■ REVIEW

Brain Specialization for Music

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Music, like language, is a universal and specific trait to humans. Similarly, music appreciation, like language comprehension, appears to be the product of a dedicated brain organization. Support for the existence of music-specific neural networks is found in various pathological conditions that isolate musical abilities from the rest of the cognitive system. Cerebrovascular accidents, traumatic brain damage, and congenital brain anomalies can lead to selective disorders of music processing. Conversely, autism and epilepsy can reveal the autonomous functioning and the selectivity, respectively, of the neural networks that subserve music. However, brain specialization for music should not be equated with the presence of a singular "musical center" in the brain. Rather, multiple interconnected neural networks are engaged, of which some may capture the essence of brain specialization for music. The encoding of pitch along musical scales is likely such an essential component. The implications of the existence of such special-purpose cortical processes are that the human brain might be hardwired for music. NEUROSCIENTIST 8(4):374–382, 2002

KEY WORDS ***PLS. PROVIDE 3-5 KEY WORDS****

To begin, I will introduce the topic of brain specialization for music by way of two examples coming from clinical neurology. The first case is a professional composer, Vissarion Shebalin, who sustained a second vascular hemorrhage in the left hemisphere of the brain at the age of 57. This stroke left him speechless and deaf to the spoken world. Although Shebalin could no longer communicate verbally, he continued to teach and to compose until his death 4 years later. Shebalin was particularly prolific musically despite his vast left hemispheric lesion; he wrote 14 chorales, 2 sonatas, 2 quatuors, 11 songs, and 1 symphony. According to Shostakovitch, one of his peers, Shebalin's music was undistinguishable from what he had composed before his illness (Luria and others 1965). The case of Shebalin, a musician with essentially no language consequent to brain damage, is known as the condition of *aphasia without amusia*. It is spectacular but not exceptional. Similar cases have been reported in the literature (e.g., Assal 1973; Basso and Capitani 1985; Signoret and others 1987).

The second case, Isabelle R., represents the reverse condition. Isabelle R. is an ordinary woman, devoid of any apparently special talents, be it musical or linguistic. She was a restaurant manager when, at the age of 28, she underwent successive brain surgeries for the repair of ruptured aneurysms in the left and right middle cerebral arteries. She survived, but with two vast brain lesions invading the auditory cortex bilaterally and extending to the frontal areas on the right side (for more details, see Griffiths and others 2000). In this context, it is surprising to note that Isabelle R. is fully functional in language, memory, and intelligence. She even writes poems (for an example, see Peretz and others 1997). Her persisting and major problem concerns music. Isabelle R. can no longer recognize the music that was familiar to her prior to her brain accident; she cannot relearn the musical corpus due to the fact that melodies no longer leave a trace in her memory; finally, she can no longer carry a tune. Isabelle R. regularly practiced these skills before her brain injury, and music was an important part of her life. She was raised in a musically inclined family; her only brother is a professional musician. Isabelle R. is a case of *amusia without aphasia*. This condition has been known for more than a century (Marin and Perry 1999), although more detailed cases have been documented recently (Peretz and others 1994; Griffiths and others 1997; Piccirilli and others 2000).

The major conclusion to be drawn from these two neurological cases is that brain specialization for music does seem to exist. Cases such as Shebalin show how these specialized neural circuitries can be selectively spared. Conversely, cases such as Isabelle R. demonstrate that these music-specific circuitries can be selectively damaged. This double dissociation points to the existence of neural networks that are dedicated to the processing of music. This point requires both clarification and elaboration. First, there is a need to specify the circumstances under which such a specialization can be observed. Second, the nature and function of the specialized mechanisms that are subserved by these music-specific neural modules must be specified. Finally, the rea-

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sons why the human brain might be equipped with musical modules must be examined. The present review will treat each of these questions in turn.

Isolation of the Music-Specific Networks

The classical method for examining brain specialization is via lesions in humans, as illustrated above and as reexamined below. Yet, this is not the only method. Identification of musical modules can take place in a variety of pathological contexts, such as autism, Williams syndrome, epilepsy, and Alzheimer disease. Moreover, it can be observed in individuals who suffer from a learning disability for music. Finally, the existence of music-specific brain circuitries may also be revealed by brain imaging and electrophysiological techniques in neurologically intact individuals.

Autism

Brain anomalies can produce cognitive deficiencies that are so pervasive that the individual needs constant assistance, even in adulthood. These anomalies can be congenital, as in autism and in Williams syndrome, or acquired late in life with the progression of the dementing process in Alzheimer disease. Yet, despite the presence of mental retardation, individuals often enjoy a fully functional system for music and can even achieve a high level of music proficiency (see Don and others 1999 for Williams syndrome; Miller L 1989 for the music-savant syndrome in autism).

