Robert J. Zatorre – Selected references

Salimpoor, V. N., Benovoy, M., Larcher, K., Dagher, A., & Zatorre, R. J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience, 14,* 257-262.
Notes: Music, an abstract stimulus, can arouse feelings of euphoria and craving, similar to tangible rewards that involve the striatal dopaminergic system. Using the neurochemical specificity of [(11)C]raclopride positron emission tomography scanning, combined with psychophysiological measures of autonomic nervous system activity, we found endogenous dopamine release in the striatum at peak emotional arousal during music listening. To examine the time course of dopamine release, we used functional magnetic resonance imaging with the same stimuli and listeners, and found a functional dissociation: the caudate was more involved during the anticipation and the nucleus accumbens was more involved during the experience of peak emotional responses to music. These results indicate that intense pleasure in response to music can lead to dopamine release in the striatal system. Notably, the anticipation of an abstract reward can result in dopamine release in an anatomical pathway distinct from that associated with the peak pleasure itself. Our results help to explain why music is of such high value across all human societies
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Hyde, K. L., Lerch, J. P., Zatorre, R. J., Griffiths, T. D., Evans, A. C., & Peretz, I. (2007). Cortical thickness in congenital amusia: when less is better than more. *Journal of Neuroscience, 27,* 13028-13032.
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Congenital amusia (or tone deafness) is a lifelong disorder characterized by impairments in the perception and production of music. A previous voxel-based morphometry (VBM) study revealed that amusic individuals had reduced white matter in the right inferior frontal gyrus (IFG) relative to musically intact controls (Hyde et al., 2006). However, this VBM study also revealed associated increases in gray matter in the same right IFG region of amusics. The objective of the present study was to better understand this morphological brain anomaly by way of cortical thickness measures that provide a more specific measure of cortical morphology relative to VBM. We found that amusic subjects (n = 21) have thicker cortex in the right IFG and the right auditory cortex relative to musically intact controls (n = 26). These cortical thickness differences suggest the presence of cortical malformations in the amusic brain, such as abnormal neuronal migration, that may have compromised the normal development of a right frontotemporal pathway

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007). When the brain plays music: auditory-motor interactions in music perception and production. *Nature Reviews Neuroscience, 8,* 547-558.
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Music performance is both a natural human activity, present in all societies, and one of the most complex and demanding cognitive challenges that the human mind can undertake. Unlike most other sensory-motor activities, music performance requires precise timing of several hierarchically organized actions, as well as precise control over pitch interval production, implemented through diverse effectors

according to the instrument involved. We review the cognitive neuroscience literature of both motor and auditory domains, highlighting the value of studying interactions between these systems in a musical context, and propose some ideas concerning the role of the premotor cortex in integration of higher order features of music with appropriately timed and organized actions

Hyde, K. L., Zatorre, R. J., Griffiths, T. D., Lerch, J. P., & Peretz, I. (2006). Morphometry of the amusic brain: a two-site study. *Brain, 129,* 2562-2570.
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Congenital amusia (or tone deafness) is a lifelong disability that prevents otherwise normal-functioning individuals from developing basic musical skills. Behavioural evidence indicates that congenital amusia is due to a severe deficit in pitch processing, but very little is known about the neural correlates of this condition. The objective of the present study was to investigate the structural neural correlates of congenital amusia. To this aim, voxel-based morphometry was used to detect brain anatomical differences in amusic individuals relative to musically intact controls, by analysing T1-weighted magnetic resonance images from two independent samples of subjects. The results were consistent across samples in highlighting a reduction in white matter concentration in the right inferior frontal gyrus of amusic individuals. This anatomical anomaly was correlated with performance on pitch-based musical tasks. The results are consistent with neuroimaging findings implicating right inferior frontal regions in musical pitch encoding and melodic pitch memory. We conceive the present results as a consequence of an impoverished communication in a right-hemisphere-based network involving the inferior frontal cortex and the right auditory cortex. Moreover, the data point to the integrity of white matter tracts in right frontal brain areas as being key in acquiring normal musical competence

