PAPERS AND ORIGINALS

Further observations on the neurology of music: musical notation and pitch discrimination*

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British Medical Journal, 1977, 1, 1121-1125

What is music? That is the question which must be posed at the outset of this address, but before we essay an answer it will be helpful to look at the beginnings of the art. The origins of music lie so deep in antiquity that any attempt to trace the early development of the art entails speculation. Many studies have shown that primitive music is closely linked with everyday life, and sociological, psychological, religious, and symbolic factors are important. This type of music comprises both singing as we recognise it, and shouting, speaking, humming, and whistling. The same melody will have different meanings according to how it is sung—for example, falsetto, nasally, or in the chest register. Primitive man only sings when he has something definite to express; given a new melody that pleases him he will fit words of his own to the melodic line.¹

As one might expect, there has been no lack of theories to explain the evolution of music. Darwin thought it might have stemmed from imitation of animal cries in the mating season, but according to Schneider¹ love songs are rare in the oldest civilisations known to us, and then they are mythological rather than erotic. Other writers believed that music evolved from a signalling system in which loud cries would produce a note of definite pitch. Consonance appeared when different persons uttered the same cry at different pitches. A more likely, though necessarily speculative, idea is that music and speech derived from a common sound-language. Speech and song have been closely related from early times, and this relationship has persisted in some primitive communities living in remote parts. Thus, in some African languages pitch determines meaning; the meaning of a speech utterance depends upon the pitch at which it is produced. This is also true of Chinese and Japanese. Our own speech continues to have a melodic line.

When we speak of music we think of it as an art form, and while we recognise that it is a language with both vocabulary

and grammar, we enjoy or dislike it on an artistic basis. According to the *Shorter Oxford English Dictionary* music is concerned with the combination of sounds in melodic or harmonic combination, produced by voices or instruments, in a beguiling or beautiful form. This dictionary definition takes insufficient account of twentieth century musical development, with its widespread abandonment of tonality and introduction of new and sometimes experimental techniques of composition and performance, often with little apparent public appeal.² Baudelaire's *Les Fleurs du Mal* (1857) has been seen as the beginning of the rebellious and disintegrative movement in poetry and other art forms which has characterised the past century. However that may be, Baudelaire's influence has continued into our own times. More than 50 years after the publication of *Les Fleurs du Mal* Marcel Proust teasingly asked his friend, the Abbé Mugnier, whether he had read the book of poems; the Abbé replied, "My dear fellow, I carry it about with me. Without the smell of sulphur how should we appreciate the scent of virtue?"³

We may safely affirm that music is art in sound, and that it is always an art, though sometimes debased. Speech remains the means of everyday communication in civilised societies, though it is sometimes an art.

The neurology of music

Brief consideration shows that the whole range of musical activity provides a series of subjects which the neurological scientist may properly adopt as his concern. Admittedly the contribution of the clinical neurologist has tended to be limited in scope in the past. Although clinicians have made important discoveries relating to the parts of the brain concerned in musical function, including the role of the non-dominant hemisphere, the clinical neurological approach has yielded limited results in displaying the basis of such musical activities as memory, music reading, and pitch discrimination.

The two clinical communications of most general interest have detailed the results of brain damage on the creativity of composers. Luria *et al*⁴ described how the Russian composer Shchepkin continued to compose and teach despite the handicaps imposed by dysphasia deriving from cerebral infarction associated with hypertension. Alajouanine⁵ gave an account of

*Based on the Langdon Brown lecture given at the Royal College of Physicians of London on 9 February 1977.

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the effects of a pathologically unidentified cerebral atrophy, causing dysphasia and apraxia, on the artistic realisation of a composer better known to Western audiences, Maurice Ravel. Ravel was born in 1875 and died in 1937. His illness began in 1933 when he was 58. Information about symptoms is scanty in the biography of Roland Manuel,⁶ but speech difficulties were probably the first manifestation, and there seems to have been progressive deterioration in subsequent years, although Ravel continued to travel, attend concerts, and lead an active social life. Alajouanine stated that oral and written language were diffusely impaired, but memory, judgment and aesthetic taste were unaffected. Apraxia interfered with piano playing and verbal writing. Writing and dictating musical notation was slow and highly inaccurate. Ravel was able to play the beginning of his *Ma Mère l'Oye* suite and the first seven or eight bars of *Le Tombeau de Couperin* "almost perfectly," but that was the limit of his performing capacity in these works. Alajouanine concluded that musical thinking was comparatively preserved while "affectivity and aesthetic sense were almost intact." Ravel's days of composition ended with the songs from *Don Quichotte*, completed shortly before his first symptoms appeared. He said that his mind was still full of musical ideas, but he could not express them; as Alajouanine wrote, "To conceive is nothing, to express is all." This is a unique account of a musical tragedy.

