Passive music listening spontaneously engages limbic and paralimbic systems

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In this PET study, non-musicians passively listened to unfamiliar instrumental music revealed afterward to elicit strongly pleasant feelings. Activations were observed in the subcallosal cingulate gyrus, prefrontal anterior cingulate, retrosplenial cortex, hippocampus, anterior insula, and nucleus accumbens. This is the first observation of spontaneous responses in such limbic and paralimbic areas during passive listening to unfamiliar although liked music. Activations were also seen in primary auditory, secondary auditory, and temporal polar areas known to respond to music. Our findings complement neuroimaging studies of aesthetic responses to music that have used stimuli selected by subjects or designed by experimenters. The observed pattern of activity is discussed in terms of a model synthesizing emotional and cognitive responses to music. *NeuroReport* 15:2033–2037 © 2004 Lippincott Williams & Wilkins.

Key words: Brain; Emotion; Limbic; Music; Temporal pole

INTRODUCTION

Human music is hypothesized to have evolutionary adaptive value as a reward system, fostering interpersonal attachment and cooperative behaviors within social groups [1,2]. As such, it capitalizes on emotional reactions (aesthetic responses) that reflect its rewarding or aversive properties. Two human neuroimaging studies have demonstrated that musical stimuli that elicit strong positive or negative emotional responses activate limbic and paralimbic areas involved in affective processing. In one study, non-musicians listened to simple, experimenter-designed chordal melodies that varied parametrically in the degree of harmonic dissonance and unpleasantness, and rated the emotional valence and intensity of their responses [3]. Subjects' dissonance ratings correlated positively with activations in the parahippocampal gyrus and precuneus (medial Brodmann area [BA] 7), and correlated negatively with activations in the orbitofrontal cortex, subcallosal cingulate (BA 25), and ventromedial prefrontal cortex (BA 10). The critical involvement of these regions in emotional processing was later confirmed in a study of the brain lesions and musical abilities of a neurological amusic patient [4].

In a second study, musically literate subjects listened passively to well-loved instrumental classical pieces that they had selected for their shiver-inducing properties [5]. The intensity of subjects' chills while listening to their favorites, when contrasted with listening to other pieces of music, was correlated with brain activations in the nucleus accumbens, orbitofrontal cortex, and ventromedial prefrontal cortex, areas involved in the processing of rewarding emotions [6]. There were also activations in bilateral insula, anterior cerebellum, anterior cingulate, midbrain, ventral striatum, thalamus, bilateral amygdala, hippocampus, visual cortex, and supplementary motor area. The latter areas are likely involved in either emotional processing or in somatosensory-motor aspects of subjects' chills.

The musical stimuli of the foregoing studies were either designed by experimenters or selected by subjects. By contrast, the current study examined non-musicians listening passively to unfamiliar selections of 1930s Greek popular music that subsequent debriefing and analysis revealed elicited strongly pleasant feelings. Our subjects did not select the musical stimuli nor were they required to engage in cognitive processing related to making judgments of emotional quality (such as pleasantness ratings). We employed a passive listening task, rather than an emotional discrimination task, in order to assess whether brain areas subserving aesthetic responses to music would respond spontaneously, even without explicit instruction for cognitive processing of emotional responses. We chose unfamiliar music in order to examine whether emotion areas would respond in the absence of prior expectations and associations. If these areas were to show responses, then this would be evidence for a more direct route for aesthetic responses.

MATERIALS AND METHODS

Subjects: Five male and five female healthy subjects, with a mean age of 33.8 years (range 21–51 years), participated in the study after giving their informed consent (according to the Declaration of Helsinki and the Institutional Review

Board of the University of Texas Health Science Center). Each individual was right-handed, as confirmed by the Edinburgh Handedness Inventory. None was taking any medication or had a history of neurological or psychiatric illness. Subjects were all amateur dancers, with an average of 8.3 years of recreational dance experience. They had minimal formal musical education, and can be considered as non-musicians. The current study was part of a larger PET study exploring the neural control of leg movements to music during dance tasks adapted to lying in a scanner.

