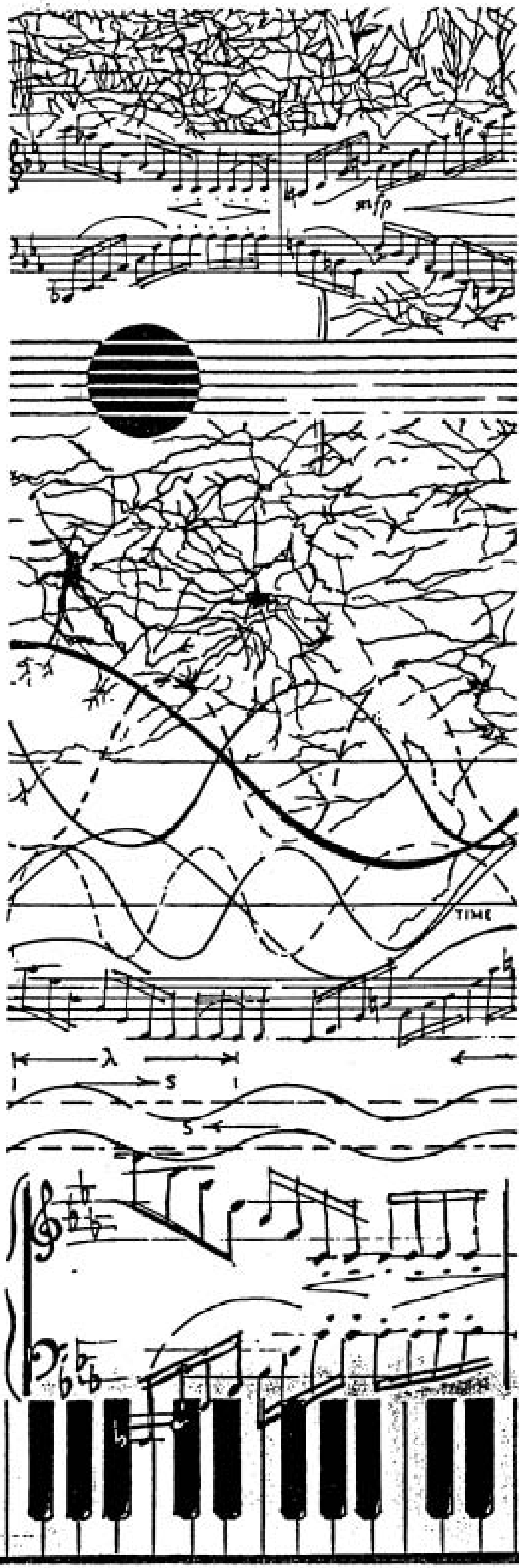

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WHEN IS MUSIC NOISY? BIOLOGICAL CONSTRAINTS ON PERCEPTION AND PERFORMANCE

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Music is unique as an art form that lends itself to scientific scrutiny. Any attempt to reduce a Rembrandt painting to a series of luminance values, or to depict it in terms of its interference patterns of light would strike us as absurd. Yet, physics and music are compatible bedfellows and we are tantalized. The psychology of music, meanwhile, occupies a position in that gray wasteland betwixt physics and aesthetics and struggles painfully to integrate the two. The wasteland is inhabited by different sorts of nomads, each with their own perplexing issues. On the one hand, there are those who seek an understanding of music through physically quantifying a musical event, assuming a non-subjective stance. At the other extreme are those who claim that not only art but all science is a product of a subjective fiction, and as art invents reality it cannot be reduced to objective terms. Somewhere in the middle are those psychologists who believe that an analysis of the product of a subjective creation can give insight into the nature of the subject, and into the nature of the brain itself.

