Supporting Information

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SI Materials and Methods

Stimuli. The musical excerpts were taken from the following pieces: (*i*) J.S. Bach, French Suite No.1 in D−, BWV812, Allemande; (*ii*) Scarlatti, Sonata in E, K.162, L.21; (*iii*) Schubert, Six Moments Musicaux, D.780, Op.94, No.3 in F−; (*iv*) Schubert, Andante in C, D.29; (*v*) Schubert, 34 Valses sentimentales, D.779, Op.50; (*vi*) J.S. Bach, Two-Part Inventions, No.5 in Eb, BWV776; (*vii*) J.S. Bach, Two-Part Inventions, No.11 in G−, BWV782; (*viii*) Scarlatti, Sonata in D−, K.10, L.370; (*ix*) Scarlatti, Sonata in D, K.21, L.363; and (*x*) Mozart, Piano Sonata in G, K.283.

Analysis of Acoustic Deviance in Key Shifts. To estimate the degree of acoustical deviance introduced by the changes of tonal key in the excerpts with key changes, we performed auditory modeling of the acoustic congruency of all key shifts with auditory sensory memory traces established by the previous chords. Snippets 4 s in duration were entered into the analysis; half of the snippets contained a key shift after 3 s, and the other half consisted of the corresponding snippets without a key shift. The modeling estimates pitch images of the auditory sensory memory: acoustic information decays but is kept in the auditory sensory memory for a certain time. The results of the modeling are correlations of the local context (pitch representation of the current chord) with the global context (pitch representation of the previous chords stored in the auditory memory). There was a drop of correlation for key shifts showing that key shifts were less congruent with the information stored in the auditory sensory memory than the regular sequences without key shifts (Fig. S1). Auditory modeling was performed with the Institute for Psychoacoustics and Electronic Music (IPEM) toolbox. The length of the local context integration window was 0.1 s, and that of the global context integration window was 1.5 s.

Additional Newborn Data Analysis. Analyses revealed that a small group of subjects ($n = 3$) showed consistent stimulus-related negative BOLD responses for all conditions compared with baseline. A reversed BOLD response has been observed in a number of fMRI studies involving infants and has been attributed to sedation, sleep, and neural or vascular immaturity (1, 2). In particular, Anderson et al. (1) reported signal decrease in bilateral primary auditory cortex in nonsedated sleeping infants in conditions similar to our experimental setup. To avoid rejecting the subjects with these "negative activations" or "deactivations," we modeled their BOLD response by convolving a negative gamma function (simulating inverted BOLD) with a square wave. The inclusion of these three subjects did not change the lateralization and overall pattern of the activation for all conditions.

Newborn Template. Because a suitable newborn template is currently unavailable, we created an ad hoc template from the subjects' whole-head EPI scans ($3.75 \times 3.75 \times 3$ mm resolution). First, a subject whose head was well positioned in the imaging space and symmetrical in shape was selected. We subsequently registered one scan per subject to the reference scan, after applying spatial filtering with an rms width of 4 mm. The chosen scans were free of artifacts and were used for within-subject motion correction and alignment. The across-subject registration algorithm (3dWarpDrive) used a 12-parameter affine-general transformation, correcting for scaling and shearing differences in addition to rigid body transformations. The registered scans were then averaged to create a group average volume. We then repeated the registration of each subject's original volume to the group volume. Finally, the scans registered to the group volume were averaged to create the infant template.

For visualization of brain activations, statistical maps in the common template space were interpolated to 1 mm^3 resolution and overlapped onto an equally interpolated anatomical T2-weighted scan from a single newborn subject.

Fetal Acoustic Exposure. There are some limits on fetal acoustic exposure. The maternal abdomen acts as a low-pass filter, with high-frequency energy rejected at a rate of ≈6 dB per octave (3). The sound energy that filters through the abdominal wall, through the uterus, and into the amniotic fluid is further filtered by the skull of the fetus, as the sound is transmitted through a bone conduction route rather than through the external and middle ear systems. This results in the fetus being able to hear the low-frequency components of speech and music (<500 Hz) but only when the airborne signal exceeds 60 dB. Voices would be detected at normal conversational levels, but many of the speech sounds would not be discriminated. In the same way, the higher frequencies of musical stimuli would be filtered out and timbre would be modified. The acoustic environment of the late-term fetus is largely composed of a stream of maternal heartbeats, maternal breathing, and words spoken by the mother (4). Nevertheless, the auditory information that gets through to the fetus is sufficient to induce recognition not only of the maternal voice (5) but of speech and musical stimuli heard during the fetal period (6, 7).

