Sounds & Music

Is language special?

- “Language is a complex, specialized skill, which develops in the child spontaneously, without conscious effort or formal instruction, is deployed without awareness of its underlying logic, is qualitatively the same in every individual, and is distinct from more general abilities to process information or behave intelligently.” (Pinker, 1995: 18)

What about music?

LANGUAGE

- Complex skill
- Exists in all human cultures
- Develops in child spontaneously
  - But only if exposed to language input
- Develops without conscious effort or formal instruction
- Deployed w/o awareness of underlying logic
- Same in every individual
  - (this is not really true)
- Distinct from more general cognitive abilities

MUSIC

- Complex skill
- Exists in all human cultures
- Develops in child spontaneously
  - But only if exposed to musical input
- *Requires conscious effort and instruction*
- Deployed w/o awareness of underlying logic
- *Ability differs greatly from individual to individual*
- Distinct from more general cognitive abilities

Language & Music: Similarities

- Rule-based system
- Require specific knowledge
- Indigenous to humans
- Composed of sequential events that extend in time
- Involve the development of expectations over time

Violations of Musical Expectancies

- Besson & Faita (1995)
- Harmonic Violation
  - A note or chord from a different key than the one that has been established (non-diatonic)
- Melodic
  - A note from the same key, but not the one that's expected (diatonic)
- Rhythmic
  - Note is what is expected, but timing relative to prior notes is unexpected (e.g. 600 ms delay)

Materials: Besson & Faita (1995)

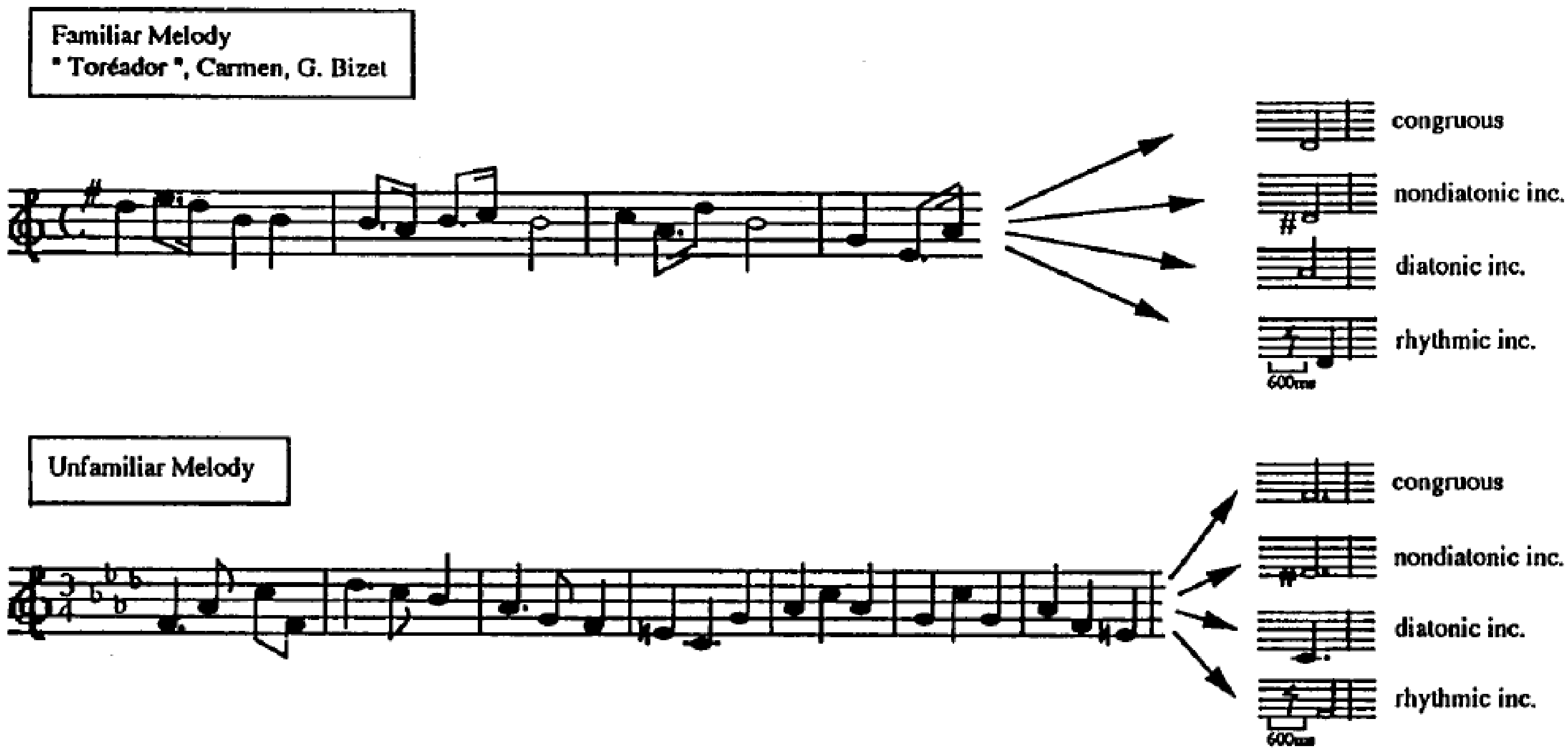
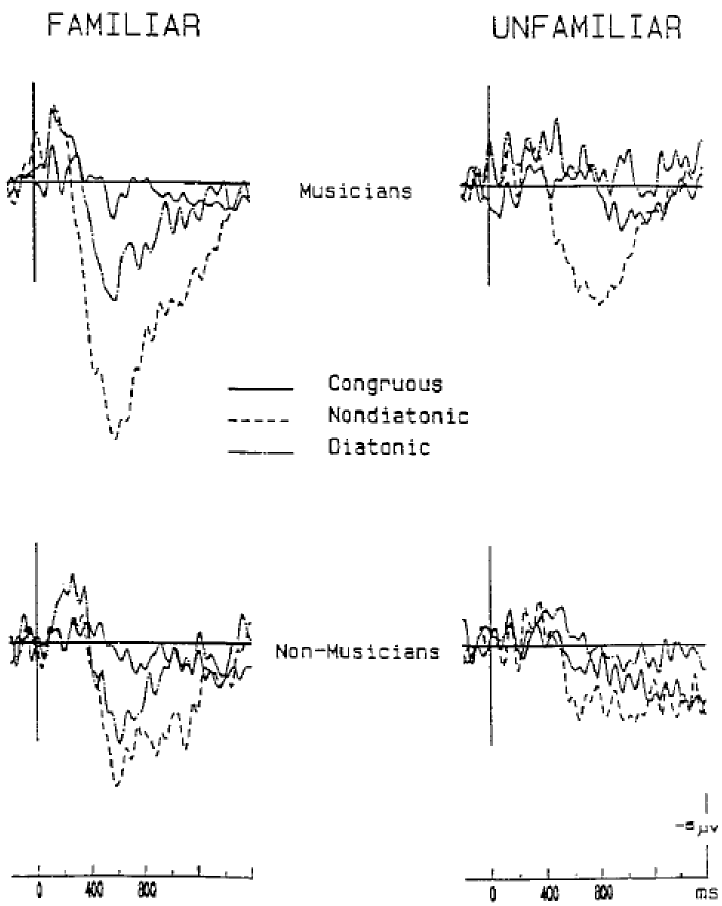


