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Research report

Activated brain regions in musicians during an ensemble: a PET study

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Abstract

As in visual processing, we speculated that, in music processing, different brain regions would activate according to the mode of music listening. Using motets by a famous composer, we studied changes in regional cerebral blood flow (rCBF) with positron emission tomography associated with concentrating on the alto-part within the harmony (alto-part-listening condition) compared to listening to the harmony as a whole (harmony-listening condition). The alto-part-listening condition was associated with bilateral increases of rCBF in superior parietal lobules, precunei, premotor areas and orbital frontal cortices. Superior parietal lobules are likely to be responsible for auditory selective attention to the alto part within the harmony and the analysis of tone pitch on a mental score. The precuneus possibly participated in writing tones of the alto part on a mental score. Based on our findings, we propose that both auditory selective attention and analytic processing play an important role in concentrating on a certain vocal part within a harmony. During the harmony-listening condition, temporal poles, the anterior portion of the cingulate gyrus, occipital cortex and the medial surface of the cerebellum were bilaterally activated. Further studies are necessary to clarify the difference in music processing between musicians and nonmusicians.

Theme: Neural basis of behavior

Topic: Cognition

Keywords: Music; Auditory selective attention; Positron emission tomography; Superior parietal lobule; Precuneus; Musician

1. Introduction

In visual processing, it has been reported that brain regions activate selectively depending on whether the subject views an object with globally or locally directed attention [9,10]. This difference in regions of activation between global and local visual processing is also supported by lesion-studies [24]. In music processing, professional musicians utilize two modes of listening to music, namely globally or locally directed attention. When professional musicians listen to music, they sometimes listen to the sound of harmony as a whole and sometimes only to a certain vocal or instrumental part within the harmony. These two modes of listening to music also function during an ensemble, typically in harmonious music. When only one player is performing a melody with harmonious accompaniment, i.e., a *solo*, in an ensemble, the player listens to the sound of harmony as a whole and emits his or her tones appropriately for keeping in harmony with the accompaniment. Whereas, when several players are performing an identical melody simultaneously with the harmonious accompaniment, i.e., *soli*, during an ensemble, professional musicians listen to and concentrate on the identical melody for the purpose of making their tones sound as if only one player were performing that melody. In order to clarify whether different regions of the brain are activated depending on the mode of listening as the results of global/local visual processing, we examined music students while they concentrated on a certain vocal part and listened to the harmony as a whole for the same

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piece of music. We compared the activated regions of the former condition with those of the latter condition, using the subtraction technique for positron emission tomography (PET).

2. Materials and methods

2.1. Subjects

Nine right-handed male volunteers (age range 21–28 years, mean 21.8 years) participated in the study. All subjects were music students at the School of Education, Akita University, Japan. None had any signs or history of neurological, cardiovascular or psychiatric disease. All subjects gave written informed consent after the purpose and the procedure of the examination had been fully explained to them. The study was approved by the Ethics Committee of the Research Institute for Brain and Blood Vessels, Akita, Japan. All experiments were conducted in accordance with the Declaration of Helsinki.

2.2. Task procedures

Stimuli were three fairly unknown motets; musical pieces of harmonious style with four vocal parts, composed by Anton Bruckner. None of the subjects had ever listened to these motets or known the lyrics of these musical pieces. These motets were played by a professional pianist and recorded on a mini-disc. All subjects performed the following two tasks during the PET measurements (Fig. 1). (A) Harmony-listening condition: subjects were required to listen to the harmony as a whole. If subjects heard a minor chord, they were instructed to make a sign with the index finger of their right hand. (B) Alto-part-listening condition: subjects were required to listen to and concentrate on the tone of the alto part of the harmony. If subjects heard the tonic or dominant tone (prescribed for each motet) in the alto part, they had to make the same sign mentioned above. Task A was first performed for all musical pieces, followed by task B in the same order. All stimuli were presented binaurally via inset stereo-earphones.

