

Speak to me, melody

Music's biological roots and its relationships with language under scrutiny

Music, more than any other art form, can raise the human spirit to the heights of joy or plunge it into the depths of sorrow. Yet, the power of music to influence our emotions, regardless of age or cultural background, has left philosophers, scholars and musicians baffled; perhaps unsurprisingly, given the inevitable subjectivity of the phenomenon (Fig 1). In the late twentieth century, biologists finally joined the fray to try to identify and decipher the molecular mechanisms that define music as a creative and cognitive activity. Indeed, music raises a range of challenging biological questions. For example, why is our brain apparently 'hard-wired' for music, for both its perception and creation, despite the apparent absence of any obvious evolutionary benefits? Why do we like some types of music and dislike others, and why does this differ between individuals? Is there a genetic component to musical aptitude and how might it work? Such questions now bring together researchers from diverse fields including genetics, developmental biology, neuroscience and music cognition, in an attempt to divine the intimate nature of music.

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A handful of recent studies have found what could be evidence of a genetic predisposition for musicality. Irma Järvelä and her colleagues at the University of Helsinki, Finland, tested more than 200 members of 15 families for musical aptitude by scoring their ability in auditory temporal structuring—which gives an indication of

whether they 'have a sense of rhythm'—and pitch and time discrimination. The results revealed a substantial heritability of musical traits. "Using molecular genetic studies of 1,113 microsatellite markers in 15 families, we were able to find genetic loci that may contain predisposing genes for musical aptitude," Järvelä said. "Our results show that the identified regions contain genes that affect cell extension and migration during neural development." In particular, their analysis revealed significant evidence of linkage for chromosome 4q22, and further linkage evidence for 8q13–21 (Pulli *et al*, 2008). "Interestingly, an overlapping region previously associated with [the] genetic locus for dyslexia was found on chromosome 18q, raising questions about [the] common evolutionary background of music and language faculties," Järvelä commented.

Järvelä and her team also studied several candidate genes associated with musical aptitude, social bonding and cognitive functions in a larger family data set that included professional musicians and active amateurs (Ukkola *et al*, 2009). "We hypothesized that humans are social animals that need each other and here music is a tool for social communication between individuals," Järvelä explained. On the basis of participants' own reports of their creative musical abilities—that is, whether they composed, improvised or arranged music—the authors estimated the heritability of musical creativity and correlated this with the results of musical aptitude tests, such as those used in the previous study. The results showed a relatively high heritability for creativity in music, and a link between high scores in musical aptitude tests and creative functions in music—suggesting that composing, improvising and arranging music requires musical aptitudes that seem to have a genetic component. "We found an association [between] arginine vasopressin receptor 1A (*AVPR1A*)

gene variants [and] musical aptitude," Järvelä said, adding that in previous studies, *AVPR1A* and its homologues have been found to be associated with social, emotional and behavioural traits, including pair bonding and parenting. "The results suggest that the neurobiology of music perception and production is related to the pathways affecting intrinsic attachment behaviour," she said. Other recent studies also suggest that polymorphisms in *AVPR1A* might be associated with short-term musical memory (Granot *et al*, 2007), or with creative dance performance (Bachner-Melman *et al*, 2005).

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Another recent study, by Jane Gitschier and her team at the University of California in San Francisco, USA, indicated that absolute pitch—the rare ability to instantaneously recognize and correctly label a note without using a reference pitch for comparison—might also have a genetic component (Theusch *et al*, 2009). On the basis of previous studies that suggested absolute pitch results from an interplay between environmental factors—such as musical training—and genetic ones, Gitschier and her colleagues performed whole-genome linkage analyses of several families with a higher incidence of absolute pitch. Among 45 families of European ancestry, they identified four regions with evidence of linkage, the most significant of them on chromosome 8q24.21. Intriguingly, when the analysis was repeated with 19 families of East Asian ancestry, only one of these four regions, 7q22.3, showed evidence of linkage. "Together, the findings

[...] provide strong evidence that at least one gene promotes the genesis of absolute pitch in individuals of European ancestry and that absolute pitch probably results from genetic factors that vary both within and between different populations," the authors concluded (Theusch *et al*, 2009). Curiously enough, none of the top linkage peaks spotted by Gitschier's team fell near the *AVPR1A* gene, which is on chromosome 12.