Tasks and stimuli: Subjects underwent four PET scans, two in the music listening condition and two during rest. The tasks were performed with the eyes closed, and the order was counterbalanced across subjects. The musical stimuli for the music listening task consisted of two wordless, instrumental songs of the rembetika style by the Greek composer Markos Vamvakaris (namely, *Frangosyriani* and *Oli i Rembetes Tou Dounia*). One song was played per scan, starting at the beginning of the song. The songs were presented via headphones using CoolEdit (Syntrillium) from a laptop computer. Subjects were instructed to listen attentively to the music with their eyes closed without making any movement or response.

All subjects reported during debriefing that the music was unfamiliar. In addition, they all reported having strongly favorable feelings for the music while listening to it in the scanner. Most of the subjects inquired into the identity of the music directly after the first scan of the music listening task, saying that they had liked the music. After completion of the study, half of the subjects consented to participate in a follow-up study of musical preferences. Subjects performed a listening task with 10 1 min musical fragments, two of which were the rembetika songs from the PET study as placed in random order. The remaining eight musical fragments were taken from international instrumental songs (e.g., Scandinavian folk songs, Argentine tangos) that were matched for the musical properties (e.g., tempo, instrumentation) of the Greek songs. Subjects responded to two questions for each fragment. First, how much do you like the song?, where a rating of 1 represents strong disliking and a 10 represents strong liking. Second, how stimulating or energizing is the song?, where a rating of 1 corresponds to low arousal or energy and a 10 corresponds to high arousal or energy. The combined mean (±s.d.) rating for the two Greek songs was (8.40±1.43) for liking and (7.50±1.84) for arousal. Over all 10 songs the mean ratings were (6.88±2.36) for liking and (7.12±1.98) for arousal. These results confirm that the unfamiliar Greek songs elicited strongly positive feelings in our subjects.

Procedure: PET was performed with a CTI HR+camera with a pixel spacing of 2.0 mm, 63 transaxial scan planes, and a z-axis field of view of 15.3 cm. Images were reconstructed using a Hann filter with a cut off frequency of 0.5 Hz, resulting in images with a spatial resolution of ∼4.3 mm (full-width at half-maximum). The data were smoothed with an isotropic 10 mm Gaussian kernal. Convex-hull spatial normalization was performed prior to group subtraction (n=10) using change distribution analysis [7]. Statistical maps were overlaid onto group mean anatomical MRI's acquired with an Elscint 1.9 T Prestige system with an in-plane resolution of 1 mm^2 and 1.5 mm slice thickness. Imaging procedures and data analysis were performed exactly as described in Parsons and Osherson [8] and Brown *et al.* [9], according to the methods of Fox *et al.* [7] and Mintun *et al.* [10]. In this method, the critical-value threshold for regional effects is not raised to correct for multiple comparisons since omnibus statistics are established before *post hoc* analysis. The musical stimuli were started 30 s prior to injection of the $H_2{}^{15}O$ bolus. The subjects heard ∼90 s of music per scan. An individualized thermally-molded plastic face mask was used during image acquisition to restrain head movement.

RESULTS

The cerebral blood flow increases reported here are for the music listening task contrasted with rest (Fig. 1, Table 1). Principal activations were seen in the primary auditory cortex (BA 41), auditory association cortex (BA 22/42) and superior temporal sulcus bilaterally, and in the middle

