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13 The Biological Foundations of Music: Insights from Congenital Amusia

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p0025 When I began to study music perception from a neuropsychological perspective, 35 years ago, the field was in its infancy. Actually, there was barely a field. Music was considered an exquisite art, but a pure invention, an ersatz of human creativity with little bearing on brain function and on how humans acquire (and sometimes lose) sophisticated auditory-vocal skills. Over the years, however, it has become increasingly clear that musical competence is not confined to an elite. Musical abilities are acquired early and spontaneously, as are language abilities. Moreover, as I have argued along with others, musical abilities might well be distinct from language and be subserved by specialized neural networks under the guidance of innate mechanisms. Accordingly, any given individual would be born with the potential to become musically proficient.

p0030 In order to identify this musical potential and to study its neural correlates and specificity for music, I study behavioral anomalies combined with neuroimaging and, more recently, genetic studies. This patient-based approach remains one of the best sources of evidence regarding the functioning of a complex system such as the system associated with musical capacity. The logic is essentially one of reverse engineering. That is, the internal workings of a complex system are best understood when the system malfunctions than when it functions smoothly. The study of such cognitive disorders finds benefit in contemporary advances made in (1) cognitive psychology, which provides the concepts, modeling, and experimental designs for behavioral analysis; (2) neuroscience, which allows the monitoring of brain processes in vivo and online with unprecedented precision; and (3) behavioral genetics, which offers unique opportunities to understand the interplay between genes and the environment. The objective of this chapter is to review what has been learned about the neurobiological basis of music through the in-depth study of individuals who were born "amusical."

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s0010 I. Congenital Amusia

p0035 The vast majority of humans are born with the potential to make music. For most persons who are musically illiterate, this musical trait is expressed by avid listening and occasional dancing and singing. Such a musical engagement ultimately gives rise to a sophisticated music processing system that is largely acquired implicitly by experience. However, a minority of individuals never acquire this core musical system, either in part or in total. It has been variously termed note-deafness, tone deafness, tune deafness, dysmelodia, and more recently congenital amusia (Peretz & Hyde, 2003). All of these terms refer to the same condition: A lifelong deficit in melody perception and production that cannot be explained by hearing loss, brain damage, intellectual deficiencies, or lack of music exposure.

p0040 I coined the term *congenital amusia* to acknowledge the possibility that there may exist as many forms of *congenital amusias* as there are forms of *acquired amusias*, which arise as the consequence of accidental brain damage. The term "congenital" means "present from birth"; it defines a likely time period but not the etiology. Recent research has made major progress, however, regarding the etiology of this disorder.

p0045 The main reason for studying congenital amusia is that such disorders offer unique insight into the behavioral, neural and genetic bases of cognitive functions in general, and music cognition, in particular. The framework adopted here closely follows the work conducted on language disorders (e.g., Bishop & Snowling, 2004). It makes a distinction between observed behavior, cognitive processes, neurobiology, and etiology. The framework is that musical abilities result from genes and environmental factors that guide brain development and shape cognitive functions by affecting neural processes, such as migration of neurons, cell death, and connectivity. Accordingly, an anomaly observed at the behavioral level can be traced back to cognitive processes, then to brain processes, and ultimately to genes and environment. As can be seen in Figure 1, anomalous behavior may also influence the environment, such that the effect is somewhat circular. For example, an amusic person may avoid challenging musical situations and, consequently, live in a musically impoverished environment. It is also possible that amusic children seek music training to compensate for their difficulties, such that by adulthood they may no longer appear to have a severe problem. Both situations would have deep influences on brain and cognition. In short, the paths from etiology to cognition via neurobiology are not simple but tractable, as illustrated here with congenital amusia.

s0015 *A. Diagnosis of Congenital Amusia*

p0050 The behavioral signature of the disorder, or its phenotype, depends on how amusia is diagnosed. Most current research on amusia is using the same tool to establish whether an individual is amusic or not. The current tool is the Montreal Battery of Evaluation of Amusia (MBEA; Peretz, Champod, & Hyde, 2003). It involves six

