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Musical Expectations Enhance Auditory Cortical Processing in Musicians: A Magnetoencephalography Study

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Abstract—The present study investigated the influence of musical expectations on auditory representations in musicians and non-musicians using magnetoencephalography (MEG). Neuroscientific studies have demonstrated that musical syntax is processed in the inferior frontal gyri, eliciting an early right anterior negativity (ERAN), and anatomical evidence has shown that interconnections occur between the frontal cortex and the belt and parabelt regions in the auditory cortex (AC). Therefore, we anticipated that musical expectations would mediate neural activities in the AC via an efferent pathway. To test this hypothesis, we measured the auditory-evoked fields (AEFs) of seven musicians and seven non-musicians while they were listening to a five-chord progression in which the expectancy of the third chord was manipulated (highly expected, less expected, and unexpected). The results revealed that highly expected chords elicited shorter N1m (negative AEF at approximately 100 ms) and P2m (positive AEF at approximately 200 ms) latencies and larger P2m amplitudes in the AC than less-expected and unexpected chords. The relations between P2m amplitudes/latencies and harmonic expectations were similar between the groups; however, musicians' results were more remarkable than those of non-musicians. These findings suggest that auditory cortical processing is enhanced by musical knowledge and long-term training in a top-down manner, which is reflected in shortened N1m and P2m latencies and enhanced P2m amplitudes in the AC.

Key words: auditory cortex, context, harmonic expectation, latency, musician, P2m.

INTRODUCTION

Western tonal music has a harmonic hierarchy that evokes musical expectancy along sequential chords. Thus, the same chords may be perceived to have different relationships depending on the harmonic context. For example, GBD–CEG can be regarded as V (dominant) – I (tonic chord) in a key of C major and I–IV (subdominant chord) in a key of G major (Regnault et al., 2001; Poulin-Charronnat et al., 2006). Such regularities establish musical syntax, which has been reported to be processed in right-lateralized structures in the frontal cortex (Maess et al., 2001; Leino et al., 2007; Kim et al., 2011; Koelsch et al., 2013), while the effects of the spectral properties of sound, training or experience, regardless of musical context, have been reported mainly in subcortical regions or auditory cortices (Marmel et al., 2011a; Fritz et al., 2013; Bidelman et al., 2014). The present question is whether harmonic expectancies generated in the frontal cortex influence auditory cortical processing in a top-down manner.

Most previous studies on auditory cortical representations, however, have not focused on the effects of context but rather on the effects of training or experience. Many studies have found that auditory-evoked potentials, N1 and P2, are enhanced by the complexity of sounds (Kaganovich et al., 2013), training or learning (Atienza et al., 2002; Pantev and Herholz,

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Abbreviations: MEG, magnetoencephalography; ERAN, early right anterior negativity; AEF, auditory-evoked magnetic field; AC, auditory cortex; V, dominant chord; I, tonic chord; IV, subdominant chord; T1 to T5, first to fifth trigger; ROIs, regions of interest; N^6, Neapolitan 6th chord; ANOVA, analysis of variance; SEM, standard error of the mean.

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2011; Seppänen et al., 2012; Itoh et al., 2012; Tremblay et al., 2014), musical expertise (Shahin et al., 2003), and musical experience (Pantev et al., 2001; Kuriki et al., 2006).

Behavioral studies have found that tonal expectations influence response times (Bharucha and Stoeckig, 1986; Tillmann and Lebrun-Guillaud, 2006; Tillmann et al., 2008). Tonally expected chords are processed more rapidly than other chords (Tillmann and Lebrun-Guillaud, 2006), and response-time patterns reflect chord ranking according to tonal structure, with faster processing for tonic chords, followed by dominant and subdominant chords (Tillmann et al., 2008). Those results might reflect enhanced auditory processing by harmonically expected chords. Furthermore, because the auditory cortex (specifically the belt and parabelt regions of the auditory cortex) is interconnected with the frontal cortex (Kaas and Hackett, 2000), harmonic expectations generated in the frontal cortex (Koelsch et al., 2000) could potentially influence auditory cortical processing. In a study on musical perception, Platel et al. (1997) reported that familiar musical tasks activate both the left inferior frontal gyrus and superior temporal gyrus, and the results indicate an interconnection between the frontal and temporal gyri in processing music. Marmel et al. (2011b) demonstrated that cognitive tonal expectations modulate early pitch processing by eliciting Nb/P1 complexes of different amplitudes. In addition, Marmel et al. (2011a) found that harmonic relationships even influence the auditory brainstem when encoding chords. However, there has been minimal research on the effects of expectations according to harmonic context on auditory cortical representations. Thus, the present study investigated the effects of musical context on the auditory cortical processing of sequential chords using magnetoencephalography (MEG).

