Speech 2
Fig. 1. Overview. This figure illustrates the different procedures involved in recording human ERPs. The left column shows the procedures involved in recording the electrical activity from the scalp. The middle column shows the procedures for analyzing these signals in a digital computer. The amplified analog activity is initially converted into digital format. Various techniques are then used to enhance the signal-to-noise ratio to determine the components of the recorded wave forms and to measure these waveforms or components. The right hand section of the figure shows different means for displaying the activity during and after its analysis.
Voltage Maps

- Nearest Neighbor
  - $d_i$: distance to electrode $i$
  - $N$: number of neighbor electrodes
  - $V_i$: voltage at electrode $i$

- Alternative
  - Spline interpolation

Fig. 19. Scalp distribution maps for the auditory evoked potential. These maps present the scalp distributions at selected latencies during the waveforms plotted in Fig. 4. The maps are based upon the average reference recordings and are plotted using an azimuthal equidistance projection extending down below the Fpz-T7-Oz-T8 equator to about the level of the mastoid electrodes. The thick line in the maps represents zero voltage. The dashed lines represent contours for negative voltages and the thin lines represent contours for positive voltages, both plotted at intervals of 1 $\mu$V. At 105 ms there is a negative wave (N1b) recorded maximally at the vertex whereas a later negative (N1c) occurs maximally in the left temporal region. The P2 wave is maximally recorded from the vertex. The sustained potential (SP) is maximally recorded from frontocentral regions with a scalp distribution somewhat more anterior than that of the N1b wave.
Current Source Density

- 2\textsuperscript{nd} spatial derivative
  - How voltage changes at each point on the scalp differ w/respect to changes at other points
- Estimates sources and sinks of radial current
  - Net current outflow: source
  - Net current inflow: sink
- Highlights activity focused on limited scalp area
- Tends to remove deep sources that show up at many electrodes
Scalp Distribution of Dipole Fields

- Oblique & Radial sources yield
  - similar scalp maps
  - different CSDs
- For deep source
  - No clear CSD
  - Deep sources equally distant from all sites
  - Look similar at all sites
  - Hard to detect with derivative measure
Neuronal current flows perpendicular to the cortex and creates dipole fields

\[ \text{net current density} \times \text{area} = \text{equivalent dipole moment} \]
Source Parameters

- Dipoles characterized by 5 parameters
  - 3 location parameters
    - Eccentricity – distance to center of head
    - Theta – angle w/vertical axis
    - Phi – angle from coronal plane
  - 2 orientation parameters
    - Theta – angle w/vertical axis
      - Positive: right
      - Negative: left
    - Phi – degrees from the coronal plane
      - Positive: counterclockwise
      - Negative: clockwise

Fig. 38. Source parameters. This figure illustrates how source analysis can describe the parameters of a dipole source. For simplicity, only one dipole is shown (a blink dipole). A source dipole is defined by its location, orientation and strength. Location is expressed by three parameters: eccentricity, azimuth (theta) and longitude (phi). Eccentricity is the distance from the source to the center of the head model. It is often expressed as a percentage of the radius of the head model used. Theta is the angle formed with the vertical axis by the line joining the source location to the center of the head. Phi is the angle formed with the coronal plane by a line joining the source and the center of the head. Orientation is expressed by two parameters: theta and phi. These are measured using the same references as the angles used to express location. The sign convention for theta is that a positive sign indicates right-sided location or right-going orientation and a negative sign indicates left-sided location or left-going orientation. For phi, a negative sign means clockwise rotation and a positive sign means anti-clockwise rotation from the coronal plane. The strength of the dipole as a function of time is given by the dipole source potentials.
Source Analysis

- Activity at each site linear combination of sources
- C here is coefficient that determines value of source at electrode \( u \) based on
  - Source Location
  - Source Orientation
  - Conductivity of brain, skull, and scalp
General Idea

• Forward Model
  – Postulate N dipolar sources with particular locations and orientations
  – Coefficient matrix C: N sources x K electrodes (values based on head model)
  – Run source magnitudes through C to yield predicted scalp voltage at each electrode: Vector U’

• Inverse Model
  – Invert matrix C
  – Multiply by actual scalp voltage matrix U
  – Yields S

• Reduce Residual Variance
  – Difference between U and U’
  – Change dipoles so as to minimize difference between U and U’

• Rinse and Repeat
There are more unknowns (dipole sources) than knowns (electrodes).
This results in infinite number of possible solutions.
Usually done as an iterative forward algorithm with a small number of equivalent source dipoles.