It is not surprising that funds for neurological research in music are almost non-existent. Much of the rewarding work published in recent years has been the by-product of other research, or it has stemmed from spare-time studies in this fascinating field. Workers in otology and physiology have increased knowledge of the auditory pathways and mechanisms, while psychologists have produced new ideas on central auditory processing. Psychologists have also been fruitful in the investigation of musical memory⁷ and the role of dominant and non-dominant hemispheres in processing musical material.⁸ Useful information on the neural control of voice production has come from the neurophysiologists.⁹

Eisler¹⁰ wrote of melancholia, "this special spiritual affliction of the artist," which provides "a recurring tragic threat in the oeuvre of such great masters of line as Leonardo, Parmigianino, Rembrandt, Salvator Rosa, Watteau, Hogarth, and Munch." Slater and Meyer¹¹ pursued this theme in their classic examination of the effects of periodic fluctuations of mood on Schumann's powers of composition, and Trethowan¹² has explored the whole subject of mental illness in composers. These publications, with others in the field, have led us to a deeper understanding of the lives and music of composers who suffered psychiatric disorder.

Critchley and Henson¹³ were joined by a large group of neurological scientists in writing *Music and the Brain, Studies in the Neurology of Music*. The central part of this address is concerned with two topics susceptible to neurological analysis that were not included in that book—namely, musical notation and pitch discrimination.

Musical notation

Many books have been written about musical notation—that is, the use of symbols to communicate musical ideas. Hugo Cole's *Sounds and Signs, Aspects of Musical Notation*¹⁴ provides an admirable exposition for the general reader. Cole states that word literacy has preceded music literacy in all known cultures. In this discussion we will be thinking solely in terms of the conventional notation used in Western music.

The written or printed score of a musical composition has three primary functions; first, it is a record of the composer's invention, notated in pitches and showing the duration of notes and their time relationships; second, it is a directive to players; and, third, it provides the basis for analysis of a composition. The score may also be used to illuminate and reinforce a heard performance, or in private reading. It is important, however, to remember that music is written to be performed, and all interpretations depend in part on the notions of conductors and players; people with a literary approach to music may ascribe an over-important place to the notated record. Scores of earlier

composers may be in a fluid state, as in the figured bass of the baroque period and the mandatory but commonly unnotated ornamentation required in performance of eighteenth century music. Some contemporary composers write permissive scores, allowing the performer a choice of notes within prescribed limits, while others produce aleatory works. And what of revised or edited compositions? When composers revise their own works one assumes that the final version is definitive, though experts may differ on this point, as with certain of Bruckner's symphonies. Turning to edited works, we may recall that conductors of *Messiah* turn to the editions of Mozart, Watkin Shaw, or other musicians, although Handel's score is still available.

There are certain unsatisfactory features about musical notation—timbre is weakly represented for the reader, and exact directions to the performer on tempi, volume, and dynamics are difficult to convey. For example, how fast is *allegro molto* and how loud is *fortissimo*? Twentieth century composers have tried to overcome this problem by providing heavily annotated directional scores which are constructed to leave the performer in no doubt of the author's intentions and requirements.

SIGHT READING

The distribution of skill in music reading among the population is not precisely known, but it is stating the obvious to say that some people find the process difficult while others find it easy. One might expect good music readers to be adept verbal readers, but there is no reason to expect the converse; no one appears to have tested this notion. Some musicians have a remarkable capacity for sight reading, and all professional players of serious music must be expert. On the other hand, there are professionals engaged in popular music who have great difficulty in reading or cannot do so at all. There seems to be evidence of innate capacity, for some young children show an extraordinary talent for reading music. One notable observation, confirmed by personal experience, is the heightened sight-reading capacity which comes to the amateur performing with professionals.