The extreme form of the subjective stance towards art was expressed by Kant when he claimed, "Aesthetic contemplation is entirely indifferent to the existence or nonexistence of its object." And so it is, but the scientific contemplation of the aesthetic is not indifferent, and this poses a procedural and logical dilemma. Any attempt to understand music or to acquire knowledge by analyzing only its physical components rather than to experience it, takes music out of the realm of art and destroys the very substance of the quest. It is like freezing a pond in order to analyze how it is moved by the wind. As an example, musicologists are able to produce a formal analysis of a Beethoven symphony, yet apart from giving us an outline of the superstructure it tells us nothing whatsoever about the impact of the music. If we go further and specify the mathematical ratios of the harmonic progressions, we have described in more precise notation what Beethoven set out originally. Nothing of the immediate quality of the music which elicits in us the emotional responses of "magnificent" or "serene" can be derived from the mathematics.

There is, nevertheless, a solution which stems from the nature of the psychological method. This method states that what most people report tells us something about the nature of the mental process. Yet the method flounders on the fundamental issue of whether the process is innate or a product of the culture. Here ethology comes to the rescue.

The current thrust of ethological argument is to combine a renewal of the belief in the potency of innate or biological mechanisms with the understanding of how such factors are influenced and altered by the force of cultural variables. As a discipline it has moved us a good deal further from the early specificity models of Lorenz and the environmentalist exclusiveness of the behaviorists. Through an analysis of inter- and intra- species universals it can be determined which factors have genuine biological antecedents and in what way these antecedents are modified by the culture.

The psychology of music faces the same dilemma as all phenomena under psychological scrutiny: What are the neural or biological constraints in processing a sequence of complex events? Researchers in the field of psychoacoustics have come to recognize that subjects deal easily with complex tones and that experiments based on pure tones (sine waves) have weak explanatory power. But is this due to our culture, our brains, or the nature of sound?

One clue comes from results obtained in the Haskins laboratory on the analysis of speech. Patterns of input are the proper stimuli for speech perception. A single phoneme is incorporated into a complex relationship with other phonemes within a morpheme, each modifying the other. Physically identical phonemes can sound different when paired with different phonemes. Similarly, the category boundaries of phoneme recognition are wide enough to encompass a letter such as "t" using dramatically different physical representations. Yet, surprisingly, the width and the demarcation of these boundaries are universal phenomena cross-culturally. If this were not the case, the learning of a second language would be impossible.

Similarly, most cultures share a logarithmic scale with the octave as a basic musical constraint. Dowling (1978) provides evidence for the universal process of mistuning octaves to the same degree across cultures. We know the brain is a "sloppy" system, being imperfectly responsive to variants in mistuning (broad category boundaries), but we also know that it resonates rather remarkably to the harmonic series, and that this sensitivity is consistent across many cultures with a musical heritage. Although Western listeners are trained in the major and minor modes, they are able to listen to music of differing cultures and are not likely to mistake other musical idioms for noise. Why should this be the case?

It is my conviction that the brain, in processing signals that create the psychological modes of perception, memory, cognition, and motoric programming, imposes constraints on what we as listeners are prepared to accept as music and what we will discard as cacophony or, in Bennett's term, "perceptual chaos." The extreme intellectualization of musical idioms causes a breakdown in our ability to process incoming information. When the overload is too great, both in terms of memory and perceptual acumen, our tolerance is breached, the concert halls empty, and the composer fails to share anything of importance with his audience. This is not to deny the process of historicity. However, in moving too rapidly beyond our inbuilt expectations based on learning, the constraints remain and these are of particular interest to our understanding of music and the brain.

If our brain imposes a system of constraints on what we will treat as musical and on what we consider pleasing, this provides a clue to the meaning of the aesthetic experience. For this reason the analysis of music has particular potency in providing an insight into the meaning of all art.

Perceptual Constraints

Through the work of Ohm, Helmholtz, and von Bekesy, we have come to understand that the ear operates as a frequency analyzer.

Although Pythagoras' notion of the perfection of harmonic ratios is somewhat wide of the mark, the auditory system is peculiarly sensitive to the interaction between the harmonic series of two complex tones. This means that tunings will be roughly Pythagorean, though, as in speech perception, the category boundaries are wide.

