Human Striatal Volume Predicts Interindividual Differences in Music-Induced Intense Emotional Responses

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Music can induce intense emotions and physiological responses, such as “goose bumps”, “shivers”, or “aesthetic chills”. Previous studies have suggested that the reward circuit is related to the anticipation and experience of such chills. In this study, we used structural magnetic resonance imaging to investigate individual differences in the intense emotional responses evoked by music. Nineteen subjects were asked to listen to music and report whether they were feeling chills by pressing a button. Each subject selected the music to which they listened based on its having induced chills previously. Our findings offer evidence that individual differences in sensitivity to music-induced emotion might be associated with the gray matter volume in the right caudate, left insula, and right postcentral gyrus. These findings constitute anatomical evidence related to the timing of the aesthetic chills and underscore the role of mesolimbic reward circuits in music perception.

Key words: music, emotion, individual differences, MRI, voxel-based morphometry

1. Introduction

Humans are drawn to sophisticated sound patterns (i.e., music) that, at times, evoke intense emotional experiences, such as “goose bumps”, “shivers”, “musical frisson”, or “aesthetic chills”, which are regarded as physical manifestations of peak emotional responses (PERs)[1] and that rest on perceptual and affective processes. Previous research has suggested that the mesolimbic striatum may play an important role in these processes. For instance, striatal activity is involved in music-induced chills[2]. Positron emission tomography and functional magnetic resonance imaging studies have found that positive emotional responses to music are associated with dopamine release in the striatum (including the right caudate), which is part of the striatal dopaminergic system[1]. These studies have also shown that PERs elicited temporally dynamic changes in the blood-oxygen-level dependent (BOLD) signals in the caudate. Although there has been increasing interest in the functional brain activities that follow the anticipation and experience of PERs, the anatomical mechanisms underpinning these phenomena have not yet been fully elucidated. Several studies have reported differences among individuals in music-induced emotional responses[3,4]. For example, aesthetic chills have been related to personality and familiarity with the arts[5]. Research on the neural correlates of individual differences in PERs have clarified the neural basis of music perception and the relevant reward processes. We

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used voxel-based morphometry (VBM), a powerful technique for studying morphometric differences, to investigate the source of individual differences. This technique has identified the anatomical mechanisms that underlie perceptual and cognitive processes. We measured the total durations of PERs and used VBM to examine individual differences in sensitivity to PERs and to determine whether the gray matter volume in the striatum predicted tendencies to experience music-induced PERs.

2. Materials and Methods

2.1 Participants

Nineteen right-handed healthy participants (13 females and 6 males, age range: 21–24 years) participated in the experiment after providing written informed consent. All participants were monolingual speakers of Japanese with healthy hearing (thresholds of < 20 dB HL at 125–8000 Hz according to an audiometer (Rion AA-77A, Tokyo, Japan)).

2.2 Stimuli

Following previous studies, subjects provided four pieces of music that had previously evoked aesthetic chills[1,6,7]. Another piece of music from the same genre or artist as the four provided by the participant was selected by the experimenter. Additionally, a neutral music composition (i.e., "Clair de lune" composed by Claude Debussy) was presented to all subjects. We added pink noise to six pieces of music to synthesize acoustic control stimuli. In total, subjects heard 12 pieces of music presented at 90–95 dB SPL while using earplugs (mean sound attenuation of 30 dB) to attenuate the scanner noise. The behavioral responses to noise-added stimuli were not included in the present analysis.

2.3 Procedure

Sound stimuli were presented via MRI-compatible headphones (AS3000K, Kiyohara Optics Inc., Tokyo, Japan) during fMRI scanning. Participants were asked to report whether they experienced aesthetic chills by pressing buttons (HHSC-1x4-D, Current Designs, Inc., Philadelphia, Pennsylvania, USA) with their left hand. Cushions were inserted between the headphones and the head coil to reduce head movement. The experiment was programmed using Presentation software package (Neurobehavioral Systems, Inc., Albany, CA, USA). Before the MRI scan, the subjects listened to the 12 pieces of music, which were separated by 5-minute breaks, outside the MRI scanner over the course of 2 days.

2.4 MRI acquisition

We recorded a T1-weighted 3-D gradient-echo structural image for each individual (TE = 4 ms, TR = 9.4 ms, flip angle = 8, FOV = 256 x 256 mm, 192 slices, inversion time (TI) = 1013 ms, voxel size = 1 x 1 x 1 mm) on a 1.5-tesla MRI scanner (Hitachi Medical Echelon Vega, Chiba, Japan). Data analysis was performed with SPM12 software (Wellcome Department of Imaging Neuroscience, London, UK; http://www.fil.ion.ucl.ac.uk/spm/). For the VBM analyses, the images were preprocessed in the following steps. The brain image was segmented into gray matter, white matter, and cerebrospinal fluid. For spatial normalization, images were nonlinearly transformed to standard Montreal Neurological Institute (MNI) space using DARTEL[8]. Tissue probability maps were modulated by the Jacobian determinants of the deformations to account for local compression and expansion due to transformations[9]. Modulated gray matter images were smoothed at 8-mm full width at half maximum (FWHM) by an isotropic Gaussian kernel.

