Imaging melody and rhythm processing in young children

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In the adult brain, melody and rhythm processing have been found to show different hemispheric dominance, with the right hemisphere apparently more sensitive to melody and the left hemisphere to rhythm. We used a novel, child-friendly scanning protocol to examine the neural basis of melody and rhythm processing in young children (mean age 6 years 4 months, n=33). FMRI data were acquired using a sparse temporal sampling technique, taking advantage of the natural delay in the cerebrovascular response to neuronal activity. We found that this group of young children showed some differential specialization for melody and rhythm processing, but to a lesser extent than previously reported in adults. These results suggest that hemispheric specialization for musical processing may develop with age. *NeuroReport* 15:1723–1726 © 2004 Lippincott Williams & Wilkins.

Key words: Auditory; Children; fMRI; Imaging; Melody; Music; Rhythm

INTRODUCTION

Melody and rhythm form the basis of musical organization [1]. They allow small perceptual auditory units to be organized into highly structured auditory sequences that the brain can easily recognize and comprehend. Stylistic norms for such auditory sequences are developed within every human culture and are learned from the earliest stages of infancy [2], possibly even *in utero* [3]. Examination of the neural basis of melody and rhythm processing in young children thus has the potential to offer important insights into the developing musical brain.

Research with adults has suggested that the brain is differentially specialized for melody and rhythm processing, with the right hemisphere predominantly involved in melody processing [4] and the left hemisphere predominantly involved in rhythm processing [5]. It is currently unknown whether such hemispheric specialization is also present in young children. fMRI is an ideal tool with which to examine this question, but conducting such research with young children presents a challenge. Children can be intimidated by the noise of the scanner environment and can find it difficult to remain still for the long time periods required for data collection. In addition, fMRI scanner noise can interfere with attention to auditory stimuli and can cause unwanted neural activation. Thus, we designed a child-friendly fMRI scanning protocol using a sparse temporal sampling technique with clustered volume acquisitions, taking advantage of the inherent delay in the cerebrovascular response to neuronal activity. Our aim was to investigate whether or not children show the same hemispheric specialization for melody and rhythm processing as reported in adults.

MATERIALS AND METHODS

Participants: Thirty-four right-handed children aged 5–7 years were recruited as part of a larger longitudinal study examining the potential effects of music training on cognitive and neural development [6]. One child's data set was removed from the analysis due to her extensive movement and talking throughout the scanning session. The resulting group of 33 children had a mean age of 6 years 4 months and included 21 males. Handedness was assessed using standard behavioral measures [7]: each child was asked to write their name, use a spoon, throw a ball and use a toy hammer. If three out of these four tasks, including writing, was performed with the right hand, the child was considered right-handed. All children and parents gave informed, written consent to take part in the study, which was formally approved by the Internal Review Board of our institution.

Musical stimuli and tasks: The musical tasks required a same/different judgment of two short musical phrases, indicated by a button press response. Five different pitches were used for the musical stimuli, corresponding to the first 5 notes of the C major scale (fundamental frequencies 264, 297, 330, 352 and 396 Hz). In order to avoid any potential

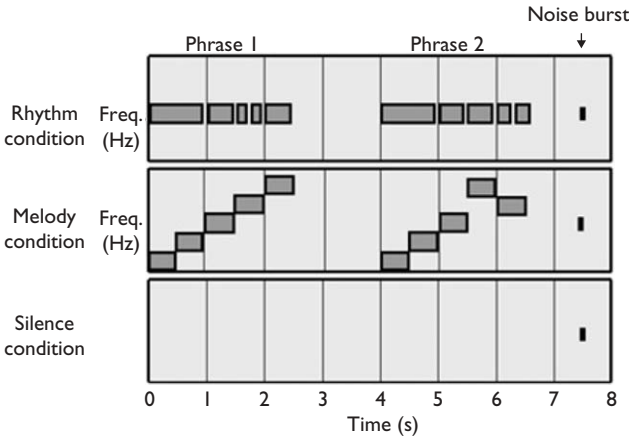

Fig. 1. Task design. Diagram to show the three task conditions: rhythm, melody and silence.

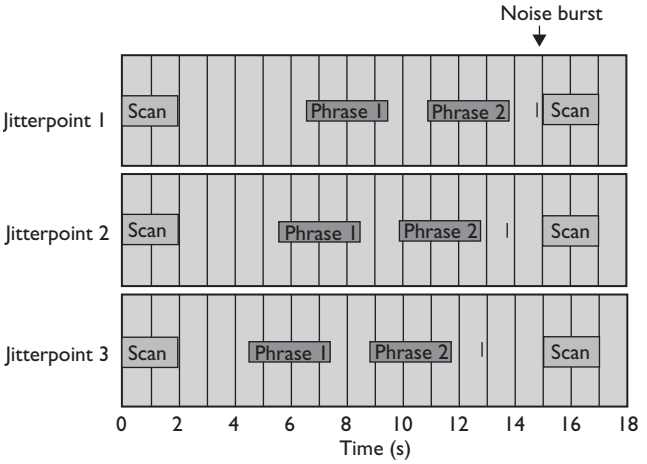

Fig. 2. Sparse temporal sampling technique. Diagram to show the method of data acquisition at three different jitterpoints, TR=15.

