someone who appreciates it, are making risky claims, particularly since objective studies of the qualitative effects of musical intervals on imagination of listeners have not been carried out formally.

In such circumstances, the informal studies that have been made by experimenters (e.g. Helmholtz, Boomsalter and Creel) and musicians (Hindemith, 1945; Chalmers et al., 1973-) ought to be given considerable weight. Even if formal objective results were to be presented, it seems to me that, even for a 'theorist', there is no substitute for personal experience, particularly in the case of a little-known perceptual phenomenon.

Why are ratio distinctions not taught?

A stronger objection to the theory of integer-ratios is that musicians are not taught to think or play in terms of ratios, that enharmonic distinctions in ratios are not usually notated, and that most studies of actual tunings used by musicians do not show that they play exact ratios (Ward, 1970). Are these final blows for any integer-ratio theory of music?

The intonation of actual music is a highly complex subject. Tanner (1976) played musicians several 'do re mi' sequences of tones. In some, the interval (frequency ratio) between mi and re, and between re and do were equal; in others, they were unequal. The musicians preferred the tuning by equal steps, even when the equal intervals were not those preferred in isolation. This would indicate that at least two factors enter into musicians' judgements of intonation; 1. the zones of tolerance, which are delimited by, or somehow 'built-on' the tone-group skeleton of extended-just ratios (Tanner, 1972); 2. attention to relative step-sizes, as part of perception of dynamic trajectory of movement within a one-dimensional pitch-height space (Tanner, 1976).

Terhardt (1977) has pointed out a third factor in musical pitch perception, one which makes the results of previous pitch-tracking experiments

suspect. Perceived pitch is shifted systematically (up to about 1%) by shifts in timbre, loudness, ear, etc. Thus any theories or studies of preferred pitch which claim to analyze perceived pitch by calculating physical frequency must make psychoacoustic corrections before claiming accuracy to much less than 1%. Until this has been done, there will have been no really accurate studies of how musicians actually play in expressive performance.

Several other faults in previous pitch-tracking experiments may be perceived:

1. 'Musicians' used as subjects may vary in level of talent and musical effectiveness. Averaging over a group of average music students will not necessarily show the same trends in the fine details of tuning, etc., as would studies of best performances by the most effective performers.

2. Averaging over several performances by one group of performers will tend to obscure the ever-present differences in degree of artistic success from one performance to another. At Ossiach (1980), Weinrich suggested having musicians record several performances, asking them to then listen and rate their own performances for correctness and artistic effect, and then weighting the averaging of the results accordingly.

3. Most studies of 'tuning preference' have used the simplistic hypothesis that musicians use either Pythagorean, just or equal-tempered tuning. The broader hypothesis, that both just and Pythagorean tunings form parts of an 'extended-just' system of integer-ratio based intervals which may be used for various musical purposes, has not usually been considered. As a result, uni-modal averaging would distort an inherently bi-modal pitch distribution (see figure 5), and give a false result favoring a 'median' equal temperament.

4. The 'stretching' and 'shifting' of intonation due to considerations of equal steps (as in Tanner's experiment), or pitch-height acceleration (as when string players decrease the size of a trilled semitone) must be carefully minimized or balanced. In other words, in dynamic musical performance, dynamic pitch trajectory or 'vocality' (Meyer, 1929) should be expected to 'pull against' the underlying tone-group framework, and the absolute frequency of the theoretical tonic of the tone-group structure may be expected to adjust itself to preceding pitches and trends.

5. The affective usefulness of dissonant tunings has usually been overlooked in psychophysical research. Do barbershop singers really prefer a beat-free sound texture, as hypothesized by Hagerman and Sundberg, (1980)? Or is the 'glassy' quality of beat-free harmonies contrary to the artistic and affective intentions of performers, as noted by Wilson?

