Neural correlates of absolute pitch differ between blind and sighted musicians

Nadine Gaab, Katrin Schulze, Elif Ozdemir and Gottfried Schlaug

Neuroimaging Laboratory, Department of Neurology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts, USA

Correspondence and requests for reprints to Dr Nadine Gaab, PhD, Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology,
77 Massachusetts Avenue, Room NE46-4037C, Cambridge, MA 02139, USA
Tel: +1 617 253 3415; e-mail: gaab@mit.edu or gschlaug@bidmc.harvard.edu

Received 22 August 2006; accepted 4 September 2006

Several reports have indicated a higher incidence of absolute pitch in blind than in sighted musicians. Employing a pitch memory task, we examined whether a blind absolute pitch musician would rely on different neural correlates than a group of sighted absolute pitch musicians. The blind musician showed significantly more activation of bihemispheric visual association areas, lingual gyrus, parietal and frontal areas than the sighted musicians. Sighted musicians showed more activation of the right primary auditory cortex and the cerebellum when compared with the blind musician. These differences in the activation pattern suggest the use of a different neural network including visual association areas while performing pitch categorization and identification in this blind musician in comparison with sighted musicians. *NeuroReport* 17:1853–1857 © 2006 Lippincott Williams & Wilkins.

Keywords: absolute pitch, blind, functional plasticity, music, occipital lobe, parietal lobe

Introduction

Blind individuals show not only superior abilities in the auditory domain (e.g. [1–3]) and alterations in the functional anatomy for a variety of auditory tasks (e.g. [4,5]), but also a higher incidence of absolute pitch [6]. Absolute pitch has been defined as the ability to identify a particular pitch of the Western musical scale without any external reference tone (e.g. [7,8]). This ability is present only in a minority of trained musicians and seems to be strongly related to an early age of commencement of musical training [9,10]. Nevertheless, even in those who start musical training early, the ability is very rare, which suggests additional factors, such as unique neural correlates and/or genetic determinants that might facilitate acquisition of absolute pitch early in life. Given the low incidence of absolute pitch in the sighted musician population, investigating the possible factors that might lead to a higher incidence in blind musicians is of particular interest.

So far only one study assessed possible differences in the functional anatomy of an auditory task in a blind musician with absolute pitch in a region-specific comparison with a group of sighted musicians [11]. Participants in this study performed a 'moveable do' solfeggio task, which is familiar to most musicians and can be performed by musicians with and without absolute pitch. Results showed an additional recruitment of visual and parietal areas in the blind musician with absolute pitch in comparison with the sighted group. These authors suggested that the investigated blind individual may have recruited additional 'visual' cortical areas for musical processing in response to deprivation of a major sensory modality, resulting in a remarkable musical aptitude. Nevertheless, it remains unclear whether this result is specific for a musical task that has a strong relationship with the absolute pitch skill itself or whether the involvement of visual areas can also be observed in tasks that do not necessarily require absolute pitch ability.

The goal of this study was to assess the shared and distinct neural correlates of absolute pitch using a classic pitch memory task and a silent scanning design (e.g. [12]) comparing a blind absolute pitch musician with a group of sighted absolute pitch musicians on a voxel-by-voxel comparison.

Materials and methods

Participants

One blind and nine sighted male musicians with absolute pitch participated in the study. The sighted participants' mean age was 23.2 years (SD 2.4) and they started their musical training at an average of 7.8 (SD 3.1) years. The blind individual was 28 years old and was diagnosed with Leber's congenital amaurosis in 1998. He gradually became blind starting from the age of 7 and turned completely blind at the age of 13 with remaining minor light perception. He started playing an instrument at 8 years of age, completed conservatory for piano and guitar and has a university degree in composition.

All individuals were strongly right handed according to a standard handedness questionnaire [13]. This study was approved by the institutional review board of the Beth Israel Deaconess Medical Center.

