Following the music to the memories

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Introduction

The evocation of autobiographical memories and associated emotions by music counts among the most poignant experiences associated with music. Accordingly, excerpts of music can serve as potent retrieval cues with which to study the functional architecture of autobiographical memory. Converging evidence suggests that the rostral aspect of the medial prefrontal cortex (BA10) is a region where music and autobiographical memories might be integrated. This study tested the hypothesis that experiencing autobiographically salient musical excerpts will result in increased activation in the medial prefrontal cortex, and that the medial prefrontal cortex will track the tonal (harmonic) structure of the musical excerpts, particularly the autobiographically salient ones.

Methods

Prescreening and memory characterization

- Thirty 30s excerpts from Billboard Top 100 Pop and R&B charts
- Randomly selected from time when subject was between 7 and 19 years of age.
- Following each excerpt, a subject reported whether the song was familiar and if so whether it evoked a weakly or strongly autobiographical memory or no clear memory at all.
- Subjects were invited to participate in the fMRI version of the experiment if >30% of the excerpts evoked an autobiographical memory.

fMRI experiment

- 13 subjects (11 female)
- 30 stimuli (selected according to the same criteria as above) across two scanning runs.
- No repeats of stimuli from prescreen.
- Ratings following each excerpt:
  - Affective valence (5-point scale)
  - Arousal (5-pt scale)
  - Familiarity (2 pt scale)
  - Autobiographical salience (3 pt scale)
  - Degree of orientation of their attention toward the memories (5 pt scale)
  - Degree of orientation of their attention toward the music (5 pt scale).

Scan parameters: Siemens 3T Trio, 34 slices (4 mm thick, 0 skip), TR=2.0s, in-plane resolution: 3.4x3.4 mm.

Analyses: Analyses were performed using SPM5. Data were spatially normalized, and variance associated with estimated movement parameters and linear trends was removed. The residuals were analysed using the models shown in Figures 1 and 4.

Group-level analyses of task effects and combination of Familiarity, Autobiographical Salience, Affect

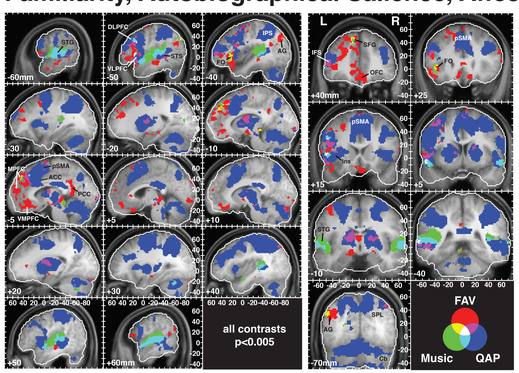


Figure 2. Group analyses for 3 basic contrasts: Music Playing (green), the Question/Answer Period (blue) and a contrast in which the Familiarity, Autobiographical Salience, and Valence effects were combined. They were combined because of the strong correlations among these variables for all subjects. Thus, areas in red, yellow, and magenta showed greater activation when the song was familiar, strongly autobiographically salient and evoked a positive emotion.

Design matrices for testing general task effects and parametric variation in subjective variables