A similar frequency analysis in sensory processing has been established for the tactile and visual systems. Irrefutable data from numerous laboratories around the world confirm that in at least three modalities, the brain operates to break down complex waves into their sine wave components by a process analogous to Fourier analysis. Evidence from Blakemore and Campbell (1969) has shown that not only is the ear peculiarly adapted to resonating to the harmonics of a fundamental frequency, but that the visual system is similarly sensitive to the harmonics of frequencies over space. Adapting the subject to a grating of a sinusoidal spatial frequency, produces an elevation of threshold to that fundamental frequency, and also the third and fifth harmonics. Similarly, work by Pribram and Lassonde (in preparation), and others, has illustrated that single cells in the visual cortex are particularly sensitive to one spatial frequency and that the tuning gradient is roughly within an octave band. Stimulating various portions of brain tissue which have previously been shown to alter recovery cycles in neural firing had <u>no</u> effect on the precision of tuning specificity, which remained constant over hours of testing.

Any parallel input, whether a complex visual pattern or a harmonic progression, creates an interaction between these neural elements in the form of an interference pattern. In the visual modality fundamental frequencies in the low to medium spatial frequency range carry information about edges and boundaries. Interference between high spatial frequency waves creates visual illusions (subjective distortions of two-dimensional line drawings), as has been demonstrated by Ginsberg (personal communication). The greater the interference, measured physically, the greater the illusion. This process may be analogous to the auditory sensation of interference patterns generated by the upper harmonics (high frequencies) of two or more fundamentals in complex ratios. Here the interference pattern is heard as noise or dissonance. The verbal description is "edgy" though the subjective experience between the two modes is different. This is because the visual system "sees" (is aware of) the nodes of interference, whereas, in the auditory realm the fundamental alone is "heard", the interference pattern of harmonic ratios producing a sensation of pleasing or unpleasing sound quality.

Dixon Ward (1972) raised a related issue concerning the relationship between auditory and visual processing by comparing sound and color frequencies over time. He pondered on the question of why two fundamental frequencies of electromagnetic energy combine to produce the sensation of the frequency value midway between the two (yellow and red combine to orange). When we present two complex sound waves, the ear maintains each fundamental as distinct entities, the harmonics creating the quality of pleasantness or unpleasantness depending on the ratios involved. The analogy may perhaps be more meaningful if soundwave frequencies are compared to spatial wave frequencies. Here the eye is even better than the ear in distinguishing the fundamental frequencies in the pattern. The discovery that the visual system performs a sine wave analysis on spatial frequencies could provide an impetus to research in the visual arts. Similar principles of harmonic combinations, interference patterns, and rhythmicities may be operating in other art forms. As yet we have no answers to these questions.

What then are the perceptual constraints in processing musical events? First, the essence of cortical analysis is that of specificity for patterned input. Phonemes combine into morphemes but by themselves are insufficient data to determine speech utterances. Similarly, complex tones with an enduring fundamental frequency are the phonemic constituents of music, but these tones must be combined into patterns either melodically or harmonically. Because the auditory system has long persistence, tones in a melodic series will overlap in time not only phenomenally, but physiologically. The system is intolerant of complex ratios and is specifically responsive to sequences with a tonal center (the harmonic series). Tonality is a crucial factor in memory as the competency of the nervous system to process a pattern in a tonal series is much greater than that for an atonal series. Tonality provides categorical boundaries which aid in chunking the input. The problem of memory is considered in the next section.

Memory and the Span of Apprehension

Perceptional units are configurations that are maintained in awareness by a so-called short-term memory system. We know from memory research and from Miller's (1956) review of these studies that the span of apprehension, which relates to what we can be aware of from moment to moment, is constrained to seven bits of information, plus or minus two. The competency of neural systems to process incoming information is often expressed in terms of "chunking" or, more specifically, recombining perceptual events. Thus, the system is most constrained when the units are unrelated to one another (cannot be combined) as in a series of digits, letters, unrelated tones, or a series of combinations of letters, such as a random string of words. When a series of words provides referentiated meaning, it is the referent that is processed and not the individual words. Thus, the learning history of the individual becomes engaged. To illustrate this point, a member of an audience attending a conference on an unknown topic may be able to extract only a few major points from an address. Those who are steeped in the discipline may be able to process and maintain a greater number of the essential points. However, in both cases the individual words are lost, and only the semantic referential content, transformed into the listener's own referential system, is retained.