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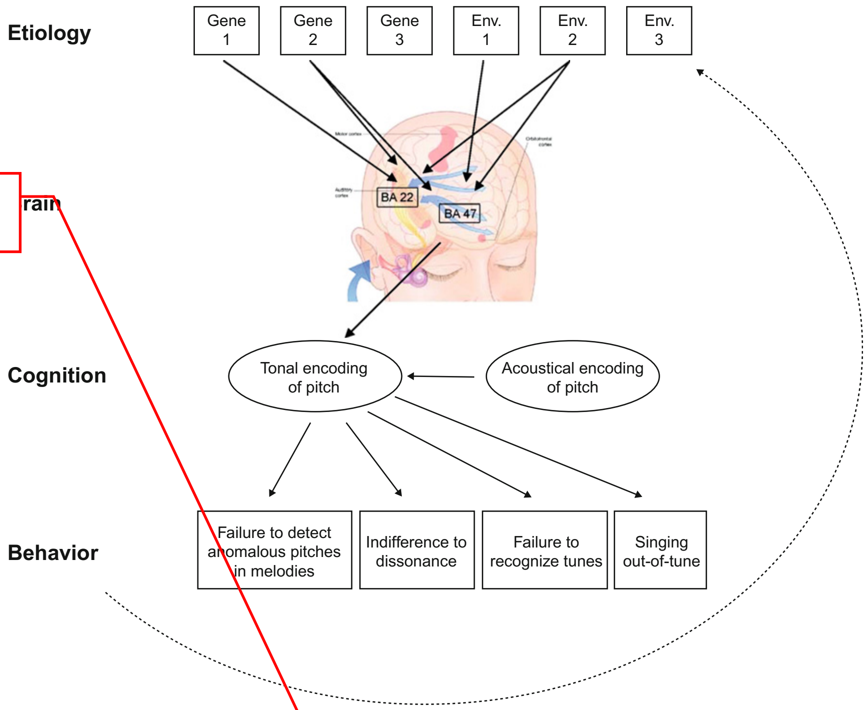

f0010 **Figure 1** Levels of causation for the perceptual form of congenital amusia. The musical deficits observed at the behavioral level can be related to difficulty in interpreting or having conscious access to melodic pitches in terms of the music tonal rules system. This impairment at the cognitive level may arise from a subtle problem at an acoustical level. The musical pitch disorder results from an anomalous connectivity between the auditory associative cortex (BA 22) and the inferior frontal gyrus (BA 47). The brain anomalies should be ultimately traced back to genes, as congenital amusia is hereditary. The dashed line emphasizes that behavior can affect the environment.
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tests (180 stimuli) that assess the different components that are known to be involved in melody processing of Western tonal music, namely contour, keys, intervals, rhythm, meter, and memory. Typically, individuals whose global score (averaged across the six tests) lies two standard deviations below the mean of normal controls are considered as amusic.

p0055 By this statistical criterion, amusia affects 5% of the general population. However, the test that is most diagnostic of amusia is the MBEA scale test, which requires participants to discriminate pairs of melodies that may differ by a single tone that is out-of-key. If we consider the scores obtained on the MBEA scale test alone, as recently indicated by a vast survey of the university population (>1,000 participants; mean age: 24 years), the prevalence of amusia is 3.2% (the percentage of test takers who perform below the cutoff of 22 out of 30 correct responses). If we consider as amusics those participants who also fail to detect an out-of-key note in the same melodies, the prevalence goes down to 1.5% of the population (Provost, 2011). A behavioral failure on the latter test is diagnostic because there is no overlap between the distributions of the scores of amusics and controls (e.g., Ayotte, Peretz, & Hyde, 2002; Hyde & Peretz, 2005). This musical pitch disorder represents a clear-cut phenotype that has served to identify the associated neurogenetic factors, as summarized later, in our laboratory.

p0060 Note that 3.3% of the population fails to detect an offbeat tone in the same melodies. To the extent that this difficulty is confirmed by poor results on the MBEA metric test, it is likely that the individual will display another form of congenital amusia, namely beat deafness (Phillips-Silver, et al., 2011). In this condition, amusia is expressed by a marked difficulty to find and synchronize with the musical beat. As only one such case has been reported to date, I will focus my review on the pitch deafness form of congenital amusia in this chapter.

