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THE AMUSIAS

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It is quite recently that the study of the neural bases of music has become a rich and promising area of research. A key investigation in this field is the study of musical disorders, known as *amusias*. In the present review, we will first describe cases of acquired amusia in the presence or absence of an acquired language disorder. Next, we will present the congenital form of amusia. This will be followed by a description of a recent model of musical processing, including a discussion of the possible lateralization of the 'musical brain'. We will conclude by presenting the existing methods used to study the amusias.

Introduction

While it is obvious how having a language disorder might deeply affect one's life, it is perhaps less obvious to surmise how living with a problem in the musical domain may be difficult. However, music and language share many similar characteristics: both are universal across all cultures, and are defined by structured codes in auditory and motor modalities, as well as in written notation. Moreover, music is sub-served by specific and dedicated neural substrates (Peretz, 2001). In a world without music, one would lose an important affective and social means of communication. Despite the importance of these manifestations, musical disorders, which we refer to as amusias, have not nearly received as much attention as their language counterparts.

Historically speaking, the existence of amusia has been previously documented on several occasions. Bouillaud (1865), Proust (1872), Jellinek (1956) and Botez and Wertheim (1959) were among the first to describe amusic patients. However these studies suffered somewhat from lack of scientific rigor (see Marin & Perry, 1999 for a review). Just as there are multiple forms of aphasia, there exist various forms of amusia. For example, cases of receptive and expressive amusias, alexias, agraphias, impairments in musical memory as well as instrumental apraxias and rhythmic impairments have all been documented. Currently, amusia is a generic term which serves to describe both acquired and congenital disorders of music perception, memory, production, reading and writing of music, which cannot be accounted for by any auditory impairment, or a motor or intellectual deficit (Marin & Perry, 1999).

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The sparse literature on the study of music, as compared to language for instance, can be explained by certain inherent difficulties in this area. First, while it is accepted that most individuals can effectively communicate verbally, read and write, there exists an important variability in the general population in terms of level of musical experience. In an attempt to classify such a musical diversity (Grison, 1972), researchers in the field first concentrated on the study of musical impairments in musicians, while it is now known that non-musicians also possess musical abilities, without any prior musical training (see Tillmann, Bharucha, & Bigand, 2000). With the knowledge that it is possible to be a non-musician with amusia, there has been an increasing interest in the study of amusia. However, there is still no consensus as to the true definition of a 'musician': is an individual only a true musician when he/she has attained a famed status in the world of performance or composition, or should the definition also include the musician that may prefer simply to 'jam'?. The notion of musical expertise seems to be a fundamental factor in the study of music since an important degree of cerebral plasticity has been observed with differing levels of musical experience. For example, several studies have shown that certain brain areas known to be implicated in musical processing are larger in individuals with greater musical experience (Pantev et al., 1998; Schlaug, Jäncke, Huang, Staiger & Steinmetz, 1995; Schneider, Scherg, Dosch, Specht & Gutschalk, 2002; Pascual-Leone, 2001). Despite these issues, it is clear that the study of the amusias is important to understanding the neural bases of music. To this aim, one key avenue is the comparison of music and language.

Music and Language

A fundamental question when comparing music and language is whether music rests on a system originally designed to process language, or whether there exists a specialized system dedicated to music. The study of amusia has previously been limited to the study of aphasic patients (see Marin & Perry, 1999 for a review). In cases where amusia and aphasia are concomitant, the same impairments will most often be seen in both music and speech. For example, a patient that it is alexic in language may also have musical reading difficulties (Kawamura, Midorikawa & Kezuka, 2000). The question arises as to whether the same cerebral network is involved in both processes, or whether they correspond to distinct but adjacent networks. It has been shown that music reading can be selectively impaired (Cappelletti, Waley-Cohen, Butterworth & Kopelman, 2000) or spared (see Assal, 1973; Signoret, Van Eeckhout, Poncet & Castaigne, 1987 for an example in Braille). The presence of a double-dissociation between the reading of written language versus the reading of musical notation suggests that there exists an independent neural network for music reading.