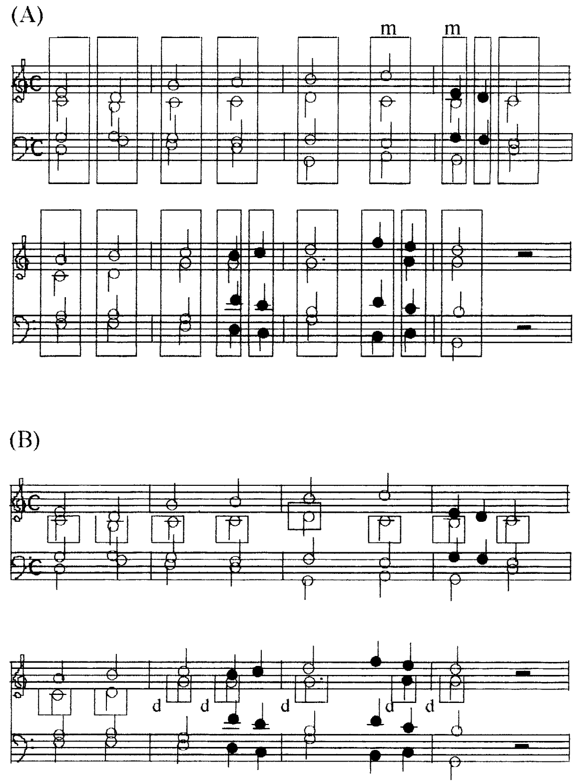

Fig. 1. Explanation of the tasks. (A) Harmony-listening condition. Subjects listened to harmony as a whole (squares). 'm' shows a minor chord. (B) Alto-part-listening condition. Subjects concentrated on the alto-part (squares). 'd' shows a dominant tone.

2.3. Positron emission tomography measurements

The protocol used at our institute to obtain quantitative images of regional cerebral blood flow (rCBF) utilizing the ^{15}O steady state method [12] has been described in detail elsewhere [30]. PET data were acquired in three-dimensional acquisition mode using the Headtome V (Shimazu, Kyoto, Japan), a PET camera providing 47 simultaneous transaxial slices of data, parallel to the anterior commissure–posterior commissure (AC–PC) plane, with an axial field of view (FOV) of 150 mm and an in-plane FOV of 560 mm. The Headtome V has an effective in-plane resolution (spatial resolution) of 4.0 mm and an axial resolution (slice thickness) of 4.3 mm full width at half maximum (FWHM) at the center of the FOV [14]. Subjects were positioned in the scanner with reference to a cranial X-ray obtained with the subject on the scanning bed. Movement artifact was reduced by encasing the head in a custom made, quick setting foam cast, and by the use of restraining straps across the forehead. Scans were performed with subjects lying supine with their eyes closed in a darkened room. Six CBF measurements were determined for each subject, three during the harmony-listening condition, and three during the alto-part-listening condition. Employing the ^{15}O labeled water ($H_2^{15}O$) intravenous bolus technique [17], emission data were collected for 90 s in each measurement following the intravenous bolus injection of 15 ml of $H_2^{15}O$. Each piece of music was started 15 s prior to data acquisition, repeated two times, and continued for about 120 s. Emission data were corrected for attenuation by acquiring 10 min of transmission data utilizing a ^{68}Ge orbiting rod source performed prior to the activation scans. A washout period of ~10 min was allowed between successive scans. For anatomical reference, T1 weighted magnetic resonance imaging (MRI) scans were obtained and transformed into standard stereotactic space.