Music is no exception to this process, but because music has no referential meaning, only structural meaning, a different set of constraints is operating. First, it is essential that the number of perceptual units are within the span of apprehension. Dowling (1978) has reviewed evidence on the ubiquity of the pentatonic and heptatonic scales in all cultures. Second, as noted above, when the units are patterned in such a way that a sense of tonality emerges, these units, like a meaningful sentence, can be maintained more readily. A tonal center allows the listener to chunk the units into more complex and memorable patterns.

Further, the repetition of a pattern of pitch changes within a musical phrase provides another aid to memory. Absolute transposition from one octave to another octave, or a modified transposition within an octave (maintaining similar relationships) are memorable forms of repetition. The work of Dowling and Fujitani (1971) have shown that tonality is particularly critical to the memory process. In fact, both trained and untrained listeners were unable to detect the difference between a transposed melody and a "tonal" answer, the former preserving identical pitch relationships, the latter maintaining contour only but using the same tonal center.

Deutsch's research (1977) has shown that the constraints of pitch relationships are often fixed to specific intervals, and that octave transpositions, such as substituting a tenth for a third, cannot be perceived as a similar pattern. Memory for the pattern breaks down in these conditions. In fact, melodies extended over two or more octaves are generally unmemorable, unless simple ratios are employed. The opening theme of Brahms' third symphony illustrates the latter case where a simple descending arpeggio of tonic, fifth, third (second), tonic, and continuing, represents a memorable melodic structure. In essence Brahms has provided the listener with only two chunks of information - two arpeggios outlining the major chord of the key, with the second tone in the scale acting as an appoggiatura.

Finally, another powerful organizing principle in musical memory is the rhythm of the melodic string. Rhythmic repetition can substitute for transpositions of pitch relationships when pitch boundaries are stretched well beyond simple repetition of exact relationships. When pitch relationships <u>and</u> rhythmic forms are reproduced exactly, memory is considerably enhanced. The system has two pieces of information rather than only one and these are mutually reinforcing. By a process of association, a rhythmic pattern can call up a melodic phrase and vice versa.

Thus, the memory system does not operate in isolation from the categorization process. Certain combinations of elements are significantly more memorable than others, and certain categories of repetitions sound familiar, whereas others seem unrelated even when they are <u>mathematically</u> similar as in an exact inversion of a melodic string.

<u>Motor Systems and Rhythmicity</u>

In his book <u>Perception and Communication</u> Broadbent (1958) raised the issue of a limited channel capacity for processing incoming information. The limited channel hypothesis relates to the discussion above, when we are aware (that we are aware) of only a few items of information at one time. Limited channel capacity, short-term memory, and attention span are all synonymous terms for the same phenomenon. Broadbent concluded that information is <u>blocked</u> from entering the system, but later revised this view in the light of subsequent research. However, he postulated that the system was <u>unable</u> to process all the information available. Erdelyi, reviewing the literature in 1974, concluded that the intake of information may not be limited and that the reason for a restricted span of apprehension is due to our inability to code everything into long-term memory. Yet we know that brain tissue is almost inexhaustible in its capacity to store information. The mechanism for this process has been outlined in the holographic theory of Pribram (1971).

Therefore, one has to look elsewhere to the constraints on attention which are psychologically real. In my view, the problem lies in translating incoming information, which arrives in a parallel fashion, to a linear sequential mode compatible with motor output systems. We are behaving organisms and have to translate parallel input into movement over time. This mapping process requires a transformation of the information into some temporal order. Thus, the limits on apprehension are due to the limits of our ability to <u>act</u> on incoming information. An action can be overtly motoric, or covertly monitoring and sorting.

Temporal sequencing involves rhythmicity. This rhythm is evident in all our motor behavior, especially in skilled performance, including speech. Rhythmicity in speech has been studied by Martin (1972) and he concludes from his data that rhythmic grouping of output not only facilitates speech production, but helps the listener to process information because important words in an utterance fall on the accented beats in a phrase. Similarly, McGuinness (in preparation) showed that rhythms with metric markers (barred phrases) were more memorable than identical rhythms with no accent cues.