In addition, cases in areas other than reading have been described (see Brust, 2001, for a review), such as cases of aphasia with no amusia (Basso & Capitani, 1985) or cases of amusia with no aphasia (Griffiths et al., 1997; Piccirilli, Sciarma & Luzzi, 2000). In the present chapter, we will pay particular attention to the latter case. Among these types of patients, are two classic ones, Chébaline and IR, each of who have a massive impairment in one of the two systems. Despite a cerebro-vascular accident resulting in aphasia, the Russian composer Chébaline was able to continue to compose highly provocative music (Luria, Tsvetkova & Futer, 1965). In contrast, IR (Peretz, Belleville & Fontaine, 1997) retained the ability to effectively communicate verbally, but lost the ability to recognize or produce musical songs that had once been familiar to her.

Thus, the musical system can be selectively impaired or spared with respect to the verbal language domain. In this case, the difference between the two domains seems to be in the nature, and not the level, of difficulty. If language and music were to lie on the same continuum of difficulty, a cerebral lesion should systematically affect the more complex domain. While this is not the case, it is possible that the two domains are independent at a certain level, but associated at another level. It is therefore essential to compare language and music at similar processing levels in order to determine which processes are dissociated and which are shared.

Songs represent a very important means for comparison between language and music, given that song is comprised of both lyrics and melody. The question arises as to whether songs might be encoded uniquely in memory, and thus that language and music may be processed under a unique code. This idea has motivated rehabilitation therapies of language disorders such as *Melodic Intonation Therapy*, which utilizes melodic and rhythmic exercises to improve speech production (Sparks, Albert & Helm, 1974).

In support of an integrated theory of song lyrics and melody (Serafine, Crowder and Repp, 1984; Serafine, Davidson, Crowder & Repp, 1986), it has been found that normal subjects have difficultly to access melody without the aid of any song lyrics. Such an integration of song lyrics and melody in song memory has also been found in brain-lesioned patients. Samson and Zatorre (1991) evaluated the ability of unilaterally temporally lesioned patients to recognize both song lyrics and song melodies. It was found that recognition of song lyrics was more difficult following a left lobectomy. Moreover, the authors also observed that melodic recognition was dependent on the lyrics with which the melodies were initially learned. These results led the authors to propose that there exist two distinct codes for song memory: a code where song lyrics and music are integrated, and a separate code for song lyrics alone.

Steinke, Cuddy and Jakobson (2000) have equally described a patient, KB, who demonstrates the same pattern of impairments, suggesting that there exists an integrated code in memory for songs. Consequent to a cerebral vascular accident (CVA) to the right hemisphere, KB was unable to recognize instrumental music, while retaining the ability to recognize previously learned song melodies with lyrics. The authors interpreted such a remarkable preservation of songs as the result of the retention of song lyrics in memory, which in turn, would facilitate musical recognition. This result is also consistent with Samson and Zatorre's proposition that there exists a type of memory for songs where lyrics and music are integrated, and another memory store for instrumental music. In this case, KB's problem would have stemmed from an impaired access to musical memory, while access to song memory was preserved.

Recent results from the study of song in aphasic patients provide further support for the idea of an integrated code for song lyrics and melodies (Hébert, Racette, Gagnon & Peretz, 2003; Peretz, Gagnon, Macoir & Hébert, 2004). Both patients had difficulty to produce song lyrics, whether by singing or speaking, however, they had no problem to hum the song melody. In this case, there would exist two separate codes for songs, one for the melody and one for lyrics. The latter code would be selectively impaired in the case of expressive aphasia, and would affect both song and speech.

In summary, the study of songs represents a unique way to compare music and language in both normal listeners and singers. It is unfortunate that such few studies have been undertaken to address these issues. It is important to note that all normal individuals possess the ability to sing. Song is not an exclusive ability to professional singers, and in future, the study of song should be addressed more systematically.

