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'Musical brain' revealed by high-field (3 Tesla) functional MRI

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THE cortical areas subserving music literacy were investigated using high-field (3 Tesla) functional magnetic resonance imaging (fMRI). The activation pattern associated specifically with music score reading was compared with that associated with reading text in a subject's primary and secondary language. While the areas of activation were predominantly identical for all three reading modalities, there were areas within the occipital cortex activated exclusively by music score reading. Grand analysis of the activation patterns of eight pianists unequivocally identified that the principal cortical area needed for music literacy is the cortex flanking the right transverse occipital sulcus (musical brain). ***NeuroReport*** **9: 3853–3856 © 1998 Lippincott Williams & Wilkins.**

Key words BOLD; fMRI; Literacy; Music; Transverse occipital sulcus

Introduction

Music and language are cognitive traits uniquely well developed in humans.[1–8] Both are distinct tools for communication and expression, and may be utilized simultaneously, as in song. As in language acquisition, humans have a natural ability for acquiring the rules of music following exposure to only a few examples and then generalize these for the purposes of composition and performance.[1–8] Also similar to language, literacy in music is a skill which requires specific and often painstaking educational effort to attain proficiency.[1–4] Should literacy in both music and language be an ability to understand a man-made coding system, the decoding strategies employed by the brain may have significant overlap. Accordingly, we investigated the pattern of cortical activation associated with reading music in comparison with that associated with reading primary language (Japanese) and secondary language (English) in subjects literate in all three symbolic notational systems, utilizing high-field (3.0 T) functional magnetic resonance imaging (fMRI).

Materials and Methods

A General Electric (Waukesha, Wisconsin, USA) Signa-3.0 T system equipped with an Advanced NMR (ANMR) EPI module was used to perform all the studies. Informed consent was obtained from all subjects. Normal volunteers were imaged according to the human research guidelines of the Internal Review Board of the University of Niigata. Subjects, all native in Japanese and right-handed, were selected for literacy in Japanese, English and music. Handedness was confirmed by the Edinburgh inventory,[13] whereas musical literacy was judged by the ability of subjects to sight-read randomly selected music scores and play these on the piano.

Subjects were asked to view a non-specific pictorial image (control state) or read the presented text, either English text (E), Japanese text (J), or music score (M), silently. Each session consisted of nine 30 s epochs configured in the box car alternative sequences.

Gradient echo echo-planar images (GE-EPI) were obtained using the following parameter settings: field of view 240 × 240 cm; matrix 128 × 64; slice thickness 5 mm; inter-slice gap 2.5 mm; TR 1 s. Spatial resolution was ~ 3.3 × 3.5 × 5 mm. Sessions which showed brain motion exceeding 0.6 mm were re-performed to avoid so-called fictitious activation due to pixel misalignment. fMRI time series data consisting of consecutive EPI images for each slice were analysed utilizing SPM96 (Wellcome Department of Cognitive Neurology).[10–12] The data were smoothed using a 3 mm full width at half maximum (FWHM) kernel. Statistical analysis was performed using a delayed (6 s) boxcar hemodynamic model function in the context of the general linear model as employed by SPM96. To minimize effects of physiological noise, a high pass filter and global normalization were applied within the design matrix. Specific effects were tested by applying appropriate linear contrasts

to the parameter estimates for each condition, resulting in a t statistic for each and every voxel. These t statistics, which were transformed to Z statistics, constitute an activation map (fMRI image, referred to as a statistical parametric map (SPM) by the developers of SPM96). These images were interpreted by referring to the probabilistic behavior of a Gaussian field. fMRI images were presented with contrast between two conditions specified and show activated areas which conform to statistical criteria of significance ($p < 0.01$).

Data were analysed and reproducibility was confirmed for each subject individually. Anatomical identification of activated areas was performed individually by mapping areas onto the subject's own anatomical images obtained with identical coordinates. Following individual anatomical identification of activated areas for each subject, the identified activated areas from multiple subjects were mapped onto the best fitted area of normalized images with standard coordinates[14] according to gyrus/sulcus patterns in three dimensional coordinates.

Result

Representative fMRI images of a pianist literate in musical score, Japanese (primary language), and English (secondary language) are shown in Fig. 1.