We have been able to observe this fascinating condition in an autistic young adult, Pauline (i.e., QC in Mottron and others 2000). Pauline lives with her parents and is unable to earn her living. She is considered to be deficient intellectually (her IQ is 70) and was diagnosed as autistic at the age of 2. Language was delayed, with the first words articulated at 30 months and the first two-word sentences at 48 months. In contrast, Pauline has always shown a keen interest for music and has displayed remarkable musical skills. She started to play piano informally at the age of 2 and received formal piano lessons at the age of 5. Since then, Pauline has continued to play music, although at a moderate pace. Her level of achievement corresponds to that of an amateur pianist with an equivalent number of years of training. However, Pauline has an exceptional memory for music; she is able to reproduce a conventional piece of music composed for experimental purposes after hearing it only once. Her reproduction is informative because she does not reproduce the piece as a recording machine; rather, she harmonizes and improvises in a skillful manner. She also possesses absolute pitch, being able to accurately sing a named pitch. None of these skills are in themselves the signature of talent or prodigy. Yet, these two skills reveal without ambiguity a fully functional musical system in an otherwise low-functioning individual.

Pauline is a typical case of the "music-savant syndrome." Similar cases have been reported in the literature (e.g., Sloboda and others 1985; Hermelin and others 1987). In general, autistic subjects are more apt in the area of music than in language (Heaton and others 1998). Autistic individuals provide strong case demonstrations of brain specialization for music because their musical abilities emerge as an isolated area of normal functioning. Their musical proficiency suggests that music must be subserved by music-specific mechanisms, which are left intact by the autistic brain pathology. Unfortunately, the neural correlates of the preserved musical skills have not yet been studied. In fact, the study of the atypical cerebral functioning in autism is just beginning (e.g., Ring and others 1999).

Epilepsy

Investigations with epileptic patients provide another valuable source of evidence that suggests the existence of neural networks that are dedicated to music. In a few individuals, music will be the exclusive trigger of the pathological firing of neurons that underlies seizures. This unusual but well-documented form of epilepsy is called *musicogenic epilepsy* and shows that the epileptogenic tissue lies in a neural region that is tied to music processing.

Epileptic attacks may be induced by simply listening to music. The musical trigger can be highly selective, as described by Critchley (1977). In one of his patients, only "classical" music provoked a seizure, although the patient confessed that she had no particular preference for this kind of music. During such musicogenic epileptic seizures, abnormalities in electrical activity (recorded from the scalp) are generally observed at the temporal lobes, with a slight bias toward the right one (for a recent review, see Wieser and others 1997). Thus, some processing component that is exclusively related to music must be located in those regions.

Musicogenic epilepsy can be simulated by direct electric stimulation of the brain (e.g., De Graaf and others 2000). It has been well known since the classical studies of Penfield and Perot (1963) that electric stimulation of particular areas of the auditory associative cortex of awake patients may produce highly vivid *musical hallucinations*. For example, Penfield and Perot (case 5, p 620) report stimulating a particular region of the first right temporal circumvolution of an awake epileptic patient before surgery. After stimulation, the patient reported that she heard music. The experimenters then repeated the stimulation, without telling the patient, who immediately reported, "I hear the music again. It is like the radio." The stimulation was again repeated and the patient shouted, "I hear it!" The electrode was kept in place, and the patient was asked to describe what she heard. The patient hummed the tune quite distinctly. The song came out so clearly that one of the nurses recognized the song "Rolling Along Together." The patient agreed that this sounded like the words in the song.

These provoked hallucinations suggest that the stimulation be applied to circuits that contain memories of musical experiences. These musical experiences are slightly more often evoked by stimulation of the right than the left temporal regions (Penfield and Perot 1963). The fact that musical memories can be selectively elicited is once again indicative of a brain specialization for music.

Brain Damage in Adults

The patient-based approach converges on an important point: neuronal networks that are situated in or close to the superior temporal gyrus participate in music perception and memory in a decisive and exclusive manner. This is best documented in cases of acquired amusia as a consequence of brain damage.

Following bilateral lesions of the auditory cortex, patients can show highly specific disorders of music perception and recognition (e.g., Peretz 1996; Peretz and others 1997). This music-specific impairment is readily discernable in experiments testing memory recognition. In the music memory test, subjects are presented with 20 tunes (taken from familiar songs) to memorize. The melodies are then represented among 20 unstudied (but equally familiar) melodies that are randomly mixed. The subject is requested to indicate which melodies were heard in the study phase. For comparison purposes, in the lyrics and the environmental sound tests, subjects are given similar opportunities to learn and recognize 20 spoken lyrics (taken from the same familiar songs) and 20 environmental sounds (e.g., a barking dog), respectively. The three tests are performed in different sessions.

As can be seen in Figure 1, the 2 patients—Isabelle R. (IR, described previously) and CN (another similar case; Peretz, 1996), who suffers from musical disorders as a consequence of bilateral lesions to the auditory cortex—perform at chance in the melody recognition test, but they perform in the normal range with spoken lyrics and environmental sounds. Importantly, the patients fail to recognize the tunes of songs from which they are able to recognize the lyrics. The disorder is clearly music specific. Thus, the critical mechanisms that are necessary for music perception and memory are not only specialized for the musical domain but also appear to be subserved by neural networks that are anatomically distinct.