Sloboda^{15, 16} has posed the question, how do good readers of music notation do it? Formal neurological studies have contributed no answers. The classic neurological method of observing the effects of focal lesions on brain function has been unrewarding, for if the capacity to read music is lost from brain damage there is usually, if not invariably, loss of other higher faculties; and neurologists have not sought the reasons for lack of the capacity in normal persons. Except for Sloboda himself, psychologists have left the field almost unexplored. Musicians take reading for granted and few show active or introspective interest in how they accomplish it. Let us begin, however, from the musical aspect and see if there are any clues to the strategies employed, firstly by reference to the keyboard player and instrumentalist.

Music is a non-verbal language,¹⁷ and reading notation demands exclusive use of the language. The position of the musician is comparable with that of the verbal bilingual exponent who thinks and speaks both his languages independently. Trained musicians think in musical terms, and while reading may sometimes entail naming individual notes or chords this does not usually obtain in sight reading or practised performances.

When music is read in practice or performance the eye is always ahead of the hands and feet, except in the case of beginners. Chunks, that is groups of notes or phrases, are read. This strategy enables future motor activity to be programmed, and it is impossible to read and play successfully in any other way. The contour or outline of a melody can be perceived by simply looking at the music. Piston¹⁸ used the term *melodic curve* to describe this outline. The amount of melodic line taken as a unit for analysis generally coincides with the length of a phrase. Knowledge of musical language and composer or period style enables the reader to predict the ways in which melody or harmonic progression will continue; admittedly, most people find this easier with music of the baroque and classical eras than with much contemporary work. Memory of what has gone before in a piece is a valuable aid to the reader, for melodies, figures, and harmonic progressions may be repeated in the same or similar form. Difficulties arise when the demands made on memory are greater than it can bear; this is exemplified in serial music, where a twelve note tone-row is used, for there are few people who can memorise such a sequence, except by practice. In contrast, a tonal tone-row is easily remembered; a good example can be found in the Kyrie of Bach's B minor Mass. Discussions with musicians and personal experience do not suggest that movements, or sensations of movements, in the hands are concerned in reading; we do not read music by sensing or imagining the movements which subserve production of the note. It is conceivable,

however, that notated or inferred position shifts may influence reading in a motor sense if one is playing a viola or cello.

SCORE READING

Reading an orchestral score is clearly more difficult than reading a piano score or the line of an individual instrument. The task is made harder by the presence of transposing instruments in the orchestra, such as the horn and clarinet. Investigation of the visual strategies employed in this exercise has not been undertaken hitherto; musicians, including conductors, accept that they have the required skills and are inclined to leave the matter at that. In practice the conductor reads and rehearses a work before performance, so he has partly or even wholly learned what he is reading on the night. Von Bülow showed his remarkable capacity in this direction by memorising a Stanford symphony in a train between Hamburg and Berlin.

Sloboda^{15 16} has scientifically investigated the mental processes of music reading, and his findings are in general agreement with the ideas extrapolated from musical experience. Using techniques and ideas derived from language research, he found that musicians did not use visual, naming, or pitch codes when learning a set of notes exposed for brief periods on a screen. He concluded that musicians may read notes in groups, and these groups may depend on melodic, rhythmic, or harmonic implications—factors which might vary from one person to another. The musician may have a vocabulary of characteristic melodic sequences and harmonic progressions; the look of the melodic sequence or harmonic progression might then suffice for identification. It is not possible to say how far the skills required in these processes are inborn or acquired by training in musical theory, but there are too many examples of children displaying early, untaught grasp of structures and styles to allow the conclusion that they derive from cultural factors alone. Sloboda¹⁵ finally asserts that skills commonly believed to be language-specific closely resemble those employed in reading music. This work deserves wider public reading; the results already published should be helpful to teachers as they instruct beginners in reading music, and there is ample scope for further research.

Pitch discrimination

All musical experience depends on the capacity to identify or discriminate the pitch of tones—a facility which is also engaged in hearing speech and natural sounds. The pitch of a tone is in general imparted by its fundamental frequency, which determines whether it stands high or low on the musical scale. One tone is discriminated from another by their differing fundamentals. We are not concerned here with the intensity or loudness of a tone, which depends on the amplitude of oscillations produced by a sounded note, nor with timbre or quality, which depends on the harmonic content of a sound, nor with duration; for although pitch, intensity, timbre, and duration are all important factors there are limits to this discussion. Music is made up of a succession of tones and combinations of tones that are perceived, analysed, and coded by the nervous system in ways to be explored, but questions of tuning and scales and human musical auditory achievement must be considered first.