- A starting point is chosen based upon additional information -fMRI etc.
- A forward solution of the scalp map is calculated.
- An iteration is chosen holding some factors constant.
  - Orientation
  - Location
  - Magnitude
- The process is repeated until a satisfactory fit of the scalp map is obtained.
Source modeling of a propagating spike (step 1)

- source model: 1
- source waveform
- scalp waveforms
- model waveforms
- relocate dipole
- minimize difference
- forward model
- inverse model
- head model
Source modeling of a propagating spike (step 2)

source model: 2

source waveforms

scalp / residual model ~ scalp

forward model

head model

inverse model

-1
Multiple sources separate activities from different brain regions

source topographies  EEG data  source waveforms

inverse multiple source operator

source montage

source 1 active

source 2 active

propagation

Inv_1  100%
Inv_1 * Top_2 = 0%
Inv_1 * Top_3 = 0%

Inv_2  100%
Inv_2 * Top_3 = 0%

Inv_3  100%
FIG. 2. Brain areas that showed significant fMRI activation to the three deviant stimuli were superimposed on an individual structural magnetic resonance image in Talairach space. Images were thresholded at $P < 0.01$. While all deviant types induced activation in the superior temporal gyrus bilaterally (left: −61, −31, 9; right: 58, −23, 9), the opercular part of the right inferior frontal gyrus (46, 20, 6) was found active only for large and medium deviants.

FIG. 3. MMN component elicited by large, medium, and small deviants when scanner noise is present. Difference waveforms were obtained by subtracting the ERPs to standard tones from those to all deviant tones separately. Note that no statistically significant MMN was observed for small deviants. For details see Fig. 1.
Conclusions?

• Their claim: early MMN temporal lobe sources, late MMN frontal source
  – Plausible a priori
• BUT: Model explains variance from .1 to .2 seconds
• Frontal source most active after that period
• Authors making big claims about the least solid aspect of their data…
Consonants

• Place of Articulation
  – Which part of mouth constricts to make consonant?

• Manner of Articulation
  – How is the sound made?

• Voicing
  – Are vocal cords vibrating or relaxed?
Consonants

- **Place of Articulation**
  - Bilabial: p, b
  - Labiodental: f, v
  - Dental: th
  - Alveolar: t, d
  - Velar: k, g
  - Glottal: ch in Bach

- **Manner of Articulation**
  - Stops: b
  - Fricatives: s, f, v, th
  - Affricates: ch, j
  - Nasals: m, n
  - Laterals: m, n
  - Semivowels: w, r

- **Voicing**
  - Voiced: b
  - Voiceless: s
Why Distinctive Features

• Phonemes described as combo of distinctive features

• Distinctive because they allow us to discriminate between phonemes
  – Voicing         t vs d
  – Manner of Articulation  n vs d
  – Place of Articulation    b vs d
McGurk Effect
McGurk & MacDonald (1977)

- Interested in whether babies attend more to face or to sound
- Plan:
  - Make sound/face mismatch video
  - Habituate babies to video
  - Then give them choice between new video that matched sound vs. new video that matched face movements
- Discovery by technician
  - Mismatch /ba/ /ga/ videos sounded like /da/!!!
Task

• Watch video and repeat sounds
• Listen to video repeat sounds
• Response Categories
• Auditory /ba-ba/ Visual /ga-ga/
  – Auditory: ba-ba
  – Visual: ga-ga
  – Fused: da-da
  – Combination: --
• Auditory /ga-ga/ Visual /ba-ba/
  – Auditory: ga-ga
  – Visual: ba-ba
  – Fused: da-da
  – Combination: gabga, bagba, baga, gaba
Results

- **Auditory (% Correct)**
  - Pre-school: 91%
  - School-age: 97%
  - Adults: 99%

- **AudioVisual (% Wrong)**
  - Pre-school: 59%
  - School-age: 52%
  - Adults: 92%

- How and why do adults and children differ here?
Hear-ba/See-ga vs. Hear-ga/See-ba

- Acoustically /ba/ and /da/ similar, /ba/ /ga/ not
- Visually /ba/ confused with /pa/
  - Not with /ga/, /da/, /ka/, or /ta/
- Visually /ga/ confused with /da/
- Hear-ba/See-ga
  - Auditory info compatible with /da/ and /ba/
  - Visual info compatible with /ga/ and /da/
  - /da/ common to both modalities (Fused Response)
- Hear-ga/See-ba
  - Auditory info compatible with /ga/ (not /ba/ or /da/)
  - Visual info compatible with /ba/ (not /ga/ or /da/)
  - Information in conflict (Combination Response)
Sams, et al. (1991)

- McGurk effect reflects a stage of audiovisual integration
- What brain area does this occur in?

