

Music, Modularity and the Brain

Peretz & Coltheart 2003

Peretz 2006

Peretz & Zatorre 2005

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- Fodor 1983: *The Modularity of Mind*
- Typical characteristics of mental modules:
 - Rapidity of operation
 - Automaticity
 - Domain specificity
 - Informational encapsulation
 - Neural specificity
 - Innateness
- NH: For Fodor, the sensory systems are modules, plus language.

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- Innateness isn't necessary:
 - Reading
- Fodor: informational encapsulation is necessary.
 - Information processing within a module is immune from influence by the “central system”.
 - A large and slowly operating encyclopedic knowledge system involved in high-level cognitive operations, such as problem solving or belief evaluation.
 - NH: C.f. Daniel Kahneman. 2011 *Thinking Fast and Slow*.
- P&C: Domain specificity is equally necessary.

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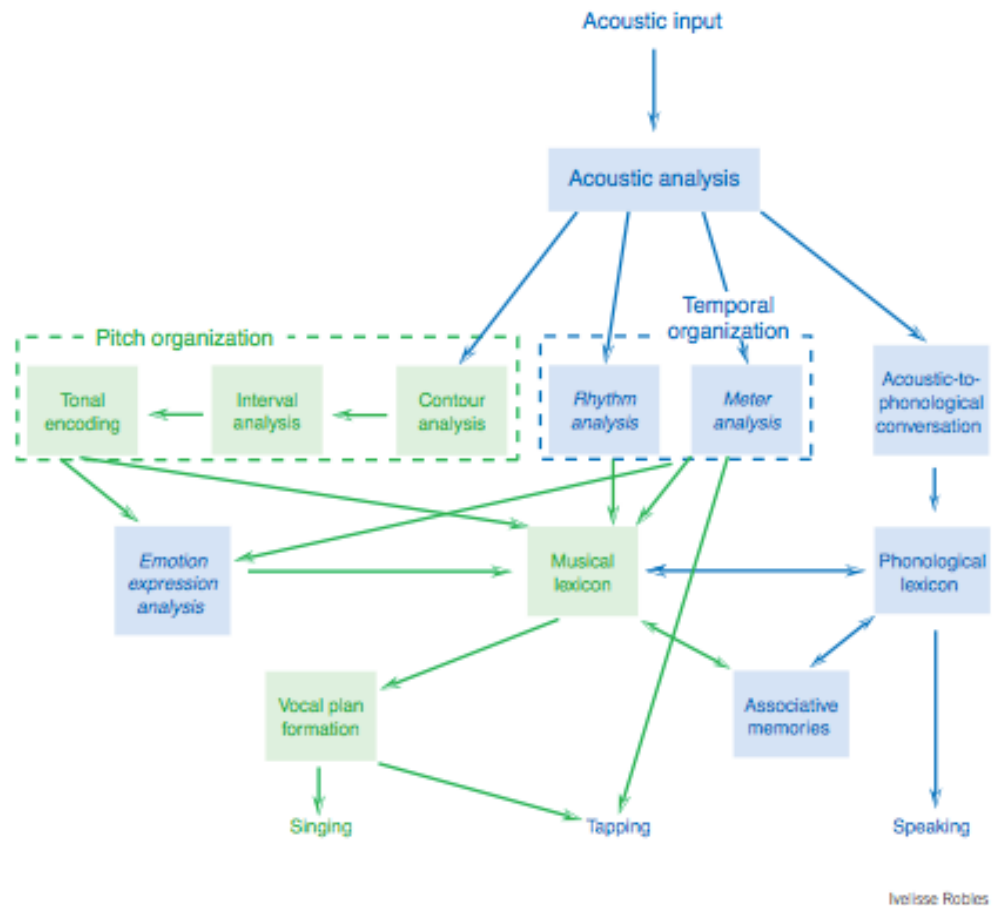
- A module can be composed of smaller processing subsystems, each of which can also be referred to as a module.
- Music may be a module.
- The putative music module may possess the property of neural specificity (neuro-anatomical separability).
 - If so, then brain damage could affect musical abilities while sparing all other aspects of cognition (e.g. auditory processing of language).
 - Such people have been found.
 - Acquired and congenital amusia.
 - Perhaps music is affected in such people because it is a less practiced skill than language, and so it is more vulnerable.
 - But there are also cases of aphasia without amusia.

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- The proposed model shows the functional architecture of music processing that has been derived from case studies of specific music impairments in brain-damaged patients.
- A neurological anomaly can either damage a processing component (box) or interfere with the flow of information (arrow) between components.
- Each component represents a break-down pattern, giving each component the property of neural specificity.
- There are submodules within the system.

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Figure 1 A modular model of music processing. Each box represents a processing component, and arrows represent pathways of information flow or communication between processing components. A neurological anomaly may either damage a processing component (box) or interfere with the flow of information between two boxes. All components whose domains appear to be specific to music are in green; others are in blue. There are three neurally individuated components in *italics*—rhythm analysis, meter analysis and emotion expression analysis—whose specificity to music is currently unknown. They are represented here in blue, but future work may provide evidence for representing them in green.