6. The experiments of Boomsliter and Creel (1963) show that even musicians who are used to performing on fixed-pitch equally-tempered instruments maintain, when given a larger fixed set of tuning choices, that they prefer tuning known melodies using intervals which do not lie within any one just or Pythagorean 7-tone group, but which are found to move systematically within the hierarchy of extended-just tone-groups, according to the feeling which the melody is meant to express.

Thus, for example, the opening of the "Marseillaise" tune was preferred by all their accomplished musician subjects with a $27/20$ fourth, an interval which is a comma higher than either the perfect $4/3$ fourth or the equally tempered fourth. With a perfect fourth, the tune has none of the proud,

stirring quality which it is intended to evoke. If one plays this tune on the piano, and listens carefully to the actual pitches of the notes, one will discover a blandness in the ordinary tuning which is usually masked by use of martial rhythmic and dynamic emphases.

Using carefully recorded sine tones, I made a tape of continuous integer-ratio intervals. When I listened to a 27/20 raised fourth, I found that I could easily perceive it as being out of tune, and dissonant. Yet when I actively imagined it as the musical expression of pride or vainglory, it seemed to sound exactly in tune. I have been able to demonstrate this phenomenon to other musicians as well. Thus it appears to be a principle that in isolation from musical context and for Western musical listeners, at least-

an interval tends to sound in tune when our imagination of the feeling or affective quality of the interval is 'in tune' with the inherent affective tendency of its harmonic composition.

Of course this sense may be altered by psychoacoustic factors, and may require a musical sensitivity not consciously used by all musicians. I state it simply as being in accord with my personal experience to date.

AFFECTIVE VERSUS ANALYTIC EXPERIENCE OF MUSICAL INTERVALS

The theory of interval affect can be seen as simply a working out of the idea that the range of affective qualities of tonal musical intervals is at least structurally similar to the structure of tonal pitch relations, based primarily, it would seem, on three underlying affective dimensions corresponding to the first linear harmonics (numbers two, three and five) of the voice and other natural and harmonic musical sounds.

Affective qualities cannot be visualized as moving points in space as can high and low pitches. They are qualities. This is the primary distinction I wish to make between 'analytic' and 'affective' perception of intervals. Analytic perception of pitch is dynamic perception of pitch contour and location in the one-dimensional space of high/low pitch judgments. My use of the term 'analytic' includes both perception of pure (sine) tone pitch and also perception of residue or fundamental pitch of complex tones (distinguished as analytic and synthetic respectively by Terhardt, 1974, 1977).

My term 'analytic pitch perception' contrasts with 'affective pitch perception', by which I mean perception of pitch relations and changes as qualities - whether of texture, timbre, association, or of feeling.

Listening at Different Levels in the Tone-Group Hierarchy

Normally, in listening to music, affective perception tends to make use of lower (finer) levels in the tone-group hierarchy than analytic perception. For instance, a chromatic semitone shift in an otherwise diatonic melody is apt to be, at least first, experienced by most listeners affectively, rather than analytically. One might say of the experience, "I felt a change, but I didn't follow the pitch going up or down." This fact has recently been

demonstrated in experiments by Balzano (1977) (who first introduced me to the idea of using group theory to model tuning theory) and was also confirmed by the Siegels in their provocatively titled paper, "Musicians can't tell sharp from flat" (Siegel and Siegel, 1977).

The same kind of experience holds (as Helmholtz noted) for pitch changes at the enharmonic (commatic, sub-chromatic) levels. Helmholtz (1862, p.407) noted that the Greeks used the word 'colorings' (chroai) to describe small pitch shifts. Boethius said that the musical scale-term 'chromatic' itself originally referred to the breaking up into pieces of the various diatonic scale-steps like broken glass prismatically refracting light into new colors (Bower, 1962). The analogy to color seems a natural one, if by it the Greeks meant that the experience of small pitch steps was largely affective, for color metaphors are very often used to describe affective qualities.