MEG Study

- McGurk Deviant
  - Hear /pa/ See /pa/ 84%
  - Hear /pa/ See /ka/ 16%

- McGurk Standard
  - Hear /pa/ See /ka/ 84%
  - Hear /pa/ See /pa/ 16%

- Control (Face Replaced by)
  - Red light 84%
  - Green light 16%
Magnetoencephalography (MEG)

• Records the *magnetic flux* or the *magnetic fields* that arise from the source current

• A current is always associated with a magnetic field perpendicular to its direction

• Magnetic flux lines are not distorted as they pass through the brain tissue because all biological tissues offer practically no resistance to them
Dipole is a small current source

- Dipole generates a magnetic field
- At least 10,000 neurons firing “simultaneously” for MEG to detect
- Dendriticic current
Recording of the Magnetic Flux

- Recorded by special sensors called magnetometers
- A magnetometer is a loop of wire placed parallel to the head surface
- The strength (density) of the magnetic flux at a certain point determines the strength of the current produced in the magnetometer
- If a number of magnetometers are placed at regular intervals across the head surface, the shape of the entire distribution by a brain activity source can be determined
Magnetic Flux Associated with Source Currents
Recording of Magnetic Signals
Recording of the Magnetic Flux

- 248 magnetometers
- The magnetic fields that reach the head surface are extremely small
- Approximately one million times weaker than the ambient magnetic field of the earth
- Because the magnetic fields are extremely small, the magnetometers must be superconductive (have extremely low resistance)
- Resistance in wires can be lowered when the wires are cooled to extremely low temperatures
Recording of the Magnetic Flux

• When the temperature of the wires approaches absolute zero, the wires become superconductive

• The magnetometer wires are housed in a thermally insulated drum (dewar) filled with liquid helium

• The liquid helium keeps the wires at a temperature of about 4 degrees Kelvin

• The magnetometers are superconductive at this temperature
Recording of the Magnetic Flux

• The currents produced in the magnetometers are also extremely weak and must be amplified

• Superconductive Quantum Interference Devices (SQUIDS)

• The magnetometers and their SQUIDS are kept in a dewar, which is filled with liquid helium to keep them at an extremely low temperature
Dipolar Distribution of the Magnetic Flux

• In the following figure, one set of concentric circles represents the magnetic flux exiting the head and the other represents the re-entering flux.
• This is called a dipolar distribution.
• The two points where the recorded flux has the highest value are called extrema.
• The flux density diminishes progressively, forming iso-field contours.
Surface Distribution of Magnetic Signals
Dipolar Distribution of the Magnetic Flux

- From the dipolar distributions, we can determine some characteristics of the source
  1. The source is below the mid-point between the extrema
  2. The source is at a depth proportional to the distance between the extrema
     - Extrema that are close together indicate a source close to the surface of the brain
     - A source deeper in the brain produces extrema that are further apart
  3. The source’s strength is reflected in the intensity of the recorded flux
  4. The orientation of the extrema on the head surface indicates the orientation of the source
Sams, et al. (1991)

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- What brain area does this occur in?

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  - Green light 16%
Fig. 1. Magnetic responses of one subject, measured with a 24-SQUID gradiometer over the left hemisphere, are shown in the top part of the figure. The upper traces of each pair show the field gradient in the vertical (v) and the lower one in the horizontal (x) direction. The exact locations and orientations of the gradiometers with respect to the head were determined by passing a current through three small coils, fixed on the scalp, and by analyzing the magnetic field thus produced. The number of averages is 520 for $V=A$ and 30 for $V=A$. The recording passband was 0.05-100 Hz; the responses have been digitally low-pass filtered at 40 Hz. The visually produced difference between the responses to the $V=A$ and $V=\neq A$ stimuli was largest at locations 1, 4, and 5. The $x$-responses at location 4 during the 3 measurement conditions are shown enlarged in the bottom part of the figure. The three pairs of traces were recorded over the same area in consecutive measurements.
ECD’s

- 100 ms deflection (N1m)
- Same direction for V=A and V~A
- Supratemporal auditory cortex

- Difference waveform (MMN?)
- More anterior and superior than for N1m
- Similar direction for V=A and V~A
- Supratemporal auditory cortex

Sams, et al. (1991)
Conclusions

• Visual information during speech affects activity in auditory cortex
• Articulatory movements often precede speech sounds by 100s of milliseconds
• How does Sams propose the brain takes advantage of this?
Colin et al.