2.5 Behavioral analysis

The duration of the PER was defined as the time during which the subject reported experiencing aesthetic chills by pressing the button. The proportion of PERs was obtained as a percentage by dividing the duration of each PER for each subject by the duration of the entire piece of music. The PER duration proportions for the subject-selected music were averaged across the four

pieces of music.

2.6 VBM analysis

To study the possible linear relationships between the PER duration proportion and the gray matter volume, we corrected for differences in total brain volume (sum of the gray matter and the white matter) and gender. We then performed a linear regression analysis on the gray matter volume treating the PER duration proportion vector as a predictor. Activations that survived at $p<0.005$, uncorrected for multiple comparisons, and had a cluster extent > 50 voxels are reported. Additionally, the volume in right caudate was significant, with small volume corrections[10] corresponding to $p < 0.05$, family-wise error (FEW)-corrected for multiple comparisons within spheres with 8-mm radius centered at the coordinates (*xyz* = 10 19 -2), based on a previous study[1] reporting dopamine release associated with the experience of pleasure. Anatomical definitions were assigned according to the SPM toolbox Automated Anatomical Labeling (AAL).

3. Results

The mean PER duration proportion for subject-selected music was 0.279 (SD ± 0.134); the proportion for experimenter-selected music was 0.263 (± 0.169); and the proportion for neutral music was 0.165 (± 0.197). Gray matter volume was correlated with PER duration proportion for subject-selected music. The interindividual differences in the gray matter volume in the right caudate were positively correlated with the PER duration proportion (*xyz* = 18 24 -5; $p < 0.05$, FEW-corrected, small volume correction; Fig. 1). Furthermore, as summarized in Table 1, the gray matter clusters were correlated with the PER duration proportion.

Table 1. Positive correlations between gray matter volume and proportionate durations of PERs to subject-selected music in the whole-brain analysis.

Regions	*x*	*y*	*z*	Voxels	*t* value
Paracentral_Lobule_R	12	-35	59	164	4.69
	17	-44	53		3.90
Insula_L	-29	9	12	82	3.97
	-38	11	14		3.42
	-47	15	11		3.36
Caudate_R	18	24	-5	62	3.83

Note: Coordinates are in MNI space.

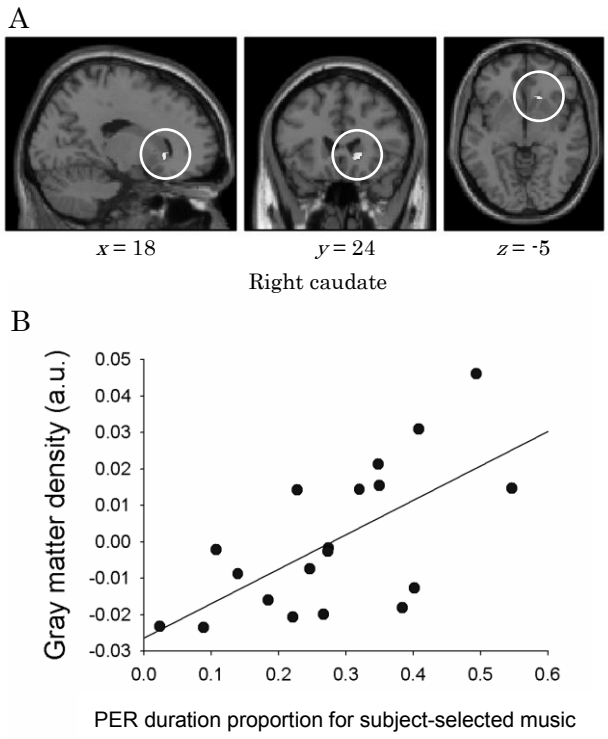

Fig. 1. VBM results. A: Increase in gray matter volume in the right caudate as a function of PER duration. B: For visualization purposes, scatter plots show the relationship between PER duration and the gray matter value of the peak voxel in the caudate.

4. Discussion

The current study provides evidence that the gray matter volume in the right striatum (including the caudate) is correlated with PER duration. In a previous study, the striatum released dopamine and showed an increase in BOLD signals during anticipation of a PER to music[1]. Indeed, the caudate may be involved in the anticipation of an emotional response to music, and the

caudate volume might reflect the availability of dopamine. One limitation of this study is its evaluation of PERs based only on self-reports. Additionally, the PER durations reported herein are longer than those reported by several previous studies. It is possible that our measurement of the duration of the PERs included the sub-chill state, which is similar to the experience of "low-pleasure" or "high-pleasure" as defined by Zatorre and colleagues[1,6]. Future studies should use physiological measurement techniques (e.g., electrodermal skin response, heart rate, and respiration) to record the activities of the autonomic nervous system accompanying music-induced chills to address this concern. In conclusion, our results suggest that the gray matter volume in the striatum play an important role in the process of reward prediction that leads to intensely emotional responses during music perception. These data shed new light on the specific contributions of the striatum to the role of anticipation in perceptual process.

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