Sensory Dissonance Attributable to Key Shifts. The key shifts introduced a higher amount of sensory dissonance than in-key chords because of the semitone shift of notes. The first tones of the key shifts formed more dissonant intervals with the preceding tones than tones of the non-key shifts [the term "sensory dissonance" is used with regard to the key shifts in the broader sense, referring to the relations between successive sounds, as reported by Parncutt (8)]. In other words, the tones of key shifts had a lower pitch commonality with the preceding notes compared with the non-key shifts (with pitch commonality being the major component of sensory dissonance).

The sensory dissonance of the permanently dissonant excerpts (without key shifts) is attributable to the simultaneous sound of tones forming dissonant intervals. We use sensory dissonance to make clear that we do not refer to "musical dissonance" in the sense that chords are perceived as unexpected because of their syntactic irregularity.

Acoustic Analysis of Stimuli With and Without Key Shifts. Part of the auditory system stores incoming auditory information in the auditory sensory memory, establishes a model of acoustic regularities inherent in the auditory input, and automatically detects acoustic changes that deviate from the regularities of the established model (9). We performed an analysis modeling the acoustic congruency of key shifts with the acoustic information of the previous musical information stored in the auditory sensory memory (details are provided in Fig. S1). Fig. S1 shows that the key shifts introduced pitch information that was less congruent with the information stored in the auditory sensory memory (compared with the pitch information of the regular sequences without key shifts). Therefore, it is likely that such acoustic deviances were automatically detected by the auditory system.

Previous functional neuroimaging studies showed that such automatic change detection mainly involves the auditory cortex [reviewed in (10)], with additional contributions from the inferior frontolateral cortex, which has been suggested to play a role in the judgment of novelty for the allocation of attentional resources (10). Note that these studies showed an increase of BOLD signal in the temporal (and frontal) cortex in response to acoustic changes (in adults, fMRI studies with infants on automatic auditory change detection are, to our knowledge, not available to date). This suggests that, in our study, changes in the auditory cortex of infants in response to the key changes were not attributable to auditory sensory memory operations related to the detection of different pitches, because key shifts led to a reduction of BOLD signal in the auditory cortex in the right hemisphere for altered music (compared with original music) and no difference in BOLD response was observed in the left auditory cortex between altered and original music.

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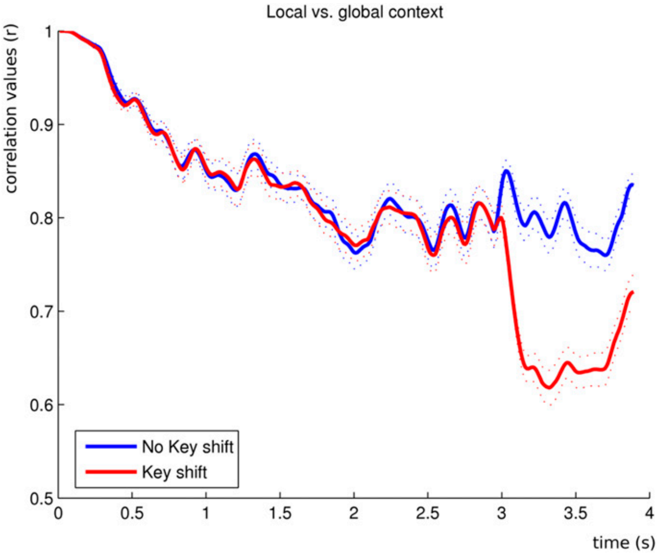

Fig. S1. Modeling of the acoustic congruency of key shifts with the acoustic information of the previous musical information stored in the auditory sensory memory. Stimulus snippets of all key shifts (and of the corresponding snippets without key shifts) were analyzed using the Contextuality Module of the Institute for Psychoacoustics and Electronic Music (IPEM) Toolbox; the length of the local context integration window was 0.1 s, and that of the global context integration window was 1.5 s, as suggested by Leman et al. [Leman M, Lesaffre M, Tanghe K (2005) IPEM toolbox for perception-based music analysis (version 1.02). Available at http://www.ipem.ugent.be/toolbox/index.htm]. The abscissa represents the time line (the key shift occurs at 3 s), and the ordinate depicts the correlation values. The data show the correlation of the local context (pitch representation of the current chord) with the global context (pitch representation of the previous musical information stored in the auditory memory), separately for key shifts (red line) and for the corresponding passages without key shifts (blue line; thin dotted lines indicate SEM). Note the drop of correlation for key shifts (red line), showing that key shifts were less congruent with the information stored in the auditory sensory memory than the regular sequences without key shifts (blue line).