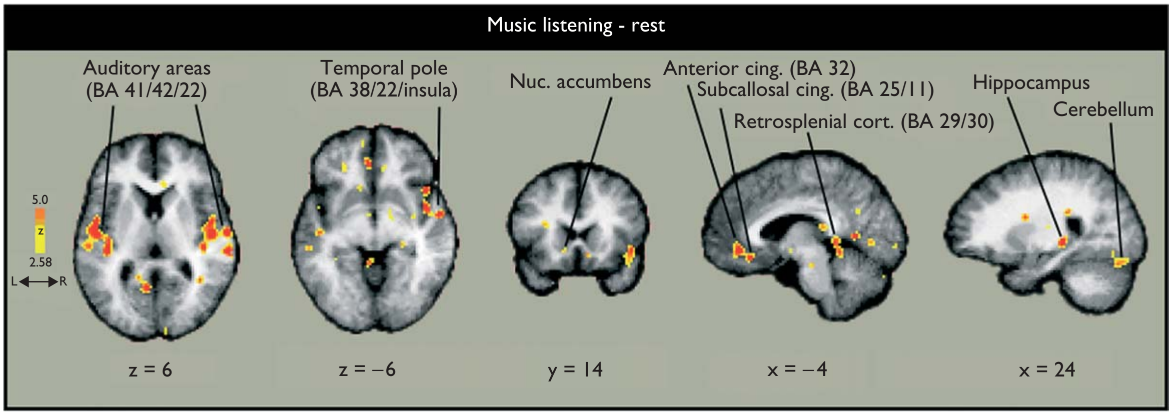

Fig. 1. Axial (left two), coronal (middle) and sagittal (right two) views of cerebral blood flow changes during music listening contrasted to rest. The Talairach coordinates of the major activations (contrasted to rest) are presented in Table 1. The averaged activations for 10 subjects are shown registered onto an averaged brain. The right side of the figure is the right side of the brain. At the left end of the figure is a color scale for the intensity of the activations. The intensity threshold is $z > 2.58$, $p < 0.005$ (one-tailed). The Talairach coordinates for the left nucleus accumbens (middle slice) are (−10, 14, −6) and those for the right lateral cerebellum (right slice) are (25, −78, −20). These two areas of interest are below the threshold for activations reported in Table 1.

Table 1. Stereotaxic coordinates and *z*-score values for activations in the music listening task contrasted to rest. Brain atlas coordinates are in millimeters along the left-right (*x*), anterior-posterior (*y*), and superior-inferior (*z*) axes. In parentheses after each brain region is the Brodmann area. The intensity threshold is $z > 3.72$, $p < 0.0001$ (one-tailed).

	Region	*x*	*y*	*z*	*z*-score
Temporal cortex					
Right	Primary auditory cortex (41)	42	−28	10	4.99
	Secondary auditory cortex (42)	60	−14	8	4.75
	Superior temporal sulcus (22/21)	60	−31	4	4.72
	Primary auditory cortex (41)	48	−18	8	4.58
	Temporal pole/planum polare (38/22)	44	12	−4	4.48
	Secondary auditory cortex (42)	64	−30	12	4.48
	Secondary auditory cortex (22)	46	−10	4	4.34
	Middle temporal gyrus (21)	54	−8	−6	4.17
Left	Superior temporal sulcus (22/21)	−48	−16	2	5.10
	Primary auditory cortex (41)	−34	−38	14	4.55
	Primary auditory cortex (41)	−38	−30	6	4.55
	Primary auditory cortex (41)	−33	−28	18	3.93
Limbic areas					
Right	Hippocampus	25	−32	−2	4.51
	Anterior insula (temporal pole)	44	−2	−6	4.44
Left	Retrosplenial cortex (BA 29/30)	−2	−44	0	4.82
	Anterior insula	−46	−6	4	4.62
	Anterior cingulate cortex (32)	−4	34	−6	4.13
	Subcallosal cingulate gyrus (BA 25/11)	−4	24	−12	3.82
Other areas					
	Lingual gyrus (18)	−6	−60	4	4.37
	Lingual gyrus (19)	16	−56	−2	4.06
	Inferior parietal lobule (39)	−34	−68	18	3.89

temporal gyrus (BA 21) of the right hemisphere. There were also activations in the right superior temporal pole, corresponding to BA 38/22 and the adjacent insula. These temporal cortical activations are presumably associated with the perceptual and cognitive representations of the structure of the presented music. In addition, there were responses in paralimbic and limbic areas: (1) the left subcallosal cingulate (BA 25/11); (2) left anterior cingulate (BA 32), the region known to activate for affective tasks [11]; (3) left retrosplenial cortex (BA 29/30); and (4) right hippocampus. Figure 1 also shows two areas of activation that occurred in regions of interest ($z > 2.58$, $p < 0.005$, one-tailed) but that were below our threshold for reporting. One occurred in the left nucleus accumbens. A second set occurred in the cerebellum, with a small focus in the right anterior hemisphere (lobule III), and more extensive ones occurring bilaterally in intermediate and lateral aspects of the posterior hemisphere in lobules VI, IV, V, and Crus I, as well as in the dentate nuclei.

