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Adults and children processing music: An fMRI study

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The present study investigates the functional neuroanatomy of music perception with functional magnetic resonance imaging (fMRI). Three different subject groups were investigated to examine developmental aspects and effects of musical training: 10-year-old children with varying degrees of musical training, adults without formal musical training (nonmusicians), and adult musicians. Subjects made judgements on sequences that ended on chords that were music-syntactically either regular or irregular. In adults, irregular chords activated the inferior frontal gyrus, orbital frontolateral cortex, the anterior insula, ventrolateral premotor cortex, anterior and posterior areas of the superior temporal gyrus, the superior temporal sulcus, and the supramarginal gyrus. These structures presumably form different networks mediating cognitive aspects of music processing (such as processing of musical syntax and musical meaning, as well as auditory working memory), and possibly emotional aspects of music processing. In the right hemisphere, the activation pattern of children was similar to that of adults. In the left hemisphere, adults showed larger activations than children in prefrontal areas, in the supramarginal gyrus, and in temporal areas. In both adults and children, musical training was correlated with stronger activations in the frontal operculum and the anterior portion of the superior temporal gyrus.

Keywords: Auditory processing; Music; fMRI; Children; Musical expertise; Functional plasticity; BA 6; BA 21; BA 22; BA 37; BA 44; BA 45; BA 47

Introduction

Music is one of the oldest and most basic sociocognitive domains of the human species. It is assumed that human musical abilities played a key phylogenetical role for the evolution of language, and that music making behavior covered important evolutionary functions such as communication, group coordination and social cohesion (Zatorre and Peretz, 2001). Likewise, it is assumed that, ontogenetically, infants' first steps into language are based on prosodic information, and that musical communication in early childhood (such as maternal music) plays a major role for emotional, cognitive, and social development of children (Trehub, 2003). However, despite the biological relevance of music, only a relatively small number of studies has so far investigated the neural basis of music processing in adults, and there is only one published study that investigated music processing in children using functional brain imaging (Overy et al., 2004, for a study investigating music perception in children with EEG see Koelsch et al., 2003). Thus, only little is known about the cerebral correlates of music processing in children, and so far, no direct comparison of such correlates between children and adults is available.

The present study aimed at further investigating the functional neuroanatomy of music perception in children and adults with functional magnetic resonance imaging (fMRI). Three different experimental groups (each group consisted of ten subjects) were investigated to examine developmental aspects and functional plasticity of music processing: (a) 10-year-old children with varying degrees of musical training, (b) adults without formal musical training (nonmusicians), and (c) adult musicians.

We investigated music processing with a chord sequence paradigm that was similar to paradigms employed in some previous experiments using electroencephalography (EEG) and magnetoencephalography (MEG; for an overview, see Koelsch and Friederici, 2003, see also below). In major–minor tonal music, chord functions are arranged within chord sequences according to regularities. These regularities build a musical structure and have been considered to represent part of a musical syntax (Koelsch and Friederici, 2003; Sloboda, 1985; Tillmann et al., 2000). The dominant-tonic progression (i.e., the progression of chords built on the fifth and on the first scale tone) at the end of a chord sequence is a prominent marker for the end of a harmonic sequence and has been considered as a basic syntactic structure of major–minor tonal music (Riemann, 1877/1971). Each sequence used in the present study consisted of five chords. The first four chords were arranged according to the classical rules of harmony and established a musical context toward the end of the sequence (Fig. 1A). The

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fourth chord of all sequences was a dominant seventh chord, which induced a strong expectancy for a tonic chord at the fifth position of a sequence (Bharucha and Stoeckig, 1986; Bigand et al., 1999; Krumhansl and Kessler, 1982). Seventy percent of the chord sequences fulfilled this expectancy and ended on a dominant-tonic progression. That is, they ended with the harmonic structure that appropriately marked the end of the harmonic progression after the presentation of the dominant seventh chord. In contrast, 30% of the sequences ended on a deceptive cadence, in which the dominant was not succeeded by a regular tonic, but by an irregular subdominant variation (a so-called Neapolitan sixth chord, see Methods; deceptive cadences and Neapolitan sixth chords are prominent stylistic elements of major–minor tonal music). Thus, the latter sequence type violated the expectancy of a regular musical structure.

Based on previous studies using similar chord sequence paradigms (Koelsch et al., 2002a; Maess et al., 2001; Tillmann et al., 2003), we expected that the musical irregularities would activate inferior frontolateral cortex, supratemporal cortex (both anterior and posterior STG), as well as the superior temporal sulcus (STS); activations were expected to be present in both hemispheres, with right-hemispheric weighting. In a previous study investigating music processing in children using EEG (Koelsch et al., 2003), children showed similar electrophysiological correlates of music processing as adults. Thus, we expected that similar anatomical structures would be activated in children compared to adults. With respect to effects of musical expertise on music processing in adults, a previous EEG study indicated that musicians react more sensitively to music-syntactic irregularities than nonmusicians (Koelsch et al., 2002b, in this study, irregular chords elicited a larger early right anterior negativity in musicians). Because previous studies suggest that neural correlates of music-syntactic processing are at least partly localized in the inferior frontolateral cortex (inferior pars opercularis, Maess et al., 2001) and in the anterior portion of the STG (Koelsch and Friederici, 2003), we expected differences in activation in these regions between musicians and nonmusicians.