familiarity with instrumental sounds, we selected a neutral musical timbre with a marimba-like quality (Cubasis Universal Sound Module no. 13). Each tone had an attack of 5 ms and gradually tailed away for the rest of the duration. In the melody condition phrase pairs were presented at a steady pulse with tone durations of 500 ms, and the pitch of each tone varied to form melodic contours. In the rhythm condition phrase pairs were presented on a single pitch (which varied between trials) and the duration of each tone ranged from 125 ms to 1500 ms to form rhythmic patterns. Thus, each condition (across all trials) had the same number of tones and overall pitch content. In the silence condition, children simply performed a bilateral button press. In order to limit the button press to the same time point in each condition and every trial, a short noise burst was used to cue the response (Fig. 1).

Trials were grouped together to create short, child-appropriate runs of 3 min (each consisting of 8 musical trials and 4 silence trials), and runs were alternated between the melody and rhythm conditions. The musical trials in each run consisted of 3 same and 5 different phrase pairs. This unequal distribution of same/different task items meant that a child who could not detect any differences, and thus pressed same on every item, would score only 37.5%. The children learned and practiced the tasks ~1 week prior to the scanning session.

Data acquisition: Functional images were acquired on a 3 T General Electric magnetic resonance imaging scanner using a gradient-echo EPI-sequence with an echo time of 25 ms and a 64 × 64 mm matrix. Using a mid-sagittal scout image, 26 slices were acquired over 1.75 s with a voxel size of 3.8 × 3.8 × 4 mm. Taking advantage of the inherent delay in the cerebrovascular response to neural activity, one volume set was acquired after each musical discrimination trial, thus reducing the amount of scanner noise and avoiding any interference with the auditory stimuli. While the scanning repetition time (TR) was kept constant at 15 s, the musical stimuli were jittered between 3 different time points, such that the onset of the first axial slice varied between 1.25 and 3.25 s after the end of the musical stimuli (Fig. 2). The data from these 3 time points were combined for statistical analysis, thus allowing for differences in the cerebrovascular peak between brain regions and between individuals [8].

Data processing and analysis: Echoplanar functional imaging data were saved as raw data for later off-line reconstruction. An additional one minute phase encoded reference scan was performed prior to functional acquisition. Reconstruction of the images was performed with in-house software, which included a geometric distortion correction performed using information obtained from the reference scan. Pre-processing and analysis was conducted using SPM99 (Wellcome Dept. of Cognitive Neurology, London, UK; www.fil.ion.ucl.ac.uk/spm/). Spatial normalization to a standard atlas was performed by matching the T1 weighted images to a pediatric template created from 28 children's anatomical images. The identical transformation was then applied to the functional data, after realignment, and smoothing was applied with an 8 mm FWHM kernel. Condition effects were estimated according to the general linear model at each voxel in brain space [9]. 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 with a cutoff of 200 s. No low-pass filter was applied and the data were not convolved with the haemodynamic response function (HRF). A box-car function was applied with an epoch length of 1 to the fMRI time series (12 acquisitions within each run), and no temporal derivatives were applied (for more details see [10]).

RESULTS

Task performance: Performance on the musical discrimination tasks during scanning did not differ from performance in the initial practice session one week prior to the scan (60% and 57% accuracy, respectively, $t=0.8$ $p=0.4$), demonstrating that the scanner environment did not have an adverse effect on performance.

fMRI data: The functional data from all 33 children were combined into a fixed effects group analysis, in order to compare activation patterns during the melody and rhythm conditions. Initially, the images from each musical condition

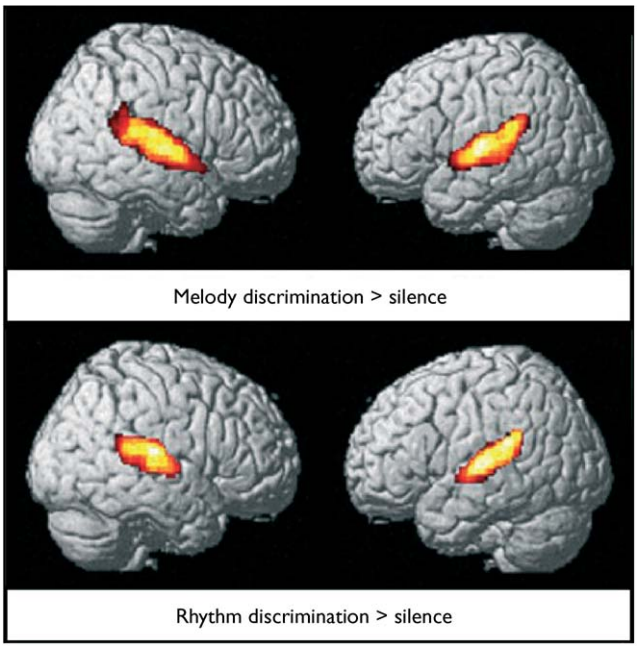

Fig. 3. Melody and rhythm processing. Group mean activations in the melody and rhythm conditions in comparison to baseline, shown at a significance threshold of $p < 0.05$, FWE corrected.