Determination of absolute pitch ability

A standard method [10] was used to test the participants' absolute pitch ability. Participants were asked to name 52

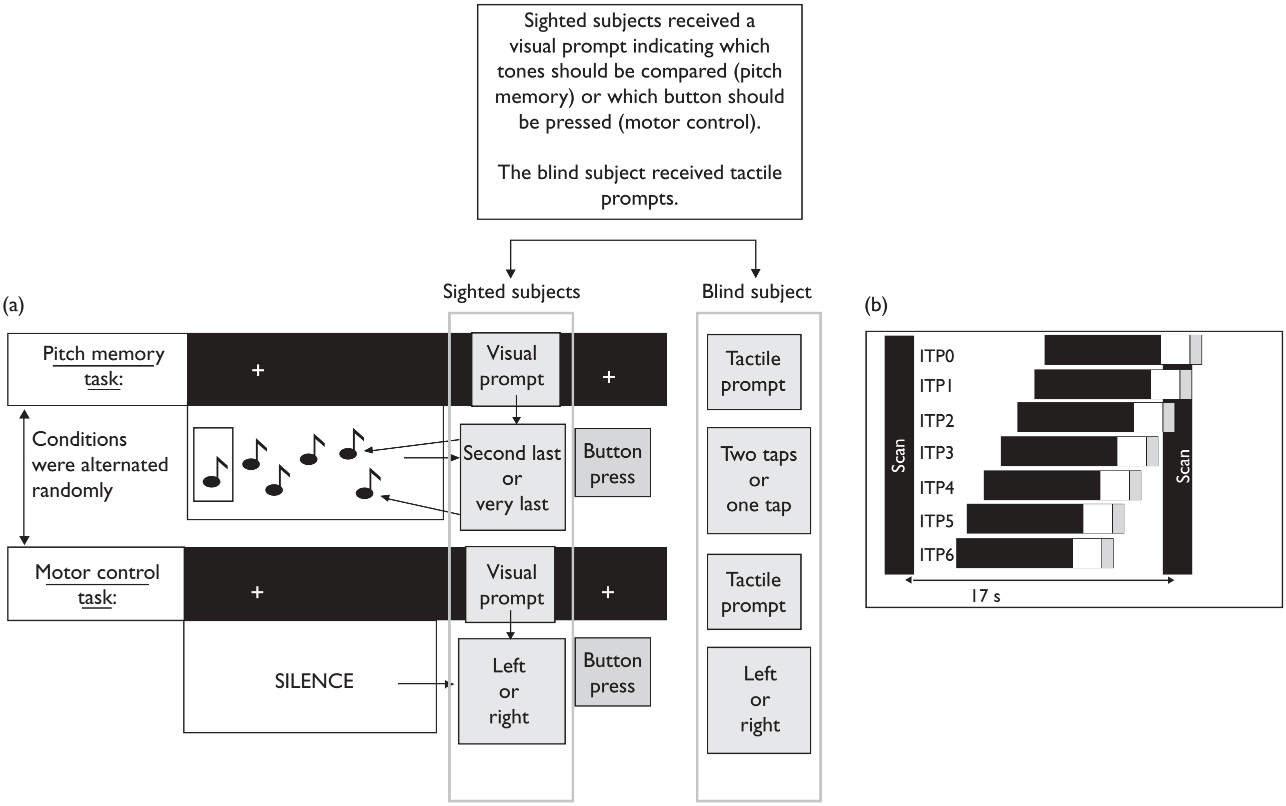

Fig. 1 (a) Experimental task for sighted and blind musicians. (b) Experimental scanning paradigm (modified from [14], with permission from Elsevier). The gap between the end of the auditory stimulation and the beginning of the image acquisition was jittered to obtain a large portion of the hemodynamic response function.

sine wave tones. According to the definition of absolute pitch [7,8], no reference tones or feedback about their performance was given to the participants at any time. Participants were instructed to press a button as soon as they knew the name of the given tone. In accordance with previous studies (e.g. [7]), we regarded discrepancies of one semitone lower or higher than the actual presented tone as a correct answer. Only participants who performed more than 90% correct were regarded as musicians with absolute pitch. The blind musician also performed within that range.

Functional magnetic resonance imaging task design (Fig. 1a)

All participants performed a pitch memory task, which was contrasted with a motor control task. During the pitch memory task, participants were instructed to listen to a sequence of individual sine wave tones (either 6 or 7) with a total duration of 4.6 s for each sequence. Participants were asked to compare either the last or the second to last tone to the first tone, and were asked to decide whether these tones were the 'same' or 'different' (Fig. 1a) [14]. The total number of tones per sequence (6 or 7) and the comparison to be made ('second to last', or 'very last' tone with first tone) varied across sequences. Target tones corresponded to the frequencies of semitones in the western musical scale (based on $A = 440$ Hz) and ranged in frequency from 330 Hz (D E4) to 622 Hz (D E5). The intervening microtones, whose purpose was solely to serve as distractors (modeled after [15]), deviated from the 12 tones of the equal tempered system. Each tone was 300 ms long with an attack and decay rate of 50 ms and a pause of 300 ms between the tones.