Congenital Amusia

In the previous sections, we have described cases of 'acquired' amusia, that result consequent to a brain lesion. These types of amusias are well known since they were discovered in patients who had undergone treatment through the health care system. The existence of an amusia that is present from birth has recently been termed congenital amusia (Peretz & Hyde, 2003). This type of amusia is not consequent to any cerebral damage and afflicted individuals have normal intelligence and a normal exposure to music. Congenital amusics are unable to recognize or hum familiar melodies, have no sensitivity to dissonance, an ability present in infants (Trainor & Heinmiller, 1998), and have great difficulty to detect wrong notes in melodies (Ayotte, Peretz & Hyde, 2002). This latter difficulty has been observed in a previous study of the British population (Kalmus & Fry, 1980). It has been estimated that about 4% of the population may be afflicted with congenital amusia.

It is possible that the origin of this amusic disorder may stem from a difficulty in the ability to discriminate fine changes in musical pitch (for example, at a semi-tone distance which corresponds to two adjacent notes on a keyboard) or smaller. This would explain why amusics have problems to perceive, and thus memorize, a melody that employs intervals of one semitone. Certain amusics are able to distinguish a question from a statement, which differ in terms of a final pitch change (Ayotte, Peretz & Hyde, 2002). It is important to note that speech employs pitch intervals that are much larger than in music, and thus explains why amusics show a deficit in musical pitch discrimination while sparing speech intonation. However, this pitch deficit is not specific to the musical domain, but rather 'musically-relevant', since music is composed of more subtle pitch variations as compared to speech (Peretz & Hyde, 2003).

Now that we have reviewed both the acquired and congenital forms of amusia, in the next section, we turn to describing a neuro-cognitive model of musical processing. This model presents the various components of musical processing, whereby the failure of one component (or box) or communication between components (an arrow) may result in an impairment in musical processing ability. In the case of a patient, a systematic evaluation will reveal at what point in the model an impairment may lie. In this way, pathologies may be very informative, in that their study enables the decomposition of a complex system into its elemental components (McCloskey, 2001).

A Modular Model of Musical Processing

In order to explain how we recognize a melody, Peretz (1993a) introduced a model where musical perception and memory are represented in a modular fashion. This model was primarily constructed by way of studies on musical recognition, a ubiquitous ability common to both musicians and non-musicians alike. Here we present the most recent version of this model (Peretz & Colheart, 2003), which has become a general model of musical processing.

Following an acoustic input, which refers to basic perceptual components including frequency, temporal duration, intensity and timbre of sound, we access a musical level of processing. This level is comprised of two principle pathways that will activate melodies stored in memory. These are the melodic pathway, which is defined by sequential pitch variations (the 'what' pathway), as well as the temporal pathway (the 'when' pathway). In perception, as well as in song and in reading, melody and rhythm can be selectively impaired, which demonstrates a certain independence (Peretz, 2001). The melodic pathway has a privileged access to the musical lexicon: through this pathway a song can be recognized with greater ease if the melody is played without rhythm, as opposed to the case where only rhythm is heard without melody (Hébert & Peretz, 1997). Moreover, a patient with an impaired melodic pathway is not able to compensate by way of the temporal pathway in order to recognize a melody (Peretz, 1994).