s0020 1. *Music Specificity*

p0065 One striking aspect of the disorder is that it affects music and not speech. Amusic individuals (amusics hereafter) have normal speech comprehension and production. In contrast, they experience difficulties in recognizing instrumental melodies; they have problems hearing when someone sings out of tune or plays a "wrong" note (typically, a mistuned or out-of-key note, as just mentioned); and the large majority sing out of tune. This dissociation between normal speech and impaired melody is best revealed in the processing of songs. The deficit can be remarkably selective. Amusics have difficulties recognizing hummed melodies from familiar songs. Yet, they can recognize the lyrics that accompany these melodies. In singing, they can recall the lyrics of familiar songs for which they can hardly produce a recognizable tune (Dalla Bella, Giguère, & Peretz, 2009; Tremblay-Champoux, Dalla Bella, Phillips-Silver, Lebrun, & Peretz, 2010).

p0070 Curiously, there is little research on this striking dissociation between music and speech. The only area of comparison studied so far concerns the melody of speech, and more specifically the intonation pattern of speech. In both French and English, intonation is used to convey a question or a statement. Amusics have little difficulty in distinguishing these (e.g., Hutchins, Zarate, Zatorre, & Peretz, 2010; Patel, Wong, Foxton, Lochy, & Peretz, 2008) although they may show mild impairments when these pitch changes are subtle (Hutchins, et al., 2010; Liu, Patel, Fourcin, & Stewart, 2010) or require memory (Patel et al., 2008). Similarly, amusics may experience difficulties when comparing lexical tones taken from Mandarin or Thai words (Tillmann, et al., 2011). Speakers of a tonal language essentially show the same profile, as further described in Section V. Thus, amusics may show a deficit in processing pitch information in speech, but this deficit is generally mild.

p0075 The clear-cut dissociation between music and speech seen in amusia provides a unique opportunity to address other fundamental questions related to the comparison of music and speech. For example, a currently hotly debated issue concerns the sharing (or overlap) of the processing involved in music and speech syntax (e.g., Patel, 2003; Patel et al., 2008). As mentioned, a behavioral failure in the detection and discrimination of melodies by an out-of-key note is diagnostic of the presence of amusia. These tests point to the presence of a "syntactic" difficulty in processing melodies because the out-of-key note is tuned correctly but violates the tonal (syntactic) relationships between notes in the given key of the melody. According to the "Shared Syntactic Resource Integration Hypothesis" of Patel (2003), amusics should exhibit similar difficulties with language syntax. Future research should determine what is the analog situation in language. In my view, as developed in Section II, there is no such analog in speech.

p0080 In general, the clear-cut dissociation between music and speech exhibited by amusics may help us to define the characteristics of music relative to speech. What counts as music or as nonmusical is not trivial (e.g., Deutsch, Henthorn, & Lapidis, 2011). For example, rap music may be heard as speech, and highly dissonant music as noise. Conversely, some speech streams, such as the typical auction speech, may not be considered as musical, and yet this form of chanting might be processed as music. Such ambiguous signals are not problematic for the auditory system, which does not need to decide which part of the auditory pattern is sent to music processors and which part to the language system. All information in the auditory input, including the text and the melody of an auction chant, would be sent to all music and language processors. The intervention of music- or language-specific components is determined by the aspect of the input for which the processing component is specialized. Thus, by studying the way amusics process different forms of music and speech, we may get insight into which aspect are essential and specific to music.

s0025 II. Pitch is Special

p0085 One critical component, if absent or poorly developed, can in principle account for all the manifestations of music specificity that we have seen so far. As mentioned, every individual who has congenital amusia fails to notice an out-of-key note that is inserted in a highly tonal melody. This difficulty in detecting pitch-related changes extends to congenital amusics' inability to perceive dissonance (Ayotte et al., 2002; Cousineau, McDermott, & Peretz, 2011). As I have argued elsewhere (e.g., Peretz, 2006), this critical component is *tonal encoding of pitch*.