The perceptual units providing the frame for rhythm patterns are ultimately reducible to duples and triples. The arrangement of strong and weak accents can be restricted to the temporal domain within the duple or triple frame or can extend beyond and encompass several marker boundaries. However, the critical elements are those marker boundaries. Even when they are absent we impose them, as we do when listening to a ticking clock during a bout of insomnia. When they are imposed by the composer, they clearly aid our processing skill and serve memory particularly well.

In a sense, rhythm is more a given than a constraint. It occurs almost willy-nilly and any attempt to eliminate rhythmic groupings in a composition requires the utmost effort as well as the denial of the very basis of our neural systems. (Yet, composers have tried!)

At a different level there is another constraint regulating the bandwidth of our temporal window. The marker boundaries must fall within this band-limited domain, otherwise, they are too slow to form a perceptual group, or too fast to be perceived as distinct. The former difficulty is well known to us when we or our students tackle a piece with a metronome mark of "60". In order to maintain a strict tempo, we interpolate beats or markers that are not there, as in "one-and-a-two", etc. This fundamental fact has something to do with the timing of all our motor behavior and may relate to cerebellar servo-control systems that wipe out their commands at a fairly rapid rate. We have a great deal of difficulty walking, or hammering a nail at one movement/second - though musicians might be better at such tasks than most people.

Similarly, in the execution of skilled acts which require speed, we regroup the movements into chunks with larger temporal boundaries. The accented groups of four notes in a four-octave scale sequence is a good example. This ability to regroup, or to chunk output, provides the same benefit to the motor system that chunking input does to memory and understanding. Without this capacity to reorganize motor commands hierarchically, rapid digital execution shown in musical performance would be impossible, given the output speed of each individual motor neurone. Rhythmicity is the key to efficiency in motor reorganization for this reason.

Thus, we have seen that the brain organizes input into its temporal or spatial frequency constituents, effectively distributes and regroups the information, maps it onto the motor system, and outputs a frequency-specific controlled action. It is a phenomenon of music that, as listeners, we unwittingly enter into this restructuring process from input to output. This is the essence of all art forms. The artist leads us through the very structuring procedures that generated the work of art. Hence, we say we are moved by the act of participating in art.

Cognitive Processes and Transformations

As was seen above, the separation of perception, memory, and motor processing is impossible -- all are interacting in complex ways. Similarly, the separation of cognition from perception and memory is difficult, but can be maintained by the view that perception groups incoming events (categories) whereas cognition performs operations and transformations on those events. The more complex the event, the more learning is involved, the more "cognitive" the process.

We have already dealt with the basic cognitive operation of chunking or regrouping perceptual units into complex entities. The process of chunking is most cognitive when we are aware of the effort involved, such as training ourselves to put a series of accents into a rapid extended sequence, or in employing organizing strategies during the memorization of a work: "a B-minor melodic scale ending on a dominant 7th chord." In fact, one aspect of cognitive endeavor is the integration of cross-modal information including mapping sensory input onto motor output. When we develop facility in these skills they become habitual and thus the awareness and sense of effort diminish.

An important, but often overlooked cognitive domain is probability coding. Storing information about probabilities of events is perhaps the most extraordinary function of the nervous system. In man it is elevated to a phenomenal degree, and underlies all of our intellectual achievements. Despite the complexity of this achievement, it can occur without conscious intervention. An example is the discovery by Mildred Mason (1975) that in acquiring reading skills, good readers code the probabilities of letter pair combinations and particularly the probabilities of spatial redundancies of individual letters in various letter strings. Poor readers, by contrast, see each letter string as a totally novel event and attempt to decipher each word phonemically as if it were a random string of letters. (Note here the critical issue of individual differences which may explain why certain people spontaneously react favorably to classical music with a minimal musical history, and why others in a musical household never acquire the taste. This is undoubtedly due to some innate predisposition to find probability information memorable or unmemorable.)