were contrasted with the images from the silence (baseline) condition using whole-brain, voxel-by-voxel *t*-test comparisons at a significance threshold of $p<0.05$, with a family-wise-error (FWE) correction for multiple comparisons. Both musical conditions led to strong bilateral activation of the superior temporal gyrus (STG) (Fig. 3).

The rhythm and melody conditions were then contrasted directly with each other, revealing no significant activation differences ($p<0.05$, FWE corrected). Considering the strength of activation in the STG during both conditions, as well as the fact that this brain region is of particular relevance during auditory processing, we limited our further analysis to the STG. Using MRIcro (http://www.psychology.nottingham.ac.uk/staff/cr1/mricro.html), Regions of Interest (ROIs) representing the left and right STG (equally sized) were drawn on the pediatric anatomical template. Using these ROIs for a small volume correction, a small region in the right STG, slightly anterior and inferior to the primary auditory cortex was found to show significantly higher activation during melody discrimination than during rhythm discrimination ($p<0.05$, FWE corrected; Fig. 4). Using the same small volume correction and the same significance threshold ($p<0.05$, FWE corrected), no regions were found to show higher activation during rhythm discrimination than during melody discrimination.

DISCUSSION

The neural basis of melody and rhythm processing were found to be very similar in this group of young children. However, once statistical analysis was limited to the superior temporal gyrus, a small region in the right STG, slightly anterior and inferior to the primary auditory cortex, was found to show significantly higher activation for

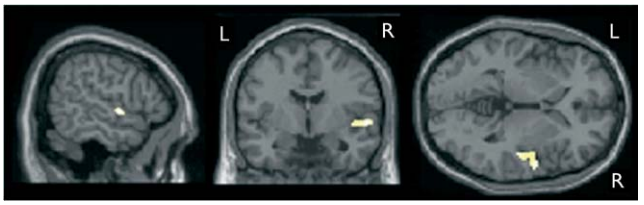

Fig. 4. Melody contrasted with rhythm processing. Three orthogonal views of group mean activation in the melody condition contrasted with the rhythm condition, shown here at a significance threshold of $p < 0.001$, uncorrected. Using a small volume correction over the superior temporal gyrus this activated region was significant at a threshold of $p < 0.05$, FWE corrected.

melody processing than rhythm processing. A similar finding in adults has been reported by Zatorre *et al.* [11]. Using PET these authors found that, compared with listening to noise burst sequences, listening to novel, tonal melodies activated a small region in the right STG, anterior and inferior to the primary auditory cortex. Taken together, the results of these two studies lend considerable support to the theory that the right auditory cortex is specialized for spectral resolution [12].

Nevertheless, it is notable that the strength of the effect in this group of children was only significant when statistical analysis was limited to the STG, while no regions were found to show higher activation for rhythm processing than melody processing. The number of subjects in the study was relatively large (n=33) and considerably above the number considered sufficient for fMRI studies of this nature [13], suggesting that the lack of strong significant differences is unlikely to be due to lack of statistical power. Thus, our results suggest that hemispheric specialization for melody and rhythm processing may be less strong in young children than in adults.

This interpretation is consistent with the results of other studies showing developmental differences between children and adults in music processing. For example, in a diatonic context adults have been found to detect non-diatonic interval changes more easily than diatonic interval changes, while infants show no such distinction, detecting interval changes of both types equally well [14]. EEG research has shown that components of the auditory evoked potential (AEP) to single violin tones change throughout childhood and adolescence, with the P1 component decreasing and the N1b component increasing between the ages of 3 and 18 years [15]. In addition, an increased appearance of the N100m response to piano tones has been found to correlate with age in children aged 7–12 [16]. Such findings lend support to our suggestion that the neural basis of musical processing may change throughout development.

CONCLUSION

The young children in this study showed very similar activation patterns for melody and rhythm processing. A higher activation for melody processing compared to rhythm processing was found in a small region near the right primary auditory cortex, as previously seen in adults, but this result was only significant after statistical analysis was limited to the superior temporal gyrus. No differential activation was found when rhythm processing was

contrasted with melody processing. These results suggest that hemispheric specialization for melody and rhythm processing may develop with age.

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