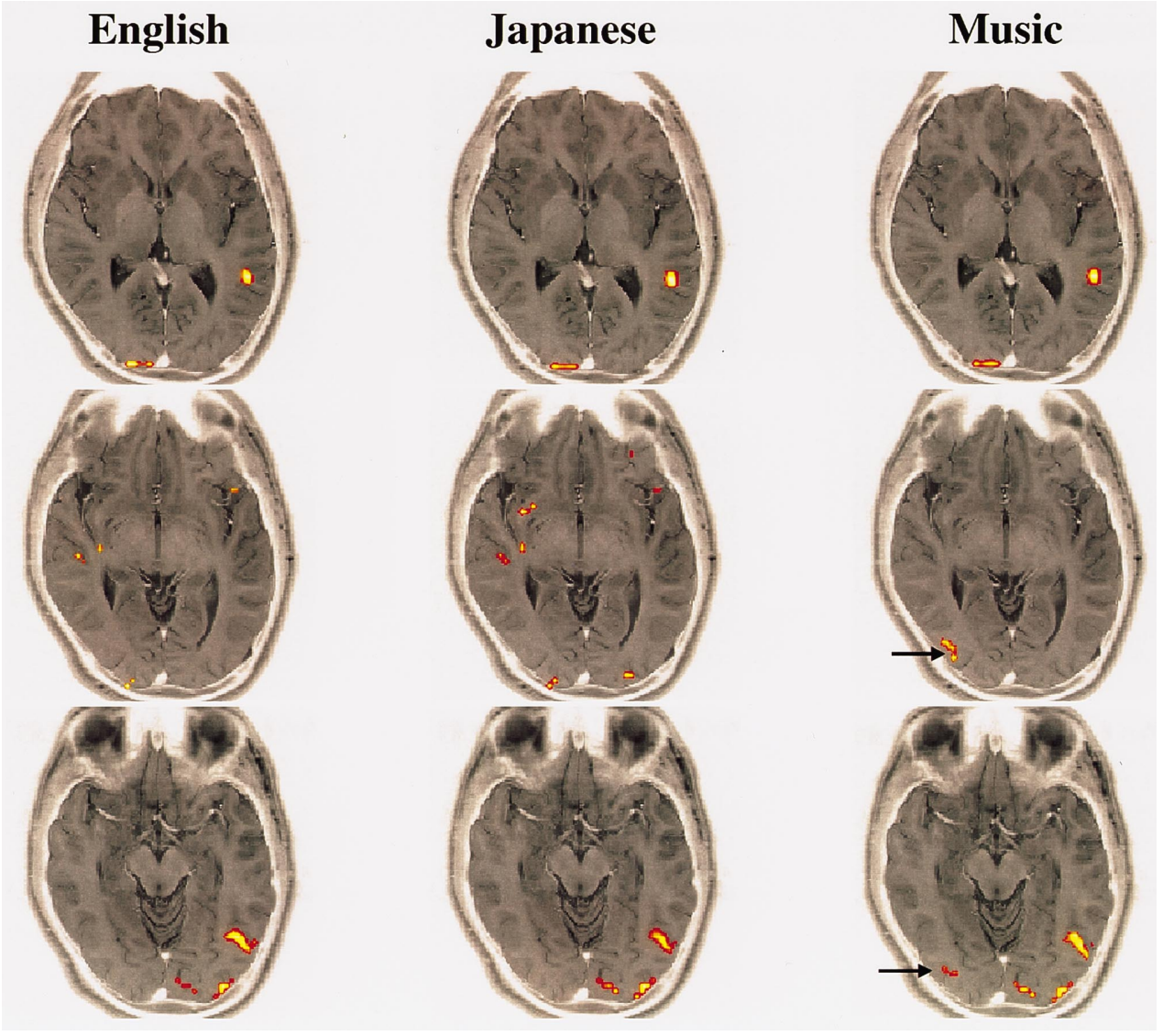

FIG. 1. Representative fMRI images of a 29-year-old Japanese male literate in English, Japanese, and music. Areas which exhibited statistically significant activation ($p < 0.01$) associated with each reading process, as contrasted against the control visual stimulation condition (black and white pictorial image), are shown in Z scale. Cortical areas related to non-specific visual processing, such as the primary visual cortex, are effectively subtracted, allowing for determination of the activation pattern more specifically associated with reading. Activation occurred predominantly within a common set of areas regardless of the reading modality (primary language, secondary language, or music), and includes the auditory and visual association cortices. An area within the right occipital cortex is uniquely identified to be activated by reading music score (arrow).

Cortical areas which exhibited statistically significant activation ($p < 0.01$), as contrasted against the control visual stimulation condition (pictorial image), are shown in Z scale.[10–12] Non-specific visual processing common to control and experimental conditions (such as within area V1) was effectively subtracted and, as a result, only those areas related to the process of reading were detected. The activated areas common to all three reading modalities included the auditory and visual association cortices. In addition, there was an area in the occipital cortex activated exclusively by reading music (arrow in Fig. 1).

Figure 2 summarizes representative slices from eight pianists (22–29 years old), all literate in music, showing exclusive activation by music score reading. None of the eight age-matched normal controls illiterate in music showed such activation, confirming the specificity of the observed activation. The activated area common to all eight pianists (arrows in Fig. 2) was identified as cortex adjacent to the right transverse occipital sulcus (Fig. 3).