p0090 Tonal encoding of pitch is the prime candidate as it appears unique to music. Pitch variations generate a determinate scale in music but not in speech intonation contours. Furthermore, the use of fixed and discrete pitches that are mapped onto musical scales are nearly universal (Dowling & Harwood, 1986). The pitch sets used in a given musical culture remain intact from generation to generation, even in the absence of acoustic instruments or notation. The vocal play of 6- to 12-month-olds that leads to singing is distinguishable from the vocal play associated with incipient speech, both in its use of stable pitch levels on vowels and in its rhythmic organization in terms of a regular beat pattern (Dowling, 1984, 1999, p. 611; Dowling & Harwood, 1986, p. 147). This finite pitch set enables the generation of an infinite number of musical structures. The eight notes of a diatonic scale can be ordered in 40,320 different ways, considering note successions without repetition. If notes are a repeat, the set expands astronomically, even without the use of concurrent notes in the form of chords. Thus, factors related to the discriminability and learnability of fixed and discrete pitches may constrain these choices. These factors may well be innate (J. Dowling, 2005, personal communication).

p0095 Learning may be guided by innate mechanisms but does not necessarily require special-purpose mechanisms. Learning may use general principles, by extracting, for example, statistical regularities in the environment. This possibility has been considered for the acquisition of tonal knowledge (resulting from tonal encoding of pitch; Krumhansl, 1990; Tillmann, Bharucha, & Bigand, 2000). Although *tonal encoding of pitch* is music specific, it may be built on "listeners' sensitivity to pitch distribution, [which is] an instance of general perceptual strategies to exploit regularities in the physical world" (Oram & Cuddy, 1995, p. 144). Thus, the input and output of the statistical computation may be domain specific while the learning mechanism is not (Saffran & Thiessen, 2007). Because amusics can learn novel syllabic structure on the basis of statistical regularities but not novel pitch motifs built along the same principle (Peretz, Saffran, Schön, & Gosselin, 2012, the general learning processes are probably not at fault. The most likely origin of the amusic pitch deficit lies at the level of the input code.

p0100 The input code is probably too coarse in congenital amusia. As demonstrated in independent samples, amusic individuals are impaired in detecting pitch directions (Foxton, Dean, Gee, Peretz, & Griffiths, 2004; Liu et al., 2010; Williamson & Stewart, 2010) and pitch deviations that are smaller than two semitones in tone sequences (Hyde & Peretz, 2004) as well as in tone pairs (Peretz et al., 2002). Given that amusic individuals are probably born with such an elemental deficit (normal infants' pitch acuity is on the order of half a semitone), they may have developed a poor structure of musical keys. They may lack the sophisticated knowledge that every normally developing individual implicitly builds on scales. Support for this tight relation between fine-grained pitch discrimination and musical abilities can be found in the strong correlation observed in the student population between pitch acuity and the melodic tests of the MBEA, the same tests that serve as screening tools for the presence of amusia (Peretz, Nguyen, & Cummings, 2011). Thus, a perceptual system that is unable to detect small pitch changes is bound to miss an essential part of musical structure (Peretz & Hyde, 2003).

p0105 Similarly, deficient pitch perception typically leads to poor vocal production of pitch in isolated tones (Hutchins et al., 2010), tone pairs (Loui, Guenther, Mathys, & Schlaug, 2008) and familiar tunes (Dalla Bella et al., 2009; Tremblay-Champoux et al., 2010). However, amusics may reproduce pitch direction better than they can perceive it (Loui et al., 2008). There are even rare persons with amusia who can sing a familiar song in tune, as matched controls do (Dalla Bella et al., 2009; Tremblay-Champoux et al., 2010). These dissociations between the pitch mechanisms that support perception and production suggest that perception and action can be "decoupled." That is, perception and production may not rely on common representations of pitch. Alternatively, pitch perception and pitch production may rely on the same codes but differ in access to consciousness. Making pitch-based information conscious would require additional computations that are impaired in amusia. We will return to this point in the next section, as neuroimaging data point to a similar dissociation between perception and awareness.