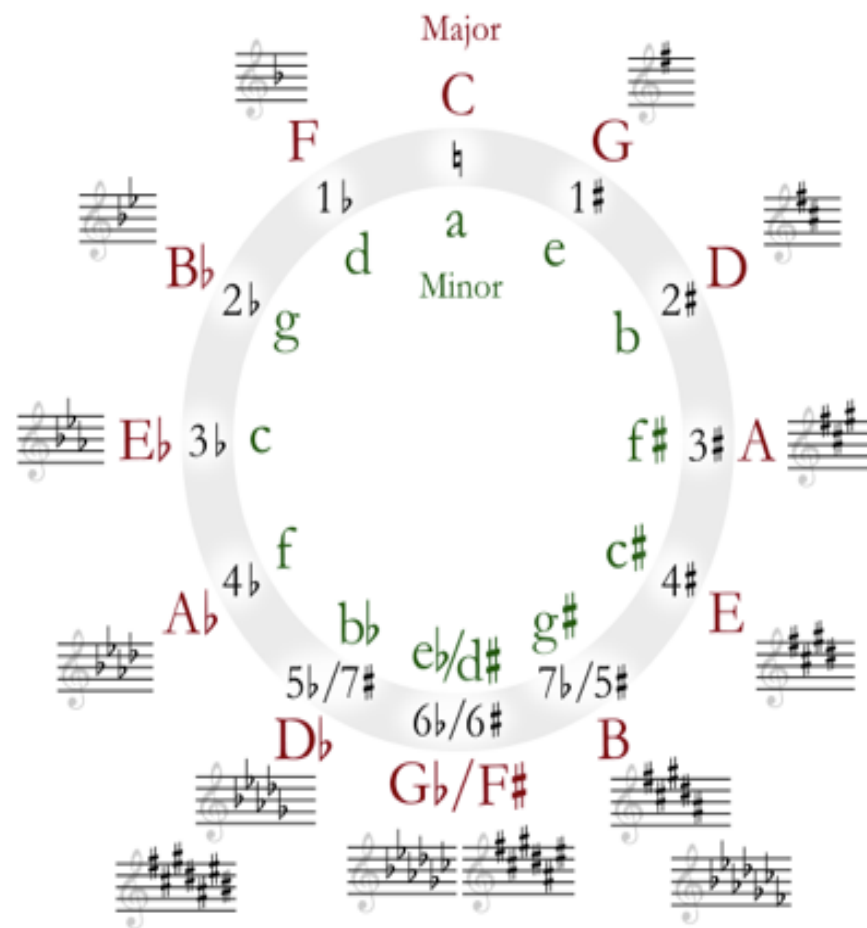
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- Some components are specific to music (tonal encoding of pitch), some are shared (contour analysis may be shared with speech intonation).
- Tonal encoding:
 - Automatic
 - Universal
 - Most musical scales use pitches of unequal spacing, 5-7 focal pitches.
 - Innate (infant studies)
 - Enhanced processing for scales with unequal pitches.
 - Neurally specific:
 - Some brain-damaged patients are no longer able to judge melodic closure properly and have severe problems with pitch memory.
 - Janata et al. 2002: Rostromedial prefrontal cortex

Janata et al. 2002 *Science*

“The cortical topography of tonal structures underlying Western music”

Western tonal music relies on a formal geometric structure that determines distance relationships within a harmonic or tonal space. In functional magnetic resonance imaging experiments, we identified an area in the rostromedial prefrontal cortex that tracks activation in tonal space. Different voxels in this area exhibited selectivity for different keys. Within the same set of consistently activated voxels, the topography of tonality selectivity rearranged itself across scanning sessions. The tonality structure was thus maintained as a dynamic topography in cortical areas known to be at a nexus of cognitive, affective, and mnemonic processing.