Amusic Adults

As a result of early abnormalities in music-specific networks, normal acquisition of musical competence would be expected to be affected in a highly selective manner. That is, certain individuals might be born with a musical deficiency. This possibility has been envisaged for more than a century (see Grant-Allen 1878 for the first report; Geshwind**[GESCHWIND IN REF.]** 1984). Such individuals are musically inept, despite a normal exposure to music, normal intelligence, and social adaptation. They are sometimes referred to as *tone-deaf*. However, this term is too restrictive. We prefer the term *congenital amusia* because it reflects better the likelihood that there are multiple forms of musical learning disabilities, as there are various patterns of acquired amusia resulting from brain accident.

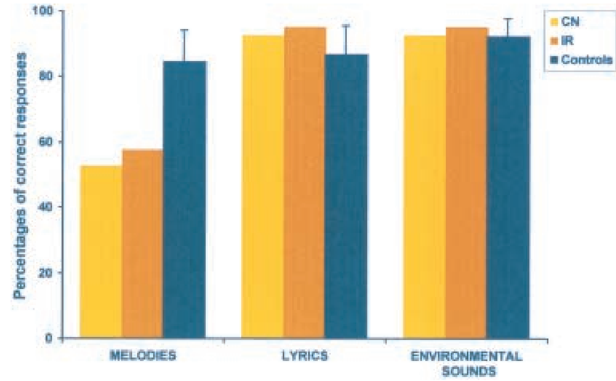

Fig. 1. Percentage of correct responses obtained by 2 amusic patients with brain damage (CN and IR) and 29 unselected control adults with no musical experience in the memory recognition of studied melodies, lyrics, and environmental sounds. Error bars represent standard deviation from the mean obtained by controls. Chance performance is 50%.

In an effort to learn more about congenital amusia, we actively searched for adults with a lifelong history of musical learning disabilities. To date, we have identified 11 such cases (Ayotte and others forthcoming). All participants declared themselves as musically impaired since birth, and their self-report was confirmed by formal testing. We selected participants who exhibited clear-cut performance deficits in laboratory tests, who had no psychiatric or neurological history, and who possessed a high level of education. To ensure adequate exposure and motivation, only volunteers who had attempted to learn music during childhood were considered.

To confirm the presence of a musical defect and to determine whether the deficit is specific to music, subjects were evaluated over numerous tests that were initially designed for the assessment of brain-damaged patients with probable acquired amusia (e.g., Peretz 1990; Liégeois-Chauvel and others 1998; Ayotte and others 2000). The most sensitive test that was able to distinguish amusic from normal performance required the detection of an anomalous pitch in an otherwise conventional melody. Subjects were presented with two sets of melodies. The first set comprised familiar melodies, and the second set had unfamiliar melodies. In each set, half of the melodies were modified by shifting the pitch of one note by one semitone so that the note fell out of key while preserving the original contour. The position of the modified note varied across melodies, avoiding the first and last note positions. The melodies were 6 to 15 notes long and were presented only once. After each presentation, subjects were asked to judge whether the melody contained a "wrong note."

As can be seen in Figure 2, the two groups can be differentiated; there is no overlap between the amusic scores and the scores of normal controls who were matched in sex, age, and education. The results obtained with this anomalous pitch detection test are important for several reasons. From a practical perspective, this test clearly distinguishes amusic subjects from normal

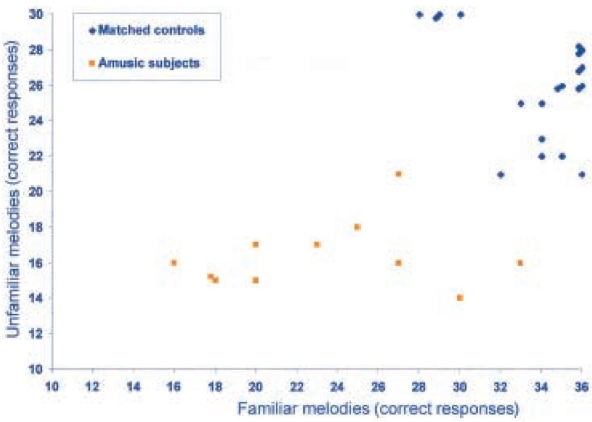

Fig. 2. Distribution of individual correct scores obtained by congenital amusic subjects relative to the distribution of the individual scores obtained by 20 nonmusicians who were matched in education, age, and sex to the amusic individuals. The scores were obtained in a pitch anomaly detection task involving 36 familiar melodies (abscissa) and 30 unfamiliar melodies (ordinate axis). Half of the melodies contained a pitch that was out of key. Note that most amusic subjects perform at chance (around 15 correct responses) in the unfamiliar melody set and that there is not overlap in the amusic and control distribution.

individuals and hence may serve as a diagnostic tool. From a theoretical point of view, the results are important because they converge with prior findings in identifying a deficiency in musical pitch perception (Kalmus and Fry 1980). Such a pitch defect is the most likely origin of congenital amusia.