Fig. 2. Examples of the stimuli used in the experiment (from Besson & Faïta, 1995).

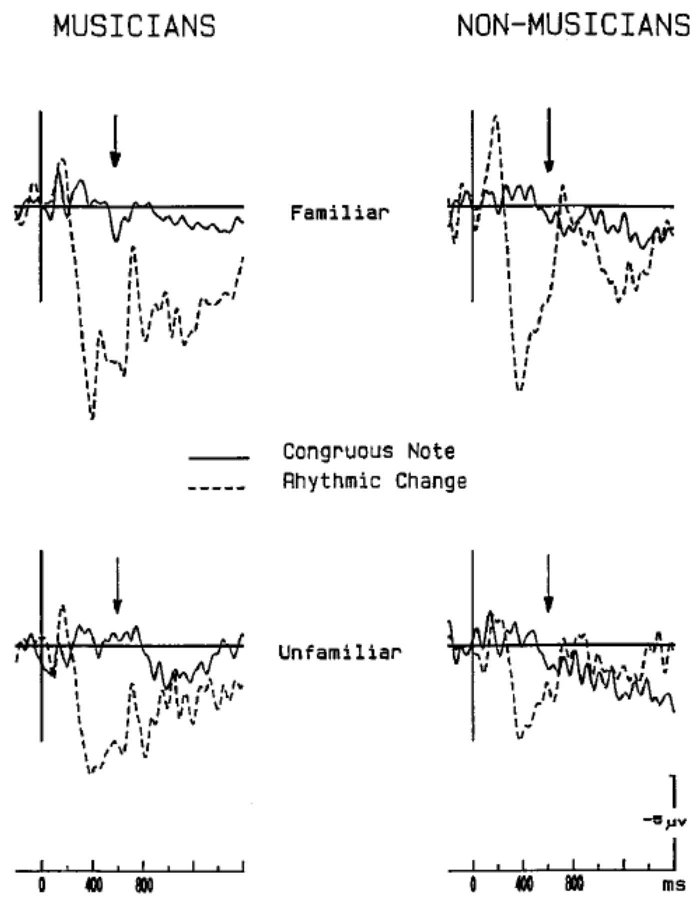
Musical Violations



- Familiar Melodies
  - P300/LPC
  - Larger for
    - Nondiatonic (out of key) than
    - Diatonic (wrong note in same key)
  - Effects larger in musicians than non-musicians
- Unfamiliar Melodies
  - P300/LPC but smaller than for Familiar Melodies
  - Larger for Nondiatonic than Diatonic
  - Larger in musicians than non-musicians
- P300/LPC sensitive to
  - Perceived badness of note
  - Ability to perceive badness