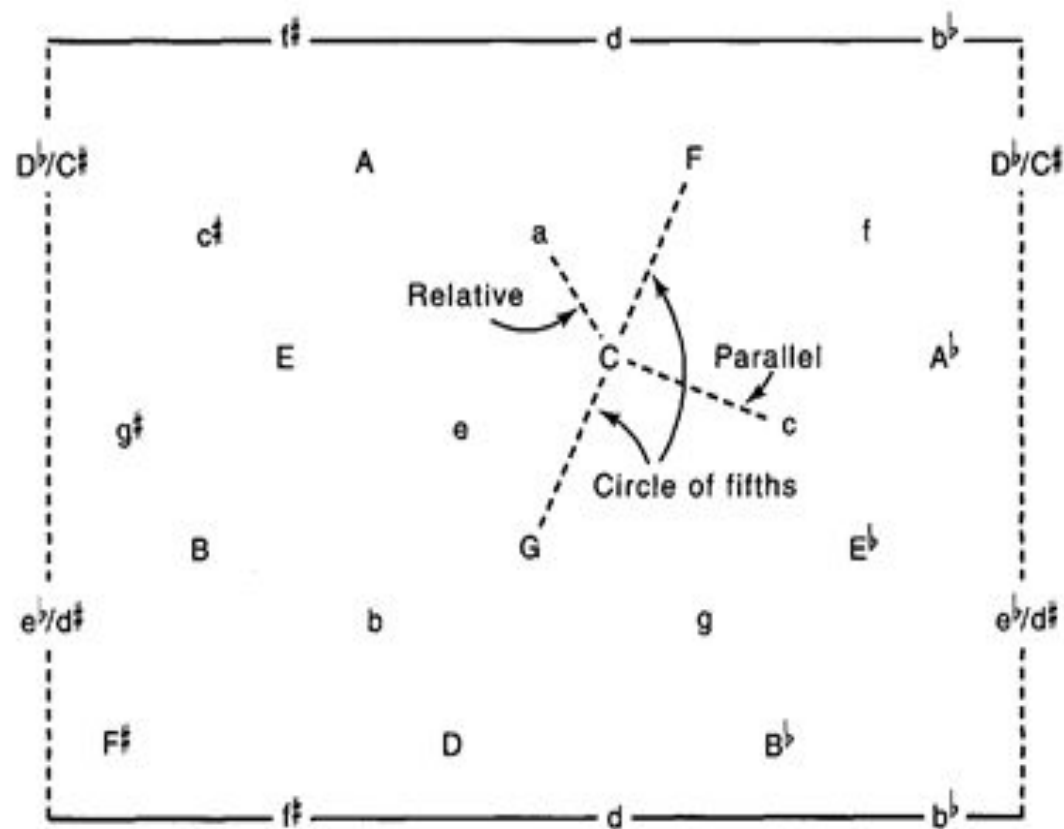


Figure 5.7 A map of psychological distances between musical keys. Major keys are indicated by uppercase letters and minor keys by lowercase letters. Dashed lines extending from the key of C major indicate related keys: two adjacent major keys along the circle of fifths (G and F; cf. Figure 5.6) and two related minor keys (see text for details). Modified from Krumhansl & Kessler, 1982.

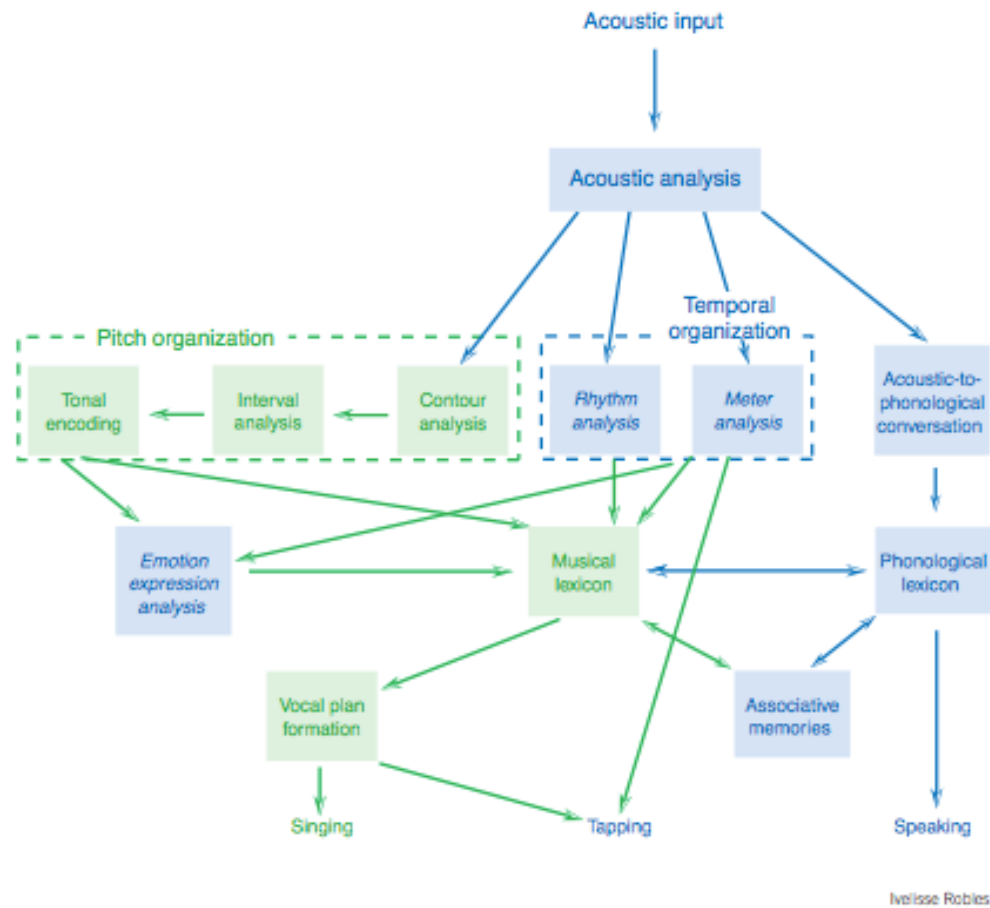
McDermott & Hauser 2005 on Janata et al. 2002.

- “A small patch of cortex is active when subjects listen to music in the key of C; a different patch is active for the key of G; and so forth. Adjacent keys on the circle of fifths seem to be represented by adjacent bits of cortex, providing additional support for the hypothesis that the neural map actually represents the psychological relations between keys. The map is not fixed but rather reorganizes itself from scan to scan and is instantiated in regions of cortex that appear to serve other functions depending on the task.”
- “The prefrontal regions they describe may correspond to the brain regions damaged in patient G.L.” Left temporal and right frontal lobe lesions.

McDermott & Hauser 2005

- G.L.
 - Normal pitch and melodic contour discrimination.
 - Interval information was disrupted but still partially available as measured by melody discrimination tasks.
 - Knowledge of tonality was completely destroyed.
 - Insensitive to scale violations: sour notes.
 - Abnormal key profiles using the probe tone paradigm.
 - No preference for melodies ending on the tonic.

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- The model takes as input any acoustic stimulus that can be attributed to a unique source, not just music.
- Output might be a representation of a song “Happy Birthday”, which then enters music and language processing in parallel.
- Only the relevant modules will respond to relevant aspects of the stimulus.