A different line of inquiry into the genetics of music is to look at the nature and origin of so-called 'musical disorders'. "Such deficiencies are termed congenital amusia, an umbrella term for lifelong musical disabilities that cannot be attributed to mental retardation, deafness, lack of exposure to music, or brain damage after birth," wrote Isabelle Peretz (Peretz, 2008), co-director of the International Laboratory for Brain, Music and Sound Research at the University of Montréal (QC, Canada). About 4% of the general population have congenital amusia, also known as tone deafness; these people have a lifelong deficit in melody perception and production and cannot, for instance, detect out-of-key notes, even in very simple melodies.

Peretz and her group tested several families of amusic individuals for auditory abilities and found that whereas only 3% of individuals in control families were tone deaf, 39% of first-degree relatives had this disorder in amusic families; moreover, congenital amusia is characterized by a deficit in processing musical pitch rather than musical time (Peretz *et al*, 2007). A few years ago, a study that analysed twins and their ability to detect pitch violations in popular melodies showed that identical twins obtained more similar scores than did dizygotic twins, with heritability estimated to be 70–80% and with no effects from a shared environment (Drayna *et al*, 2001). Together with Peretz's research, this finding seems to support the hypothesis that musical pitch perception in humans has a strong genetic component. "I think that the study of the genetic origins of congenital amusia will inform us about the origins of musicality in general. Much in the same way that the study of congenital speech disorders informed us about *FOXP2* as critically involved in speech disorders," Peretz commented. "As congenital amusia appears to be a pitch-based disorder, it might be a mirror form of disorders that



Fig 1 | The Guidonian hand, a mnemonic device widely in use in the Middle Ages, primarily to instruct vocalists with hymns. Notes of the scale are assigned to the various joints and lines on the hand; a teacher would point to parts of the hand to indicate which notes students were to sing. Its invention is (not universally) attributed to Guido d'Arezzo, a mediaeval music theorist and the inventor of modern musical notation. Image from MS 1087, a sixteenth century Italian vocal manuscript kept in the Jean Gray Hargrove Music Library, University of California, Berkeley, USA. Reproduced with permission.

can inform us about the neurobiological origins of music."

However, unravelling the mysteries of music through genetics does not convince Dale Purves, a neurobiologist at Duke University (Durham, NC, USA). "I think the idea that music will be

understood on the basis of genetics is nonsense," he said. "To take absolute pitch as a relatively simple example—'artistic creativity' is of course vastly more complex—most researchers agree that nearly anyone can develop this talent with enough practise. Most people with absolute pitch whose native language is

non-tonal (like English) are accomplished musicians, and a large percentage of people with no musical training in cultures where a tone language (like Mandarin) is spoken have absolute pitch," he explained. "I very much doubt that there are any identifiable 'genetic roots' for music, although genes are of course involved in the expression of this or any other brain function. The genetics of language is mired in similar controversy and my view—along with many others—is that the controversy mainly reveals a widespread misunderstanding of the developmental biology that ties genotype to phenotype."