Klein, D., Zatorre, R. J., Chen, J. K., Milner, B., Crane, J., Belin, P. et al. (2006). Bilingual brain organization: a functional magnetic resonance adaptation study. *NeuroImage, 31,* 366-375.
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We used functional magnetic resonance adaptation (fMRA) to examine whether intra-voxel functional specificity may be present for first (L1)- and second (L2)-language processing. We examined within- and across-language adaptation for spoken words in English-French bilinguals who had acquired their L2 after the age of 4 years. Subjects listened to words presented binaurally through earphones. In two control conditions (one for each language), six identical words were presented to obtain maximal adaptation. The remaining six conditions each consisted of five words that were identical followed by a sixth word that differed. There were thus a total of eight experimental conditions: no-change (sixth word identical to first five); a change in meaning (different final word in L1); a change in language (final item translated into L2); a change in meaning and language (different final word in L2). The same four conditions were presented in L2. The study also included a silent baseline. At the neural level, within- and across-language word changes resulted in release from adaptation. This was true for separate analyses of L1 and L2. We saw no evidence for greater recovery from adaptation in across-language relative to within-language conditions. While many brain regions were common to L1 and L2, we did observe differences in adaptation for forward translation (L1 to L2) as compared to backward translation (L2 to L1). The results support the idea that, at the lexical level, the neural substrates for L1 and L2 in bilinguals are shared, but with some populations of neurons within these shared regions showing language-specific responses

Peretz, I. & Zatorre, R. J. (2005). Brain organization for music processing. *Annual Review of Psychology, 56,* 89-114.
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Research on how the brain processes music is emerging as a rich and stimulating area of investigation of perception, memory, emotion, and performance. Results emanating from both lesion studies and neuroimaging techniques are reviewed and integrated for each of these musical functions. We focus our attention on the common core of musical abilities shared by musicians and nonmusicians alike. Hence, the effect of musical training on brain plasticity is examined in a separate section, after a review of the available data regarding music playing and reading skills that are typically cultivated by musicians. Finally, we address a currently debated issue regarding the putative existence of music-specific neural networks. Unfortunately, due to scarcity of research on the macrostructure of music organization and on cultural differences, the musical material under focus is at the level of the musical phrase, as typically used in Western popular music

Zatorre, R. J. & Halpern, A. R. (2005). Mental concerts: musical imagery and auditory cortex. *Neuron, 47,* 9-12.
Notes: Most people intuitively understand what it means to "hear a tune in your head." Converging evidence now indicates that auditory cortical areas can be recruited even in the absence of sound and that this corresponds to the phenomenological experience of imagining music. We discuss these findings as well as some methodological challenges. We also consider the role of core versus belt areas in musical imagery, the relation between auditory and motor systems during imagery of music performance, and practical implications of this research
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Zatorre, R. J., Belin, P., & Penhune, V. B. (2002). Structure and function of auditory cortex: Music and speech. *Trends in Cognitive Sciences, 6,* 37-46.
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We examine the evidence that speech and musical sounds exploit different acoustic cues: speech is highly dependent on rapidly changing broadband sounds, whereas tonal patterns tend to be slower, although small and precise changes in frequency are important. We argue that the auditory cortices in the two hemispheres are relatively specialized, such that temporal resolution is better in left auditory cortical areas and spectral resolution is better in right auditory cortical areas. We propose that cortical asymmetries might have developed as a general solution to the need to optimize processing of the acoustic environment in both temporal and frequency domains

Peretz, I., Blood, A. J., Penhune, V., & Zatorre, R. (2001). Cortical deafness to dissonance. *Brain, 124,* 928-940.
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Ordinary listeners, including infants, easily distinguish consonant from dissonant pitch combinations and consider the former more pleasant than the latter. The preference for consonance over dissonance was tested in a patient, I.R., who suffers from music perception and memory disorders as a result of bilateral lesions to the auditory cortex. In Experiment 1, I.R. was found to be unable to distinguish

consonant from dissonant versions of musical excerpts taken from the classical repertoire by rating their pleasantness. I.R.'s indifference to dissonance was not due to a loss of all affective responses to music, however, since she rated the same excerpts as happy or sad, as normal controls do. In Experiment 2, I.R.'s lack of responsiveness to varying degrees of dissonance was replicated with chord sequences which had been used in a previous study using PET, in examining emotional responses to dissonance. A CT scan of I.R.'s brain was co-registered with the PET activation data from normal volunteers. Comparison of I.R.'s scan with the PET data revealed that the damaged areas overlapped with the regions identified to be involved in the perceptual analysis of the musical input, but not with the paralimbic regions involved in affective responses. Taken together, the findings suggest that dissonance may be computed bilaterally in the superior temporal gyri by specialized mechanisms prior to its emotional interpretation