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- The musical input modules are organized into parallel pitch processing and temporal information processing units.
 - The “rhythm analysis” component deals with the segmentation of the ongoing sequence into temporal groups on the basis of durational values without regard to periodicity.
 - The “metrical analysis” component extracts an underlying temporal regularity of beat, corresponding to regular alternations between strong and weak beats
 - Feeds into a foot tapping output, which can be impaired in congenital amusia.

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- Both the melodic and temporal pathways send their outputs to either the 'musical lexicon' or 'emotion expression analysis' component.
 - The musical lexicon contains representations of all the musical phrases one has been exposed to, and keeps a record of any new musical input.
 - Associative memories are evoked when the task is to name the tune or retrieve a related experience from memory.
 - The emotion expression analysis component takes as input mode (major, minor), and tempo (slow, fast), etc. allowing the listener to recognize and experience emotions evoked by the music.
 - It's not yet clear if this component is specific to music.
 - This feeds into the musical lexicon component, aiding in recognition.

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- Neural systems which are domain-specific and localized do not have to innate.
 - Reading depends critically on phonological awareness and on the visual word form system
 - A left inferior temporal region specifically devoted to the processing of letter strings (Cohen et al. 2000).
- Innateness can be posited for a function or task without invoking specialized or localized mechanisms.
 - Trehub & Hannon 2006
 - Music perception is the product of general mechanisms operating in conjunction with an innate motivational disposition towards music.

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- In contrast, Lerdahl & Jackendoff, Dowling, Peretz & Coltheart have proposed that music processing components, rely on domain specific mechanisms and specialized neural networks.
 - E.g. tonal encoding of pitch.
- Genetic basis for this:
 - Draina et al. 2001
 - 136 identical twins and 148 fraternal twins were required to detect out-of-key notes in popular melodies.
 - Performance was more similar between identical twins.
 - 70-80% heritability.
- Such strong evidence for the biological thesis of music cannot be made as forcefully for other music components.

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- Domain specificity
 - Although “domain specificity” is typically used to refer to a faculty, there is no reason to exclude it from applying to a component.
 - A domain may be as broad as *auditory scene analysis* (which intervenes for all incoming sound) or as specific as *tonal encoding of pitch* (specific to music).
 - Domain-specificity can emerge through learning.
 - The learning may be guided by innate mechanisms.
 - It may also use general principles, e.g. extracting statistical regularities from the environment.
 - The input and output of the statistical computation may be domain-specific while the learning is not.
 - Once acquired, the functioning of the system may be modular.

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- Domain specificity cont.
 - The fact that *auditory scene analysis* and *auditory grouping* both use Gestalt principles such as pitch proximity, does not entail that their functioning is general-purpose and mediated by a single processing system
 - Visual and auditory scene analysis both obey Gestalt principles.
 - The input codes may transform general-purpose mechanisms into highly specialized ones.
 - Modularization is efficient
 - To what extent does music processing rely on dedicated mechanisms?

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- Domain specificity cont.
 - Is only the tonality system dedicated to music?
 - Pinker 1997: the other components of music are parasitic on e.g. the language module.
 - But autistic individuals are more apt in music than in other domains, including language (Henton et al. 1998), and there are tone deaf individuals who are normal in language.
 - There are also cases of acquired amusia.
 - Double dissociations between music and language are convincing evidence for modularity.
 - Although double dissociations can be simulated in an artificial network that is built on a unitary system (Plaut 1995).
 - An impairment in tonal encoding of pitch may arise as a consequence of a lower-level deficiency, involving fine-grained pitch analysis or pitch direction extraction.
 - Rhythm disorders can occur independently from pitch disorders, but music specificity here is not yet known.

Table 1

Case reports of selective impairment and selective sparing in the auditory recognition of words, tunes, and other meaningful sounds (left panel) and in the production of notes, words, and intonation (right panel)

Reports	Input domains			Reports	Output domains			
	Tunes	Words	Other familiar sounds		Singing		Speaking	
					Notes	Words	Intonation	Words
Peretz et al. (1994) C.N. and G.L.	—	+	+	C.N. and G.L.	—	+	(+)	+
Peretz et al. (1997). I.R.	—	+	+	I.R.	—	+	(+)	+
Griffiths et al. (1997). H.V.	—	+	+	Schön et al. (2004). 1 case	—	+	(+)	+
Wilson and Pressing (1999). H.J.	—	+	+	Murayama et al. (2004) 1 case	—	+	(+)	+
Piccirilli et al. (2000). 1 case	—	+	+					
Steinke et al. (2001). K.B.	—	+	+					
Ayotte et al. (2002). 11 cases of congenital amusia	—	+	+	11 cases of congenital amusia	—	+	(+)	+
Sato et al. (2005). 1 case	—	+	+					
Laignel-Lavastine and Alajouanine (1921). 1 case	+	—	+	Hébert et al. (2003) CC	+	—		—
Godefroy et al. (1995). 1 case, during recovery	+	—	+	Peretz et al. (2004) GD	+	—		—
Mendez (2001). N.S.	+	—	+	Racette and Peretz (in press) 8 cases	+	—		—
Metz-Lutz and Dahl (1984). G.L.	+	—	—					
Takahashi et al. (1992). 1 case	+	—	—					
Yaqub et al. (1988). 1 case	+	—	—					

+, preserved; –, impaired; (+), preserved but not formally tested.