Rhythmic Violations

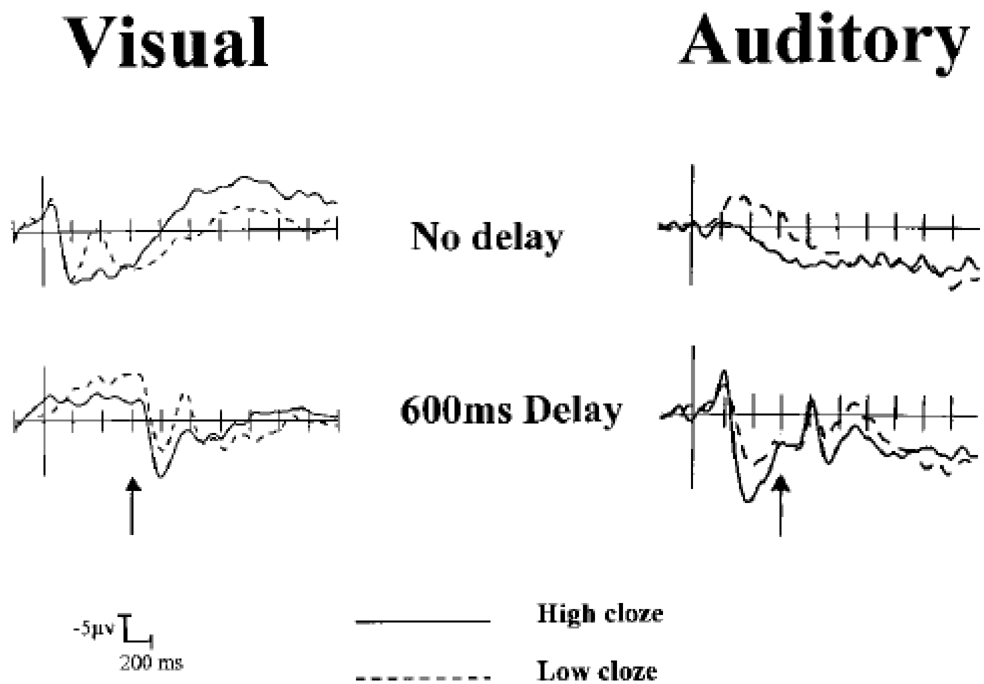
- Delayed last note elicits biphasic negative-positive complex
  - Larger for Familiar than Unfamiliar melodies
  - Similar in Musicians & Nonmusicians
- Emitted stimulus potential
  - also elicited in auditory oddball paradigms if a regular stimulus is interrupted
  - "Pause" positivity elicited in Van Petten et al. (1999) spoken sentences (dolphin/dollar/muffin) study
- Arrow marks actual presentation of note
- Actual note elicits N1-P2 complex typically evoked by tones