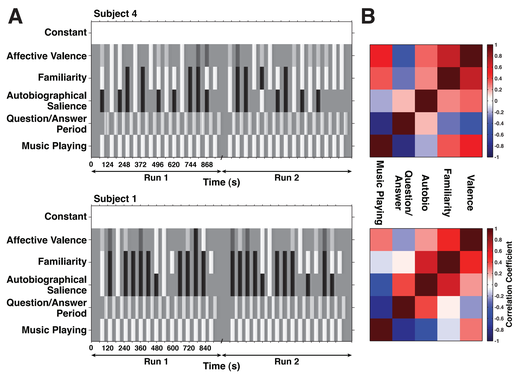


Figure 1. Design matrices for two subjects illustrate the statistical models that were used.
The grayscale codes the regressor values, with black representing the most negative values and white the most positive. The ubiquitous gray represents zero. A) 30s music epochs alternated with the question/answer periods. Answers on the multipoint scalse were used to code parametric regressors for Autobiographical Salience, Familiarity and Affective Valence. Black bars represent song excerpts that were unfamiliar or not autobiographically salient, whereas white bars represent songs that were familiar and strongly autobiographically salient. Valence ratings range from very displeasing (black) to very pleasing (white) with neither pleasing nor displeasing represented by zero. B) Correlation matrices of the design matrices shown in A. The Familiarity, Autobiographical Salience, and Valence regressors showed moderate to strong correlations among each other. This was true across all subjects.

Group-level analyses of each subjective variable contrast

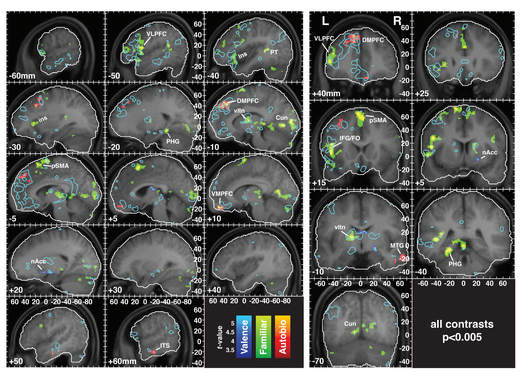
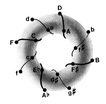
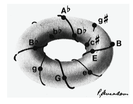


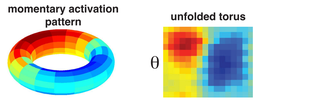
Figure 3. Individual effects of **familiarity (green)**, **autobiographical salience (red)**, and **affective (positive) valence (blue)**. For purposes of comparison, the cyan outlines are the borders of the FAV contrast shown in red in Figure 2.

Modeling music's movement in tonal space



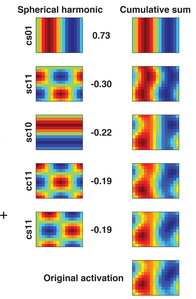


Converging evidence from music theory, cognitive psychology, and self-organizing neural networks indicates that the system of major and minor keys in Western tonal music can be represented on the surface of the torus.
As a piece of music unfolds, the changing harmonies and chord progressions create a changing pattern of activity on the surface of the torus, providing a signature of a piece of music.

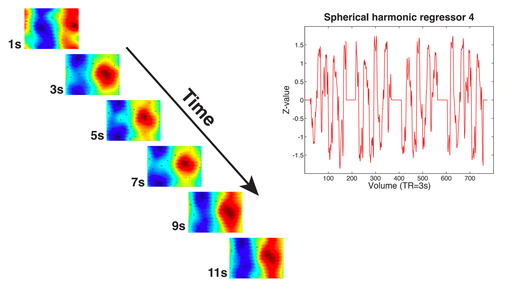


The activation pattern on the torus at any given moment in time can be described as a weighted-sum of a set of spherical harmonics (spatial frequencies) using the equation below.

$$f(\theta,\phi) = \sum_{m=0,n=0}^{M,N} a_{mn}^{cc}\cos(m\theta)\cos(n\phi) + \sum_{m=0,n=0}^{M,N} a_{mn}^{cs}\cos(m\theta)\sin(n\phi) + \sum_{m=0,n=0}^{M,N} a_{mn}^{sc}\sin(m\theta)\cos(n\phi) + \sum_{m=0,n=0}^{M,N} a_{mn}^{ss}\sin(m\theta)\sin(n\phi)$$



As the activation pattern changes during the course of a song, so do the weights for each spherical harmonic. These changing weights are entered as regressors for each of 34 spherical harmonics.