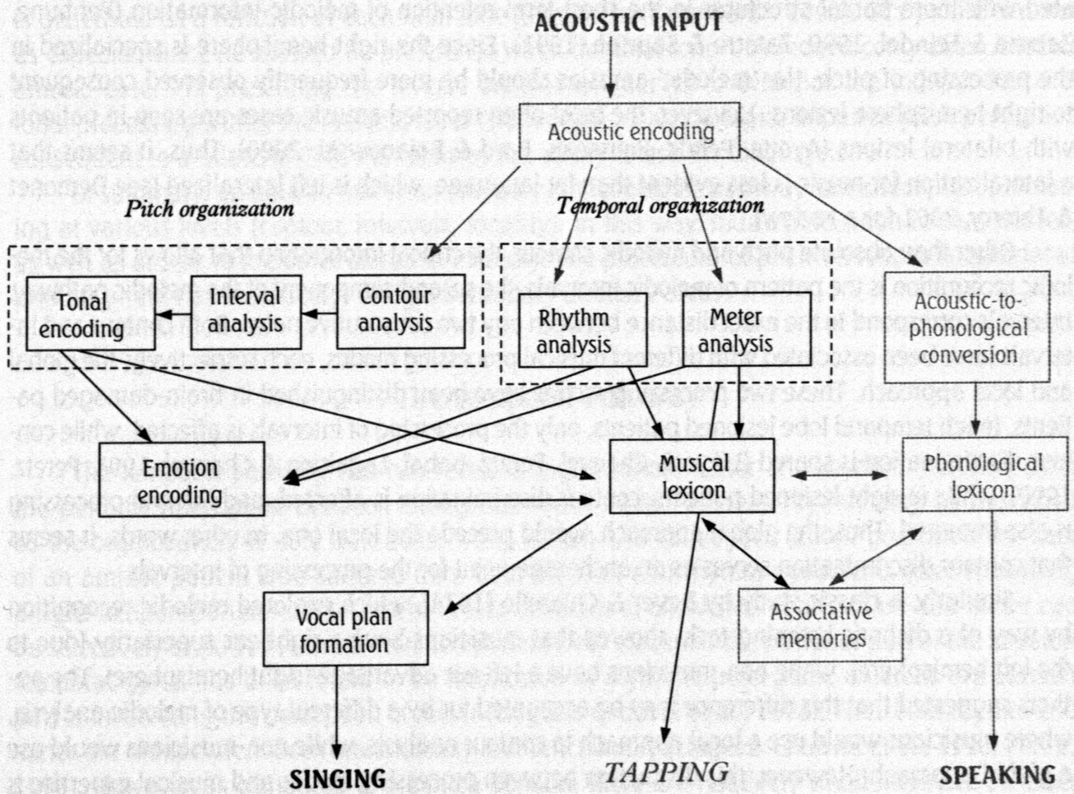

Figure 1. The modular musical processing model of Peretz & Coltheart (2003). An amusia may result consequent to damage to one component (a box) or the flow of information between components (an arrow)

The Melodic Pathway

The melodic pathway is comprised of three components: contour, intervals and tonality. Contour is described as the trajectory of the melodic line, in both ascending and descending directions. This pattern is stored in working memory as basic information, following the novel presentation of a melody (Dowling, 1982). Musical contour is similar to intonation, the melody of language. Several studies of amusic patients have explored to what degree the same process may play a role in music and language. It has been found that contour discrimination of music and intonation (with no verbal component) can both be impaired or spared, which suggests the existence of shared mechanisms between language and music (Nicholson et al., 2003; Patel, Peretz, Tramo & Labrecque, 1998). However, as we have previously seen in the case of congenital amusia, the processing of intonation contour may be spared in the presence of amusia. In this case, the dissociation would result form a mildly severe impairment in acoustic pitch discrimination common to both intonation and music.

Studies of brain-lesioned patients and neuroimaging studies of normals, have illustrated the role of the right superior temporal gyrus in the processing of sequential tonal pitch (Zatorre, 1985; Zatorre & Binder, 2000; Zatorre, Evans & Meyer, 1994). This region seems to be associated with more frontal structures in the short-term retention of melodic information (Penhune, Zatorre & Feindel, 1999; Zatorre & Samson, 1991). Since the right hemisphere is specialized in the processing of pitch, the 'melodic' amusias should be more frequently observed consequent to right hemisphere lesions. However, the most often reported amusic cases are seen in patients with bilateral lesions (Ayotte, Peretz, Rousseau, Bard & Bojanowski, 2000). Thus, it seems that a lateralization for music is less evident than for language, which is left lateralized (see Demonet & Thierry, 2001 for a review).