Sighted individuals had to compare either the last or the second to last tone depending on a visual prompt 'second last' or 'very last' to the first tone and we asked individuals to decide whether these tones were the same or different (Fig. 1). The blind individual received a tactile prompt (one tap for 'very last' or two taps for 'second to last' on the left or right leg) for the pitch memory task. The sequence length was kept constant for the six and seven tone sequences by introducing a short pause before the first tone for the six tone sequences. Sighted musicians were asked to keep their eyes open and fixate a cross in the middle of the screen that was only interrupted for the visual prompt. The motor control task was a rest condition with eye fixation. Participants were asked to press a button depending on a short visual or tactile prompt ('right' or 'left'; Fig. 1). The behavioral performance during the functional magnetic resonance imaging (fMRI) session was calculated as correct responses (%).

Functional magnetic resonance imaging scanning

FMRI was performed on a Siemens Vision (Siemens, Erlangen, Germany) 1.5 T whole-body magnetic resonance imaging scanner using the standard head coil. A gradient-echo echoplanar imaging sequence with an effective repetition time of 17 s, an echo time of 50 ms and a matrix of 64×64 was used. Using a midsagittal scout image, a total of 24 axial slices ($4 \times 4 \times 6\,\text{mm}^3$ voxel size) – parallel to the bi-commissural plane – were acquired over 2.75 s, each 17 s. Initiation of the first set of 24 slices was triggered by a transistor–transistor logic pulse from a PC and all subsequent magnetic resonance acquisitions were synchronized with stimulus presentation. A high-resolution T1-weighted scan ($1\,\mathrm{mm}^3$ voxel size) was acquired for anatomical coregistration. We used a variation of a sparse temporal sampling technique ([12], Fig. 1b) acquiring one set of 24 axial slices every 17 s to circumvent the scanner noise interferences.

Functional magnetic resonance imaging data analysis

FMRI data were analyzed using the SPM99 software package (Institute of Neurology, London, UK). Each set of axial images for each participant was realigned to the first image, coregistered with the corresponding T1-weighted data set, spatially normalized to the SPM99 template and smoothed with an isotropic Gaussian kernel of 8 mm. Condition and participants' effects were estimated using a general linear model [16]. The effect of global differences in scan intensity was removed by scaling each scan in proportion to its global intensity. Low-frequency drifts were removed using a temporal high-pass filter (cutoff 200 s). As we employed a sparse temporal sampling design, we did not convolve our data with the hemodynamic response function and we did not apply a low-pass filter. We used a fixed-effects model for all 10 participants together, and group analyses were performed by directly contrasting the appropriate scans within the fixed-effects model but weighting the blind musician appropriately in the contrast manager (nine times higher than each of the sighted musicians). All results are reported for the contrast pitch memory > motor control. All reported coordinates are Montreal Neurological Institute coordinates.

Results

Mean activation in sighted musicians (FDR-corrected, $P<0.05$)

This group analysis revealed activation of the bilateral superior temporal gyrus (−64/−22/4; 66/−14/4), bilateral inferior frontal gyrus (−52/12/24; 52/14/−14), bilateral cerebellum (−38/−68/−26; 30/−72/−26), anterior cingulate (2/26/36), bilateral middle frontal gyrus (−46/46/−8; 30/52/−12), bilateral inferior parietal regions (−40/−56/54; 48/−50/56) and cuneus (0/−84/14).

Activation in the blind musician (FDR-corrected, $P<0.05$)

Regions activated for the blind musician included the bilateral middle occipital gyrus (−34/−78/−16; 28/−84/−16), bilateral inferior/superior parietal lobe (−32/−54/64; 28/−68/54), bilateral inferior frontal gyrus (−52/10/28; 54/4/34), left middle frontal gyrus (−48/2/46; 50/−2/46), right angular gyrus (38/−80/28), bilateral superior temporal gyrus (−64/44/6; 66/−22/8), left cuneus (−8/−94/2), left middle frontal gyrus (−40/46/18), right middle temporal gyrus (64/−38/2), bilateral precuneus (left: −24/−72/50 and right: 12/−94/0), posterior cingulate (2/−46/6), left inferior temporal gyrus (−50/−68/−2), left lingual gyrus (−18/−84/−16), left cerebellum (−40/−48/−30) and right medial frontal gyrus (4/−4/60).