The comments by Rameau (1750) on use of enharmonic intervals in his music show that he was acutely aware of their harmonic and affective natures. Although Rameau was an early champion of equal temperament as a practical method of harpsichord tuning, his comments on the affective qualities of intervals in fact fit the experience of their extended-just, rather than their equal-tempered versions.

The gradually progressive exclusive use of equally tempered tuning in European music during the eighteenth and nineteenth centuries is apparently correlated with the progressive use of more and more complex harmonies. As the affective distinction between enharmonic variations in intervals was less appreciated, harmonic affect came to be suggested by much more extreme harmonic combinations than had been permissible previously. This is the conclusion of several theorists who have experimented both with extended-just and tempered intervals (including Helmholtz).

Nowadays, the atonal music of the twentieth century avant garde is still experienced with discomfort by those who are used to listening to diatonic or mildly chromatic music, but is not necessarily experienced as unpleasant by those who have learned to listen more analytically at the chromatic and enharmonic levels. In turn, the 'simplistic' diatonic music of the sixteenth century sounds dull to singers trained to sing harmonically more complex music, until the original extended-just (or only partially tempered) intervals are used, when the music seems to take on subtle but much-appreciated richness of experience.

Furthermore, the testimony of those who have experimented with composing in different forms of equal temperaments (Darreg, 1975) indicates that tonal music performed in equal temperaments (for example of 12, 19, 22 or 31 tones to the octave) tends to have a characteristic mood which corresponds to the affective qualities of those extended-just intervals which are approximated most closely by intervals in the temperament (Makeig, 1979). I have previously shown (Makeig, 1979) that the characteristic mood of each equal temperament can be calculated as a vector in the space of interval affect, corresponding to the rotation angle of the natural linear mapping from the temperament to the web-of-fifths-and-thirds representation of the extended-just tone-group.

CONCLUSION

Relatively little research has been done since the 1930's on musical affect.* Distinctive among recent work is Clynes' 'sentic' theory of the dynamic and rhythmic expression of emotions (Clynes, 1977, 1980). For the study of the theory of interval affect using projective and multi-dimensional scaling techniques, the following questions and applications suggest themselves:

- Might music synthesized using tone-group theory be effective in influencing mood?
- Might use of extended-just ratios either in foreground or in background sound have psychotherapeutic uses?
- Would the theory of interval affect be validated in field studies of non-Western musical cultures?
- In what other ways might the affective power of music be explored and refined?
- How do the static and dynamic aspects of musical affect interact and combine?

Though I have developed and exposed the theory of interval affect in relation to common-practice Western tonal music, it is quite possible that the observations and conclusions may apply as well to other types of known music; they also suggest many compositional possibilities. I believe that the inspirational and also the therapeutic possibilities of music are as yet little understood and rarely put to full use. For this reason I recommend that the detailed study of musical affect be not ignored, but on the contrary encouraged.

SUMMARY

How music suggests or communicates feelings is largely unknown. This paper discusses how the affective experience of tonal harmonies is linked to their objective structure.

In Western tonal music, I maintain, the basic harmonic and modal pitch relations among tones, intervals and chords form a hierarchy of highly structured 'tone-group' relationships which can be considered to be generated by compounding of small-integer frequency ratios. This hierarchy of 'tone-groups', defining successively finer pitch categories, is generated by the interaction of a small number of principles, and also may be modelled spatially.

* Charles Meyers' study (1927) of what listeners report experiencing when they listen to music is a particularly good example of descriptive psychology of that era.

The French ethnomusicologist Alain Daniélou has proposed that the range of affective characters of musical intervals can be modelled in a similar way, based on three fundamental affective dimensions, linked to the (2/1) octave, the (3/2) fifth, and the (5/4) major third. This theory is in accord with many longstanding observations on the affective qualities of tonal chords and intervals; it also predicts that their affective characters can be focused or varied through fine-tuning to underlying larger tone-groups of pitch ratios.

I discuss the unity of analytic and affective experience of tonal harmony in terms of, and with implications for present psychoacoustics, psychology, and music theory.

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