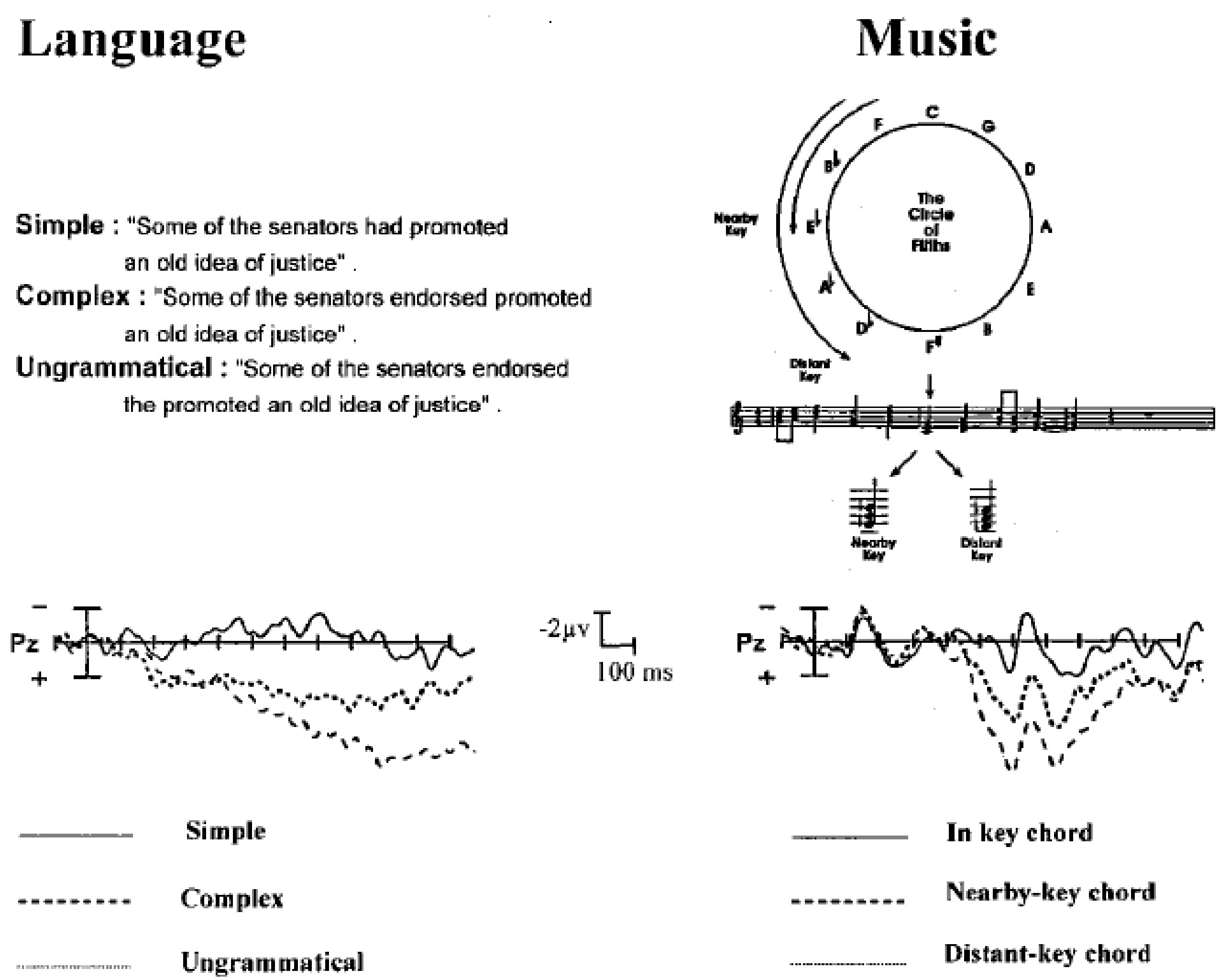
Rhythmic Violations in Music & Language

- Emitted potentials for delay of final note in melody
- What about temporal disruptions in language?
  - Besson et al. (1997)
- Visually presented sentences that end congruously vs. incongruously
  - One word at a time
  - 200 ms duration
  - 300 ms ISI
  - Delay final word 600 ms
- Slow negative component: CNV!
- Same materials via auditory presentation
- Emitted potentials!