Activation in the blind compared with the sighted participants (FDR-corrected, $P<0.05$)

This comparison revealed activation of the bilateral lingual/middle occipital gyrus (−34/−78/−16; 28/−84/−14), left inferior parietal regions (−40/−44/50), bilateral inferior/middle frontal regions (−52/10/30; 54/4/34), bilateral superior occipital gyrus (−30/−84/22; 38/−82/28), right superior parietal regions (28/−68/54), left middle frontal regions (−40/46/18), left inferior temporal gyrus (−50/−68/−2), left precuneus (−24/−72/48), anterior cingulate (4/2/50) and left superior temporal lobe (−62/−46/4).

Activation in sighted musicians compared with blind

No significant differences were observed at FDR-corrected $P<0.05$ level. At a lower level ($P<0.001$, uncorrected), the sighted musicians with absolute pitch had more activation of the right superior temporal gyrus (66/−12/2), left cerebellum (−2/−58/−38), right inferior parietal regions (52/−52/54), bilateral precuneus (−44/−74/36; 2/−62/32) and right supramarginal gyrus (56/−54/28).

Activation in sighted and blind musicians

Sighted masked with blind (inclusive mask, FWE corrected, $P<0.05$): this analysis revealed activation of the bilateral superior temporal gyrus (−64/−22/4; 66/−16/6 and more anterior −54/16/−12; 52/14/−14), bilateral inferior parietal regions (−40/−56/54; 52/−40/52), bilateral inferior frontal regions (−52/12/24; 54/12/24), bilateral cerebellum (−28/−74/−24; 30/−72/−26), bilateral superior parietal regions (−18/−66/54; 10/−70/56), right middle frontal gyrus (36/2/62) and the anterior cingulate (2/28/36) (Fig. 2).

Discussion

When contrasting the two groups, the blind musician showed more activation of a set of brain regions that included the lingual gyrus, parietal and visual association areas. Numerous studies have suggested a recruitment of visual areas when blind individuals process auditory and somatosensory information (e.g. [17–19]).

Our study showed an involvement of visual association but not primary visual areas within a blind musician with absolute pitch performing a classical pitch memory task. This strongly supports the study by Ross *et al.* [11], who revealed cross-modal plasticity in visual association and parietal areas in a congenitally blind musician while performing a different music task. These authors interpreted their results with a recruitment of visual areas as accessory musical processing regions in response to sensory deprivation. Furthermore, they suggested that their participants' outstanding musical aptitude might have been the result of early reorganization in the visual system. The results of our study show that this functional reorganization of the visual system is not restricted to one musical task and suggests that the additional recruited regions are not necessary for accessory musical processing regions but necessary for more accessory auditory processing regions.

Several studies for blind and deaf individuals have revealed that the processing demands of a person appear to influence what aspects of auditory or visual processing might be modified in the brain (e.g. [20]). In our case, the blind musician had to rely on auditory information only since the age of 13 years and started playing an instrument at the age of 8. This supports the theory that the additional