s0030 III. Right Frontotemporal Connectivity is Key

p0110 On gross inspection, amusic brains do not have any detectable neurological abnormality. Neural anomalies are detected only when series of amusic brains are considered in fine-grained automated analyses of magnetic resonance images. Compared with controls, amusic brains have less white matter in the right inferior frontal gyrus (IFG; BA 47) whereas they have thicker cortex in the same right inferior frontal area and the right auditory area (BA 22; Hyde et al., 2007). Decreases in gray matter in the same two regions on the left side of the brain have been uncovered in another amusic sample (Mandell, Schulze, & Schlaug, 2007). These gray matter differences suggest the presence of cortical malformations in the amusic brain that may have compromised the normal development of frontotemporal pathways, particularly on the right side of the brain. Supporting evidence has recently been provided by a diffusion tensor imaging study, showing that amusic brains have an abnormal reduction of fiber connectivity along the right arcuate fasciculus—a fiber tract that connects the auditory and inferior frontal cortices (Loui, Alsop, & Schlaug, 2009). These anatomical anomalies in the amusic brain are related to their behavioral deficits on pitch-based musically relevant tasks (Hyde et al., 2007; Hyde, Zatorre, Griffiths, Lerch, & Peretz, 2006; Loui et al., 2009; Mandell et al., 2007).

p0115 These anatomical measurements are supported and further informed by functional investigations. Using electrical brain potentials (event-related potentials, or ERPs) in amusics while they monitor five-tone sequences for the presence of a pitch change, we found that the amusic brain did not detect pitch deviances smaller than one semitone, whereas the normal controls did so reliably. In contrast, the amusic brain ''overreacted'' to large pitch changes by eliciting an N2 (that was not present in control brains) and a P3 that was almost twice as large as that observed in controls' brains. This altered pattern of electrical activity did not seem to arise from an anomalous functioning of the auditory cortex because the N1 component appeared to be normal. Rather, the enhanced N2-P3 complex in amusic brains might reflect difficulties that occur in later stages of processing along the auditory pathway that involves frontal regions because it seems to be related to the attentional demands of the task.

p0120 Attentional requirements (or awareness) seem to play a key role in the behavioral manifestation of congenital amusia. Using the same method of ERPs, we showed that the amusic brain can track quarter-tone (50-cent) ~~pitch differences in melodies~~ and eighth-tone (25-cent) pitch ~~differences~~, as evidenced by an early right-lateralized negative brain response. The early negativity, or mismatch negativity (MMN), was obtained while participants either ignored the sounds (Moreau, Jolicoeur, & Peretz, 2009) or failed to detect the pitch change at a behavioral (conscious) level (Peretz, Brattico, Jarvenpaa, & Tervaniemi, 2009). These findings were replicated when amusic persons were scanned while passively listening to pure-tone melody-like patterns in which the successive tones differed in small steps from zero to two semitones (Hyde, Zatorre, & Peretz, 2011). Both amusic and control participants showed a positive linear blood oxygenation level−dependent (BOLD) response as a function of increasing pitch distance (including 25 and 50 cents) in bilateral auditory cortices (on the border of the planum temporale and lateral Heschl giri).

p0125 The relatively normal functioning of the auditory cortical responses to pitch changes in amusia suggests that the principal functional abnormality lies outside the auditory cortex, with the evidence pointing instead to the frontal cortex. In the functional magnetic resonance imaging (fMRI) study, we observed an abnormal response in the pars orbitalis of the right IFG (BA 47/11). Whereas the control participants had a slight increased BOLD activation in the right IFG, the amusic participants showed a decreased BOLD activation in the same area. Second, the functional connectivity analyses revealed that the auditory cortex was functionally related to the right IFG in the normal brain but showed decreased functional connectivity in the amusic brain. These findings indicate an abnormal propagation of sequential pitch information between the auditory cortex and the right inferior frontal cortex in the amusic brain.