Timing important for music and speech



Syntactic vs. Harmonic Violations



Semantic vs. Harmonic Violations

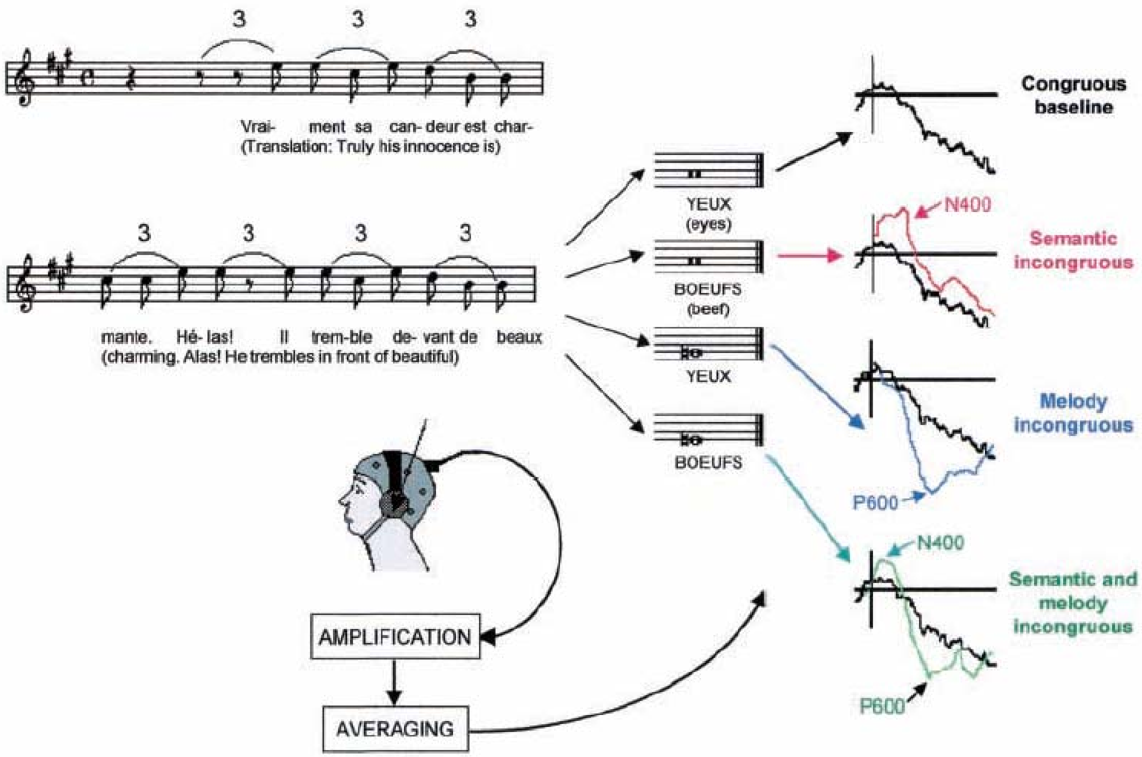


Fig. 3. Example of opera excerpt that was sung *a capella* by a professional singer with four different endings. The final word was either original, in being semantically and melodically congruous, and served as the baseline condition; semantically incongruous and sung in key; semantically congruous but sung out of key; or both semantically and melodically incongruous. Neurologically intact musicians monitored the presence of these incongruities in 200 opera excerpts, and event-related potentials that were time-locked to the final word onset were recorded, amplified, and averaged for the four conditions separately and then averaged for the 16 musicians. The resulting averaged waveform is illustrated on the right side of the figure for the midline parietal electrodes, with negative being up. The vertical bars represent the onset of the final word.

Music vs. Language

- Semantic violations elicit N400 while Harmonic violations elicit LPC
  - Additive relationship of N400 & LPC in opera study points to
  - independent processing of semantic vs. harmonic relationships
- Syntactic violations elicit P600/LPC as do Harmonic violations
  - Similar topographies
  - Similar sensitivity to complexity and violation
- Dissociation between linguistic and tonal components of songs in line with patient data where people can recognize the words of well-known songs but not the melodies