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- Innateness
 - The FOXP2 gene
 - Half the KE family suffer from a speech and language disorder (Hurst et al 1990).
 - Three generations: half the children of affected individuals have the disorder and none of the children of unaffected members do.
 - A chance discovery of another individual with the disorder narrows it down to a mutation of a specific gene, FOXP2. (Lai et al 2001)
 - The disorder also affects oral movements.
 - Alcock et al 2000 tested nine affected members of the KE family and showed they were impaired in rhythm production and perception but not in melody processing.
 - Perhaps a deficit in sequential temporal processing.

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- Innateness cont.
 - Congenital amusia, which often involves pitch but not rhythm deficits, also runs in families.
 - Thus, the available data are compatible with the idea that there are two innate factors guiding the acquisition of the musical capacity, with one related to temporal sequencing and the other, pitch sequencing.

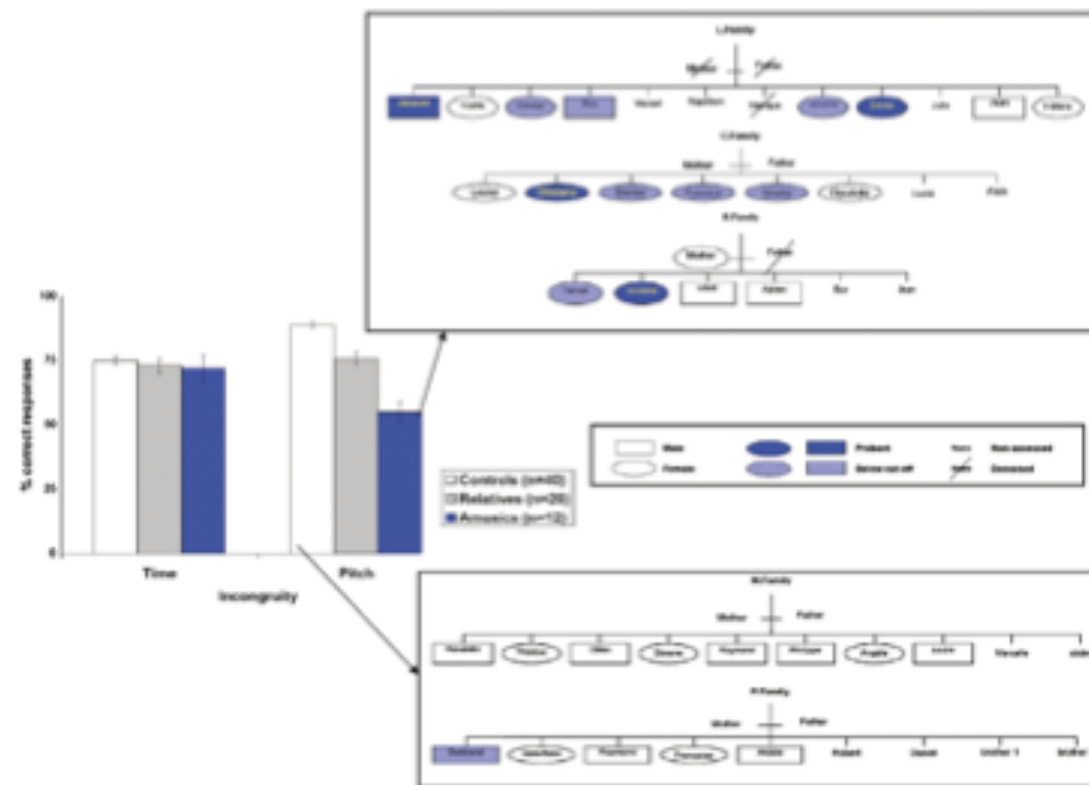


Fig. 2. Amusics and their first degree relatives were significantly impaired in the detection of a pitch anomaly in melodies as compared to their matched controls (see left graph). In contrast, all subjects performed similarly in the detection of time delays inserted in the same melodies. This pattern is supported by a significant interaction between Group and Condition ($F(2,69) = 20.45, p < .001$). As can be seen in the pedigree of three representative amusic (proband) families (top) and two representative control families (bottom), the presence of a musical pitch disorder runs in families; a pitch deficit corresponds to a score that lies 2 *SD* below the mean of the control group (below cut-off). Moreover, not all family members are affected, discarding an environmental factor as a plausible cause.

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- Innateness cont.
 - Infants are predisposed to appreciate music
 - 6-9 month infants process consonant intervals better than dissonant ones and exhibit enhanced sensitivity to musical scales with unequal steps (Trehub et al. 1999).
 - Infants prefer music that is subject to an isochronous temporal pulse (Demany et al. 1977).
 - However, precocious abilities could be the result of formidable plasticity in the infant brain.
 - The human brain is thought to be born prematurely with little pre-wiring.
 - Simple exposure to music may create connections and networks.
 - Caregivers sing slowly, at a high pitch level, with exaggerated rhythm and in an emotionally engaging manner.
 - Infants prefer infant-directed singing to infant-directed speech.

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- Innateness cont.
 - Infants are predisposed to appreciate music
 - Trehub & Hannon 2006: the propensity to listen to music may be innate.
 - Such a “music detector” system could be coupled with a general-purpose system that acquires musical rules through learning or experience.
 - Modularization might emerge later as the result of fine-tuning such mechanisms.
 - But such a learning approach can’t readily account for the preference for consonant intervals: octaves and perfect fifths; or for unequal scale steps.