Contemporary agreed orchestral pitch is 440 Hz for A'. International agreement became necessary because different pitches were used in different places, and because there was a progressive heightening of pitch in the nineteenth century so that A' reached 461 Hz in some musical centres. Musical scales are sets of pitches arranged in such a way that they contain a maximum of consonances and a minimum of dissonances. Theoretically, the just scale, in which the intermediate steps are determined by the smallest whole-number ratios possible, is the best scale because it contains the maximum number of just intervals; however, like the Pythagorean scale, which is constructed on a succession of perfect fourths and fifths, it has been discarded because retuning is required with key changes, and modulation is inhibited. Furthermore, the intervals of just intonation are less aesthetically appealing to the majority than the intervals of equal temperament. Tuning in equal temperament has held the field for some three centuries because it has practical advantages over the other systems; in particular, there is no need for retuning with key changes. The octave is divided into 12 equal log steps, each representing a frequency 5.9% greater than the step below. These steps, called semitones, are each divided into 100 further equal steps or cents, and an octave equals 1200 cents. This method of tuning is imperfect and less accurate than the Pythagorean scale; as Barbour¹⁸ wrote, "all

players and singers are playing false most of the time . . . these are errors of equal temperament."

Have we an inbuilt tuning system? Training and early exposure to musical stimuli make this question impossible to answer with assurance. However, the musician's internal pitch scale corresponds to equal temperament, but with a slight tendency to sharpen all notes relevant to the tonic; the target pitch for notation is a shade sharper than equal temperament. Acceptably accurate tuning is essential in any performance and, while critics mention remarkable divergence, observations like that of Claude Pascal²⁰ are the exception; writing in *Le Figaro* recently of a performance of Schütz's *Kleine Geistliches Konzerte* in Saint Chapelle he said, "J'ai remarqué l'accord du clavécin, un quart de ton plus bas que notre diapason actuel."

NORMAL CAPACITIES FOR PITCH DISCRIMINATION

The normal range of heard frequencies is age dependent and contingent on what is meant by hearing a frequency, for some organ pipes are felt rather than heard. The figures commonly given are 16-20 000 Hz for young people and 20-16 000 Hz for adults—that is nine octaves. While practice improves pitch perception, its physical limits are not increased by training. Hearing is most sensitive for frequencies between 1000 and 3000 Hz and is much reduced in the extreme lower and higher ranges; at low frequencies there is also a reduction, probably due to masking by physiologically produced noise. Individual capacity for pitch discrimination—that is, the ability to identify auditory stimuli on the basis of pitch—ranges from the tune- or tone-deaf to those with absolute pitch sense; it is probably continuously, if not normally, distributed throughout the population. While the capacity is highly developed in some people, there is no experimental evidence that accuracy can exceed consistent discrimination of quarter-tone intervals.^{21 22}

The term just noticeable difference (jnd) denotes the minimum detectable change in frequency which the listener can identify. The jnd jumps sharply at 4000 Hz. Changes in sustained tone are more easily perceived than differences between two tones presented successively, and the use of a melodic line in testing facilitates pitch discrimination. For good practical reasons many workers investigating pitch discrimination have tended to employ musical subjects, and this must account for records of superlative ability.²³ Presumably professional musicians are selected by reason of pitch discriminatory capacity, among other attributes.

Some writers—for example, Révész,²⁴ speak of tone height and tone chroma: tone height simply means pitch, whereas tone chroma indicates the colour or affective sense of a tone. It has been postulated that tone chroma plays a part in pitch identification. Roederer²⁵ believed that there was no psychoacoustic foundation for the notion of tone chroma, because all intervals are equal in the tempered scale, only the pitch is different; he wrote, "there can be slight differences in the sound of various keys . . ." due to physical factors, such as the larger number of black notes or open strings in a certain key, but that is all. Maybe this is a question of aesthetics, but there must be few musicians who would agree that C major sounds the same as Eb major.