DISCUSSION

These findings demonstrate spontaneous activation of limbic and paralimbic areas during task-free, passive listening to unfamiliar although liked music. As expected, activations were observed in primary and secondary auditory cortices, in agreement with studies of passive listening to either monophonic melodies or harmonized music [12–14]. Unlike previous studies, we observed additional activations in the temporal pole and several limbic and paralimbic areas, including the subcallosal cingulate gyrus, the affective division of the anterior cingulate cortex, retrosplenial cortex, hippocampus, anterior insula, and nucleus accumbens. These findings probably reflect the fact that the stimuli we used were musically complex and were strongly liked by the subjects. Consistent with hypotheses about positive emotions being supported by the left hemisphere, we observed more limbic and paralimbic activations on left, perhaps reflecting subjects' positive aesthetic responses. These functional neuroanatomical data complement studies of music and emotion using high-temporal-resolution methods such as electroencephalography and magnetoencephalography.

These findings can be usefully compared with the two prior studies of aesthetic responses to music. In the study of dissonance and consonance discrimination [3], "pleasantness" ratings by subjects were positively correlated with activation in the left subcallosal cingulate gyrus and right orbitofrontal cortex (BA 11), and negatively correlated with activation in the right parahippocampal gyrus and precuneus. We observed activity in left subcallosal cingulate, close to that in the prior study (−4, 24, −12 and −1, 17, −15, respectively). Because our study involved passive listening without discrimination processing, we can conclude with greater confidence that areas such as the subcallosal cingulate are related to the experience of occurrent emotions rather than discrimination processing for emotion. Our medial prefrontal activations were at the border of BA 25/11, and hence we did not observe a distinct activation in the orbitofrontal cortex (BA 11). In light of the previous findings about dissonance discrimination [3], we would expect there to be spontaneous activations in brain centers mediating aversive emotions during passive listening to unfamiliar music that elicits negative emotional responses.

In the study of aesthetic responses to shiver-inducing music [5], the intensity of chills was positively correlated with activations in the ventral striatum (nucleus accumbens), right thalamus, right orbitofrontal cortex, anterior cingulate (BA 24/32), bilateral insula, supplementary motor area, midbrain, and cerebellum. Several of these regions were active in our study, although not always in the same location. Some differences between the two sets of data are perhaps related to the physical responses (chills) of the subjects, which apparently did not occur here. Our anterior cingulate activation was 2 cm more ventral than that observed in the prior study, squarely within BA 32 rather than at the junction of BA 24 and BA 32. Our activation in the left nucleus accumbens at (−10, 14, −6) replicated that reported earlier at (−13, 12, −5). In addition, we detected activations in right hippocampus and left retrosplenial cortex (BA 29/30), areas implicated in emotional processing [15] but not active in earlier studies.

Activity was also detected in the anterior and especially posterior cerebellum, although at a slightly reduced threshold of significance. Because there was no motor behavior or observable motor cortical activity, these activations are not likely related to the motor function classically associated with the cerebellum. A number of recent studies have observed cerebellar activity in support of non-motor processing, often with corroborating evidence from neurological patients (reviewed in [16]). Cerebellar activations during melody or pitch discrimination tasks, in which motor components are absent or are eliminated through subtraction, have been observed bilaterally in posterior lateral cerebellar regions (lobules V and VI) close to those seen here [17]. Thus, the activations observed here in posterior regions would appear to support aspects of perceiving music. Activity in intermediate anterior cerebellum may be in support of affective processing [16].