Other than absolute pitch and melodic contour, the critical information that allows for the melodic recognition is the pattern of melodic intervals, the second component of the melodic pathway. Intervals correspond to the exact distance between any two consecutive notes. Both contour and intervals have been associated with different musical processing modes, each respectively, the global and local approach. These two processing modes have been distinguished in brain-damaged patients. In left temporal lobe lesioned patients, only the processing of intervals is affected, while contour discrimination is spared (Liégeois-Chauvel, Peretz, Babaï, Laguitton & Chauvel, 1998; Peretz, 1990), while in right lesioned patients, contour discrimination is affected, and interval processing is also impaired. Thus, the global approach, would precede the local one. In other words, it seems that contour discrimination serves as an anchorage point for the processing of intervals.

Similarly, a classic study by Bever & Chiarello (1974), which explored melodic recognition by way of a dichotic listening task, showed that musicians have a right ear superiority (due to the left hemisphere), while non-musicians have a left ear advantage (right hemisphere). The authors suggested that this difference may be accounted for by a different type of melodic analysis, where musicians would use a local approach to contour analysis, while non-musicians would use a global approach. However, this distinction between processing modes and musical expertise is not absolute. Musicians are able to employ global contour (Peretz & Babaï, 1992) and non-musicians are able to extract local interval changes (Peretz & Morais, 1987).

The third component of the melodic pathway concerns the encoding of musical intervals by way of Western music 'tonal' rules. In music, pitch variations generate a determinate scale, a pattern of unequal-spaced pitches that are organized around 5 to 7 focal pitches. Scale tones are organized around a central tone, called the tonic, and typically a piece of music starts and ends on the tonic. Among the other scale tones, there is a hierarchy of importance or stability where the non-scale tones are the least related and often sound anomalous. This implicit tonal knowledge allows any given individual to detect when a musician strikes a wrong note for example. Indeed, sensitivity to musical tonality appears very early on in development, since babies have demonstrated preferences for scales with unequal steps, as in the tonal musical system (Trehub, Schellenberg & Kamenetsky, 1999). However, this widespread ability may, be lost or compromised as a consequence of brain damage.

I. Peretz (1993b) presents the case of GL, an amusic patient with an impaired ability to use this type of tonal knowledge, while both the use of contour and intervals as well as the temporal pathway are preserved. GL suffered from amusia consequent to a bilateral rupture of the middle anterior cerebral artery. Contrary to normal control subjects, GL had an impaired ability to detect a wrong note in a melody (Anomalous Pitch Detection), and did not show the typical preference for tonal excerpts versus atonal excerpts. The classic probe-tone method is another way to evaluate sensitivity to tonality. In this task, the participant has to indicate whether the final (probe) tone is congruous or not with the preceding tonal context. Next, a profile based on the context is generated as a function of each final tone judgement (Krumhansl, 1990). GL's profile was not as expected since he showed no preference when the final tone was indeed congruous. Another amusic case, MS presenting the reverse dissociation, serves to evidence the independence of tonal processing within the melodic route (Tramo et al., 1991). Despite impaired pitch perception consequent to a bilateral CVA, MS retained the ability to use the tonal system.

In summary, an amusia due to an anomaly in the melodic pathway can affect pitch processing at various levels (contour, intervals, tonality). In this way, music perception is then limited, as well as access to melodies stored in memory. The processing of pitch variations is associated primarily (but not exclusively) to right secondary auditory areas.

The Temporal Pathway

The temporal pathway has two levels of organization: meter and rhythm. Meter refers to the periodic alternation between strong and weak beats, whereas rhythm may be described as the organization of note durations. While Wilson and colleagues (2002) presented the case of an amusic patient who suffered from both metrical and rhythmic problems after sustaining a right temporoparietal infarct, there is also evidence to show that both rhythm and meter can be selectively impaired in brain-lesioned patients. For example, the posterior part of the superior temporal gyrus has been found to be implicated in rhythmic perception, whereas the anterior part is involved in the perception of meter (Liégeois-Chauvel et al., 1998). Thus both rhythm and meter are independent both anatomically and functionally (Liégeois-Chauvel et al., 1998; Peretz, 1990). However, as compared to the pitch domain, there is a relatively small literature on cases of patients with temporal deficits.