Discussion

Music and language have in common the natural medium of auditory perception and vocal output. In both cases notational systems were developed to convey written information. These symbolic notations are decoded principally through the visual system, i.e. reading. As in the case of any alphabet-based language, such as English, music consists of notes, which, in principle, are phonetic symbols. Music contains additional notations to denote time and rhythm. Our data support the notion that, as far as the reading process is concerned, music indeed shares a large portion of cortical processing with language. Music reading, however, recruits additional cortical areas, especially those adjacent to the right transverse occipital sulcus.

Whether music is a right hemisphere or left hemisphere function oversimplifies the neuroscience of music.[1–6] Nevertheless, clinical reports have indicated that the right hemisphere is more specifically related to musical function. Those patients who developed disorder of music associated with left hemispheric lesions almost always have accompanying language disorders. By contrast, virtually all patients with musical disorders unaccompanied by noticeable language deficits had right hemispheric lesions.[6–8] Our data clearly illustrated that literacy in music is specifically dependent on the cortical area adjacent to the right transverse occipital sulcus. Investigations on the musical abilities of each hemisphere using the Wada test have previously shown that barbiturate injection into the right hemisphere can produce severe deficit in melody recognition. On the other hand, barbiturate injection into either hemisphere cannot produce total block of rhythmic capability. Although the functional significance of the observed activation specific to reading music score shown here remains to be clarified, it provides a specific substrate for further investigation.

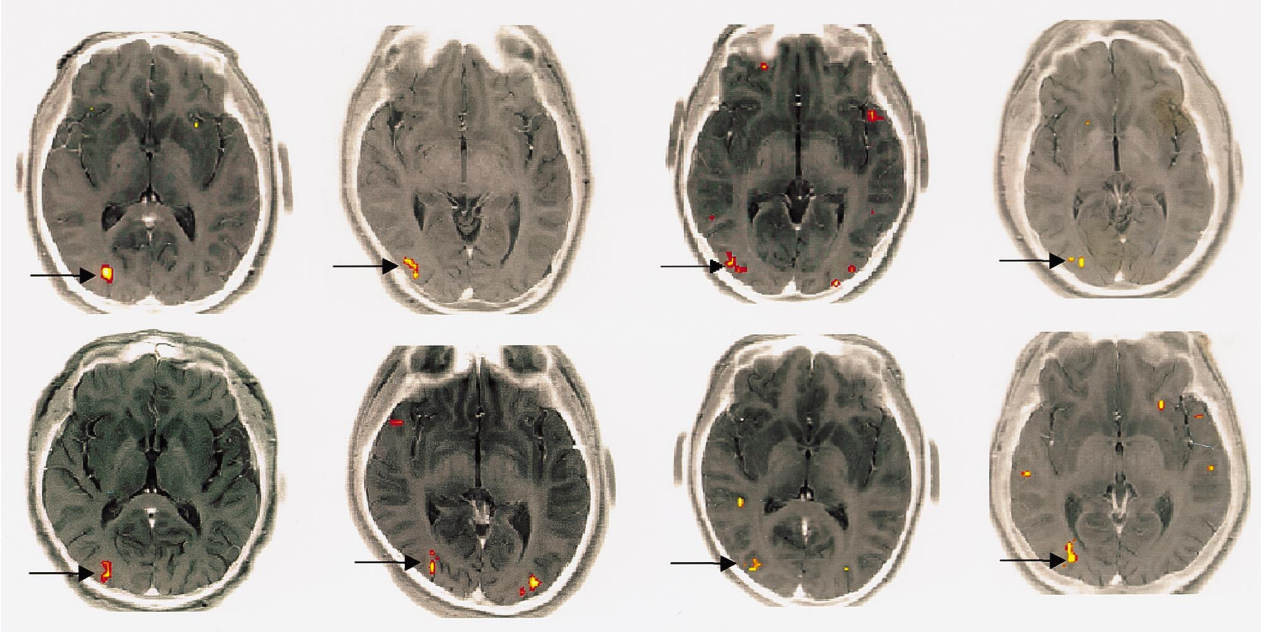

FIG. 2. Summary of the area activated exclusively by music reading for the eight subjects studied. The principal component common to all eight subjects was found to be located in the cortex adjacent to the right transverse occipital sulcus (arrow).

FIG. 3. Schematic presentation of 'musical brain' using Talairach and Tournoux coordinates (light blue). Red indicates the areas common to all eight subjects, while yellow to more than two subjects. Left: +4 mm transverse section corresponding to Fig. 118 in the Talairach–Tournoux atlas; right: –85 mm coronal section corresponding to Fig. 97 in the Talairach–Tournoux atlas.

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