The notion that congenital amusia results from a basic auditory problem related to fine-grained pitch discrimination has theoretical appeal. Fine-grained discrimination of pitch is probably more relevant to music than to any other domain, including speech intonation. Speech intonation contours, for example, use variations in pitch that are larger than half an octave to convey relevant information (e.g., Patel and others 1998). In contrast, melodies mostly use small pitch intervals (of the order of a one-twelfth or one-sixteenth of an octave). Therefore, a degraded pitch perception system may compromise music perception but leave speech prosody unaffected. Yet, we were able to show that when discrimination of intonation is made difficult by removing speech cues and involving short-term memory, amusic subjects have difficulties with prosodic patterns as well (Hyde and others 2001; Ayotte and others forthcoming; Peretz and others submitted**[PLS. PROVIDE YEAR MS. WAS COMPLETED]**). This suggests that the pitch perception deficit experienced by congenital amusic subjects is not specific to the musical domain but is *domain relevant*.

It is worth emphasizing that the defect appears indeed limited to the musical domain. For example, our group of congenital amusics behaves exactly as brain-damaged patients who suffer from acquired amusia in the memory recognition of melodies, lyrics, and common environmental sounds (see Fig. 1). Thus, congenital amusics appear to be born without the essential neural elements that allow development of a normally functioning system for music. Yet, these individuals have achieved a high degree of proficiency in most, if not all, other domains.

Therefore, congenital amusia is another pathological condition that reveals brain specialization for music. Because congenital amusia is the mirror image of the music-savant syndrome described earlier in autism, it provides strong evidence for the presence of early pressures to develop neural networks that are dedicated to music. These predispositions may not fine-tune the neural circuitries of the congenitally amusic's brain properly, whereas the same predispositions may adequately guide the neural wiring of the autistic brain.

Normal Adults

Up to this point, we have seen how various brain anomalies can reveal the existence of music-specific networks. Imaging and electrophysiological explorations of the brain of normal subjects might also be expected to provide relevant information, especially regarding the localization of these networks. However, this is a complex task. Musical abilities are numerous and dissociable (for an example, see Peretz 2001a), and domain specialization must be examined at the level of each relevant processing component. Hence, the search for convergence between pathological and normal brain conditions will require sustained research efforts.

The recent study of song component processing provides a good illustration of both the advances and difficulties that characterize the current search of music-specific networks in the normal brain. In accordance with the patient-based approach, the processing of melody and lyrics of a same song has been shown to be separable in the brain of normal individuals. Event-related brain potentials have been recorded while musicians listened to excerpts from an opera sung without accompaniment. Excerpts were ended by semantically congruous or incongruous words sung either in or out of key. The situation is illustrated in Figure 3. The evoked responses associated with the semantically incongruous sung word showed a negative waveform component that peaked 400 ms (N400) after word onset. In contrast, the brain potentials evoked by a congruous word that is sung out of key showed a late positive deflection (P600). When the sung word is both semantically and melodically unexpected, the obtained waveform shows an additive effect of the N400 and the P600. This electrophysiological pattern suggests that the monitoring of speech and music in songs is performed by independent neural processors (Besson and others 1998).

Converging evidence was later obtained with the same opera excerpts in a functional brain imaging study that used the positron emission tomography technique (Warrier and others 1998). Monitoring for semantic incongruity produced activation localized to the left inferior frontal cortex (Brodmann's areas 44 and 45). This region was not involved in the monitoring of the same song excerpts for the presence of melodic incongruities. However, more recent data obtained with mag-