p0130 The abnormal decrease of activity in the right IFG in amusic brains may be related to a dysfunction in the conscious, attentive monitoring of pitch sequences. Support for this idea comes from findings implicating the IFG in tasks requiring the conscious detection of musical key violations in normal subjects (Maess, Koelsch, Gunter, & Friederici, 2001; Tillmann, Janata, & Bharucha, 2003). The amusic data in turn suggest that tonal encoding of pitch plays a critical role in making melodic pitch information accessible to consciousness. The right IFG is also involved in the maintenance of pitch in working memory (Zatorre, Bouffard, & Belin, 2004). This is also a likely origin of the amusic disorder because working memory is by definition a conscious system (Baddeley, 2003), and working memory for pitch is severely impaired in amusics (Gosselin, Jolicoeur, & Peretz, 2009; Tillmann, Schulze, & Foxton, 2009; Williamson & Stewart, 2010). Future research should be focused on determining which set of mechanisms critically contributes to the expression of amusia.

p0135 To summarize, current research suggests that the amusic brain is equipped with the essential neural circuitry to process fine-grained pitch differences in melodies. What distinguishes the amusic from the normal brain is a decreased functional connectivity between the auditory and inferior frontal cortices. By inference, the results point to the integrity of a right frontotemporal pathway for developing normal musical competence.

s0035 IV. Music Genes

p0140 Cortical anomalies provide a crucial link in the understanding of the chain of events through which a genetic mutation may result in a disorder. For instance, we can narrow down the search for the genes that encode frontotemporal fiber tracks. Migration of cortical neurons is coded in the DNA. Genes do not specify behavior or cognitive functions. Genes influence brain development by affecting processes such as proliferation and migration of neurons, programmed cell death, axonal path, and connectivity (Fisher, 2006). Thus, we predict that the genes involved in neural migration and guidance are good candidates for congenital amusia. Furthermore, the expression of these genes in the cortex should mostly affect the right auditory-frontal pathway.

p0145 To identify these genes, we need to examine at least one large family in which the disorder is inherited over several generations. To achieve this goal, we studied 9 large families of unrelated amusic individuals. The results confirm that congenital amusia is expressed by a deficit in processing musical pitch but not musical time, and they also show that the pitch disorder has a hereditary component. In amusic families, 39% of first-degree relatives have the same cognitive disorder, whereas only 3% have it in the control families. The identification of multiplex families with a high relative risk for experiencing a musical pitch deficit enables the mapping of genetic loci for hereditary amusia (Peretz, Cummings, & Dube, 2007). The molecular analysis of the DNA collected in one large family is in progress in Montreal.

p0150 It is worth pointing out that our family segregation study of amusia is consistent with results of a prior study of twins (Drayna, Manichaikul, de Lange, Snieder, & Spector, 2001). In that study, monozygotic twins obtained more similar scores than dizygotic twins did in detecting pitch violations in popular melodies. Genetic model fitting indicated that the influence of shared genes was more important than shared environments, with a heritability of 70% to 80%.

p0155 Nevertheless, congenital amusia is likely influenced by the environment. One important environmental factor that was identified in the family aggregation study is musical experience during childhood. Music processing, as with most complex cognitive systems, owes its ultimate functional properties both to the genetic prewiring and to experience-based plasticity.

s0040 V. Limited Plasticity

p0160 Which environmental factors can aggravate amusia, or compensate for it, in the context of genetic vulnerability is presently unknown. In our family aggregation study, we noted a remarkable difference in music experience across generations. Our amusic pool of participants is less musical than their offspring. Most offspring had music lessons during childhood and were still playing at the time of testing. This considerable music experience may explain the lower incidence of detectable amusia in the younger generation. Thus, early and continuous music practice may compensate for predispositions of congenital amusia.

p0165 The music environment has changed drastically in recent years with the advent of digital media. This raises fundamental questions about the potential benefit of regular music listening to auditory brain mechanisms and attention. One recent suggestion is that listening to music daily can change brain activity and cognitive recovery after a stroke (Särkämö, et al., 2008, 2010). Similarly, learning to play a musical instrument changes both brain anatomy (Hyde et al., 2009) and brain activity (e.g., Münte, Altenmüller, & Jäncke, 2002). Regular music exposure may mediate at least in part these cortical plasticity effects. Thus, we were interested to examine whether the profile of amusia in the young generation whose brain is most plastic may be shaped differently by being constantly exposed to music.