Attend to Language vs. Attend to Music

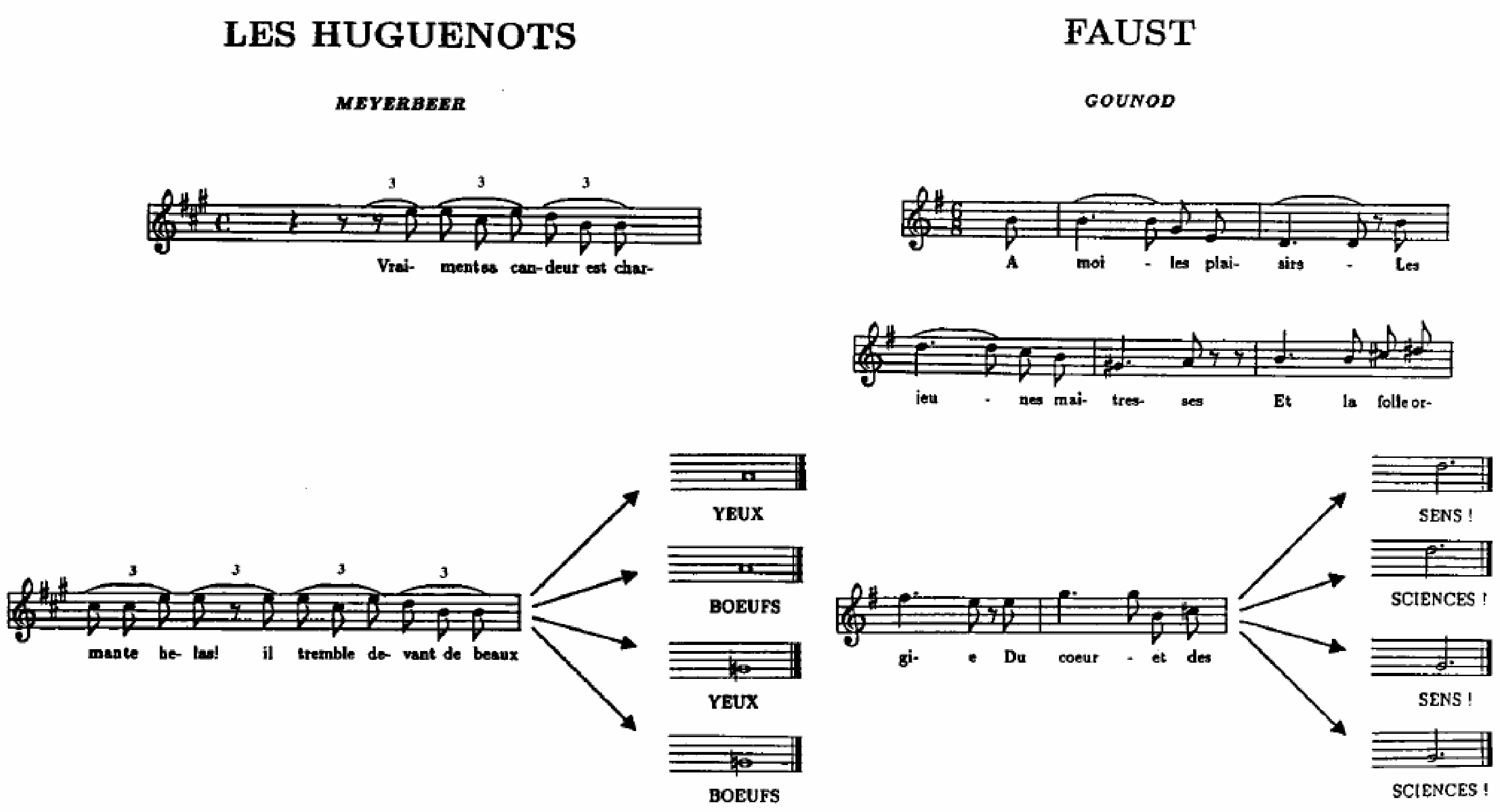
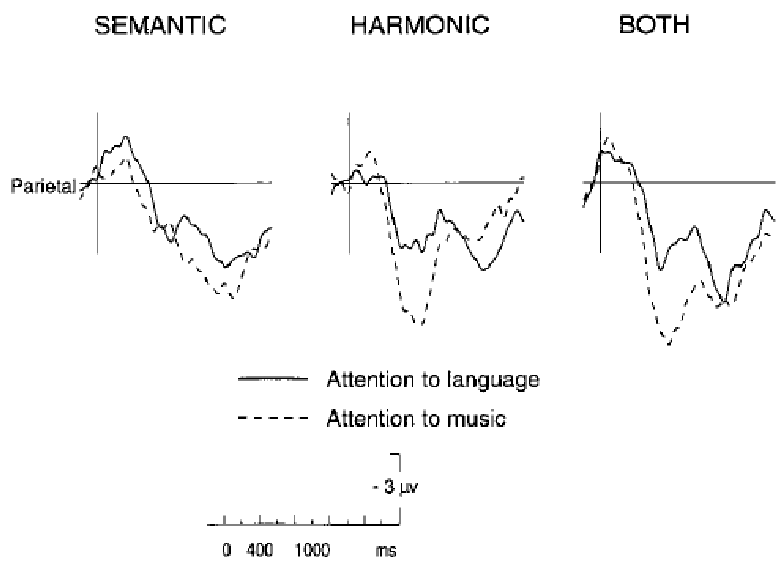


Fig. 7. Examples of the opera excerpts used in the experiment. Note that, in french, the final incongruous words, "boeufs" and "sciences", rhyme with the expected completions, "yeux" and "sens". The final word of the excerpt is sung in or out of key (from Besson et al., 1998).

Focused Attention

- Semantic incongruities elicit larger N400 when attending language than music
- Harmonic incongruities elicit larger LPC when attending music than language
- When final word is incongruous and out of key, LPC larger when attending music
- But latency of neither N400 nor LPC was affected by attention
- Some people find it odd that LPC to harmonic incongruities is so late (relative to semantic incongruities)



Musical Meaning

- Iconic meaning
  - Musical sounds that resemble sounds or qualities of objects
- Emotional meaning
  - Suggestion of a particular mood (happiness)
- Associative meaning
  - Extramusical associations (national anthem; “our” song)
- Musical tension
  - Via the combination of chords
- Musical resolution
  - Via the combination of chords

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  - **Via the combination of chords**

Koelsch et al. (2003)