A sense of relative pitch—that is, the relationship of the height of one tone to another—is necessary for hearing or singing a simple tune. Most of us perceive and remember music in terms of changing sequences of pitch rather than in terms of orchestral or other pitch values. The human capacity to make such judgments consistently is truly remarkable. Absolute or perfect pitch is the ability to name a sounded note or identify its frequency, or to do both this and to sing a given note accurately without adjustments using relative pitch. This rare facility has been prized by musicians, and a certain mystique attaches to it. The subject has been reviewed by Ward.^{21 22 26} Possessors of absolute pitch appear to have an immutable, relative pitch grid, a fixed internal template, against which to match incoming sounds. There has been a prolonged debate whether absolute pitch is inborn or acquired, but the current majority view is that both heredity and environment play their parts. Investigation of this function is a complex matter, for the aim is to study the ability to classify auditory events on the basis of pitch alone, and other factors such as loudness must be excluded; furthermore, there may be considerable lability or flexibility in the pitch reference points from day to day.^{22 27}

Early training is needed for the development of absolute pitch; crucial requirements may include long exposure to stimuli of constant frequency and single critical pitch experiences, but Ward suggested^{21 22} that absolute pitch may be the normal manner in which humans deal with frequency, though it is trained out of us by our relative pitch musical environment. Questions like this seem unanswerable, but they

may be almost irrelevant. Absolute pitch can be learned or developed in early childhood, but while pitch identification can be improved with training, no one has hitherto been able to train an adolescent or adult who had little original ability in pitch-naming. Ward²² believed that highly developed pitch-naming ability probably always derives from deliberate reinforcement of a child's behaviour by an adult.

The days when absolute pitch or an approximation to it was required of entrants to some music academies and colleges have now passed, and the subject is of less practical importance than it was. While absolute pitch is an advantage in some aspects of practical musicianship, it also carries handicaps—for example, the need for conscious transposition by the singer when a key is changed.²³ In most adult listeners information on absolute pitch is discarded,²³ although all normal people can retain such information for short periods, ranging from 10 seconds to a few minutes.²⁹

ASPECTS OF MUSICAL PERFORMANCE IMPORTANT FOR AUDITORY THEORY

First, musical notes must be sounded for minimum periods of usually two or three cycles before their frequencies can be determined with any precision. Second, the ear and the brain are more susceptible to the pitch changes of a melody or figure than to the blurred acoustic pattern of pianistic glissando or vocal portamento. This is a good physiological reason for the general rejection of these techniques as unacceptable in serious music.

Problems of tuning and intonation must also be taken into account. Electronic analysis shows unexpected variations and excursions in pitch in instrumental and vocal performances. The tendency to sharpen upper notes of all melodic intervals has been noted in the earlier discussion on tuning, but the violin player shows a standard deviation of 10 cents in tuning his instrument.³⁰ Mason³¹ has made similar observations on the intonation of woodwind players. Greene^{32, 33} studied intonation among a group of six professional violinists. Small but significant deviations from equal temperament and just intonation were found, and these differed from one player to the next, as one might expect. In other words, they were not all playing the same frequency for given notes.

Vibrato, a variation or oscillation of frequency, is used consistently by string players and singers. At what note is a vibrato heard? Some singers oscillate to a degree that might be regarded as a manifestation of vocal insecurity rather than musical accomplishment. The heard pitch is probably the mean frequency of the vibrato, but there are dissenters from this view; for example, Kuttner³⁴ thought that the pitch corresponded with the lowest point. With the larger excursions of vibrato the desired effect is lost and the listener hears a trill or shake.

What does the hearer make of all these problems, players not exactly in tune and singers producing oscillating frequencies? Fortunately the auditory processing mechanism ignores minor fluctuations in pitch so that tones are clearly categorised; with larger fluctuations the tone may either seem out of tune, with the appearance of beats, or be perceived as the next semitone or tone above or below the desired pitch. With these phenomena in mind Houtsma and Goldstein³⁵ have suggested that pitch may be defined operationally as the subjective correlate of each one of the auditory events contained in a musical performance.