...the way we make and appreciate music is apparently rooted in the nature of periodic sounds that our own body creates and that form the basis of speech

Purves himself is trying to understand why and how the appeal of music is embedded in our biology. In a key study published in 2007, he and his colleagues began their research based on the fact that music is created using subgroups of the same 12 notes—the chromatic scale—irrespective of geography and culture (Ross *et al*, 2007). The team recorded and analysed spoken vowels in English and Mandarin—in human speech, the vibration of the vocal cords that occurs during vowel vocalization is responsible for the tonal quality, or periodicity, of speech. Each vowel is characterized by several formants, which are peaks of intensity in the sound spectrum; although the absolute frequency values of formants varies from speaker to speaker, the ratio between the first two formants is characteristic for each pronounced vowel and the basis of vowel identification. The scientists found that the frequency relationships of these formants in vowel sounds in both English and Mandarin specifically represent all 12 intervals of the chromatic scale. Thus, the way we make and appreciate music is apparently rooted in the nature of periodic sounds that our own body creates and that form the basis of speech. "The significance of this work and more recent studies we have done on scale preferences and the different emotional impact of major and minor music is that many aspects of tonal music appear to be based on the spectral characteristics

of speech," Purves commented. "We are exposed to these characteristics on a daily basis, but in contrast to tempo, intensity, timbre and pitch, spectral relationships as such do not enter consciousness. This fact has made it more difficult to recognize that our appreciation of musical tones comes from the biological importance of social communication by vocal means."

Additional comparative studies are generating evidence that challenges the traditional view that music and language are two largely independent neurocognitive systems (Johansson, 2008; Patel 2008). Indeed, although music and language have common features—such as basic sound elements and a syntactic structure—researchers had long believed that they resulted from essentially different processes in the brain. Instead, the newly evolving scenario reveals two overlapping cognitive and neural systems that share brain structures and are more closely related to each other than previously thought. Aniruddh Patel, from the Neurosciences Institute in San Diego (CA, USA), has proposed that, "linguistic and musical syntax share certain syntactic processes—instantiated in overlapping frontal brain areas—that apply over different domain-specific syntactic representations in posterior brain regions" (Patel, 2003). Put another way, although words and their syntactic features in language and chords and their harmonic relations in music are stored in distinct brain networks, the networks that provide the neural resources for the activation of stored syntactic representations overlap.

Other theories have been proposed in recent years—both on the basis of new experimental observations and existing evidence—that attempt to reconcile, or at least to reconnect music and language and to explain the nature of music itself. "According to my theory, music is a super-stimulus for the perception of 'musicality' in normal speech," commented Philip Dorrell (Wellington, New Zealand), who developed a hypothesis, which matches the findings of Purves and others, that music is a form of speech that has retained many traces of its origins from language (Dorrell, 2005). "The perception of musicality is a hidden aspect of speech perception. It is hidden because it acts gradually and in the long-term, to alter the listener's perception of reality, but it does not have any immediate effect on

the perception or understanding of any particular speech utterance," he said. "Music itself can be regarded as an artificially contrived form of speech, contrived so as to have an exaggerated musicality (sufficiently exaggerated that it is no longer so hidden)."

Dorrell is indeed hinting at a crucial question that has generated intense debate: is music related to language in evolutionary terms and if so, how? More specifically, does—or did—our ability to perceive and create music serve any adaptive and/or survival purpose and did this intersect with speech? "There has been discussion about common roots of music and language in human evolution. We think that music is preserved in human evolution as it is a tool to communicate even without words. Music is unique in its ability to evoke a wide spectrum of emotions," Järvelä commented. "Music is social communication between individuals. Darwin proposed that singing is used to attract the opposite sex. Furthermore, lullabies are implied to attach [an] infant to a parent and singing or playing music together [might increase] group cohesion." As such, Järvelä thinks that it is justifiable to hypothesize a link between musical perception and/or creativity in music and the same phenotypic spectrum of human cognitive social skills that include human bonding and altruism, both of which have been reported to be associated with *AVPR1A*.

"Being in-tune could be one force behind sexual selection and being in-time could be a group cohesive force"

"If we can show that music dissociates from language at the brain and genetic level, it constitutes the clearest path to demonstrating a separate faculty of music and perhaps support[s] Steven Mithen's [an archaeologist and anthropologist at the University of Reading, UK] hypothesis that pitch could have preceded rhythm (and speech) in evolution, and that pitch and rhythm could have independent evolutionary forces," Peretz said. "Being in-tune could be one force behind sexual selection and being in-time could be a group cohesive force."