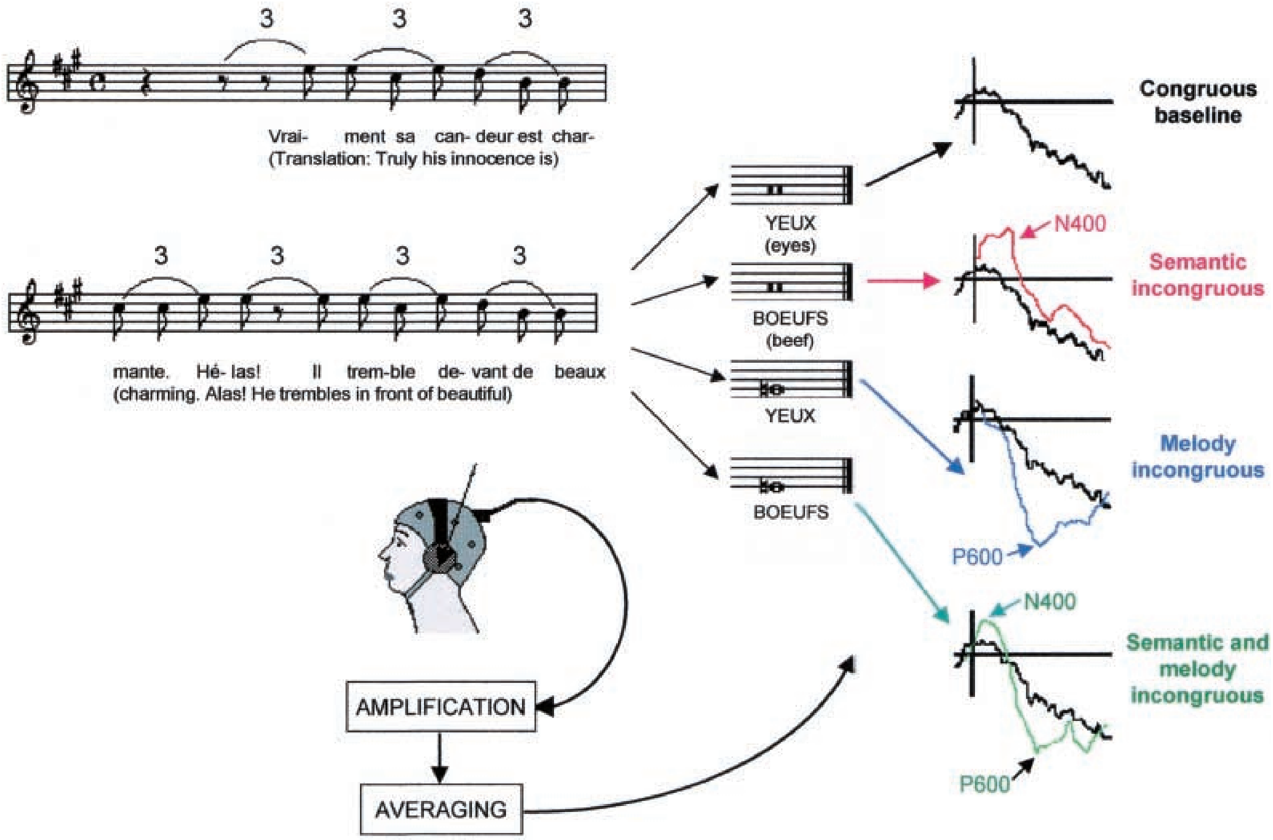

Fig. 3. Example of opera excerpt that was sung *a capella* by a professional singer with four different endings. The final word was either original, in being semantically and melodically congruous, and served as the baseline condition; semantically incongruous and sung in key; semantically congruous but sung out of key; or both semantically and melodically incongruous. Neurologically intact musicians monitored the presence of these incongruities in 200 opera excerpts, and event-related potentials that were time-locked to the final word onset were recorded, amplified, and averaged for the four conditions separately and then averaged for the 16 musicians. The resulting averaged waveform is illustrated on the right side of the figure for the midline parietal electrodes, with negative being up. The vertical bars represent the onset of the final word.

netoencephalography suggest that the detection of a harmonic incongruity in music might also involve Broca's areas (e.g., Brodmann's area 44) (Maess and others 2000). Therefore, the implication of the left inferior frontal cortex might not be specific to language but could reflect a general intervention in detecting rule violations. This latter result highlights the difficulty in trying to identify brain areas that work solely during musical tasks. However, the evidence is scarce because the issue has not been sufficiently addressed.

The Origins of Brain Specialization for Music

Taken together, neuropsychological explorations, particularly the patient-based approach, point to the existence of brain specialization for music. One important implication of this observation is that music does not seem to be a by-product of a more important brain function, such as language. However, brain specialization for music does not entail that a "musical center" must exist in the brain. Rather, brain specialization for music may lie in several largely distributed neural circuitries that are essential to the normal functioning of musical activities.

One essential mechanism was delineated previously in the study of congenital amusia. This mechanism is related to the computation of musical pitch. However, it seems unlikely that a function as complex as music appreciation and expression could be reduced to a single mechanism. During music acquisition, it is possible that a faulty perception of pitch might bring the development of the entire musical system to a halt. However, in a fully and normally developed musical system, many other essential processing components intervene. Clearly, what is needed at the present stage is a grid that allows specification of the processing mechanisms that are essential and specific to music. Once these essential ingredients have been identified, their respective localization can, in principle, be tracked down in the brain of musicians and nonmusicians of different musical cultures. The research agenda involved will only be briefly sketched in the next section.

Music Essential Mechanisms

Likely candidates for brain specialization are those mechanisms that are acquired by all individuals, musicians and nonmusicians alike. This common core of musical abilities is supposed to allow each member of the same culture to appreciate the music of their community, to sing and to dance together. These shared musical abilities can probably be reduced to a few essential processing components that capture the essence of brain specialization for music. From this perspective, there is no need for all musical abilities to have initial specialization. Brain specialization for a few mechanisms that are essential to the normal development of musical skills should suffice.