2.4. Data analysis

PET data analysis was performed on a SGI Indy running IRIX 6.5 (Silicon Graphic, CA, USA), using an automated PET activation analysis package [21] composed of six main processing stages [5]. Most of the procedures were performed automatically by the software. Stage one consisted of intra-subject co-registration which accounts for any head movement that might have occurred between sequential scans. For each subject, one image set was used as a standard, then transverse and coronal rotations, as well as image centering operations, were performed on the remaining images. Stage two involved intra-subject normalization of non-quantitative pixel counts to the mean global counts, followed by scaling to a standard value [22]. Pixel normalization helps to account for inter- and intra-subject variability in both regional and global CBF changes [13], as well as the effects of inter- and intra-subject differences in the activity of the bolus delivered during sequential scans. Stage three consisted of automatic detection of the AC–PC line for realignment in terms of the stereotactic co-ordinate system. The AC–PC line was estimated on intra-subject averaged image sets by detecting the mid-sagittal plane [22]. Edge detection, interpolation, and profile curve analysis techniques were used to identify the location of four internal landmarks in the mid-sagittal plane: the frontal pole, the occipital pole, the inferior aspect of the anterior corpus callosum and the subthalamic point [22]. The AC–PC line was then estimated by fitting a line to these anatomical landmarks using simple linear regression [22]. Stage four involved the detection of multiple stretching points and surface landmarks on intra-subject averaged image sets for the purpose of linear scaling and non-linear anatomical standardization [22]. The algorithm determined linear scaling factors for the correction of individual brain size by estimating the antero–posterior brain length, brain width, and brain height. These scaling factors were used to stretch the stereotactically aligned image sets to correspond to the standard dimensions of the Talairach brain atlas [28]. Regional anatomical differences between individual brains and the standard atlas brain were minimized by utilizing an automated non-linear warping technique incorporating the predetermined multiple stretching points and surface landmarks. Deformation of the individual brains to correspond to the standard atlas brain was achieved by spatially matching the individual landmarks to the corresponding predefined standard surface landmarks and maximizing correlation coefficients of regional profile curves between the stretching centers [22]. Then, in stage five, inter-subject summation and statistical analyses were carried out. Maps representing voxel-by-voxel t-statistic values, calculated using a pooled variance, were generated to reflect the differences between the inter-subject averaged image sets of the harmony-listening and alto-part-listening conditions. Since this method results in t-statistic maps that are a close approximation to the Gaussian distribution [29], it is usual to describe these values as Z-scores. Activation foci were described in terms of the stereotactic coordinates of the peak activated pixels, percentage change in CBF, t-value (effectively equal to Z-score), and the associated P-value. Foci were considered to be significantly activated if the corresponding P-value was less than a pre-determined threshold ($P<0.01$, uncorrected for multiple comparisons). The last stage consisted of superimposing the statistical results onto the stereotactic MRI for visual interpretation and display purposes. Anatomical identification of the activation foci was achieved by referring the stereotactic coordinates of the peak activated pixels to the standard Talairach brain atlas [28].

3. Results

For behavioral measures of performances, all subjects showed about 70% correct responses in both the harmony-listening and the alto-part-listening conditions. The two tasks performed in this study were not tasks which required 'same–different' discrimination. In the harmony-listening condition, eight kinds of chords could be contained in the musical pieces with four vocal parts, namely minor, major, diminished and augmented triad and seventh chord. For the alto-part-listening condition, subjects answered by listening to the tonic or the dominant tone from

Table 1
Regions showing significant changes in rCBF during the alto-part-listening condition

Anatomical structure	Brodmann area	Talairach coordinate			Z
		x	y	z	
Superior parietal lobule	7				
Lt		−15	−69	43	5.32
Rt		14	−55	50	4.72
Precuneus	7				
Lt		−1	−60	38	4.99
Rt		8	−69	45	4.41
Premotor area	6				
Lt		−30	5	56	4.59
Rt		19	12	47	3.85
Orbital frontal cortex	11				
Lt		−28	53	−7	3.42
Rt		33	53	−7	4.05

Coordinates x, y, z, are in millimeters corresponding to the atlas of Talairach and Tournoux. The x-coordinate refers to the medial–lateral position relative to the midline (negative=left); y-coordinate to the anterior–posterior position relative to the anterior commissure (positive=anterior); z-coordinate to the superior–inferior position relative to the anterior commissure–posterior commissure line (positive=superior); Z refers to the Z-score of the maximum pixel in the region. L and R refer to the left and right hemisphere, respectively.

among 12 tones, namely A, A sharp, B, C, C sharp and so on, which constituted the scale of that musical piece. Thus, the chance level of both conditions was very low. Therefore, we regarded the correct response of performances in our experiment as reasonably satisfactory.