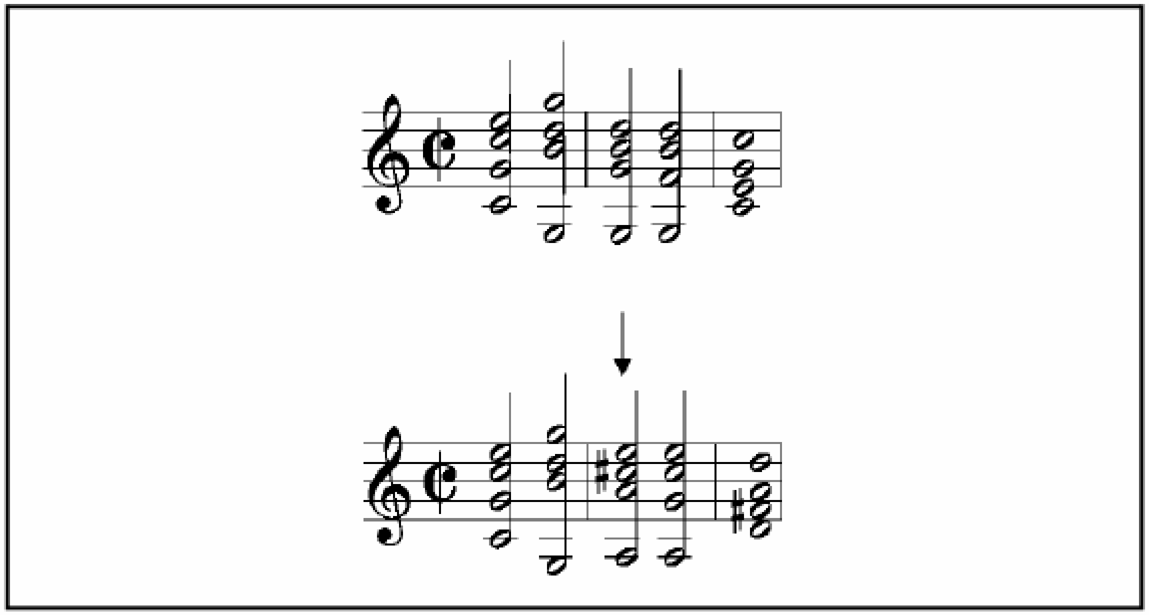


Figure 1. Examples of stimuli. Top: C major chord sequence exclusively consisting of in-key chords. Bottom: chord sequence modulating from C major to D major. The second chord is the pivot chord, functioning as dominant in C major, as well as subdominant in D major. The third chord of the modulating sequence (indicated by the arrow) is the dominant chord of D major, introducing one out-of-key note in respect to C major.

