Human Auditory Cortical and Behavioral Sensitivity for Transitions Between Order and Disorder

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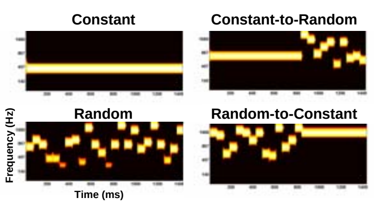
INTRODUCTION

Sensitivity to changes in sound is important to auditory scene analysis and detection of the appearance of new objects in the environment. Here we use the high temporal-resolution of MEG to explore the neural mechanisms underlying listener's ability to detect changes in ongoing stimuli, and compare these with psychophysically derived behaviour. In particular, we study the temporal dynamics of the process by which listeners detect transitions from "disorder" to "order" and vice versa. This is relevant to auditory scene analysis: the appearance of a coherent object within noisy background can be understood as a sudden emergence of order within the ongoing random signal. Likewise, the appearance of an unexpected event can be understood as a disruption of a previous, predictable, order. Here we combine, psychophysical measures and non invasive brain-imaging via Magnetoencephalography (MEG) to study how the human auditory cortex processes these changes. 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.

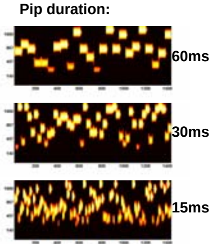
In a pervious pair of behavioural and neurophysiological experiments transitions between 'disorder' and 'order' were modelled as a change from interaurally-uncorrelated to correlated noise and vice-versa [1]. Here, they are modelled with a sequence of tone pips of random frequency followed by a constant tone and vice-versa.

STIMULI AND METHODS

Frequencies are chosen semi-randomly from 222-2000 Hz (in log steps). To assure that the change is adequately perceptible, the frequency step at 840 ms post onset is always at least 20%. Constant-to-Random and Random-to-Constant signals are created as mirror images.



Pip duration:



The auditory system uses an integration window that extracts statistics from the ongoing signal. With MEG, we measure the latency of brain responses to change and investigate the properties of these temporal integration windows. We used signals with different pip durations in order to examine how adjustable are these mechanisms, How fast adjustment occurs, and whether it requires attention.

In the MEG study, subjects listened to these stimuli while performing an irrelevant task that did not require conscious change detection.

NOTATION:

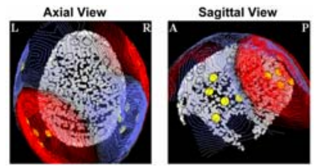
CF Constant First: Stimuli where the reference (first 840 ms) is a constant tone. These stimuli are coded in blue

RF Random First: Stimuli where the reference is a random sequence of tone pips. These stimuli are coded in green

MEG (1.5 hours recording per subject):

Stimuli with different tone pip durations were presented in separate blocks, the order of presentation was randomized (Latin square design) across subjects. Within each block, subjects heard 120 repetitions of each of the 4 conditions (RF, CF, R, C; randomized). Target stimuli (30%; not analyzed) were 200ms noise bursts. ISI was randomized between 1-2 sec. Subjects were instructed to press a button held in their right hand as soon as they heard a noise burst. The target stimuli assured the subject's alertness and focused attention on the auditory stimuli but did not require any conscious processing of change.

MEG MEASUREMENT AND ANALYSIS



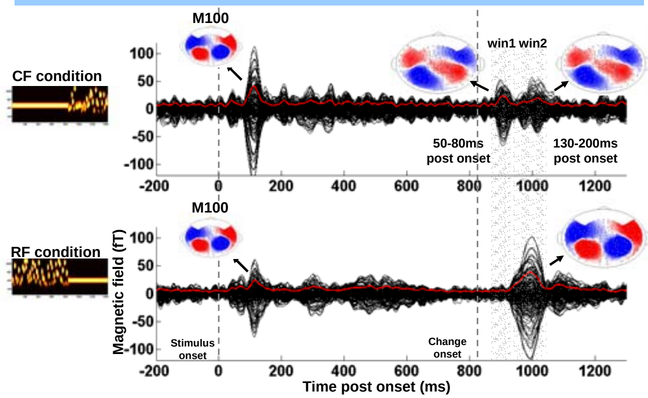
Auditory cortical responses were recorded using a 160 channel whole head MEG system (KIT, Kanazawa, Japan).

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

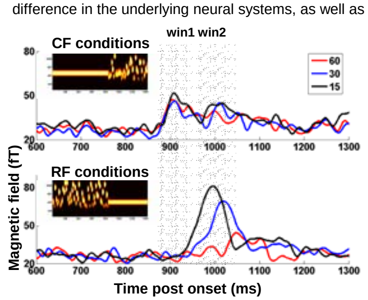
All statistical analysis is performed on each-hemisphere, subject-by-subject (based on the 20 channels selected for each) basis. Grand-average plots are presented for illustration purposes only.