- **Auditory Theory Speech Perception**
  - Speech perception based on acoustic information

- **Motor Theory Speech Perception**
  - Visual & Auditory Information immediately converted to intended articulatory gestures
  - Percept in McGurk effect is phonetic (not auditory)

- **Fuzzy Logic Model of Perception**
  - Visual & Auditory Information Processed in Parallel
  - Integrated at a late stage of perception
Colin et al.

• If a McGurk stimulus is the deviant in a passive auditory oddball paradigm, will it evoke an MMN?
• Same acoustic stimulus, different percept
**Auditory Alone**

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Block A</th>
<th>Block B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent</td>
<td>/bi/</td>
<td>/gi/</td>
</tr>
<tr>
<td>Rare</td>
<td>/gi/</td>
<td>/bi/</td>
</tr>
</tbody>
</table>
Fig. 1. Auditory alone presentation. In this and subsequent figures, the potentials evoked by the standard (thin line) and deviant (thick line) stimuli are superimposed and represent grand averages across all subjects. The classical exogenous P1, N1, and P2 components are readily identified. The derived waveform obtained by subtracting the standard response from the deviant one is plotted below the exogenous waveforms. The lowest trace illustrates the result of the statistical testing on a binary mode: the level is raised during each period of consecutive significant t-tests exceeding Guthrie's temporal threshold. The black triangles indicate the temporal position of the deviant consonant burst; the open triangle indicates deviant voicing onset. Both contrasts evoke an MMN at Fz location, whereas none is found at Oz.
## Visual Alone

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<td>/gi/</td>
</tr>
<tr>
<td>Rare</td>
<td>/gi/</td>
<td>/bi/</td>
</tr>
</tbody>
</table>
Visual Alone

Fig. 3. Visual alone presentation. The arrows indicate the onset of articulatory movement of the deviant stimuli. No MMN can be detected whenever the contrast and the scalp location.
## Audiovisual

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</tr>
</thead>
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<td>A/bi/ V/bi/</td>
<td>A/gi/ V/gi/</td>
</tr>
<tr>
<td>Rare</td>
<td>A/bi/ V/gi/</td>
<td>A/gi/ V/bi/</td>
</tr>
</tbody>
</table>
Psychophysics Experiment

• Do these stimuli elicit McGurk type effects?
• 74% elicited combination illusions bgi or gbi
• 66% elicited fusion illusions di
Audiovisual (McGurk Effect)

Fig. 4. Audiovisual presentation giving rise to the McGurk illusion. Arrows and triangles indicate the same stimulus temporal features as in previous figures. Both contrasts elicit MMN in Fz only. When /gi/ is deviant, 3 components are identified. The first two cover most of the exogenous waves, the third one is very late. When /bi/ is deviant, two components are identified: one over the N1 time slot and the other over the second half of P2.
Results

• Audio
  – MMN
  – polarity reversal between Fz & M1

• Visual
  – No MMN

• AudioVisual
  – MMN
  – No polarity reversal Fz & M1
Discussion

• McGurk stimuli do elicit MMN
• But different topography than auditory MMN
• What does that mean?
  – Generally?
  – For this issue?
Speech Perception Theories

• Auditory Theory
  – Acoustic

• Fuzzy Logic Model Perception
  – Automatic vs. Controlled

• Motor Theory
  – Phonetic vs. Bimodal
Ventriloquist Illusion

- Speech comes from man, but seems to come from puppet
- When there are synchronized auditory and visual events displaced in space, perceived auditory location shifted in space towards visual event
- Perceptual system integrates discrepant stimuli
Cross-Modal Integration


- What is the time course of the cross modal integration in the ventriloquist illusion?
- Is it early enough to elicit a MMN?
  - Spatial displacement of a sound elicits MMN
  - Does *illusory* displacement of a sound elicit MMN?
  - If it did, what would it mean?
Ventriloquist MMN Paradigm

STANDARD

DEVIAN'T
Results

- MMN auditory condition
  (dashed line)
- MMN AV-V condition
  (solid line)
- Similar amplitude & topography
- What does it mean?

*Fig. 2. Grand average difference waves at midline sites for the ventriloquist MMN (AV-V) and the auditory MMN (A).*

*J.J. Stokkon et al. / Neuroscience Letters 357 (2004) 163–166*