EXPERIMENTAL PROCEDURES

Participants

Fourteen subjects, including seven female musicians (mean age ± SD, 23.6 ± 10.91 years) and five female and two male non-musicians (mean age ± SD, 20.4 ± 1.72 years) participated in the experiment. The study was approved by the Ethics Committee of Seoul National University, Korea. All of the participants signed informed consent forms in accordance with the Institutional Review Board, and the experiment was performed in accordance with the Declaration of Helsinki. The participants were right-handed and had Edinburgh Handedness Inventory scores exceeding 79%. The participants in the musician group had majored in piano, violin, and composition and had spent an average of 25,370 h (minimum of 19,580 h) studying music throughout their lives, whereas the participants in the non-musician group had taken <600 h of formal music lessons.

Stimuli

The harmonic progressions used in the experiment consisted of five chords and a rest. The duration of the first to fourth chords was 800 ms, the fifth chord lasted 1200 ms, and the rest (silence) lasted 400 ms. Each chord was a major triad (e.g., C-E-G and G-B-D), representing a consonance. The standard progression was I – I – V – V – I. We manipulated harmonic expectations at the third trigger (T3) to create three conditions with different degrees of harmonic expectancies (Fig. 1). First, a dominant chord (V) at T3 was highly expected. Second, a Neapolitan 6th chord (N^6: F-A$^{\flat}$-D$^{\flat}$ in the key of C major) at T3 was less expected than a dominant chord but remained plausible because N^6 functions as a predominant chord (before V), which is similar to a subdominant (IV) chord according to Western traditional music theory, although N^6 has two out-of-key notes. Third, a flatted mediant chord ($_{\flat}$III) at T3 was unexpected and implausible in the musical context, although $_{\flat}$III had two out-of-key notes similar to N^6. A dominant (V), Neapolitan 6th (N^6) and flatted mediant chord ($_{\flat}$III) at T3 are all consonances as major triads but have different expectancies depending on musical context. The three types of stimuli were transposed into 12 keys, and each sequence was presented five times in a pseudorandom order to avoid repeating the same keys twice in a row.

Although T1, T2, and T5 were identical as tonic chords, T2 was simply a repetition of T1, and T5 was presented with strong expectations because T4 and T5 built a perfect authentic cadence (V – I) (Fig. 1). T2 was superior to T5 in terms of acoustic similarities between previous chords, whereas T5 was superior to T2 in terms of harmonic expectations. Thus, the former (acoustical similarities) is related to a bottom-up process, whereas the latter (harmonic expectations) is related to a top-down process. Hence, a comparison between the effects of T2 and T5 helps untangle the two types of processes.

Procedures

The participants sat in a magnetically shielded room listening to the musical stimuli at a sound pressure level of approximately 60 dB using a STIM 2 system (Neuroscan, Charlotte, NC, USA) via MEG-compatible tubal-insert earphones during the MEG recording. Before the experiment, the participants were instructed to stay awake and to view a fixation cross at a comfortable distance to reduce retinal movement while the evoked magnetic fields were being recorded. Two sessions were conducted, and in each session, the participants listened to 180 sequences consisting of five chords. Participants wanting to rest between the sessions were allowed to do so. Each of the two sessions lasted approximately 11 min.

MEG recordings

AEF recordings were acquired using a 306-channel whole-head MEG system (VectorView, Elekta Neuromag Oy, Helsinki, Finland) at the Seoul National University Hospital. This system measured magnetic field strength in 102 locations, which were covered by a triplet of sensors (two planar gradiometers and one

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