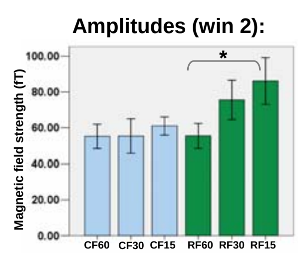
MEG RESULTS (N=24)



The Figure above shows the grand-average (over all 160 channels, in black) of auditory cortical responses to CF and RF (Pip size=15ms) stimuli. The root mean square (RMS) is plotted in red. The stimulus onset response is similar in both conditions and is characterized by an M100 peak at ~100ms post onset. The distribution of the magnetic field over the scalp (derived from the grand-average data) is shown.

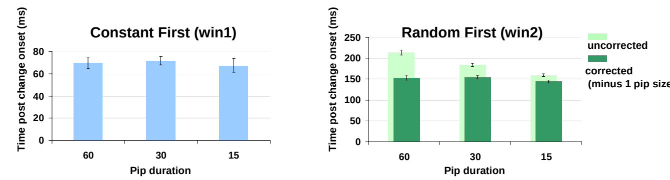
The response to the change (840 ms post stimulus onset) is characterized by sequential increases in activity in 2 temporal windows ~70ms (Win1) and ~150ms (Win2) post change. The responses in the CF and RF conditions exhibit a different dynamic pattern such that CF has pronounced coherent (dipolar) activity in both time windows, but the RF condition has a peak only in the 2-nd time window. Remarkably, the corresponding magnetic contour maps are of opposite polarity, indicating a difference in the underlying neural systems, as well as in the time course of processing.





Group RMS (RMS of individual RMSs) in the Left Hemisphere.

BRAIN RESPONSE LATENCY



CF win1 peak latencies did not differ with pip duration and were constant at about 70 ms post change. RF win2 peak latencies were modulated by pip duration (light green). After correction (subtraction of one pip duration) the peak latencies in all conditions were constant at about 150ms post change.

Constant-to-random responses are faster than random-to-constant responses, as predicted theoretically. Focusing on the size of the integration window used to detect the change, we show that listeners adjust the integration window to the statistical properties of the signal even when not actively attending to the changes.

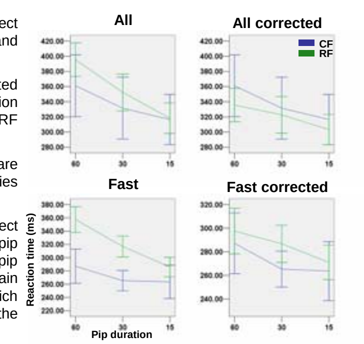
COMPARISON WITH BEHAVIOR

MEG responses were recorded while subjects were not actively paying attention to the changes. Yet, brain responses showed an accurate adjustment to signal statistics. After correction for pip duration, the difference in first peak latency between CF and RF conditions was about 80ms. If subject behavior is directly affected by these mechanisms, we expect behavioral reaction times to follow the same trend.

BEHAVIOURAL STUDY (1.5 hours):

The stimuli were the same as in the MEG study except that target stimuli (noise bursts) were not presented. Subjects heard 120 repetitions of each condition (different pip sizes were presented in separate blocks) and were instructed to press a button as fast as they can when they hear a change in the sound from constant to random or vice versa. A practice session preceded data collection.

- Data for all (N=24) subjects showed no effect of type (CF vs. RF) in both corrected and uncorrected analyses.
- Data for the fast subjects (N=12) exhibited effects similar to the MEG data, but reaction time differences between CF and RF conditions were small.
- Similar 'Fast' vs. 'Slow' subject effects are commonly observed in reaction time studies (e.g [2]).
- Both 'All' and 'Fast' groups had a main effect of pip duration such that responses in short pip blocks were significantly faster than in long pip blocks, for both CF and RF conditions. Brain responses did not exhibit such an effect, which suggests an indirect relationship between the observed MEG responses on behavior.



DISCUSSION

Data are very similar to interaural-correlation change data [1], indicating that the mechanisms observed are general change detectors. The investigation of these general change detecting mechanisms may reveal the statistical heuristics with which the human brain samples pre-attentively, represents, and detects changes in the acoustic environment,

REFERENCES

[1] Chait, M., Poeppel, D., de Cheveigne' A. & Simon J (2005), Auditory cortical sensitivity to changes in interaural correlation. J Neurosci.14;25(37):8518 –27

[2] Dupoux E (1993) The time course of prelexical processing: The syllabic hypothesis revisited. In: Cognitive Models of Speech Processing (G. Altmann & R. Shillcock (Eds.)), pp. 81-114. Hillsdale, NJ: Erlbaum.

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