Brain tuned to music

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Music is the art of thinking in sounds.[1] With its power to evoke and communicate emotions it has long intrigued philosophers, but only recently has it claimed the attention of neuroscientists. Even today, there are some who see it as a mere epiphenomenon.[2] Many others, however, are exploring the neurological foundations of music perception. In this review article we focus on mechanisms by which music is processed by the brain.

THE POINT OF STUDYING MUSIC PERCEPTION

From the perspective of evolutionary psychology, natural selection shapes species to their environment not only in physical and physiological traits but also in behavioural traits. The higher the species in the evolutionary hierarchy, the more important are the psychological traits related to behaviour; it is noteworthy that people spend more money and time on music than on sex.[3] No matter how advanced or how backward a society is technologically, music is always an integral part of it. That this is not a recent development is illustrated by archaeological findings such as a bone flute at least 43 000 years old.[5]

Any trait that has evolved with time is likely to be universally distributed, to be found in immature members of the species and to be processed with some degree of automation. These characteristics apply to music. First, as regards universality, there is evidence of common features, across different music styles, in the principles underlying melody[6] and in response to features such as consonant/dissonant intervals, pitch in musical scales and metre.[7,8] Secondly, the way an infant processes musical patterns is similar to that of adults;[9] infants respond to melodic as well as to harmonic consonant patterns, and to complex metric rhythms.[9,10] There is reason to believe that infants possess absolute pitch early in life but change to relative pitch later,[11] and that they have long-term musical memory.[12] Finally, evidence that structural components such as pitch contour and pitch interval are encoded automatically, even by non-musicians,[13] suggests that our auditory pathways are hard-wired to deal with music-related stimuli.[14]

Apart from the intrinsic interest of neural structures processing music, work in this area could yield important insights into the functional organization of auditory cortex.[15] Also, since processing of music is a complex set of perceptive and cognitive operations with links to memory and emotion, it offers a window to the understanding of higher brain function.[16] Finally, a musician's brain provides a model of neuroplasticity, allowing study of structural and functional reorganization as training proceeds.[17]

AMUSIA

Most early reports on the cortical localization of music processing were based on cases in which patients with brain lesions had lost the ability to process complex music or certain elements of it. These disorders, termed amusia, can be broadly classified into two types—acquired, as a consequence of accidents or diseases; and congenital, due to heritable factors. A rarer neurological disorder is that in which epileptic seizures are triggered by listening to or playing music.

Clearly, the relation of amusia to aphasia (loss of speech) is relevant, since both are in auditory domain and they often coincide, though each can occur in the absence of the other.[18] A famous instance of amusia was the French composer Maurice Ravel, in whom a progressive cerebral disease caused aphasia with alexia (inability to read), agraphia (inability to write), and ideomotor apraxia (inability to move in a coordinated way). In addition, he slowly lost his ability to compose music.[19] The effects of the disease are seen in works such as *Bolero* composed in his later years, with timbres coming to dominate at the expense of melodic complexity. Evidence has emerged that the damage was to his left hemisphere and we owe the extraordinary richness of timbres to preservation of the right hemisphere (which is known for processing of timbre). By contrast, aphasia without amusia developed in the Russian composer Shebalin, whose musical abilities survived after severe damage to his left hemisphere. In cases of amusia where speech is spared, the involved site of damage is the right hemisphere; the symptoms include difficulty recognizing sounds as musical, loss of rhythmic sense, hearing musical sounds 'out of tune', and hearing

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both voices and music as monotonal.[18] In general, lesions in the right hemisphere interfere with pitch-related tasks more than rhythm-related tasks.[21] Right temporal lobotomy disrupts the recognition of timbre but spares rhythm.[22]

Cases of acquired amusia have shed light on two important aspects of music perception and processing. First, both melodic and temporal perception require local and global auditory information processing; with respect to melody, pitch intervals are local and melodic contours are global. Similarly, there are local strategies for the perception of duration and temporal distance between auditory events (known as rhythm) and global mechanisms for the perception of metre (the temporal variance of recurrent pulses providing durational units by which we recognize a waltz or a march[23,24]). Temporal structures of music, rhythm in particular, are preferentially processed in the left hemisphere. In relation to the processing of pitch, lesions on the right side impair perception of melodic contour, whereas unilateral lesions impair perception of pitch intervals.

Congenital amusia, or tone deafness, has been studied much less. The impairments cannot be explained by hearing loss or by cognitive slowing or by lack of exposure to music.[25] Peretz and her group have lately reported[25,26] cases of congenital amusia in which the most basic musical abilities were lacking, such as recognition of pitch changes and discrimination of one melody from another, despite intact intellect and language skills. This suggests that congenital inability to recognize pitch results in a cascade of impairments of global and local pitch processing. That this is an inherited trait is suggested by work in twins.[27] When they were asked to detect incorrect pitch inserted into popular melodies, the performance of identical twin pairs match more closely than that in non-identical pairs. More work is needed to show whether any musical component other than pitch is heritable.

ELECTROPHYSIOLOGY AND IMAGING

Although much has been learned from the effects of brain lesions, these tell us mainly about what has been lost. For information on the role of other cortical regions and their cooperation we must turn to studies in healthy individuals. Such techniques have proved rewarding.