The results of this study can be embedded in a fuller view of brain areas subserving both the emotive and structural (auditory) aspects of musical experience. It is possible that the superior temporal pole (i.e., BA 38/22 and the adjacent insula) serves as a point of bifurcation in neural circuitry for processing music. Specifically, we surmise that neurons from this region project both to limbic/paralimbic areas involved in emotional processing and to premotor areas which may be involved in discrimination and generative processing. The latter regions, in turn, are implicated in processing structural features of music. In this sense, the superior temporal pole may be in a position to convey the confluence of affective and structural information elicited by musical sound.

There is evidence that the superior temporal pole receives afferents, and hence lower-level auditory information, from secondary auditory cortex (BA 22). An anatomical tracer study in monkeys demonstrated that the dorsolateral part of the temporal pole (which may correspond to BA 38 in humans) receives inputs from posterior auditory association cortex [18]. Unfortunately, anatomical data on the afferent connections of the temporal pole in humans is lacking. However, a host of imaging studies has shown that auditory tasks employing complex musical stimuli activate the superior temporal pole [9,19,20]. Such results suggest that the superior temporal pole comprises a type of tertiary auditory cortex, receiving input from more posterior parts of the superior temporal plane. Interestingly, in the previous study of emotional discrimination processing [3], subtraction of a noise-listening condition from either the most dissonant or the most consonant conditions led to signal in right superior temporal pole, in nearly the identical location to that reported here. As this activation occurred in both the most dissonant and most consonant conditions, the authors interpreted it as being related to auditory processing rather than emotion. However, this finding is fully consistent with the notion that the superior temporal pole is a gateway to the limbic areas highlighted in both studies. Additional cytoarchitectonic support for this role comes from the observation that the temporal pole is composed of dysgranular, paralimbic-type association cortex representing the cytoarchitectonic transition between granular isocortex and agranular allocortex [21].

Looking now to projections, the temporal pole projects to orbitofrontal cortex, subcallosal cingulate, amygdala (basolateral nucleus), and hippocampus [22]. There is a well-characterized fiber pathway, the uncinate fasciculus, that connects the temporal pole with the orbitofrontal cortex (BA 11 and 12) and subcallosal cingulate (BA 25). Thus, the uncinate fasciculus appears to be a good candidate for a pathway carrying information from the superior temporal pole to orbital prefrontal cortex in the service of emotional processing of music.

Finally, the superior temporal pole may also project to premotor areas implicated in structural processing for music. A major component of this system is the frontal operculum (i.e., the opercular part of BA 6/44/45). This area, while not activated in the current study of passive listening, has been implicated in several kinds of neuroimaging studies, for example, of singing [9], auditory mental imagery for song [23], and discrimination processing for pitch and rhythm [12,19,24]. At present, we know of no evidence for direct connectivity between the temporal pole and frontal operculum. However, there is strong evidence in both the human and monkey that the opercular part of the temporal pole has reciprocal connections with the anterior insula [25], an area active in the current study. In addition, there is evidence that the insula has reciprocal connections with the frontal operculum (BA 44/45), including a projection from the middle region of the insula to the opercular part (i.e., the face representation) of the premotor cortex [25]. Thus, it is possible that the temporal pole communicates with the frontal operculum by means of the insula. If so, this would lend further support to a pivotal gateway function of the superior temporal pole in music processing.

CONCLUSIONS

The findings of the current study demonstrate that novel musical stimuli heard without a conscious goal can elicit strongly positive feelings and limbic activations, just as familiar favorites do. This suggests that there is a direct route for such aesthetic responses, one that may serve as the initial basis for our preferences as well as the basis for the multiple social uses of music, such as in film and television.