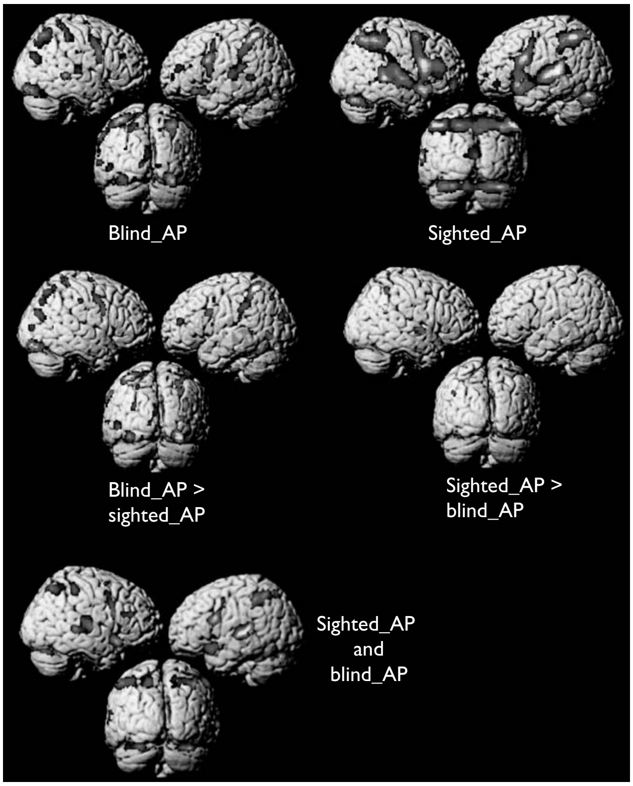

Fig. 2 The first row shows the activation pattern (pitch memory > control) for the two groups separately. The second row shows the direct voxel-by-voxel comparison between the two groups. The third row shows the inclusive mask of both groups that shows regions that are activated in both groups.

recruitment of visual areas might have led to the development of absolute pitch through the recruitment of accessory auditory processing regions. One alternative explanation might lie in the differences between our task for the sighted and the blind individuals. The sighted musicians were prompted for their behavioral response with a visual prompt, whereas the blind participant received a tactile prompt. Nevertheless, we do not think that this led to the differences in the functional anatomy between the two groups for the following reason: the prompt was presented after the tone sequence and the peak of the hemodynamic response function in response to this prompt will occur after 4–6 s, and therefore would only be picked up by a minority of our image acquisitions owing to the jittered timing. Furthermore, increased activation of visual association areas might have been expected in the group that had their eyes open and not the blind one.

In addition to the increased use of visual areas in the blind individual, there is a decrease in activation within the temporal lobe and the cerebellum in comparison with the sighted individuals. Several studies showed the involvement of the cerebellum in several auditory and musical tasks (e.g. [12,14]). The lack of cerebellar activation in the blind musician could be an additional indicator for a use-dependent reorganization. Important functions of the cerebellum might have been redirected to the visual association areas or the lingual gyri in the blind musician.

Furthermore, sighted absolute pitch musicians seem to rely more on auditory regions within the temporal lobe indicating a network consisting of auditory, parietal and cerebellar regions in the sighted individuals, whereas the blind musician showed a network consisting of less auditory activation but more activation of visual association areas and the lingual gyri, an area that has also been identified as being involved in visual processing (e.g. [21]). This could be explained by the fact that the sighted individuals are dependent on 'typical' auditory areas to process incoming auditory information and cannot rely on additional areas within the visual areas, whereas the blind individual uses different areas for the incoming auditory stimuli. This suggestion is supported by several studies, which showed improved auditory processing for various stimuli within the blinds compared with sighted individuals [2,4,22,23], which could be due to the fact that the blind recruit additional cortical structures for auditory processing.

A growing body of evidence indicates that early blind individuals are able to recruit the visually deafferented occipital cortex for nonvisual tasks, including auditory information processing [23,24]. This cross-modal plasticity may provide an additional substrate for the development of absolute pitch in the blind compared with the sighted, which could account for the higher than expected prevalence and prolonged critical period of absolute pitch development in the blind [6]. The ability to perceive auditory stimuli as belonging to categories is the key feature that differentiates musicians with absolute pitch from individuals without. Recent evidence demonstrates that visual association areas are involved in the processing of categorical visual information (e.g. [25]). In the absence of sight, these visual association areas may facilitate categorization of auditory information. Such cross-modal cortical plasticity may at least partially account for our finding that blind individuals with absolute pitch are not as dependent upon the same structure in the auditory cortex that correlate with absolute pitch ability among the sighted.

This study is the first one that compared a blind absolute pitch musician with a control musician group with absolute pitch on a voxel-by-voxel comparison. Although our report is limited in its scope and does not establish a specific mechanism for the acquisition of absolute pitch in blind musicians, our results argue that absolute pitch among the blind is not due to an enhancement of the same determinants that are critical within sighted absolute pitch musicians.

Conclusion

The notion that cross-modal plasticity involving the occipital cortex may provide an additional neural substrate for the development of absolute pitch in the blind is an intriguing hypothesis that merits further investigation. It would be informative for future studies to replicate the current findings in a larger group of blind musicians as well as to further investigate the anatomical and functional underpinnings of absolute pitch in blind and sighted musicians.

Acknowledgements

We thank all participants in this study.