I am proposing that the two anchorage points of brain specialization for music are the encoding of pitch along musical scales and the ascribing of a regular beat to incoming events. The notion that a special network exists for tonal encoding of pitch is presently compelling, as summarized below. Moreover, the notion that regularity might be fundamental to music appreciation is slowly emerging (e.g., Drake 1998), although its specificity to music is rarely addressed.

Encoding pitch along musical scales is construed as a building block of the musical knowledge that is embedded in one of the music-specific networks of the brain. It involves knowledge and procedures that reflect the highly organized use of pitch in the music of the environment. Generally, music makes use of a limited set of discrete pitches. In a given piece, only a small subset (around seven pitches) is used and is referred to as scale tones. These are not equivalent and are organized around a central tone, called the tonic. Usually, a piece starts and ends on the tonic. For example, "The Star-Spangled Banner" starts with a tonic chord (C-E-G) followed by C, the tonic; then E, the third; then G, the fifth degree; and then back to the tonic C, but played an octave above. These three notes reflect a hierarchy of importance or stability in the key of C major, with the fifth scale tone (G) and the third scale tone (E) being more closely related to the tonic (C) than the other scale tones (i.e., D, F, A, B). The nonscale tones that do not belong to the key (e.g., C# in the key of C major) are the least related; the latter often sound like "foreign" tones. Listeners are highly sensitive to this hierarchy of pitches, as illustrated in Figure 4. This sensitivity reflects the tonal knowledge that is proposed to be essential to music development and to be subserved by specialized neural networks.

The encoding of pitch variations in music is crucially dependent on tonal functions but also involves other melodic features. However, these other melodic features are not unique to music. For example, pitch contours and intervals are also used in speech prosody, as mentioned earlier. In contrast, tonal encoding of pitch can be considered as the "germ around which a musical faculty could have evolved" (Jackendoff 1987, p 257). In music, pitch variations generate a determinate scale, whereas in human speech the intonation contours do not usually elicit such effects (Balzano 1982). Moreover, perception of tonal pitch may require universal processing mechanisms. These mechanisms are probably related to the exploitation of scale peculiarities. Indeed, most musical scales make use of unequal-spaced pitches and are organized around 5 to 7 focal pitches (Dowling 1982).

There is substantial empirical evidence that listeners use tonal regularities in an implicit manner (for a recent review and a computer simulation, see Tillman and others 2000). Moreover, as we have argued elsewhere in detail (Peretz and Morais 1989), translation of pitch into tonal scales fits with the definition of a modular system in Fodor's (1983) sense. Most notably, the tonal system seems to mediate perception of musical pitch in an automatic way and without conscious awareness (Shepard and Jordan 1984) and to operate very early in ontogenetic development (e.g., Trehub and others 1999). Finally, tonal knowledge can be selectively impaired by brain damage (Peretz 1993).

In effect, selective disturbance in tonal interpretation of pitch, as opposed to difficulties from other sources (such as an impairment in short-term memory, contour, or interval processing), can be observed after brain damage (e.g., Peretz 1993). This impairment affects perception of pitch structure so that pitch is no longer encoded in terms of its tonal function but is perceived into a continuum of pitch height (i.e., intervals) and pitch direction (i.e., contour).

One of the tasks that we used to document this selective impairment is a classical paradigm in the psychological literature. It is called the probe-tone task (for a detailed analysis of the task, see Krumhansl 1990). In this paradigm, listeners hear a context sequence followed by a tone that can take any value in the octave (see the musical score at the top of Fig. 4). Their task is to assess the extent to which the final tone constitutes an acceptable conclusion to the melody. Judgments given by children and by adults with no musical training generally correspond to tonal constraints—subjects systematically prefer scale tones, most notably those making up the major triad (e.g., C, E, G in C major). In contrast, the judgments of the brain-damaged patient under study (GL) were determined by pitch direction and pitch proximity, not the tonal status of the pitches. In GL's brain, the lesions had selectively interfered with the normal operation of the tonal module.

As mentioned above, this tonal module is expected to be one origin of brain specialization for music. However, and despite several attempts, brain localization of this network is undetermined (for a recent review, see Peretz 2001a).[1] It is hoped that the increase in temporal and spatial resolution of the new brain imaging techniques should provide some insight into this area.

In summary, there are good reasons to view musical pitch perception as an essential mechanism underlying brain specialization for music. Likewise, perceiving reg-

1. It is worth adding that this search of a neural substrate for a music-specific circuitry should not be limited to the Western culture. Modularity for tonal encoding of pitch is not meant to apply only to the Western tonal system. This specificity refers to some sort of abstract principles that are instantiated in the tonal system but that essentially cut across styles and time. It is an analogous claim, in essence, to the less controversial notion that there are modules devoted to the understanding of speech in general, not just of French in particular.