CENTRAL AUDITORY PROCESSING

Understanding of the mechanisms of central auditory processing is sadly deficient. The function of a central pitch processor should be the transformation of auditory neural activity into patterns, so that all stimuli of the same periodicity are similarly represented.²⁵ This would result in individual, peculiar pitch sensation. It is known that most primary auditory fibres are spontaneously active and that this activity is modified in various ways by cochlear stimulation. The need for a system capable of categorical assessment and of dealing with tones of neighbouring frequency, or with shared harmonics, has been noted previously. The auditory system must integrate stimuli presented to both ears, and its ability to do this is shown by the way harmonic components of a tone fed simultaneously into both ears combine to produce that tone as a perceptual experience.

The natural stimuli that assail our ears continuously—the murmuring of elms, the whispering of leaves, and sounds of water—are all complex sounds, and the understandable use of pure tones in physiological studies fails to provide the subject with a normal or

adequate stimulus. Cells in the auditory cortex of animals are unresponsive to pure tones, except perhaps to their onset and cessation, but they fire vigorously to modulated tones; there are cells in the auditory cortex of the monkey that only respond to particular sounds uttered by his fellows. Normal auditory experience, including music, derives from sequences of complex, not pure, tones.³⁶ We may conclude that the auditory cortex of man may be expected to respond to natural, complex sounds as its primary function. The value of pure tones in research on animals and in assessing hearing in man is therefore limited, as otologists recognise when they use not only pure tones but also speech audiometry in testing their patients.

There is good evidence that the minor hemisphere plays a predominant part in the recognition of musical passages. Indeed, it has been known for many years that anterior right-sided lesions may cause defects in expressive or receptive musical activity (amusia) in right-handed persons. Nevertheless, the roles of major and minor hemispheres have yet to be defined. Musically trained people appear to use primarily the left (major) hemisphere in musical analysis, and this may be the fruit of auditory and verbal linkages in the memory store and of a literary approach to music. On the anatomical side there is no good evidence that the size of the primary auditory cortex, the planum temporale, is of any importance for musicality.³⁷

The physiological mechanisms subserving hearing at the peripheral level are also not clear. Nerve cells in the basilar membrane of the cochlea are activated by a travelling wave, dependent on the frequency of the sound wave. High frequencies cause vibrations in a restricted portion of the base of the cochlear partition, while low frequencies set the whole membrane into vibration; the basilar membrane appears to act as a mechanical form of frequency analyser.³⁸ Ninety-five per cent of all fibres innervating the cochlea reach inner hair cells, and these are mostly afferent, whereas 90% of the fibres serving the outer hair cells are efferent. While the peripheral analysis of high frequency tones may be explained by the location of the different receptors throughout the cochlea, this theory is less acceptable for low tones, which cause the whole basilar membrane to vibrate, and an additional form of frequency analysis, the volley hypothesis, first attributed to Wever, has been adduced.³⁹ Possibly place and frequency and temporal patterns may both play a part in pitch perception. The first stage of analysis by the basilar membrane, however, is not sufficient to account for pitch discrimination; hence a second tuning stage is required, and this probably involves the outer hair cells. The efferent fibres to the external hair cells are presumably carried in the olivocochlear bundle. This system is thought to be responsible for fine tuning or sharpening necessary to the ear's remarkable capacity for pitch discrimination; by tuning and sharpening we mean inhibition or extraction of tonal material peripheral or marginal to the discriminatory task on hand.

Conventional neuroanatomical and neurophysiological studies have given little information about the organisation of central auditory processing. Webster and Aitkin³⁹ speculate that the ventral cochlear nucleus and the pathways that connect it with the primary auditory cortex are predominantly concerned with auditory perception, whereas a second pathway, comprising the dorsal cochlear nucleus and its connections with the secondary auditory cortical areas, may be concerned with non-specific acoustic features and may be the origin of acousticomotor connections.

Studies on the afferent auditory paths from the cochlea to the temporal lobe show that while the frequency organisation of the cochlea is maintained, synchrony of neural discharges diminishes progressively. Yet this work on the relationships between unit discharges in the auditory pathway and the precise anatomical location and morphology of the responding element has resulted in few correlations. The effect of anaesthesia upon auditory neural responses in experimental animals has provided an added source of difficulty.³⁹ Celestia⁴⁰ observed that evoked responses to clicks from the superior temporal gyri could only be obtained in conscious patients. On the other hand, responses could be obtained from Heschl's gyrus in patients under light halothane-nitrous oxide general anaesthesia.