According to Barbro Johansson, a neuroscientist at the Wallenberg Neuroscience Center in Lund, Sweden, the linkage between music and language might also

play a role in the development of the latter during childhood. "From an evolutionary perspective, studies on the early development of language and music abilities in children are particularly interesting and have so far indicated some overlapping and possibly shared neural resources," he said. "Musical training facilitates pitch processing in both music and language, and children with specific language impairment also show impairment in music-syntactic processing."

Given that it requires a higher precision of pitch and rhythm to appreciate music than to understand speech, Dorrell believes that the only reason humans are so good at perceiving pitch is to appreciate music. "[This] strongly suggests that our ability to appreciate music has some biological purpose, since the mechanism of precise pitch perception presumably has a non-trivial implementation cost in terms of brain growth and operation, and wouldn't exist if it didn't have some value. But this doesn't get us any closer to knowing what this purpose is," he said. "The extra precision required for music perception is, however, consistent with the hypothesis that the perception of musicality represents the perception of unintentionally leaked information which the 'sender' is making no effort to send, and even perhaps trying not to send."

Scientists have just begun to scrape the surface of the biological essence of music and its connections with other cognitive domains, such as language or learning. "Interaction between music and language in bilingual children would be another fascinating area of investigation," commented Johansson. "Taking advantage of the unfortunate fact that a large part of the human population is still illiterate, it would be feasible to initiate studies on the effect on the brain of learning to read in different languages and writing systems, and on the possible interactions between local language and music traditions."

In this intellectual and scientific endeavour to understand one of our most emotive forms of expression, the tools of molecular biology—and genetics in particular—will certainly have a role, although it is too early to say how fundamental this might be. Nevertheless, regardless of the contribution of any one discipline, the result should be a deeper comprehension of the mechanisms our brain uses to decode and process sound-driven information.

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doi:10.1038/embor.2009.241

Me, myself and I

The genetics and molecular biology behind self-incompatibility and the avoidance of inbreeding in plants

The emergence of sex was a huge leap for evolution. The development of sexual reproduction meant that random mutations were no longer the only source of genetic variety on which selection could act. By mixing up parental alleles, sex essentially put evolution on afterburners; it creates a rich abundance of new varieties, which are the substrate for the process of natural selection and evolution.

However, sexual reproduction came with a new set of problems. On the one hand, incest must be avoided, as reproduction between closely related individuals leads to the accumulation of detrimental traits owing to the lack of genetic variety; on the other hand, inter-species reproduction creates sterile individuals. Animals have thus evolved a range of molecular and behavioural strategies to cope with incest, while at the same time ensuring that they only reproduce with their own kind.

Plants have faced the somewhat larger challenge of overcoming their lack of mobility and resulting inability to directly select their mates. They have therefore

evolved sexual reproduction that utilizes mobile male gametes—pollen—that must be transmitted to another plant where they fertilize the oocyte, which will develop into a seed (Fig 1). Early plants released their pollen into the air, relying on the wind to carry it away to other plants. But the emergence of flowering plants—angiosperms—refined this process to commandeer insects to transport pollen from one plant to another. Yet, neither strategy solves the problem of incest, as both the wind and insects are likely to carry pollen to a flower from the same plant, or to a very closely related individual.

The emergence of self-incompatibility (SI) to prevent inbreeding and enable outcrossing was therefore a major evolutionary breakthrough for angiosperms, as it allowed them to diversify rapidly and to dominate the surface of the Earth about 150 million years ago. Charles Darwin first described SI mechanisms (McClure, 2009) and appreciated their significance, but it is only recently that the genetic and molecular details behind SI have started to emerge.