References

1. Gougoux F, Lepore F, Lassonde M, Voss P, Zatorre RJ, Belin P. Neuropsychology: pitch discrimination in the early blind. *Nature* 2004; **430**:309.
2. Roder B, Teder-Salejarvi W, Sterr A, Rosler F, Hillyard SA, Neville HJ. Improved auditory spatial tuning in blind humans. *Nature* 1999; **400**: 162–165.
3. Yabe T, Kaga K. Sound lateralization test in adolescent blind individuals. *Neuroreport* 2005; **16**:939–942.
4. Liotti M, Ryder K, Woldorff MG. Auditory attention in the congenitally blind: where, when and what gets reorganized? *Neuroreport* 1998; **9**: 1007–1012.
5. Voss P, Gougoux F, Lassonde M, Zatorre RJ, Lepore F. A positron emission tomography study during auditory localization by late-onset blind individuals. *Neuroreport* 2006; **17**:383–388.
6. Hamilton RH, Pascual-Leone A, Schlaug G. Absolute pitch in blind musicians. *Neuroreport* 2004; **15**:803–806.
7. Miyazaki K. Musical pitch identification by absolute pitch posessors. *Percept Psychophys* 1988; **4**:501–512.
8. Takeuchi AH, Hulse SH. Absolute pitch. *Pychol Bull* 1993; **113**: 345–361.
9. Gregersen PK. Early childhood music education and predisposition to absolute pitch: tearing apart genes and environment. *Am J Med Genet* 2000; **98**:280–282.
10. Keenan JP, Thangaraj V, Halpern AR, Schlaug G. Absolute pitch and planum temporale. *Neuroimage* 2001; **14**:1402–1408.
11. Ross DA, Olson IR, Gore JC. Cortical plasticity in an early blind musician: an fMRI study. *Magn Reson Imaging* 2003; **21**:821–828.
12. Gaab N, Gaser C, Zaehle T, Jancke L, Schlaug G. Functional anatomy of pitch memory- an fMRI study with sparse temporal sampling. *Neuroimage* 2003; **19**:1417–1426.
13. Annett M. A classification of hand preference by association analysis. *Br J Psychol* 1970; **61**:303–321.
14. Parsons LM. Exploring the functional neuroanatomy of music performance, perception, and comprehension. *Ann N Y Acad Sci* 2001; **930**:211–231.
15. Deutsch D. Generality of interference by tonal stimuli in recognition memory for pitch. *Q J Exp Psychol* 1974; **26**:229–234.
16. Friston KJ, Holmes A, Worsley KJ, Poline JB, Frith CD, Frackowiak RSJ. Statistical parametric maps in functional imaging: a general linear approach. *Hum Brain Mapp* 1995a; **2**:189–210.
17. Burton H, Diamond JB, McDermott KB. Dissociating cortical regions activated by semantic and phonological tasks: a FMRI study in blind and sighted people. *J Neurophysiol* 2003; **90**:1965–1982.
18. Buchel C, Price C, Frackowiak RS, Friston K. Different activation patterns in the visual cortex of late and congenitally blind subjects. *Brain* 1998; **121**:409–419.
19. Sadato N, Pascual-Leone A, Grafman J, Ibanez V, Deiber M-P, Dold G, Hallett M. Activation of the primary visual cortex by Braille reading in blind subjects. *Nature* 1996; **380**:526–528.
20. Bavelier D, Neville HJ. Cross-modal plasticity: where and how? *Nat Rev Neurosci* 2002; **3**:443–452.
21. Lee HW, Hong SB, Seo DW, Tae WS, Hong SC. Mapping of functional organization in human visual cortex: electrical cortical stimulation. *Neurology* 2000; **54**:849–854.
22. Kujala T, Huotlainen M, Sinkkonen J, Ahonen AI, Alho K, Hamalainen MS, *et al.* Visual cortex activation in blind humans during sound discrimination. *Neurosci Lett* 1995b; **183**:143–146.
23. Weeks R, Horwitz B, Aziz-Sultan A, Tian B, Wessinger CM, Cohen LG, *et al.* A positron emission tomographic study of auditory localization in the congenitally blind. *J Neurosci* 2000; **20**:2664–2672.
24. Rauschecker JP. Compensatory plasticity and sensory substitution in the cerebral cortex. *Trends Neurosci* 1995; **18**:36–43.
25. Spiridon M, Kanwisher N. How distributed is visual category information in human occipito-temporal cortex? An fMRI study. *Neuron* 2002; **12**:1157–1165.