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- Brain localization
 - A domain-specific processor or module need not be confined to a focal neural network as opposed to a vastly distributed neural network.
 - There is no clear correspondence in neural terms for language modules (Hickok & Poeppel 2004).
 - A music module could be intermingled with networks devoted to the processing of other complex patterns, such as speech intonation.
 - But brain-damage shows some neuroanatomical isolability of music modules.
 - Music processing recruits a vast network of regions located in both hemispheres, with an overall right-sided asymmetry for pitch-based processing.

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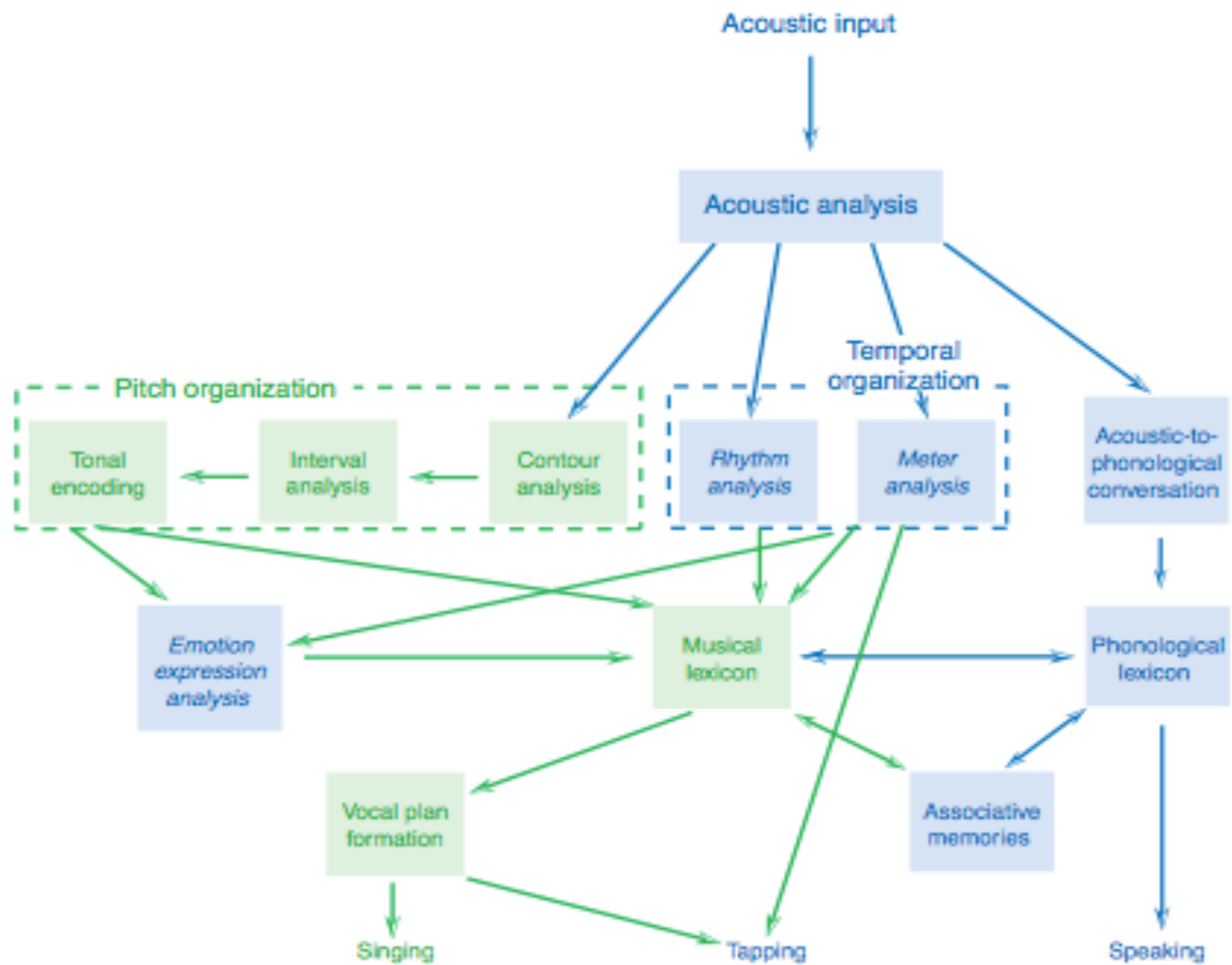
- Brain localization
 - Music and language processing seem to overlap.
 - Patel 2003, Koelsch et al 2004, etc.
 - But we should be cautious.
 - E.g. Broca's area is a vast brain region that can easily accommodate more than one distinct processing network, and activation in some studies is not limited to the left hemisphere.
 - As attempts for neural separability fail, we should become increasingly skeptical regarding the complete isolation of music processing from language processing.

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- Brain localization
 - One would expect a pre-wired organization to exhibit consistency in brain localization.
 - Such a prediction is nontrivial in music because there is a wide variability of experience.
 - Musicians' brains are different.
 - The cortical representation of the digits of the left hand are larger for string players (Elbert et al. 1995).
 - Brain responses to piano tones are 25% larger in musicians (Pantev et al. 2003).
 - Early responses to pure tones and grey matter volume in part of Herschel's gyrus are 100% greater in musicians (Schneider et al. 2002).

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- Brain localization
 - The brain system that underlies specialization for pitch processing may be fixed (probably innate).
 - Other brain systems involved in music might be more plastic within a time period (critical period).
 - And finally others may be plastic over an entire lifetime.