The results of the subtractions, in terms of significant regions activated during the alto-part-listening but not the harmony-listening condition, are given in the Table 1, together with stereotaxic coordinates based on the brain atlas of Talairach and Tournoux. These results show areas of relative blood flow changes that emphasize differences between the two music-listening tasks and minimize the areas that are common to both. The alto-part-listening condition produced increases in blood flow in bilateral superior parietal lobules, bilateral precunei, bilateral premotor areas and bilateral orbital frontal cortices, compared with the harmony-listening condition (Fig. 2). The regions for which the harmony-listening condition produced sig-

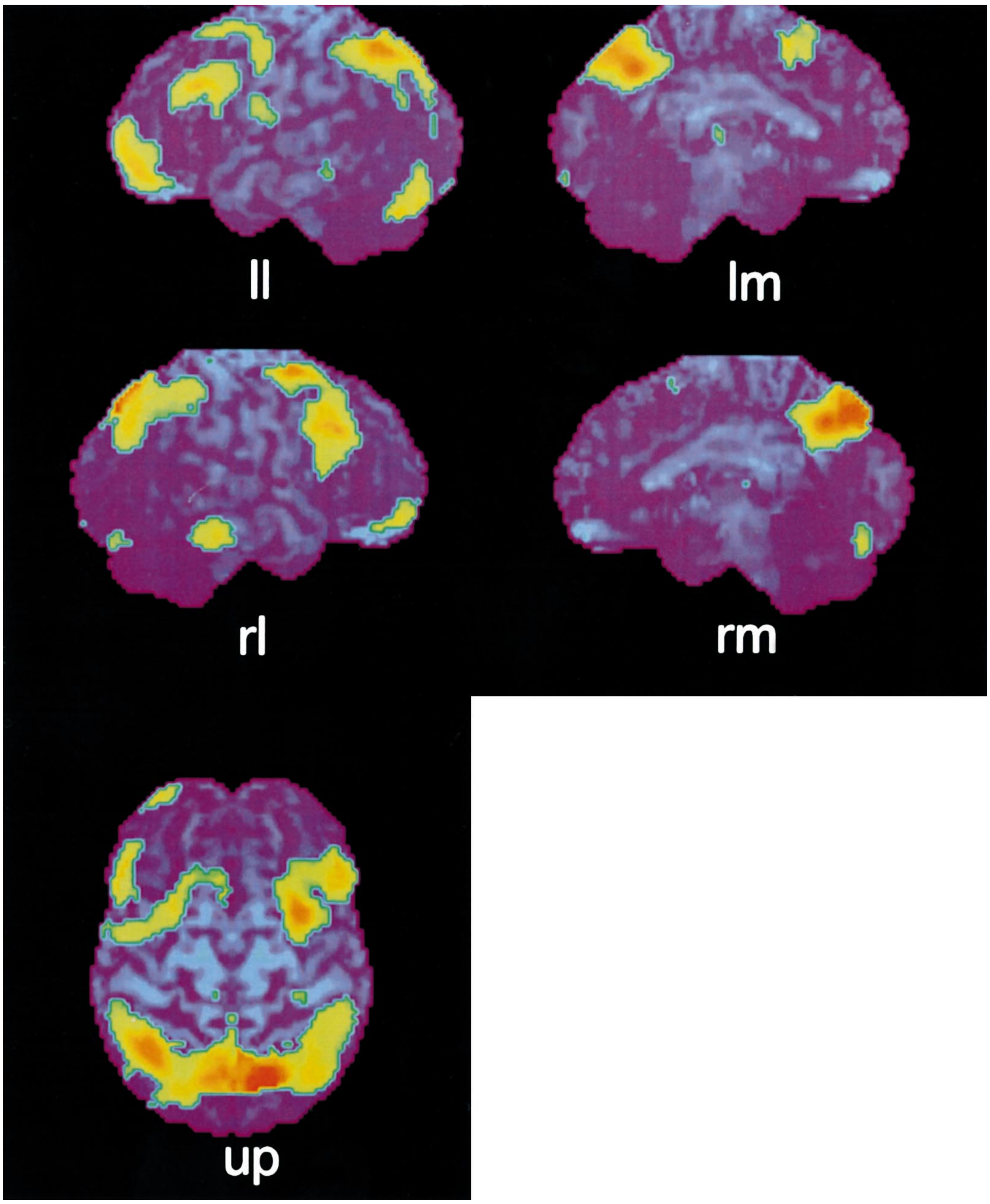

Fig. 2. Activation maps for the subtraction of the alto-part-listening versus the harmony-listening conditions. Areas of significant activation ($P<0.01$) are superimposed onto the surface maps of the averaged MRI of the brains of nine subjects. Bilateral superior parietal lobules and precunei were remarkably activated. Areas in bilateral premotor and orbital frontal cortices were also activated. The left side of the bottom-image shows the left side of the brain. ll: Lateral surface of left hemisphere, lm: medial surface of left hemisphere, rl: lateral surface of right hemisphere, rm: medial surface of right hemisphere, up: upper surface.