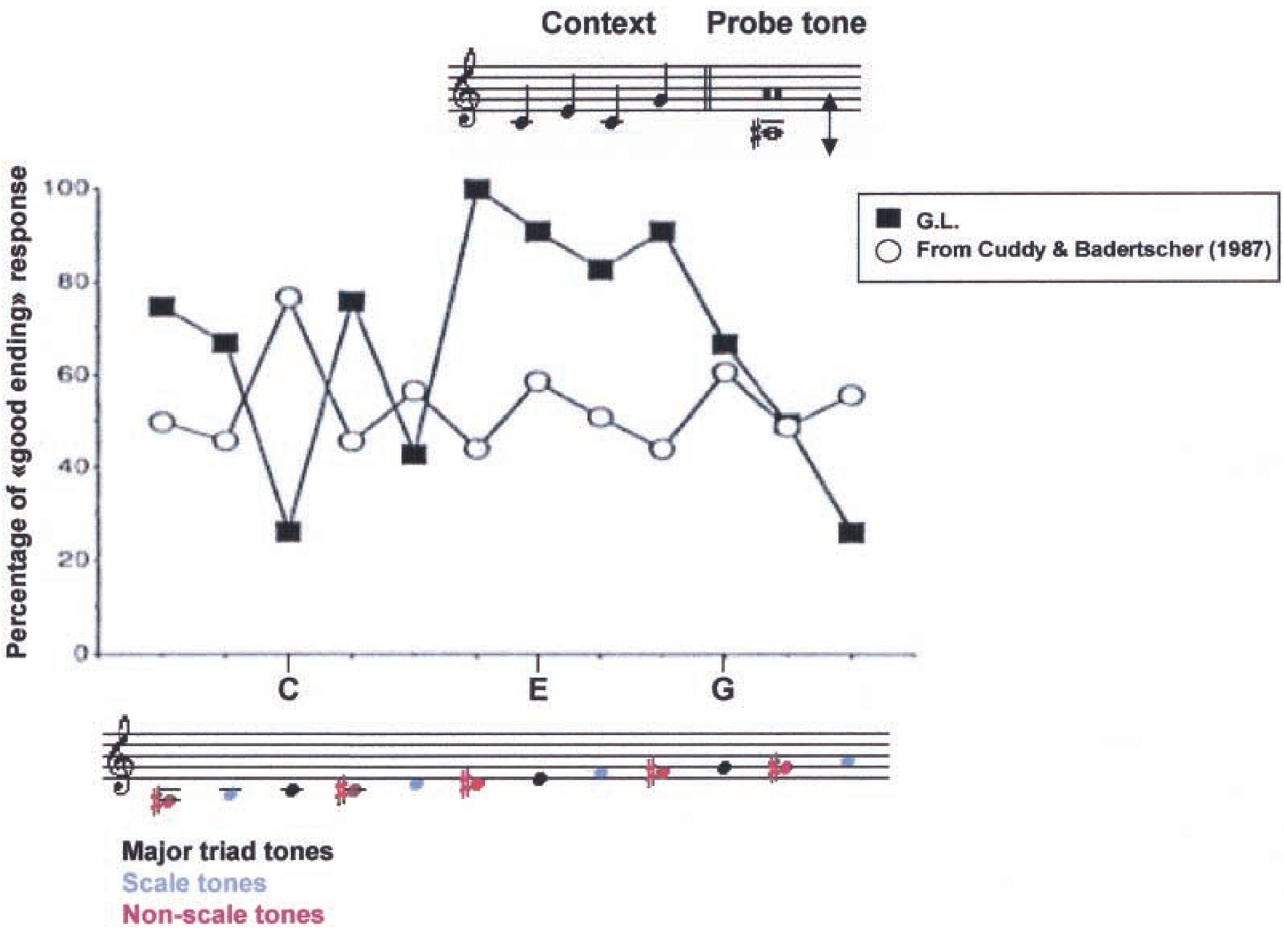

Fig. 4. The probe-tone task used with the brain-damaged patient (GL) is represented with the stimulus in the upper musical staff and GL's judgments of appropriateness of final tone below. The stimulus consists of a context (C, E, C, G, which correspond to the major triad tones in the key of C major) followed by a probe tone that could take any musical pitch value between A# and A. The results obtained under the same conditions by 6-year-old children tested by Cuddy and Badertscher (1987) are included for comparison. Children's judgments preserve tonal constraints—they systematically prefer scale tones (black and blue notes on the musical staff) and, most notably, those making up the major triad (black notes on the same staff). GL, however, proceeded otherwise. As he himself explained, his judgments were based on his impression that singers normally conclude on a note that is close but lower in pitch. In other words, he relied on interval size and contour. This is effectively what emerges from an analysis of his responses. Apart from the most distant tones (A# and B, which in fact had an ambiguous pitch), GL felt that the last tone was appropriate when it descended (i.e., all tones preceding G), more particularly so when it was close in pitch, and rejected those that ascended (i.e., G#, A). His judgments were thus made without regard to the tonal status of the pitches.

ularity in music might be another candidate for music specificity. Both abilities are fundamental to musical activities. Pitches that stand in a tonal relation allow harmonious voice blending and regularity favor motor synchronicity. These two musical features are highly effective at promoting simultaneous singing and dancing (Brown 2000). This type of synchronization may well be specific to music. In language communication, for instance, intelligibility requires individuality (i.e., avoidance of simultaneity).

