MEG Investigations of Spectral and Temporal Resolution Properties of Human Auditory Cortex

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• Speech perception and hemispheric asymmetries in speech processing

• Auditory perception and cortical sound processing

• Cortical language function and mapping in healthy adults and pre-surgical patients

• Neurobiology of language dysfunction in developmental disorder

• History of neuroscience: Carl Wernicke’s model for language and his theory of conceptual representation in cortex
Research Goals:

To understand neural mechanisms that underlie speech and language processing in healthy adults and typically developing children.

To elucidate neural processes that underlie language dysfunction in developmental disorder, such as autism.

To understand the correspondence between genetics, brain, and behavior in the language domain.
Speech perception and hemispheric asymmetries in speech processing

Auditory perception and cortical sound processing

Cortical language function and mapping in healthy adults and pre-surgical patients

Neurobiology of language dysfunction in developmental disorder

History of neuroscience: Carl Wernicke’s model for language and his theory of conceptual representation in cortex
Plan of the Talk

Studies of cortical sound processing in adults
- Spectral resolution properties of auditory cortex
- Integrative processes underlying cortical evoked components
- Temporal resolution properties of auditory cortex

Cortical sound processing in typically developing children and children with autism
- Spectral resolution for speech and non-speech sounds
- Maturational changes in cortical evoked components
- Temporal resolution properties of auditory cortex

A case study:
Child with autism and language impairment, a rare chromosome deletion on a region implicated in language, and extreme sensory reactivity
Temporal Resolution of Auditory Cortical Systems

The temporal resolution of the auditory system is exquisite, with neural systems that decode features in the acoustic signal capable of submillisecond resolution.

The high level of resolution in auditory cortical systems provides the capability for decoding fine-grained fluctuations in sounds, critical to the accurate perception of speech.
Magnetoencephalography (MEG)

- Millisecond temporal resolution
- Post-synaptic, dendritic flow
- Synchronized response of populations of neurons
- Time-locked to a stimulus event
- Modeled by a single equivalent current dipole

Neuromagnetic Auditory Evoked Field
Basic Principles of MEG

Magnetic Fields Sources

Orientation of Neurons

Detection Device

Liquid Helium
SQUID
Superconducting Coils

Magnetic Field

Magnetic Field Pattern

Model

Right
Left
M100 Dipole
MEG recording of neuromagnetic evoked fields is entirely non-invasive … and silent
Sensor coils

148 Channel Sensor Array

Nose

Left and Right Hemisphere

Auditory Cortical Dipolar Activity
Magnetic Field Contour Map

Left and Right Hemisphere Auditory Cortical Dipolar Activity
A prototype auditory evoked neuromagnetic field detected by MEG; 37 channels with y-scale representing evoked response magnitude in units of femtotesla (fT) are shown collapsed on the same horizontal time axis.
MEG Investigations of Spectrotemporal Resolution
Properties of Auditory Cortex in Adults
Frequency Dependence of the M100: In healthy adults, M100 latency is modulated by tone frequency, with longer latencies for low (100-200 Hz) as compared to high (1000-3000 Hz) frequency tones.

For sinusoidal tones, M100 latency is modulated as a function of tone frequency, with a ‘fixed cost of ~100 ms plus a period dependent time that is roughly equal to 3 periods of the sinusoid (~30 ms for a 100 Hz, ~3 ms for a 1kHz tone). The dynamic range of frequency modulation in adults is ~25 ms.
M100 Role in Speech Perception
Does the M100 reflect sensory (acoustic) or perceptual (representational) processes?

Frequency of $F_1$ is inversely related to vowel height, with lower $F_1$ associated with high vowels (/u/) and higher $F_1$ with low vowels (/a/).

Vowel Continuum varying in values for $F_1$ but otherwise matched.