Table 2
Regions showing significant changes in rCBF during the harmony-listening condition

Anatomical structure	Brodmann area	Talairach coordinate			Z-score
		x	y	z	
Temporal pole					
Lt	38	−24	10	−29	−4.44
	21	−62	1	−16	−2.54
Rt	38	26	5	−32	−3.83
	21	48	−4	−18	−3.09
Cyngulate gyrus					
Lt	32	−6	30	−7	−2.78
Rt	24	6	32	2	−2.7
Occipital cortex					
Lt	17, 18	−8	−73	14	−3.83
Rt	17, 18	15	−87	14	−2.47
Cerebellum					
Lt		−30	−40	−22	−4.49
Rt		21	−46	−14	−3.38

Details as for Table 1.

nificantly greater activation than the alto-part-listening condition included bilateral temporal poles, bilateral cingulate gyri, bilateral occipital cortices and medial surface of bilateral cerebellum (Table 2, Fig. 3).

4. Discussion

4.1. Superior parietal lobule

PET studies of attention using the visual modality have provided evidence for neuroanatomical models with three attention networks, namely the posterior and anterior attention networks, and the vigilance network [3]. Superior parietal lobules belong to the posterior attention network and are thought to be involved in selective attention [3]. In a study of global/local visual processing using PET, Fink et al. reported that activation in left parieto–occipital cortex was observed, comprising the posterior portion of superior parietal lobule, during locally directed attention [10]. Based on these findings, superior parietal lobules may be activated when the subject selects and pays attention to a part of the target during both visual and auditory processing. In the alto-part-listening condition, our subjects listened to a harmony in which four vocal parts were simultaneously sounding and selected the tone of the alto part within the harmony. Whereas, in the harmony-listening condition, subjects answered only by listening to the harmony as a whole. Namely, subjects utilized more complex cognitive processing in the alto-part-listening condition compared with the harmony-listening condition. We think that bilateral superior parietal lobules were significantly activated by auditory selective attention in order to select the tone of the alto part within the harmony. It may be worth mentioning that right and left parietal cortices were activated by spatial and temporal attention, respectively [7]. Parietal cortex was bilaterally activated when subjects attended to both spatial and temporal aspects simultaneously [7]. Taking into account the difference in cognitive processing between the alto-part- and harmony-listening conditions, we can say that both spatial and temporal attention might have played a role in the activation of bilateral parietal cortices in the alto-part-listening condition.

We can interpret the activation of superior parietal lobule besides attention. In our study, left superior parietal lobule was possibly activated by the analysis of pitch, namely by spatial analysis of notes on a mental score. A PET study has shown that, when professional pianists read musical scores without listening or playing, the left parieto–occipital junction comprising the posterior portion of superior parietal lobule is activated [27]. The authors regarded the activation of this area as the participation of the dorsal visual system in spatial processing for reading scores, because the information of musical notations was derived through analysis of the spatial location of the notes and through their relative height separation directly related to pitch intervals. In our study, although subjects did not read scores visually, they imaged and read scores mentally, in order to analyze the pitch of the tones of the alto part. Therefore we speculate that left superior parietal lobule is involved in reading mental scores through the dorsal visual system as has been previously suggested [27].

4.2. Precuneus

In the experiment using functional MRI (fMRI), Le et al. reported that shifting attention for visual stimuli, when compared to sustained attention, produced the activation of bilateral cuneus/precuneus, bilateral superior parietal lobules and cerebellum [19]. Though the exact function of each region is still unclear, bilateral precunei and superior parietal lobules might be involved in visual attention. Consequently, we think that these two regions are playing a role in auditory attention in our experiment, too.