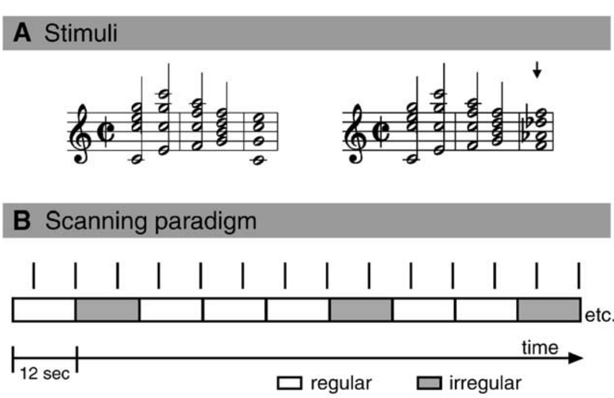

Fig. 1. (A) Examples of stimuli: chord sequence ending on a regular tonic chord (left), and on an irregular Neapolitan sixth chord (right, the Neapolitan chord is indicated by the arrow). In the experiment, 72 different chord sequences were presented in all 12 major keys. (B) Experimental design: the rectangles indicate mini-blocks, each comprising three chord sequences (resulting in a duration of 12 s per mini-block). White rectangles indicate mini-blocks with sequences ending on (regular) tonic chords, grey rectangles indicate mini-blocks with sequences ending on (irregular) Neapolitan chords. Vertical lines indicate scans (TR: 6 s, clustered volume acquisition).

In contrast to a previous fMRI study with a similar experimental design (Koelsch et al., 2002a), the present study has the advantage that (1) fMRI scanning covered the whole brain, (2) less frequent acquisitions were used (so that the musical stimulus was mostly presented during the silence period between two scans), (3) both adults and children were measured, (4) subjects with and without formal musical training were measured, and (5) Neapolitan chords were used as music-structural irregularities, enabling us to relate the present study to previous studies that employed a very similar musical stimulus using EEG (Koelsch et al., 2000, 2001, 2002b,c, 2003) and MEG (Maess et al., 2001).

Methods

Subjects

Three groups of subjects were investigated. Each group consisted of 10 participants (5 males and 5 females): (a) nonmusicians (age range 20–36 years, mean 25.6 years), none of them had any formal musical training (except normal school education), and none of them played a musical instrument; (b) musicians (age range 21–34 years, mean 26.8 years), who had learned an instrument for 4–18 years (mean: 9.4 years); (c) children (age range 9.5–10.9 years, mean 10.2 years). Three children did not play any musical instrument, four children had played an instrument for less than 1 year, and three children had played an instrument for more than 1 year (2, 4, and 8 years). Children were categorized into three groups (children with no, medium, and extensive musical training) to conduct a regression analysis between the activation pattern and musical training. All subjects were right-handed and reported to have normal hearing.

Stimuli

Stimuli were 72 chord sequences, each consisting of five chords (see Fig. 1A for two examples). The first chord was always the tonic of the following sequence. Chords at the second position were tonic, mediant, or subdominant. Chords at the third position were subdominant, dominant, or dominant six–four chords. Chords at the fourth position were dominant seventh chords. The chord at the fifth position was either a tonic (regular) or a Neapolitan chord (irregular, a Neapolitan is a minor subdominant with a diminished sixth instead of a fifth). Classically, Neapolitan chords are sixth chords, but for a proper comparison between Neapolitans and tonics, both tonic and Neapolitan chords were presented equiprobably in root position and as sixth chords. Chord sequences were presented with different melodic outlines (e.g., starting with the third, the fifth, or the octave in the top voice). Presentation time of chords 1–4 was 666.7 ms, chord 5 had a duration of 1333.2 ms, resulting in a total duration of 4000 ms per sequence. All chords had the same decay of loudness, sequences were played in direct succession, creating the sensation of a musical piece (there was no silence period between chords or chord sequences, sound examples can be downloaded from www.stefan-koelsch.de/fMRI_AdultsAndKids). Chords were presented under computerized control via MIDI on a synthesizer (ROLAND JV 1010; Roland Corporation, Hamamatsu, Japan) with a piano timbre (General MIDI #1). The musical stimulus was played with approximately 75 dB SPL using an MRI compatible headphone with piezo-electric transmission.