A Note on Brain Localization

Localization of the music-specific neural networks remains elusive (see also Tramo 2001). The only consensus that has been reached today regarding the localization of music-processing components concerns pitch contour. Both lesion studies and neuroimaging explorations converge in locating the pitch contour extraction mechanism in the superior temporal gyrus and frontal regions on the right side of the brain (e.g., Zatorre and others 1994; for a recent review, see Peretz 2001a). However, this mechanism may not be dealing with music exclusively. The same mechanism may be involved in the monitoring of speech intonation (e.g., Patel and others 1998). Nevertheless, this consensus concerning the processing of pitch contours may explain why the right hemisphere of the brain has been traditionally viewed as the "musical hemisphere."

However, there is increasing evidence that musical functions recruit neural mechanisms in both cerebral hemispheres and also engage multiple brain regions in each hemisphere. Moreover, Patel and Balaban (2000) have recently suggested that music processing may be distinguished by its characteristic dynamic activity and the pattern of brain interactions it engenders rather than by the particular brain regions that respond to it. Thus, brain specialization for music may not only be reflected in the location of the music-specific neural networks, as traditionally construed, but also may lie in the dynamic characteristics of their functioning and interactions. Thus, brain localization of musical functions is a complex issue. Advances in this direction depend not only on the dynamic resolution of neuroimaging techniques but also on the relevance of the fractionation that is operated in musical processing skills.

A Note on Emotions

Discrimination and memorization are not the central reason why people listen to music. Humans are musically inclined because music has emotional appeal. The question, then, is how the evidence reviewed previously on brain specialization relates to emotional responses to music. Surprisingly, we cannot provide a clear answer at this stage because of the scarcity of relevant studies. Humans have been mostly studied as information-processing machines without emotional biases. Part of this situation may be attributed to the widely held belief that emotional responses to music are highly personal and variable, hence precluding scientific examination. This belief appears to be false. A recent study (Peretz and others 1998) shows that emotional appreciation of music is highly consistent across individuals, has immediacy, and is available to the layman without conscious reflection and with little effort. Therefore, emotional appreciation of music fits well with the product of a specialized cortical arrangement.

It remains to be determined to what extent musical emotions are distinct from other kinds of emotions, such as those evoked by vocal sounds, and to what extent musical emotions rely on the operation of specialized mechanisms such as those involved in the tonal encoding of pitch. Provisional answers are reported in Peretz (2001b) and Peretz and others (2001). We propose that the emotional pathway is isolable from the nonemotional analysis of music. However, we do not conceive the emotional pathway as entirely parallel to the rest of the musical system. Rather, we propose that the perceptual analysis that takes place prior to emotional evaluation requires cortical mediation and cuts across judgments and tasks. The study of emotional appreciation of music is a fairly novel research avenue in both cognitive psychology and cognitive neuroscience. Hence, progress in this direction should not take long.

Why Is There Brain Specialization for Music?

Showing brain specialization for music suggests but does not imply that the brain is prewired for music. Music may simply recruit any free neural space in the infant's brain and modify that space to adjust it to its processing needs. These needs may be computationally complex to satisfy and hence require free and plastic neural tissue. This adaptation of the brain to musical pressures might simply be an adjustment to a "pure pleasure technology" (Pinker 1997, p 528) and not a response to a biological force.

However, I am more inclined to endorse the view that brain specialization for music has evolved as a response to the needs of a faculty that fulfills important needs. In my view, music pertains more to biology than to culture because music cannot be reduced to an ephemeral (cultural) product. Music was not invented by a group of individuals. Rather, music exists in all forms of societies. Moreover, music seems to have emerged spontaneously and very early in human evolution (Wallin and others 2000). Thus, not only is music ubiquitous to human societies, but it is also old in evolutionary terms.

The key question, obviously, is why music would have biological foundations. What adaptive function was served by music in ancestral activities to provide its practitioners with a survival advantage in the course of natural selection? There are two main explanations. The initial account was provided by Darwin himself (1871), who proposed that music serves to attract sexual partners. This view has been recently revived by G. Miller (2000), who reminds us that music making is still a young male trait. However, the dominant view of the adaptive value of music lies at the group level rather than at the individual level because music promotes group cohesion. Music is present in all kinds of gatherings—in dancing, religious rituals, ceremonies—thereby strengthening interpersonal bonds and identification with one's group. The initial step for this bonding effect of music could be the mother-infant interactive pattern created through singing and mothereese (which refers to the musical way adults talk to infants), thereby favoring emotional communion. These different adaptive roles attributed to music do not need to be mutually exclusive. As pointed out by Kogan (1994), individuals taking the lead in ceremonies by virtue of their musical and dance prowess can achieve leadership status in the group, a factor that contributes to reproductive success. All these forces may explain why the human brain has evolved so as to accommodate neural networks to deal exclusively with music.

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