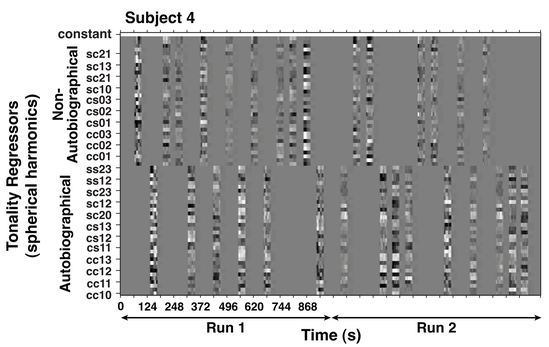


Figure 4. Design matrix in which tonality tracking is estimated separately for songs that did and didn't elicit autobiographical associations. False-positives were controlled for by comparing the residual variance of the veridical model against the distribution of residual variances obtained from 100 models in which the ordering of the songs was permuted.

Tonality-tracking responses

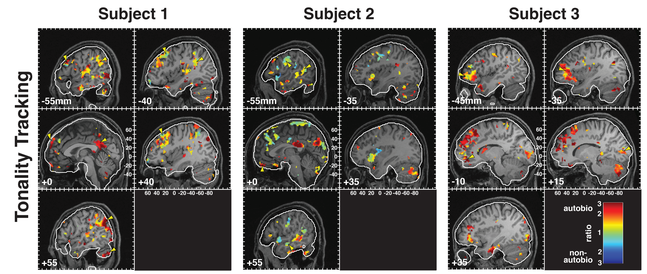


Figure 5. These tonality tracking images show the proportion of variance explained by the tonality tracking regressors modeling autobiographically salient pieces of music relative to those modeling pieces of music that elicited no autobiographical association. The color scale represents the ratio of these variances, with each variance corrected by the number of music excerpts contributing to its estimate. Red values indicate a bias toward tonality tracking associated with an autobiographical memory, and blue denotes tonality tracking without an associated autobiographical memory.

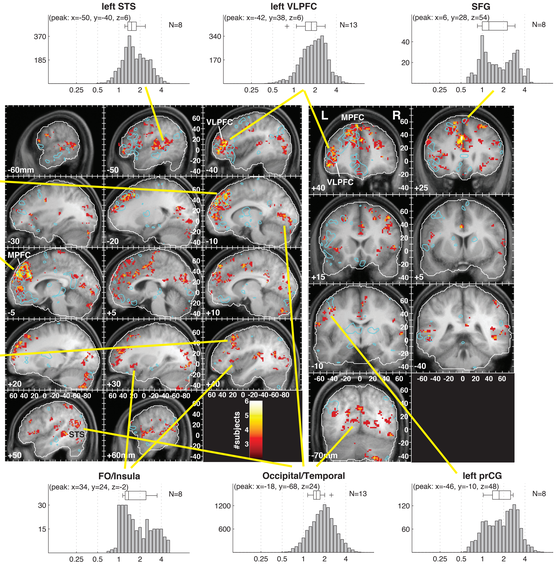


Figure 6. A summary of brain areas exhibiting tonality-tracking behavior. The color of each voxel indicates the number of subjects in whom that voxel showed significant tonality-tracking behavior. The cyan contours demarcate the borders of the FAV-related activations shown in Figure 2, and illustrate the co-localization of the FAV and tonality-tracking effects in MPFC. The insets show distributions of tonality tracking biases for all voxels in clusters of voxels that showed tonality tracking for a majority of subjects. A ratio of 1 indicates equal tracking of autobiographically salient and non-salient songs, whereas larger ratios indicate a bias toward tracking of autobiographically salient songs. The box and whisker plots provide information about the distribution of mean tonality-tracking biases across subjects.

Conclusions

Dorsal medial prefrontal cortex exhibits properties of an area that binds together music with autobiographically salient memories, in that it responds more strongly during autobiographically salient songs and it also follows the structure of the music, predominantly for songs that are autobiographically salient. Left VLPFC shows similar properties. The effects of familiarity and autobiographical salience (lateralized to the left hemisphere) and tonality tracking were distributed across a number of prefrontal, temporal, and occipital areas, as would be expected given the interactions of frontal memory retrieval mechanisms with content representations in posterior cortices.

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