Activation of the left precuneus is possibly related to mental imagery processing of the alto part, namely to writing the alto part on a mental score. Using PET, Fletcher et al. reported the activation of precuneus as reflecting visual mental imagery [11]. In another PET study of functional neuroanatomy in nonmusicians, Platel et al. observed activation of the left cuneus/precuneus during a pitch task [23]. Platel et al. thought that the activation of the left cuneus/precuneus was due to the mental imagery strategy employed to perform the pitch task, since subjects had to write the tones on a 'mental stave' in terms of 'high' and 'low'. In our experiment, because subjects had to discriminate two tones which were separated by an octave and had the same syllable or pitch

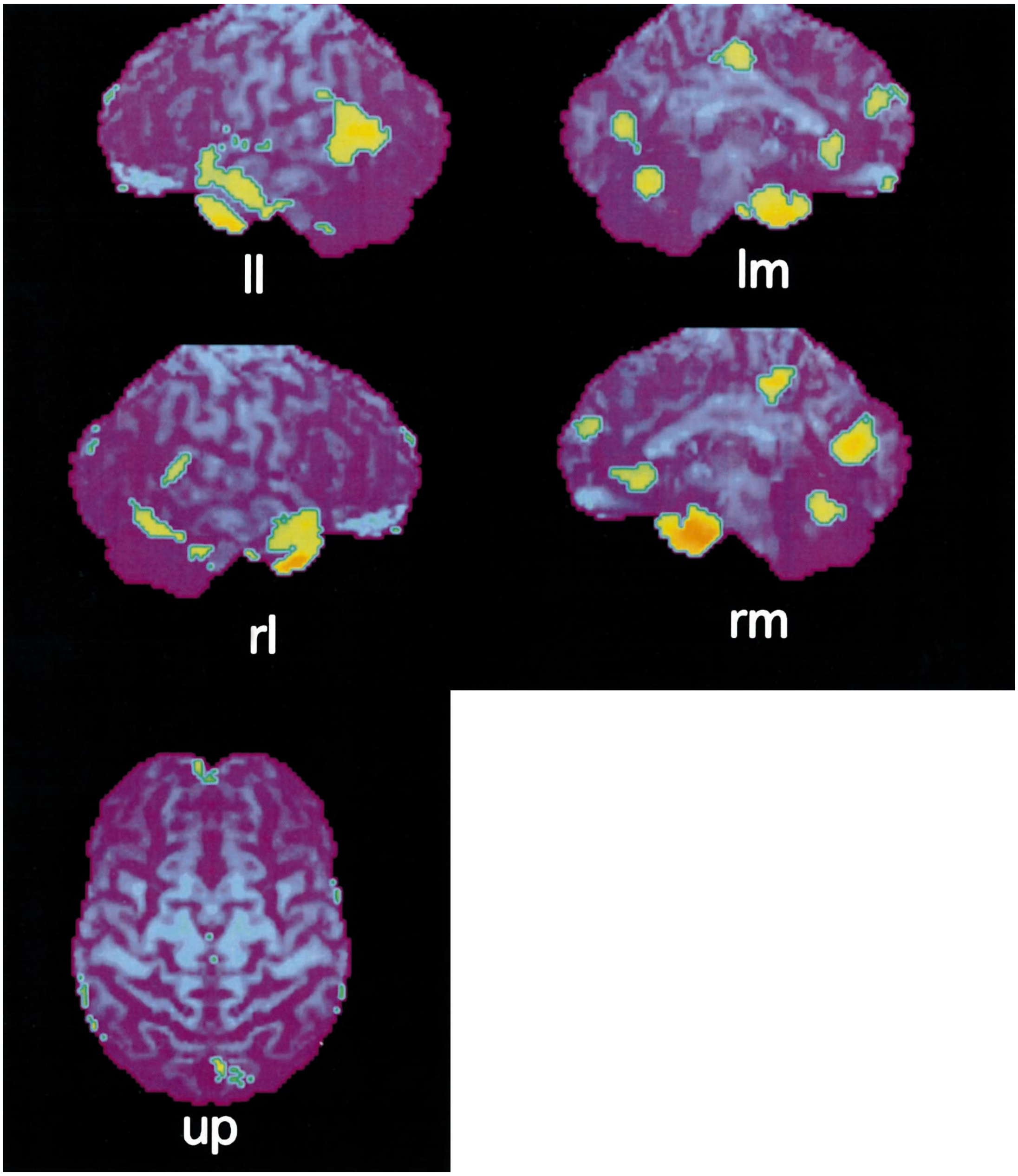

Fig. 3. Activation maps for the subtraction of the harmony-listening versus the alto-part-listening conditions. Areas of significant activation ($P<0.01$) are superimposed onto the surface maps of the averaged MRI of the brains of nine subjects. Temporal poles, anterior cingulate gyri, occipital cortices, and the cerebellum were bilaterally activated. Details as for Fig. 2.