REFERENCES

1. Wallin NL, Merker B and Brown S (eds). *The Origins of Music*. Cambridge, MA: MIT Press; 2000.
2. Brown S. Biomusicology and three biological paradoxes about music. *Bull Psychol Arts* 2003; **4**:15–17.
3. Blood AJ, Zatorre RJ, Bermudez P and Evans AC. Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature Neurosci* 1999; **2**:382–387.
4. Peretz I, Blood AJ, Penhune V and Zatorre RJ. Cortical deafness to dissonance. *Brain* 2001; **124**:928–940.
5. Blood AJ and Zatorre RJ. Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proc Natl Acad Sci USA* 2001; **98**:11818–11823.
6. Berridge KC. Pleasures of the brain. *Brain Cogn* 2003; **52**:106–128.
7. Fox PT, Mintun M, Reiman E and Raichle ME. Enhanced detection of focal brain responses using inter-subject averaging and change-distribution analysis of subtracted PET images. *J Cerebral Blood Flow Metab* 1988; **8**:642–653.
8. Parsons LM and Osherson D. New evidence for distinct right and left brain systems for deductive *vs* probabilistic reasoning. *Cerebr Cortex* 2001; **11**:954–965.
9. Brown S, Martinez MJ, Hodges DA, Fox PT and Parsons LM. The song system of the human brain. *Cogn Brain Res* 2004; **20**:363–375.
10. Mintun M, Fox PT and Raichle ME. A highly accurate method of localizing regions of neuronal activity in the human brain with PET. *J Cerebr Blood Flow Metab* 1989; **9**:96–103.
11. Bush G, Luu P and Posner MI. Cognitive and emotional influences in anterior cingulate cortex. *Trends Cogn Sci* 2000; **4**:215–222.
12. Zatorre RJ, Evans AC and Meyer E. Neural mechanisms underlying melodic perception and memory for pitch. *J Neurosci* 1994; **14**: 1908–1919.
13. Ohnishi T, Matsuda H, Asada T, Aruga M, Hirakata M, Nishikawa M *et al*. Functional anatomy of musical perception in musicians. *Cerebr Cortex* 2001; **11**:754–760.
14. Menon V, Levitin DJ, Smith BK, Lembke A, Krasnow BD, Glazer D *et al*. Neural correlates of timbre change in harmonic sounds. *Neuroimage* 2002; **17**:1742–1754.
15. Cato MA, Crosson B, Gokcay D, Soltysik D, Wierenga C, Gopinath K *et al*. Processing words with emotional connotation: an fMRI study of time course and laterality in rostral frontal and retrosplenial cortices. *J Cogn Neurosci* 2004; **16**:167–177.
16. Schmahmann JD (ed.). *The Cerebellum and Cognition*. San Diego: Academic Press; 1997.
17. Gaab N, Gaser C, Zaehle T, Jancke L and Schlaug G. Functional anatomy of pitch memory: an fMRI study with sparse temporal sampling. *Neuroimage* 2003; **19**:1417–1426.
18. Moran MA, Mufson EJ and Mesulam M-M. Neural inputs into the temporopolar cortex of the rhesus monkey. *J Comp Neurol* 1987; **256**: 88–103.
19. Koelsch S, Gunter TC, von Cramon DY, Zysset S, Lohmann G and Friederici AD. Bach speaks: a cortical ''language-network'' serves the processing of music. *Neuroimage* 2002; **17**:956–966.
20. Parsons LM, Sergent J, Hodges DA and Fox PT. The brain basis of piano performance. *Neuropsychologia*, in press.
21. Mesulam M-M. Patterns in behavioral neuroanatomy: association areas, the limbic system, and hemispheric specialization. In: Mesulam M-M (ed.). *Principles of Behavioral and Cognitive Neurology*, 2nd edn. Oxford: Oxford University Press; 2000, pp. 1–70.
22. Chabardes S, Kahane P, Minotti L, Hoffmann D and Benabid AL. Anatomy of the temporal pole region. *Epileptic Disord* 2002; **4**:S9–S15.
23. Halpern AR and Zatorre RJ. When that tune runs through your head: a PET investigation of auditory imagery for familiar melodies. *Cerebr Cortex* 1999; **9**:697–704.
24. Rao SM, Mayer AR and Harrington DL. The evolution of brain activation during temporal processing. *Nature Neurosci* 2001; **4**:317–323.
25. Mesulam M-M and Mufson EJ. The insula of Reil in man and monkey. In: Jones EG and Peters AA (ed.). *Cerebral Cortex*, Volume 4. New York: Plenum Press; 1985, pp. 179–226.

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