Human Auditory Cortical Processing of Changes in Interaural Correlation

Maria Chait*, David Poeppel*, Alain de Cheveigne' and Jonathan Z. Simon***

**Neuroscience and Cognitive Science Program, University of Maryland College Park*
*** CNRS (UMR 8581), Université Paris 5 and École Normale Supérieure, Paris, France*

INTRODUCTION

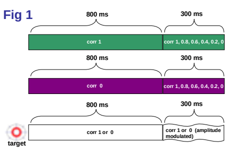
Sensitivity to interaural correlation (IAC), the similarity of the sound waveforms at the two ears, plays a key role in auditory scene analysis and the process of extracting targets from background. Stimulus IAC affects the subjective sensation and also the ability to perform binaural detection and discrimination tasks. For example, the ability to detect changes in IAC has been suggested to play a crucial role in the phenomenon of binaural unmasking (BMLD) [1][2]. Psychophysically, listeners' sensitivity to changes in IAC is asymmetrical such that discrimination is good for deflections from IAC=1 (completely correlated signals) but poor for deflections from IAC=0 (uncorrelated signals) [3][2][4]. The present study explores the neural mechanisms that underlie this behavior. Natural environments are characterized by dynamic changes in interaural correlation as objects appear and disappear. Here we combine, for the first time, psychophysical measures and non invasive brain-imaging via Magnetoencephalography (MEG) to study how the human auditory cortex processes these changes. Specifically, we measure early (~50-150 ms post change) cortical responses to changes in interaural coherence, and compare these to behavior. With its fine temporal resolution, MEG is particularly useful for studying the *time-course* of cortical activation, thus allowing for comparison with the time-course of behavioral responses and an investigation of the dynamics of the construction of perceptual experiences..

STIMULI AND METHODS

MEG (1.5 hours recording per subject):

Signals are 1100 ms long, consisting of 800 ms of interaurally correlated (IAC=1) or uncorrelated (IAC=0) wide-band noise, followed by 300ms of the same wide band noise with different degrees of IAC (1, 0.8, 0.6, 0.4, 0.2, 0). The changes at 800ms occurred without any detectable monaural change and any differences can be interpreted as specifically relating to binaural interaction. Subjects heard 120 repetitions of each condition (randomized). The noise waveforms were constructed in the same way as in [2]. Target stimuli (30%; not analyzed) consisted of 800 ms of IAC of 1 or 0, followed by 300 ms of IAC of 1 or 0 with an amplitude modulation (10Hz). ISI was randomized between 1-2 sec. Subjects were instructed to press a button held in their right hand as soon as they heard the noise change into a modulated noise. The target stimuli assured the subject's alertness and focused attention on the time of change (800ms post onset) but did not require any conscious processing of IAC.

Fig 1



BEHAVIOURAL STUDY (1 hour):

The stimuli were the same as in the MEG study except that target stimuli were not presented. Subjects heard 60 repetitions of each change condition and 300 repetition (50%) of each control condition (1→1 or 0→0) and were instructed to press a button as fast as they can when they hear a change in the noise. A practice session preceded data collection.

NOTATION:

1→ stimuli where the reference (first 800 ms) is completely correlated (IAC=1) noise. These stimuli are coded in green

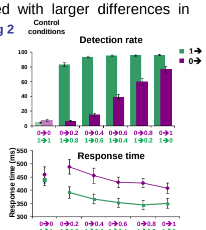
0→ stimuli where the reference IAC is completely uncorrelated noise (IAC=0). These stimuli are coded in purple

X→Y stimulus with a reference IAC of X that changes into IAC of Y (for example 0→0.8 or 1→0.6)

BEHAVIORAL RESULTS (N=15)

Performance was as in previous reports. Listeners were almost at ceiling for deflections from IAC=1 (1→ condition), but performed much poorer on same size deflections from IAC=0 (0→ condition). The rate of correct IAC change detection increased with larger differences in correlation. Response time analysis reveals the same trend but with an approximately constant ~80ms latency difference between 1→ and 0→ conditions.

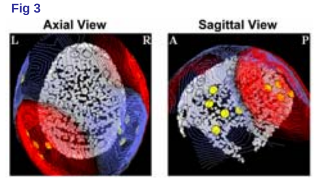
Fig 2



Note the asymmetry between the 1→0 and 0→1 conditions (both in detection rate and in response time).

MEG MEASUREMENT AND ANALYSIS

Fig 3



Auditory cortical responses were recorded using a 160 channel whole head MEG system (KIT, Kanazawa, Japan).

Signals were delivered with Etymotic ER3-A insert earphones.

Channel selection: 5 most active channels in each sink (green) and source (red) of the pre-test M100 response were selected for further analysis

All statistical analysis is performed on each-hemisphere, subject-by-subject (based on the 20 channels selected for each) basis. Figs 4 and 8 present a grand-average plot for illustration purposes only.