Ivelisse Robles

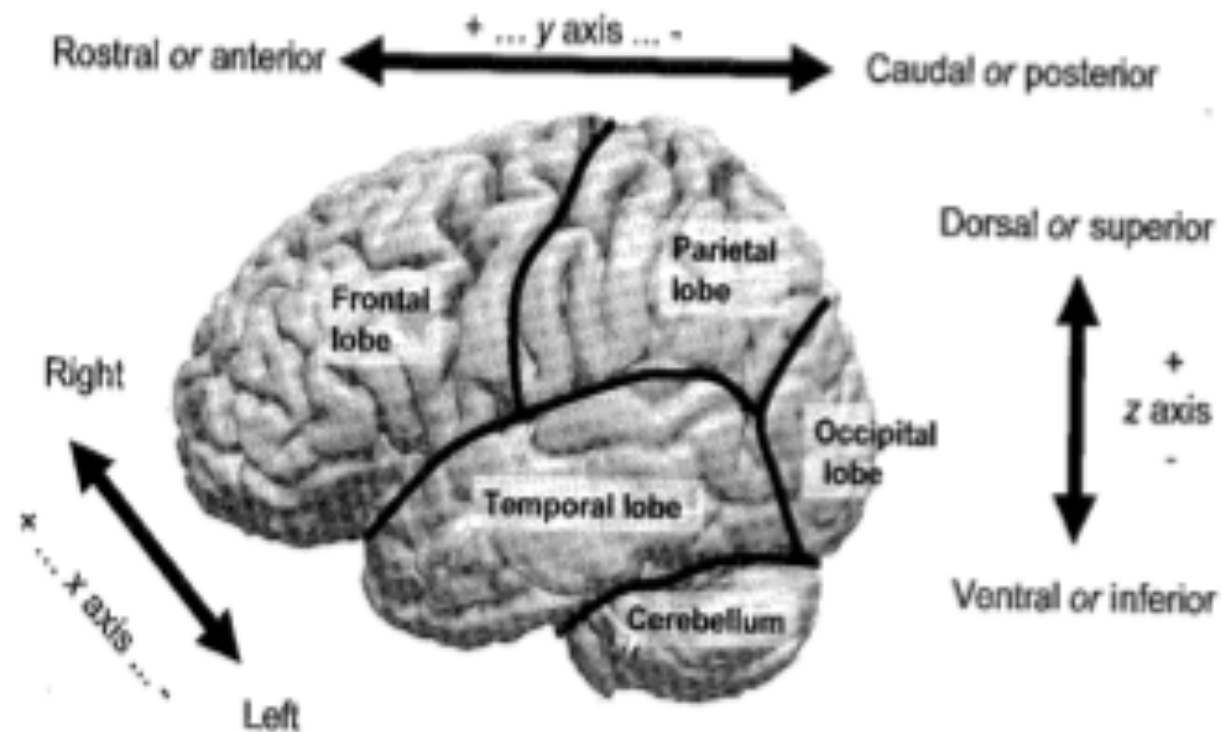


Figure 4.1 Lobes of the neocortex and the cerebellum, along with coordinate labels. The left hemisphere of author PQP's brain is shown.

Source: Brain image scans produced in collaboration with the Buffalo Neuroimaging Analysis Center (Robert Zivadinov, M.D., Ph.D., Jennifer L. Cox, Ph.D.) www.bnac.net. Used by permission from BNAC.

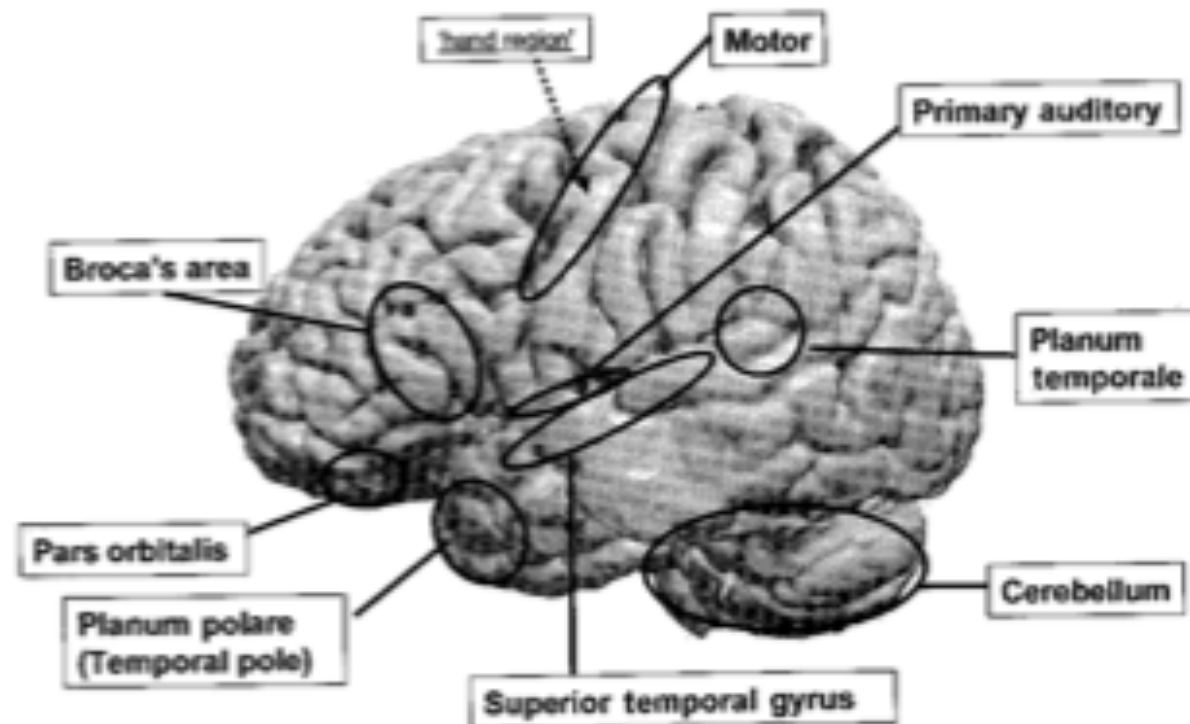


Figure 4.2 Surface regions of the brain associated with music. The left hemisphere of author PQP's brain is shown. Arrows are used to indicate regions on a more localized scale.