p0170 The recent discovery of a case of congenital amusia in a 10-year-old child suggests that congenital amusia can be observed in the "i-pod generation" (Lebrun, Moreau, McNally-Gagnon, Mignault-Goulet, & Peretz, 2012). However, amusic individuals may avoid musical stimulation. Such a form of musical deprivation may aggravate their musical handicap. Thus, we tested amusic teenagers before and after they had listened to music on a daily basis for 4 weeks. We found essentially the same profile of amusia as observed in older adults in this young generation. Daily exposure to music did not affect this profile. After treatment, the amusic teenagers remained very poor at detecting pitch anomalies in melodies and at detecting fine-grained pitch deviations (Mignault-Goulet, Moreau, Robitaille, & Peretz, 2012). Thus, regular music listening has limited impact on the expression of amusia.

p0175 The other environmental factor that we have studied so far concerns early exposure to a tone language. Tone languages, such as Cantonese and Mandarin Chinese, use relatively subtle pitch differences to indicate changes in word meaning. As described earlier, we showed that most (Western) amusic persons have difficulties distinguishing words that differ only by tone (Tillmann et al., 2011) and, as a consequence, may experience difficulties in learning a tone language. In contrast, early and extensive exposure to a tonal language may fine-tune pitch discrimination abilities. This attunement that contributes to language may transfer to music, in which it plays an important role. For example, Deutsch, Henthorn, Marvin, and Xu (2006) have proposed that categorical interpretation of pitch in language facilitates the acquisition of musical pitch categories such as absolute pitch. One might surmise, therefore, that the prevalence of amusia in these populations might be extremely low. However, there is little support for such a hypothesis (Jiang, Hamm, Lim, Kirk, & Yang, 2010; Nan, Sun, & Peretz, 2010). Rather, we found that about half of the amusic speakers of Mandarin were impaired at discriminating and identifying Mandarin lexical tones (Nan et al., 2010).

p0180 Thus, speakers of tone languages such as Mandarin may experience musical pitch disorder despite early exposure to speech-relevant pitch contrasts. This raises interesting questions related to the interplay between genes and environment. Indeed, a connection between the type of language (tone language) a population speaks and genes related to brain growth has been highlighted (Dediu & Ladd, 2007). Our results with amusic speakers of Mandarin suggest that perhaps the same genes are involved in both tone language and musical pitch processing. It would be interesting to examine whether these genetic variations contribute to variations in both the acquisition of a tone language and the prevalence of congenital amusia.

s0045 VI. Conclusions

p0185 Congenital amusia can offer special insight into the behavioral, neural, and genetic bases of musical abilities because these disorders provide a natural experiment, a rare chance to examine how a selective cognitive deficit emerges, tracing the causal links between genes, environment, brain, and behavior. In this perspective, music disorders are as interesting as language disorders because both types of disorder will provide unique and complementary answers to fundamental questions of innateness and modularity, such as: How can genetic abnormalities lead to domain-specific disorders? Such questions can be answered only by studying the full complexity of the relations from cognition to brain to gene and vice versa. From a clinical point of view, study of the environmental factors that contribute to the emergence of amusia and that can counteract its full expression is very important because such studies will guide the nature of the interventions. Such clinical impact is not limited to musical abilities but can be transferred to a large variety of neurological conditions, such as speech recovery in aphasia (Racette, Bard, & Peretz, 2006) and dyslexia (Tallal & Gaab, 2006).

s0050 Acknowledgments

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NON-PRINT ITEM

Abstract

The past decade of research has provided compelling evidence that the ability to engage with music is a fundamental human trait, and its biological basis is increasingly scrutinized. In this endeavor, the detailed study of individuals who have severe musical problems are particularly informative because these deficiencies have neurogenetic underpinnings. Such a musical disorder is termed "congenital amusia," an umbrella term for lifelong musical disabilities that cannot be attributed to mental retardation, deafness, lack of exposure, or brain damage after birth. Congenital amusia provides a natural experiment—a rare chance to examine the biological basis of music by tracing causal links between genes, environment, brain, and behavior. Here, I review the main insights that the study of congenital amusia has provided on the biological foundations of music.

Key Words

amusia, pitch, domain-specificity, neural connectivity, heritability, tone language, development.