name, we think that subjects also had to write the tones of the alto part on a mental score. As suggested by Platel et al., the left precuneus in our experiment might also be playing a role in writing tones on a mental score by identifying the pitch.

4.3. Other activated regions during the alto-part-listening condition

We believe that premotor areas and orbital frontal cortex were activated by the selective attention, attentional effort, and/or tonal-verbal associations of the pitch. Because the alto-part-listening condition utilized more complex cognitive processing than the harmony-listening condition, the former possibly required more attentional effort than the latter. Corbetta et al. reported that lateral orbito frontal cortex and premotor area were activated during selective attention [6]. The involvement of frontal lobe structures is thought to be proportional to the attentional effort [18]. The left premotor area might also have been related to making tonal-verbal associations for identification of pitch as shown by a PET study involving a pitch-interval classification task [31].

4.4. Regions activated during the harmony-listening condition

Regarding the activation of bilateral temporal poles, some authors have investigated patients who have undergone lobectomy of the anterior portion of unilateral temporal lobe [20,25]. These patients showed impairment in short term memory for melodies [25] and in discrimination of the metre [20]. Though their results were based on the assessment of nonmusicians, bilateral temporal poles might have been involved in the perception of music.

As for the activation of bilateral anterior cingulate gyri and occipital cortices, we think that it might be related to mental processes involved in trying to identify the musical pieces subjects listened to for the first time. In the PET study by Platel et al. mentioned above, left anterior cingulate gyrus and occipital cortex were activated during a familiarity task which required subjects to answer whether the tonal sequence brought to mind something that they knew [23]. We speculated that, in the harmony-listening condition, our subjects also tried to judge whether they had ever listened to or were familiar with that musical piece.

It is well established in clinical neurology and neuroscience that the cerebellum is essential for the coordination of movements. To date, anatomical, physiological and functional neuroimaging studies have suggested that the cerebellum participates in the organization of higher cognitive functions [26]. The cerebellum may be called into action particularly in anticipation of difficult, new learned tasks in which there is a need for high-quality sensory information [1,15]. In our experiment, the harmony-listening condition was performed first followed by the alto-part-listening condition. Thus, we propose that, in the harmony-listening condition, the cerebellum might also have been activated by anticipation of the task that required our subjects to deal with musical pieces that were unknown to them.

4.5. Hemispheric lateralization

In our study, there was no apparent lateralization between right and left hemisphere. Our results were not in agreement with the results of the reported literatures that showed the dominance of the left hemisphere in musicians dealing with musical stimuli, and of the right hemisphere in nonmusicians [4,8,16]. However, there is some evidence to oppose the left hemisphere dominance hypothesis in musicians [2]. Therefore, further studies are necessary in order to clarify the problem of hemispheric lateralization in musicians and nonmusicians.

5. Conclusion

When subjects concentrated on the alto part of the harmony, bilateral superior parietal lobules, bilateral precunei, bilateral premotor areas and bilateral orbital frontal cortices were significantly activated compared with the harmony-listening condition. We propose that functional neuroanatomical processes during the alto-part-listening condition were as follows: superior parietal lobules are activated in relation to auditory selective attention. The tones of the alto part are written on a mental score and left precuneus takes part in this process. Then, again in superior parietal lobules, the pitch of the tone of the alto part is analyzed on a mental score, such as whether the tone is tonic or dominant. Premotor areas and orbital frontal cortex play a role in selective attention and/or attentional effort. Bilateral precunei may also be related to auditory attention. We can say that both auditory selective attention and the perception of music via analytic processing allow musicians to listen to a certain vocal part within a harmony and, consequently, to play in soli during an ensemble. Further studies are necessary to clarify the differences of music processing between musicians and nonmusicians.

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