Source: Brain image scans produced in collaboration with the Buffalo Neuroimaging Analysis Center (Robert Zivadinov, M.D., Ph.D., Jennifer L. Cox, Ph.D.) www.bnac.net. Used by permission from BNAC.

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- Pitch relations
 - The data are quite consistent in implicating the right secondary auditory cortex region in operations related to processing relationships between pitch elements as they change over time, especially if the pitch changes are small.
 - When listeners rely on contour representation to discriminate melodies, the right superior temporal gyrus plays a critical role.
 - When contour cues are not available and interval information is required, both the right and left temporal structures appear to be involved.
 - The evidence points to the existence of neural networks that are specialized for the processing of scale structure in melodies. Their localization, however, remains to be determined.
 - The data point to bilateral involvement of the inferior frontal regions (Broca's area) in detecting deviations from harmonic expectancies.

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- Time relations
 - Subjects more easily tapped a rhythmic pattern with their right hand and the beat with their left hand than the other way around. These findings suggest that the right hemisphere better handles meter, whereas grouping would rely essentially on the left.
 - Two brain-damaged patients, after lesions of the right temporal auditory cortex, could no longer tap the beat or generate a steady pulse.
 - Patients fail on meter evaluation after a right-sided lesion of the anterior part of the superior temporal gyrus.
 - Imaging studies converge on the conclusion that a supramodal cerebellar timing system is involved in processing temporally organized events. Other fMRI studies have produced evidence for the possible involvement of the basal ganglia in both motor and perceptual timing.
 - Finally, several studies have pointed to the involvement of motor cortical areas in rhythm perception and production, including the supplementary motor area, premotor cortex, and parietal cortex

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- Memory
 - Lesion studies focusing on working memory for pitch materials have implicated the right auditory cortex.
 - Working memory for tones engages interactions between frontal cortical and posterior temporal areas, as is true for other domains.
 - Working memory for pitch may be seen as a specialized subsystem within the framework of general working memory.
 - A lesion to either medial temporal region led to initial difficulties in learning the melodies; after right-sided lesions, retention of melodies was affected more severely and selectively over time.
 - Difficulties in recognizing familiar melodies tend to occur after a surgery to either superior temporal region. Moreover, the participation of left inferior temporal and frontal areas for recognizing familiar music has been pointed out in neuroimaging studies.
 - Retrieval processes from long-term representations, such as might occur when generating [through imagery] a familiar tune, tend to engage inferior frontal regions.

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- Emotion
 - Recognition of the emotional tone in music can be spared by brain damage while recognition of music identity is impaired, indicating that emotion recognition may rely on perceptual determinants that play little role in identity recognition.
 - While people experienced musical chills, cerebral blood flow changes occurred in several brain areas, including the dorsal midbrain, ventral striatum (which contains the nucleus accumbens), insula, and orbitofrontal cortex.
 - Some of these regions have previously been implicated in response to highly rewarding or motivationally important stimuli, including food and drugs of abuse. Thus, under certain circumstances, music can access neural substrates that are primarily associated with biologically significant stimuli. Whether music is unique in this respect remains to be seen; it may be one of a class of human constructs that elicit pleasure by co-opting ancient neural systems via inputs from neocortex.

Hickok & Poeppel Blog 2011-2012

- [On the relation between language and music.](#)
- fMRI study shows little overlap between language and music processing.
- Rogalsky, Rong, Saberi, & Hickok. 2011 *Journal of Neuroscience*.

- Language and music exhibit similar acoustic and structural properties, and both appear to be uniquely human. Several recent studies suggest that speech and music perception recruit shared computational systems, and a common substrate in Broca's area for hierarchical processing has recently been proposed. However, this claim has not been tested by directly comparing the spatial distribution of activations to speech and music processing within subjects.

In the present study, participants listened to sentences, scrambled sentences, and novel melodies. As expected, large swaths of activation for both sentences and melodies were found bilaterally in the superior temporal lobe, overlapping in portions of auditory cortex. However, substantial nonoverlap was also found: sentences elicited more ventrolateral activation, whereas the melodies elicited a more dorsomedial pattern, extending into the parietal lobe. Multivariate pattern classification analyses indicate that even within the regions of blood oxygenation level-dependent response overlap, speech and music elicit distinguishable patterns of activation.

Regions involved in processing hierarchical aspects of sentence perception were identified by contrasting sentences with scrambled sentences, revealing a bilateral temporal lobe network. Music perception showed no overlap whatsoever with this network. Broca's area was not robustly activated by any stimulus type. Overall, these findings suggest that basic hierarchical processing for music and speech recruits distinct cortical networks, neither of which involves Broca's area. We suggest that previous claims are based on data from tasks that tap higher-order cognitive processes, such as working memory and/or cognitive control, which can operate in both speech and music domains.