Electroencephalogram

Event-related potentials (ERP) are derived from the electroencephalogram (EEG) by neuroimaging of responses to a repeated stimulus. In line with the lesion studies, results with ERP[28] suggest that musical processing has global (holistic) and local (analytical) elements. Comparison of musicians and non-musicians has produced intriguing data. When non-musicians listened to chord sequences, a violating chord gave rise to an early right-anterior negative (ERAN) response, reflecting the unexpected.[29] Irrespective of musical training, we respond quickly to incongruities. However, with more complex musical irregularities, the amplitude of ERAN is larger for musicians than for non-musicians.[30] Furthermore, there is evidence[31] that musicians develop a sensory-related memory that perceives changes in temporal structure of sound patterns at preattentive level (a task formerly thought to depend on attention-related brain processes).

There is much evidence[32,33] that, during higher cognitive functioning, different areas of brain cortex become not only coactive but also functionally interdependent. Analysis of the EEG in people listening to music of various kinds pointed to simultaneous and homogeneous activity in different cortical regions. This effect was most pronounced in the high frequency γ-band which is proposed to reflect temporal coding and binding.[35] In addition, the degree of γ-band synchronization between near and distant cortical regions was much greater in musicians than in non-musicians while they listened to music, though there were no differences in resting conditions or during text processing.[36,37] Larger involvement of long-term musical memory, stronger music-induced attention, and greater ability to anticipate musical patterns are some of the possible reasons for the higher degrees of synchronization in the musicians. Since γ-band synchronization relates to cognitive tasks, the work supports our contention that music perception is a useful model for study of high level brain function.

Imaging

Modern imaging techniques allow detection of the cortical and subcortical structures activated by exposure to music. In general, work of this kind points to right hemisphere specialization for perception and working memory for pitch (short-term retention of tonal patterns) and left hemisphere specialization for rhythm and processing of musical semantic information (identification and recognition of melodies). As regards the role of the right auditory cortex in tonal processing, a wide variety of perceptual tasks has been examined.[15,38–41] In one study, activation of right auditory cortex was reported when the subject mentally reproduced a familiar melody.[42] However, deeper investigations are needed into auditory processing. In pitch processing, many different cortical regions distributed bilaterally are involved in an anatomical and functional hierarchy extending from ear to brainstem, thalamus and auditory cortex. The auditory cortex itself presents a hierarchy with a central core region containing the primary auditory cortex (A1), a surrounding belt, and a parabelt. In a recent study,[43] a special pitch stimulus generated almost symmetrical bilateral activations from brainstem to cortex, including Heschl's gyrus containing the core of A1. In addition, noise and fixed pitch stimuli produced symmetrical activations in Heschl's gyrus and in planum temporale, with more activation of Heschl's gyrus by pitch stimuli than by noise. Asymmetry towards the right auditory cortex was seen only when the stimulus was a melody,[44] which produced additional activations of planum temporale and superior temporal gyrus. These results are consistent with the lesion studies[45] in which patients with right lobe lesions encroaching Heschl's gyrus showed impairment in the ability to discriminate pitch directions. Thus, it is from both lesion studies and imaging studies that asymmetries arise when the task involves processing of perception and tracking the direction of pitch, which in turn require activation of superior temporal gyrus and planum temporale.

Consistent with the above idea are observations with various pitch-related stimuli such as binaural presentation of an instrumental music stimulus,[46] pairs of tones played successively,[47] or melodic sequences;[48,49] all these showed clear involvement of right superior temporal gyrus with lateralization. Furthermore, in subjects with relative pitch but not with absolute pitch,[48] right prefrontal cortical regions become activated when working memory is involved in the pitch comparison tasks.

A hotly debated topic is the possible difference in cerebral asymmetry between musicians and non-musicians. In a pioneering behavioural study[50] Bever and Chiarell reported right-ear (left hemispheric) dominance in musicians, left-ear dominance in non-musicians. The first imaging study,[38] with positron emission tomography (PET), showed that right>left asymmetries in non-musicians confronted with timbre, chord and pitch tasks, but left>right asymmetries in musicians. The authors speculated that the left-sided dominance in musicians might be related to an analytical process—i.e. they interpret music more deeply than non-musicians. Musicians also showed increased blood flow velocity in the left hemisphere whereas non-musicians showed right hemispheric lateralization only during harmony perception. In a magnetic resonance study,[46] musicians showed higher activation than non-musicians in the secondary auditory area and in dorsolateral prefrontal regions of the left hemisphere, whereas non-musicians displayed opposite dominance. Further, in musicians, activation of the left planum temporale, which was also anatomically larger than in non-musicians,[52] was found to be stronger. This left lateralization in musicians has been replicated by other groups.[47,53] A point to note is that, for musicians, mere passive listening is more difficult because of their spontaneous analytical processing, and this possibly contributes to the left lateralization.

The ability of music to induce emotions is universal: simply, we are 'moved' by it. A PET study[54] showed that activity in several paralimbic regions correlated with emotions (unpleasant or pleasant) generated by musical stimuli with varying degrees of dissonance. While the subjects were listening to their favourite music, brain areas (ventral striatum, dorsolateral midbrain) associated with reward or pleasure were activated.[55]

CONCLUSION

In this short review, we have presented evidence that perception of music, with its immense emotional power, can be studied in scientific ways. Further work in this area can be expected to yield information on matters such as the existence of an inherently musical mind, the relation between music and language, and the process of creativity.

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