MEG RESULTS (N=18)

Fig 4

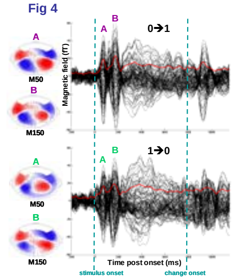
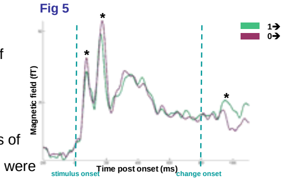


Fig 4 shows the grand-average (over all 160 channels, in black) of auditory cortical responses to 0→1 and 1→0 stimuli. The root mean square (RMS) is plotted in red. The noise onset response is similar in both conditions and is characterized by two peaks at ~70ms (M50) and ~170ms (M150). The distribution of the magnetic field over the scalp (derived from the grand-average data) is shown on the left.

Fig 5 compares the group RMS (RMS of individual RMSs) to 1→ and 0→ conditions in the right hemisphere (similar results are obtained for the left hemisphere). Amplitudes of onset responses (M50 and M150) to uncorrelated noise were significantly higher than responses to correlated noise.

Fig 5



AUDITORY CORTICAL SENSITIVITY TO IAC CHANGES

Fig 6

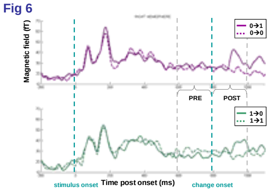
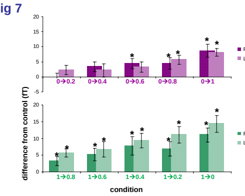


Fig 7



In order to examine the sensitivity of the auditory cortex to changes in IAC, we subtract for each subject and in each condition the average amplitude value of interval PRE in the RMS from interval POST (*DIFF=POST-PRE; see Fig 6*). Positive DIFF indicate increase in activity relative to the activity before the change in IAC. Values in Fig 7 indicate difference between DIFF values in the change conditions vs. control conditions. These physiological responses track behavioral responses by being larger for correlated references and for bigger changes in correlation.

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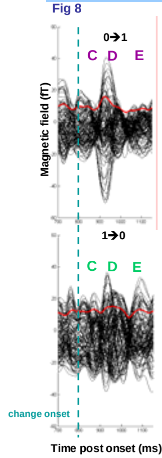
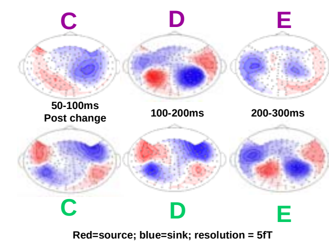
DIFFERENT PROCESSING MECHANISMS?

Fig 8



The response to the change in correlation was characterized by sequential increases in activity in 3 temporal windows ~70ms (C), ~130ms (D) and ~200ms (E) post change in correlation (Fig 8 zooms in on the post IAC change interval in Fig 4).



The responses in the 1→ and 0→ conditions exhibit different magnetic contour map patterns such that 1→ has pronounced coherent (dipolar) activity in all 3 time windows, but the 0→ condition has a coherent pattern only in the 2-nd time window (D).

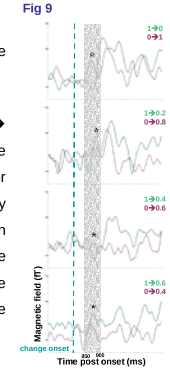
Note the asymmetry at time D between the1→0 and 0→1 conditions

ACCOUNTING FOR BEHAVIOR (Where are the ~80ms difference?)

There was no difference in peak latency (window D) between the 0→ and 1→ conditions.

As just seen, the first increase in activity is evident in all 1→ conditions at approx 50ms post change in correlation (time window C) activity in this time window is significantly stronger for 1→ conditions than 0→ conditions Fig 9 demonstrates this by comparing RH responses to 1→ and 0→ conditions with an equal IAC change. This response appears approx 80ms before the first peak in the 0→ condition (window D) and is a possible candidate to be the electrophysiological correlate of the observed behavioral response time differences.

Fig 9



DISCUSSION

1. **The difference in brain activation between the responses in the two conditions (1→/ 0→) indicates that each activated a different processing mechanism.**
2. **Similar findings were reported in vision regarding perception of changes in correlation for dot arrays [7]. The suggested explanation is that more effort/time is required to go from a disordered state (e.g. uncorrelated) to an ordered one (e.g. correlated) than vice versa. Do these mechanisms reflect a general change-processing mechanism?**
3. **These data (including the amplitude difference at onset) are also compatible with the Equalization-Cancellation model [8] that proposes that the inputs to the two ears are subtracted from each other, and the remainder constitutes the representation of binaural information.**
4. **The asymmetry in behavioral and brain responses between 0→1 and 1→0 conditions suggests that discrimination of correlation differences is not symmetrical and thus cannot be modeled by a simple decision axis.**