In production, rhythmic tasks often involve the reproduction of rhythmic sequences, while a typical metrical task would involve tapping the beat to different musical styles (e.g. disco, folklore, classical etc.) By way of these types of tasks, cases of dissociations between rhythm and meter have been described (Polk & Kertesz, 1993). Mavlov (1980) described the case of a professional musician who had rhythmic difficulties, where he was unable to recognize or reproduce rhythmic sequences. This type of rhythmic impairment, consequent to a left cerebro-vascular lesion, seems to result in a severe receptive and expressive amusia. Fries & Swihart (1990) described the case of a patient with metrical problems. Consequent to a right hemisphere lesion, this left-handed patient could no longer tap the beat along with melodies, but did retain the ability to reproduce rhythmic sequences.

In summary, impairments along the temporal pathway can selectively affect either rhythm or meter. The impact of these impairments are not necessarily specific to musical processing, but can also affect temporal processing in other modalities (Mavlov, 1980). This view is supported by a recent theory postulating that the left hemisphere would be preferentially sensitive to rapidly changing temporal information, as in speech, whereas the right hemisphere would be specialized for the processing of fine spectral changes as used in music (Zatorre, Belin & Penhune, 2002). The localization would no longer be dependent on the domain, but rather the required type of acoustic processing.

The Musical Lexicon

The melodic and temporal pathways give access to the musical lexicon, which comprises all of the melodies that have been previously heard and allow new representations to be stored in memory. The recognition of a melody is only possible if there is an adequate matching between the abstract representation made by both analysis pathways (with a greater importance on the melodic pathway in our Western musical system) and the representation stored in the musical lexicon. The musical lexicon is not limited to musical recognition. It is possible for the representations stored in the musical lexicon to activate perceptual pathways as well. This is a reverse pathway from recognition, and occurs when we hear a melody 'in our head'. This so called 'musical imagery', activates brain regions similar to those implicated in musical perception (Zatorre, Halpern, Perry, Meyer & Evans, 1996). The musical lexicon also plays a role in production, by activating processes responsible for humming or playing a familiar melody.

According to the model detailed above, an impaired musical recognition system may be due to a deficit in the access to the musical lexicon despite an intact lexicon (aperceptive amusia), or in the event of an actual damaged musical lexicon (associative amusia) as in the famous case of CN (Peretz, 1996). CN showed a selective impairment on tasks requiring the recognition of musical material such as familiar or non-familiar melodies, while she performed as controls in the recognition of non-musical material such as environmental sounds and song lyrics. In sum, the musical lexicon is considered the memory component of the modular model of music processing. Any alteration to this model will compromise the recognition and production (of memory) for familiar music.

Evaluation of the Amusias

Based on the model described above, and with the aim to screen for amusia, a battery of musical tests has been developed, the Montreal Battery of Evaluation of Amusia (Peretz, Champod & Hyde, 2003). The battery involves six tests which correspond to the components in Peretz (1993a) model. Three of these assess the ability to discriminate changes in melody (by pitch contour, scale, and interval size), while one tests rhythmic discrimination (by temporal grouping). Both the melodic and rhythmic tests use a "same-different" discrimination task, with the same set of novel but conventional sounding music. In a metric task, the subject is asked to decide whether a heard melody corresponds to a march (binary meter) or a waltz (ternary meter). The final test is an incidental memory task, where the subject must decide if a melody corresponds to one heard previously or not.

The MBEA has served as a diagnostic test for musical disorders in brain-lesioned patients (Ayotte et al., 2000; Liégeois-Chauvel et al., 1998; Peretz et al., 1997; Peretz, 1994; Steinke et al., 2001) as well as in congenital amusia (Ayotte et al., 2002; Peretz et al., 2002). For more details on the MBEA, it is possible to visit our laboratory website where norms are available (www.fas.umontreal.ca/psy/iperetz.html).

Conclusion

In conclusion, the systematic and relatively recent study of the amusias has revealed that there exists a neural network for music processing that is independent from that of language. As we have documented, this musical processing system is very complex, and is composed of multiple treatment components, each of which can be selectively impaired or spared. In this way, the study of the amusias constitutes one of the richest avenues to better understand the musical brain.

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