As noted earlier, simple melodies or harmonies are pleasing or "musical" to most people in most cultures. When composers begin to develop more complex harmonic progressions or melodic sequences, these developments extend our repertoire of experience and ultimately become part of a cultural heritage of musical expression, truly "cognitive." In particular, transitional probabilities, such as harmonic progressions and cadence forms are either probable or improbable in our culture. The important fact about probabilities is that they build expectancies in the listener. These expectancies turn out to be the key to our understanding of how music engages our interest throughout an extended work.

At the extreme end of the cognitive dimension is the evolution of musical form. Form is a purely intellectual construct, but one which is derived from the more basic notion of repetition. Music is, after all, a means of structuring repetitious events (see chapter by Pribram, this volume). From a simple chant (a phenomenon common in children) involving strict and monotonous repetition, Western music has evolved immensely complex formal systems such as Sonata Allegro, Theme and Variations, Rondo, etc. These elegant superstructures are a means of achieving unity in a work; a unity which is beyond the restriction of mere tonality, in itself a more primitive unifying principle.

The important aspect of cognitive or intellectual intervention in elaborating artistic endeavors is that some recognition of the history of expectations must be encompassed by the artist. Each successful Western composer extended our repertoire of probabilities. Often the listener balks and may even become so distressed that riots break out in concert halls, as was the case with Stravinsky's Sacre du Printemps. Ultimately, it is the listener and not the composer, who determines the acceptable boundaries. With persistence these boundaries can be enlarged, but only by degrees; not by a radical overturning of all our prior learning experience, nor by denial of the way perception, memory and action occur.

Feelings of Interest

When any event is repeated we habituate to that event both neurally and behaviorally. If some dimension of the stimulus is altered, an orienting response occurs and upon further repetition habituation sets in once more. Habituation to one's environment produces a feeling of familiarity but can lead to boredom. What we are most comfortable with therefore, can ultimately produce the greatest disinterest. However, this process of responding to new information, coding it over time until it is habitually ignored, engages another aspect of our behavior, and that is "competency." Interest is maintained when competency is just inadequate to deal with the complexity of the information in the environment. If competency is too little or information demands too great, stress is induced, and we attempt to shut down or avoid the situation. Likewise, when competency exceeds the challenge in the environment, we become bored. We like the familiar only up to a point, and then something must change, for boredom, as overload, leads similarly to stress.

The important aspects of the phenomena of habituation and interest for music is that the repetition must be structured in such a way that all our expectancies are not met, only some of them. This is analogous to the discovery that partial reinforcement causes an animal to persist in a task for a much longer time than when reinforcement is suddenly withdrawn altogether.

Our competence in turn determines our expectancies. When we are familiar with a composer's style, we can follow the music more readily with a greater degree of involvement. When the composer produces a phrase, cadence, or rhythm which is incongruous or unexpected, our interest is aroused. Because competency is related to memory, what is initially most memorable becomes least interesting in the fastest time. This explains why experiments asking subjects about their preferences for popular music versus classical music demonstrate that the most liked initially (popular music) becomes least liked after several repetitions. (A number of such experiments are reviewed by Lundin, 1967.)

This analysis is apparently somewhat at odds with that proposed by Zajonc (1968) who has shown that liking increases with familiarity. What is ignored in this set of experiments is the opportunity for competence to increase with familiarity and to reach a level at which it exceeds the challenge of the information. Zajonc's results are therefore not comparable to the results of the study outlined above.

However, Zajonc's research is interesting because of his discovery that each sense experience evokes a dual affective/cognitive reaction. The affective response, which is largely an approach/ avoidance reaction, is entirely independent of cognitive judgment. The finding that students who initially like certain forms of music, but who on repetition like this music less indicates that at some point in the process an affective domain interacts with the cognitive domain and the two become integrated at a further level which could be called the "aesthetic."