PSYCHOLOGY

The slow development of knowledge has led some workers to use ideas comparable to those employed by Hubel and Wiesel in their successful work on vision. Roederer⁴¹ has published an important book, *Introduction to the Physics and Psychophysics of Music*, which is required reading for those interested in the subject. He discusses Goldstein's model of a central pitch processor, based on the assumption that neural information on the places of maximum displacement of the basilar membrane is not sharply defined, fluctuating statistically around average values. The template match, discussed below, which

leads to the ultimate pitch sensations, is one which minimises the differences between the inbuilt template values and those of the incoming signal. Roederer proceeded to explain some quantitative characteristics of complex tone-pitch perception in algebraic form and proposed a speculative neural model that could accomplish the functions of a central pitch processor. It is too early to determine the ultimate value of this and other similar work—for example, Deutsch.⁷

Some psychological interpretations have been mentioned earlier in this address, and it is time to determine whether current psychological theories, such as the template-matching, feature analysis, and schema theories¹¹ might be relevant to the problem of musical pattern recognition and discrimination. The template-matching theory proposes that new incoming patterns of nervous impulses are compared with an inbuilt standard; the feature analysis theory considers that the presence of distinctive parts or features in a pattern are decisive for its discrimination and recognition; whereas the schema theory is based on the idea of cognitive structures that organise systems of stored information, perhaps by forming images to represent the central tendency of a category and using this as reference point. This was the idea behind Head's notion of the schema¹²⁻¹³; by this term he meant the neural organisation of past experiences, both motor and sensory, which is necessary for sensory experience and motor response.

Of these three theories template-matching probably offers the firmest basis for understanding the process of pitch discrimination. We may speculate that pitch is discriminated and recognised by a template-matching process; however, such a match between the sensory input and the store "standard" derived from past experience is likely to affect more than one memory code. That is to say, other factors, such as semantic memory, musical memory, prediction, and set and bias can be expected to play an important part, not only in the analysis of pitch discrimination, but also in other types of musical experience. Moreover, the psychological processes concerned differ from one person to the next. Thus, for the person without absolute pitch the sound of 440 Hz on an oboe is a musical note of approximate height; for the person with absolute pitch it is A', the note used for orchestral tuning. The second analysis requires both auditory and verbal codes. More complex but popular musical stimuli activate verbal and other memory codes in all listeners—for example, "God Save the Queen."

Prediction, or anticipation, is an integral part of our response to music. The sound of a chord or the series of pitches in the line of a phrase or melody sets the listener thinking "What comes next?" He may be correct in his prediction, and that brings a sense of satisfaction; he may be wrong, but then he has a new musical experience to add to his memory store.

The subject of musical memory remains relatively unexplored, and this is not the place or time to speak of it, nor of the related topic, auditory imagery.^{2-7, 14} It would be wrong, however, to ignore the remarkable way in which music can be analysed, learned, and stored. Knowledge of composer style and memory of individual works may result in instant auditory and verbal recognition and identification, sometimes on the basis of a single but characteristic chord or short phrase. This discussion has left few questions answered, but the simple statement of the problems concerned with pitch discrimination and related matters shows how much we have to learn in this field.

Conclusion

In conclusion, the subject "music to die to" forms a fitting end to a medical address on music. Musicians sometimes discuss the topic as a somewhat recondite party game; presumably each person chooses a piece which has particular emotional significance for him, summing up the experience of a lifetime and expressing expectation or hope of what may lie ahead. Guillaume Dufay (c 1400-1474), the Burgundian composer from Cambrai, desired in his will that when he had received the last sacrament and was in articulo mortis eight choristers of the cathedral should sing very softly by his bedside the hymn *Magno salutis gaudio*, after which the altar boys, with their master and two choristers, should sing his motet, *Ave Regina Coelorum*.⁴⁵ His wishes were not entirely fulfilled, for the hymn and motet were sung not at his bedside but in the chapel beside his body. Fritz Kreisler, the great violinist, chose Schubert's quintet in C major, op 163, for deathbed listening.

There was once an old lady who had been a member of the Bach Choir, or so I have been told. She said that she would like

to die singing the Sanctus from the B minor Mass. Her wish like Dufay's was not fulfilled, but she was listening to the work at her end. Many of us will agree that she was right in choosing the celestial Bach as her musical companion at this unique and poignant time.

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(Accepted 25 February 1977)