<table>
<thead>
<tr>
<th></th>
<th>/u/</th>
<th>/a/</th>
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<tbody>
<tr>
<td>$F_0$</td>
<td>100 Hz</td>
<td>100 Hz</td>
</tr>
<tr>
<td>$F_1$</td>
<td>250 Hz</td>
<td>50 Hz steps</td>
</tr>
<tr>
<td>$F_2$</td>
<td>1000 Hz</td>
<td>1000 Hz</td>
</tr>
<tr>
<td>$F_3$</td>
<td>2500 Hz</td>
<td>2500 Hz</td>
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Investigative Question:
Will M100 latency reflect the spectral center of gravity of 3 formant vowels (curvilinear function) or vowel identity (stepped function)?
**M100 latency** reflects vowel identity as well as secondary spectral features in speech sounds.
M100 amplitude reflects experience with speech sounds, with lower response amplitudes to novel tokens.
Neural mechanisms underlying the M100 component reflect phonetically-relevant features in speech

**M100 latency** reflects vowel identity as well as secondary spectral features in speech sounds.

**M100 amplitude** reflects experience with speech sounds, with lower response amplitudes to novel speech-like tokens.

Roberts, Flagg, & Gage, 2004
The M100 component has a brief (~35 ms) and finite integrative window during which stimulus attributes are accumulated in the processes leading to the formation of the M100 peak.

Within this integrative window, it is stimulus presence -- and not peak or integrated energy -- that dominates the processes underlying the M100.

Gage & Roberts, 2000
M100 is highly sensitive (within a brief integrative window) to transient features in consonants that cue distinctive feature contrasts in speech, such as manner and place of articulation, voicing.

The selective activation of the M100 for some stimulus features (periodicity, formant transitions) and not others (absolute sound level) has led to its description as an intermediate processing stage between sensory (acoustic) and perceptual (representational) processing.

Gage et al., 1998, Gage et al., 2002
What is the Temporal Resolution for Resolving Brief Discontinuities in Sounds within the M100 Integrative Window?
Temporal Resolution of the Auditory M100: Gap Detection Experiments

Psychophysical investigations of auditory perceptual acuity frequently employ gap detection paradigms, where a silent gap is inserted in a tone or noise burst and the minimum detectable gap is measured.

Gap detection thresholds correspond to speech perception acuity, indicating that similar or overlapping neural processes are employed both in detecting brief silent gaps and in resolving the fine structure of the speech signal.

The investigation: we know that the M100 is sensitive to the presence of a stimulus within a brief and finite integrative window.

What are the lower limits of the resolution for brief discontinuities – or the absence of a stimulus – within the M100 window of integration?

Gage, Roberts, & Hickok, In Press 2005
How sensitive is the M100 to fine-grained temporal discontinuities in sounds?

We address this question by inserting brief gaps of silence at +10 ms post stimulus onset and measuring M100 modulation as a function of gap duration.

In a second condition, we inserted gaps at +40 ms post onset. Here we predicted that M100 would not be modulated by gaps of silence because the gaps were inserted outside the integrative window.
Results: M100 Latency is modulated by Gap Duration.
Results: M100 Amplitude is modulated by Gap Duration
Results: M100 is not affected when gaps are inserted at +40 ms post onset
Conclusions

A Finite Temporal Window of Integration for the M100

These data provide further evidence for a short (~35 ms) and finite window of integration in the accumulation processes leading to the M100 peak.

Fine-grained Temporal Resolution of the M100

The integrative processes underlying M100 formation are highly sensitive to fine-grained discontinuities in sounds.

M100 sensitivity to the shortest gap (2 ms) corresponds to clinical and behavioral measures of auditory acuity, where detection thresholds have been reported for gaps of <5 ms.
The Time Course of Auditory Cortical Processing
Integrative Windows for the M50 and M100 Components
Reflect Underlying Sensory and Perceptual Mechanisms

M100 - ~35 ms TWI
Secondary Auditory Cortex
Feature Discrimination Processes

M50 - ~10 ms TWI
Primary Auditory Cortex
Detection, Habituation Mechanisms

Gage, Hickok, & Roberts, 2005
The CNL Team ...