It would seem that given the constraints set out in this chapter, and the listening history of a subject, there might be a curvilinear function of musical appreciation related to the cognitive effort involved in processing the music. At some optimum point music engages our interest because it is nearly, but never entirely predictable or memorable (performers can modify phrasing, tempi, etc.). Music which is easy to memorize soon bores us; and overly complex music music (as a listener) frightens or frustrates us.

Feelings and Emotion

An affective response is emotional in the true meaning of the word: to be taken out of motion. Any sufficiently novel event, a sudden loud sound, etc., produces the orienting response outlined above. If the interruption is moderate, we are interested. If the interruption is great or the information overwhelming, we become frightened or angry. The same brain systems that can be stimulated to induce behavioral orienting can, with a sufficient increase in electrical current, cause an animal to attempt escape or go into a rage, attacking any moving object in his field of vision. Thus, orienting behavior is on a continuum with fear and rage.

Feelings are engaged when there is an appraisal of the environmental situation in conjunction with the anticipated competencies to deal with it. Feelings are cognitive labels for degrees of quite basic reactions to upset. As Zajonc noted an affective reaction is primarily "approach-avoid." At a slightly higher level of analysis, we make fairly automatic qualitative judgments of all our experience. Osgood (1953) has determined through factor analysis that these judgments are evaluative (good-bad) and have a potency dimension (powerful-weak), as well as an active dimension (slow-fast). Most of our complex labels for feelings are merely quantitative dimensions for these basic reactivities, which occur below the awareness of conscious processing; e.g., we do not know why that particular object is rated as fairly slow, not at all powerful, and quite awful.

It is interesting that Zajonc's "gut-level" reaction occurs instantly to music. "Turn it off" or "turn it up" are the ends of a continuum at the middle of which is that indecisive state where one just cannot be bothered to get up and change the music.

Also of interest is how well Osgood's dimensions fit certain aspects of the musical experience. Degree of tonality, harmony, melody, etc., evoke feelings of consonance-dissonance (pleasant-unpleasant or good-bad). Patterns of rhythm and tempo evoke feelings of being moved or slowed down (the active-passive dimension). Finally, dynamics and phrasing, involving shifts in volume and timing, supply the powerful-weak domain, and also convey urgency and calm. As an example of the importance of dynamics to affect, an experiment during World War II attempted to output control-tower information more efficiently by electronically clipping the amplitude (volume) information in the signal. The speech was completely intelligible, but pilots refused to act on instructions because the _intentional_ content could not be determined. Pilots could not tell whether or not the operators were _sincere_. The affective meaning was lost. Thus, feelings are both immediate (affective) and cognitive, and derive from a number of levels of experience.

Coda

Art is particularly powerful in inducing feeling states for several reasons:

a) Music, in particular, taps consonances, is in tune with our perceptual-motor systems, and maps simply onto neural processing mechanisms.

b) Certain perceptual configurations are pleasing when they have psychologically valid categorical boundaries, giving them unity and completeness, and when they are readily related to surrounding configurations - temporarily or spatially.

c) Art moves us through a certain degree of ambivalence (surprise, novelty) towards respose and finality. This creates a resolution of tension.

d) Interest produced by the meshing of information with our competencies creates feeling of intellectual quality. We _admire_ a composer for stretching our awareness of the possible - for surprising us.

Thus, the key to understanding the meaning of all art is that the perceiver shares in the process of the creative act, the structuring, rather than the structure. However, if an artist is to engage our interest and our feelings, his own creative energies generating this process must spring from the same source of energy as our own. His psychological reality must relate to ours. In Bernstein's words, music is rooted in the earth, the "ground" of common experience, in nature. When we share in the artistic process we allow ourselves to be moved, literally and emotionally. As the artist moves us through his world of experience we forego momentarily our own sense of time and join in another's temporal world. Thus, art enfolds time. At some point, the whole emerges and encorporates both the units and the process.

Because the artist engages us in his creative endeavor, this is not to say that the artist wants to communicate something to his audience. It is not his intention to communicate (music has no referential meaning), but to tune us to his dance. If he is successful, he can share his art. Therefore, art is not a communication (a language), but a communion, something to be shared. Ultimately, an artist is defined by his audience; otherwise, he is in communion only with himself.

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