Subcortical and cortical neural correlates of individual differences in temporal auditory acuity

Inyong Choi, Scott Bressler*, Hari Bharadwaj and Barbara Shinn-Cunningham

*Corresponding author's address: Center for Computational Neuroscience and Neural Technology, Boston University, 677 Beacon St., Boston, MA 02215, bressler@bu.edu

Parsing complex auditory scenes requires the activation and coordination of many neuronal centers, both in subcortical and cortical portions of the auditory pathway. Several studies have demonstrated that even normal-hearing listeners exhibit a range of abilities on various auditory tasks. Previous work in our lab suggests this variability may be due, in part, to degraded temporal encoding of supra-threshold stimuli at the level of the brainstem. A family of studies has shown that musical experience is correlated with differences in brainstem encoding as well as long-term plasticity in the cortex, results that provide the intriguing possibility that training may influence supra-threshold sound encoding. Here we explore methods for measuring subcortical and cortical neural activity in response to complex stimuli using electroencephalography (EEG). Subjects were tested in a passive mismatch negativity (MMN) paradigm using musical chords and tones. Brainstem frequency following responses (FFRs), a measure of subcortical temporal coding acuity, were measured in the same subjects using click trains. Finally, the same subjects performed a spatial selective attention task. These three measures were compared across the subject population to look for orderly relationships between brainstem coding, cortical response strength, and perceptual ability on an attentionally demanding task.

Published by the Acoustical Society of America through the American Institute of Physics
Introduction

Parsing complex auditory scenes requires the activation and coordination of many neuronal centers, both in subcortical and cortical portions of the auditory pathway. Several studies have demonstrated that even normal-hearing listeners exhibit a range of abilities on various auditory tasks. Previous work in our lab suggests this variability may be due, in part, to degraded temporal encoding of supra-threshold stimuli at the level of the brainstem [1,2]. Based on recent physiological studies, it may be that these inter-subject differences reflect the status of low spontaneous-rate fibers in the auditory nerve, which appear to be preferentially damaged by noise exposure even before high-spontaneous rate fibers (which probably determine hearing threshold) are affected [3,4]. A family of studies has shown that musical experience is correlated with differences in brainstem encoding as well as long-term plasticity in the cortex [5,6,7], results that provide the intriguing possibility that training may influence supra-threshold sound encoding. Here we explore methods for simultaneously measuring subcortical and cortical neural activity in response to complex stimuli using electroencephalography (EEG). Subjects were tested in a passive mismatch negativity (MMN) paradigm using musical chords and tones. Musical context was manipulated by controlling the statistics of chords presented within a run. Deviations from the expectations created by the musical context were measured by comparing late evoked cortical potentials in response to the same stimulus in different contexts (one was it was expected, one was it was unexpected). Brainstem frequency following responses (FFRs), a measure of subcortical temporal coding acuity, were measured in the same subjects using click trains. Finally, the same subjects performed a spatial selective attention task, using spatial auditory cues to focus attention on a target stream from a particular direction that was played in a sound mixture. These three measures were compared across the subject population to look for orderly relationships between brainstem coding, cortical response strength, and perceptual ability on an attentionally demanding task.

Method

Subjects

Three normal hearing subjects participated in the pilot study. They provided written consent via forms approved by the Institutional Review Board at Boston University.

Experiment 1: Behavioral Task

Listeners sat in a sound-treated booth wearing headphones. Three speech streams of vowel utterances were presented, separated by interaural time differences (ITDs) of -300, 0, and +300 µs. Listeners were instructed to attend the center (“0” ITD) stream and count the number of “o”s it contained (either 1, 2, or, 3; chance performance was 33% correct).

Experiment 2: Brainstem Response Measurement

We measured the frequency-following response (FFR), a measure of temporal coding precision in the brainstem measured via scalp electrodes, in each subject (in response to a periodic click train (100Hz fundamental) low-pass filtered at 10kHz; 70dBSPL). Each stimulus was 300ms long. The inter-stimulus-interval (ISI) was randomly varied between 450ms and 550ms. Sounds were presented in opposite polarity on half the trials (500 times for each polarity). Temporal fidelity in the coding of the temporal envelope was summarized by computing the phase locking value (PLV) across individual trials at harmonics of 100 Hz, incorporating all trials of both polarities.

Experiment 3: MMN Measurement

The mismatch negativity (MMN) paradigm consisted of presenting many “standard” stimuli, interspersed with rare, “oddball” or “deviant” tones. The auditory stimuli were either complex tones or a chord (three complex tones). Each complex tone had 10 harmonics, all in cosine phase. The duration of each tone, or chord, was 100ms. ISI was randomly jittered (550ms - 650ms). There was one experimental session and four control sessions. An experimental session consisted of a frequent standard sound of an A-major chord (A3, C#4, E4 notes played simultaneously) and...
rare deviant individual complex tones. There were three “consonant” single notes: A3, C#4, and E4, and one “dissonant” single note: A#3 (see Figure 1).

“A-major” chord    “A3” note    “C#4” note    ”E4” note    “A#3” note

FIGURE 1. Musical notation of stimuli

In the experimental session, the sequence contained 4000 sounds in total: 3360 A-major chord presentations (probability of occurrence = 0.84) and 160 presentations of each single complex tone (probability of occurrence = 0.04 each). A sample of an experimental session presentation sequence is shown at the top of Figure 2.

In each control session, a different note single tone complex (A3, A#3, C#4, E4; i.e., the deviant tones in the experimental block) was the standard (84% probability) and each of the other tones was used as a deviant (4%). This allowed us to compute the MMN as the difference of the neural response to exactly the same sound, but occurring in a different sound context (i.e., when that sound is the expected standard vs. when it is the unexpected deviant). See Figure 2 for musical notations of the sequences. A sample of a control session presentation sequence is shown at the bottom of Figure 2.

Results and Discussion

FIGURE 3. MMNs and FFRs of three pilot subjects

Figure 3 shows MMN waveforms (top row, one panel for each of three pilot subjects) and FFR PLVs as a function of frequency (bottom row). While all three pilot subjects had significant MMNs and PLVs, there were differences in their strengths. Subject 1 had both the strongest FFR at the stimulus fundamental frequency (100Hz)
and the biggest peak-to-peak MMN amplitude for A#3, the dissonant, note. Subject 3 had both the smallest MMN and weakest FFR. That is, for these subjects, the strengths of subcortical and cortical responses had the same rank order (Figure 4, left). Importantly, the behavioral performance of these three subjects in the selective attention task also had the same rank order when compared to both the subcortical PLV scores and the cortical MMN amplitudes (see Figure 4, right). The proposed project will explore whether these ordered relationships hold across a large sample of subjects.

![Figure 4](image-url)

*Figure 4.* Relationship between 1) FFR and MMN, 2) FFR and selective attention performance, 3) MMN and selective attention performance. Each circle represents one pilot subject. Subject numbers are shown next to the circles.

**REFERENCES**