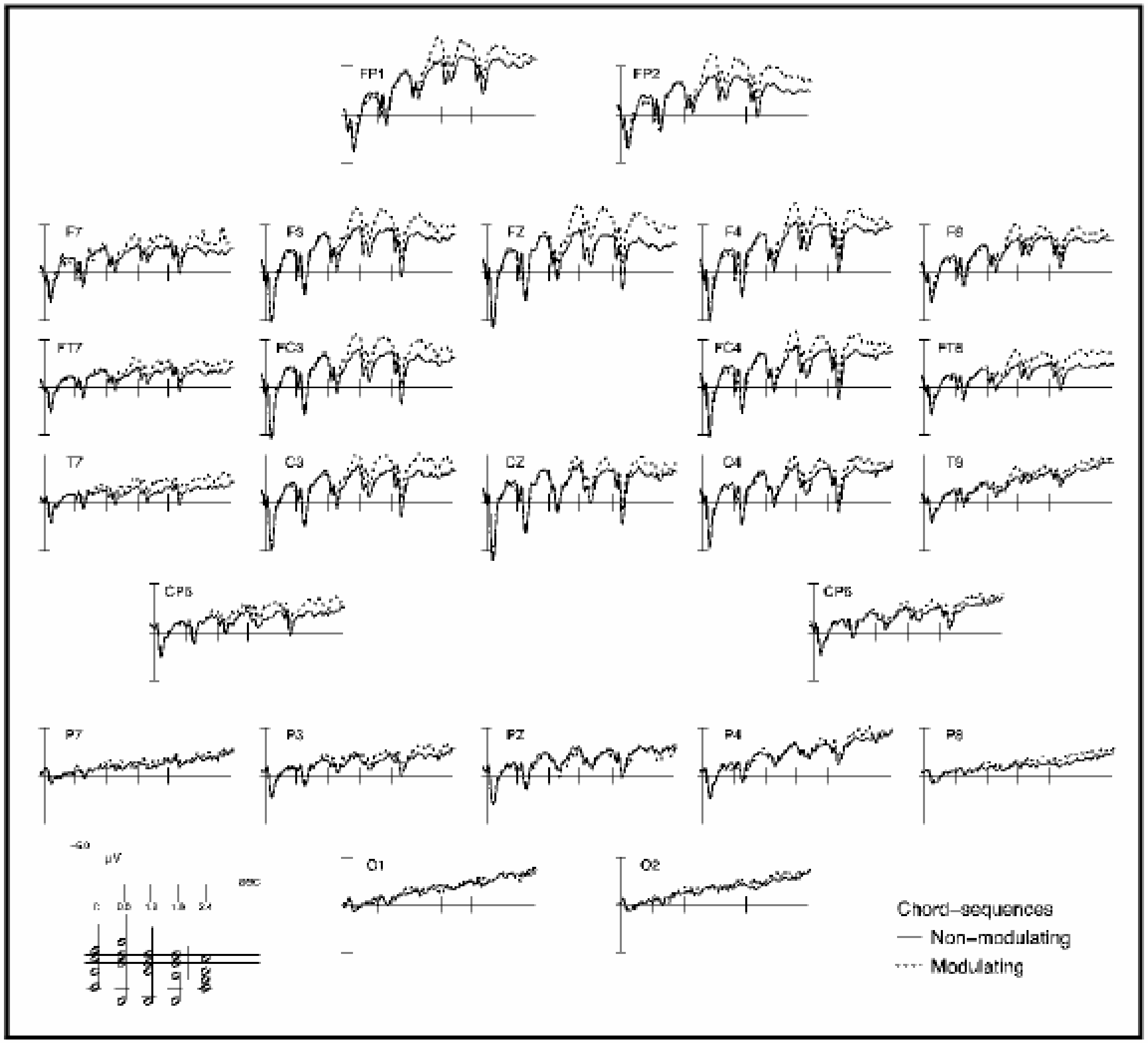


Figure 2. Grand average ERPs of entire chord sequences, separately for in-key and modulating sequences. Each vertical line corresponds to the onset of a chord. Modulations (presented from positions 3 to 5) elicited negative effects with frontal preponderance.

ERAN & N5

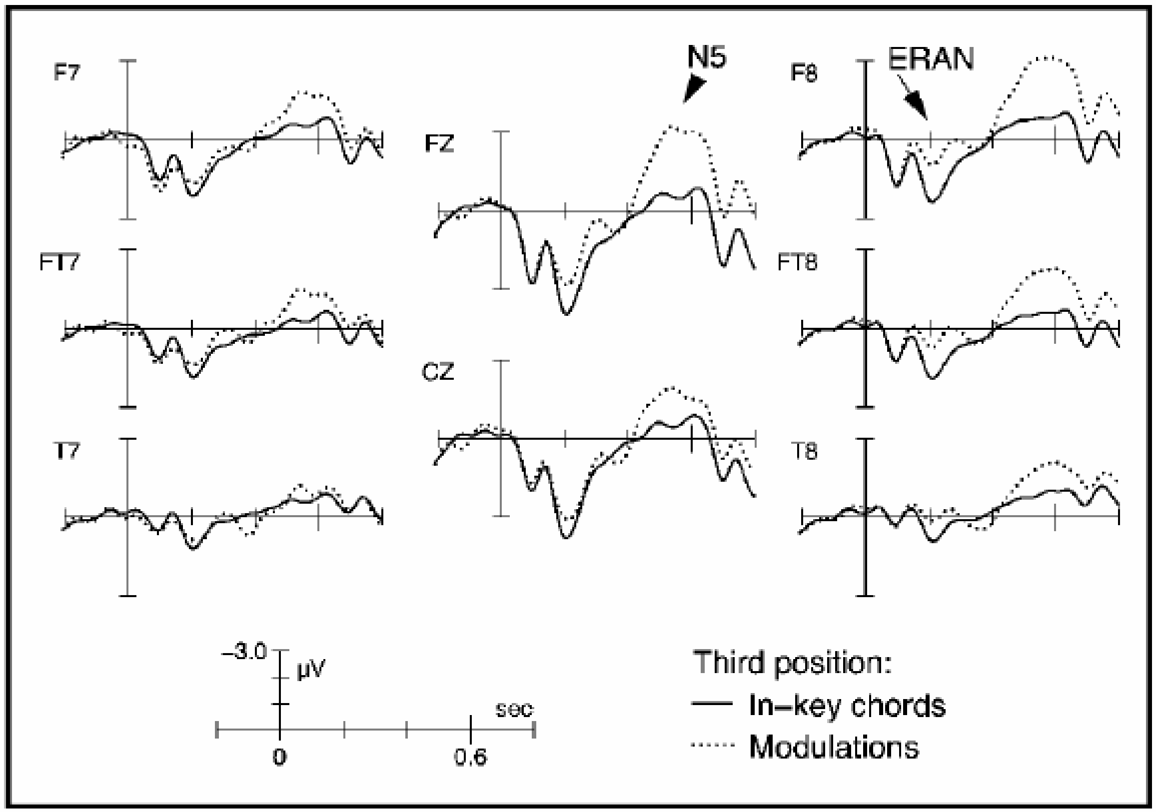


Figure 3. Grand average ERPs elicited at position 3 of the sequences, separately for modulating and in-key chords. Modulating chords elicited an early right anterior negativity (long arrow) and a late right frontal negativity (N5, short arrow).

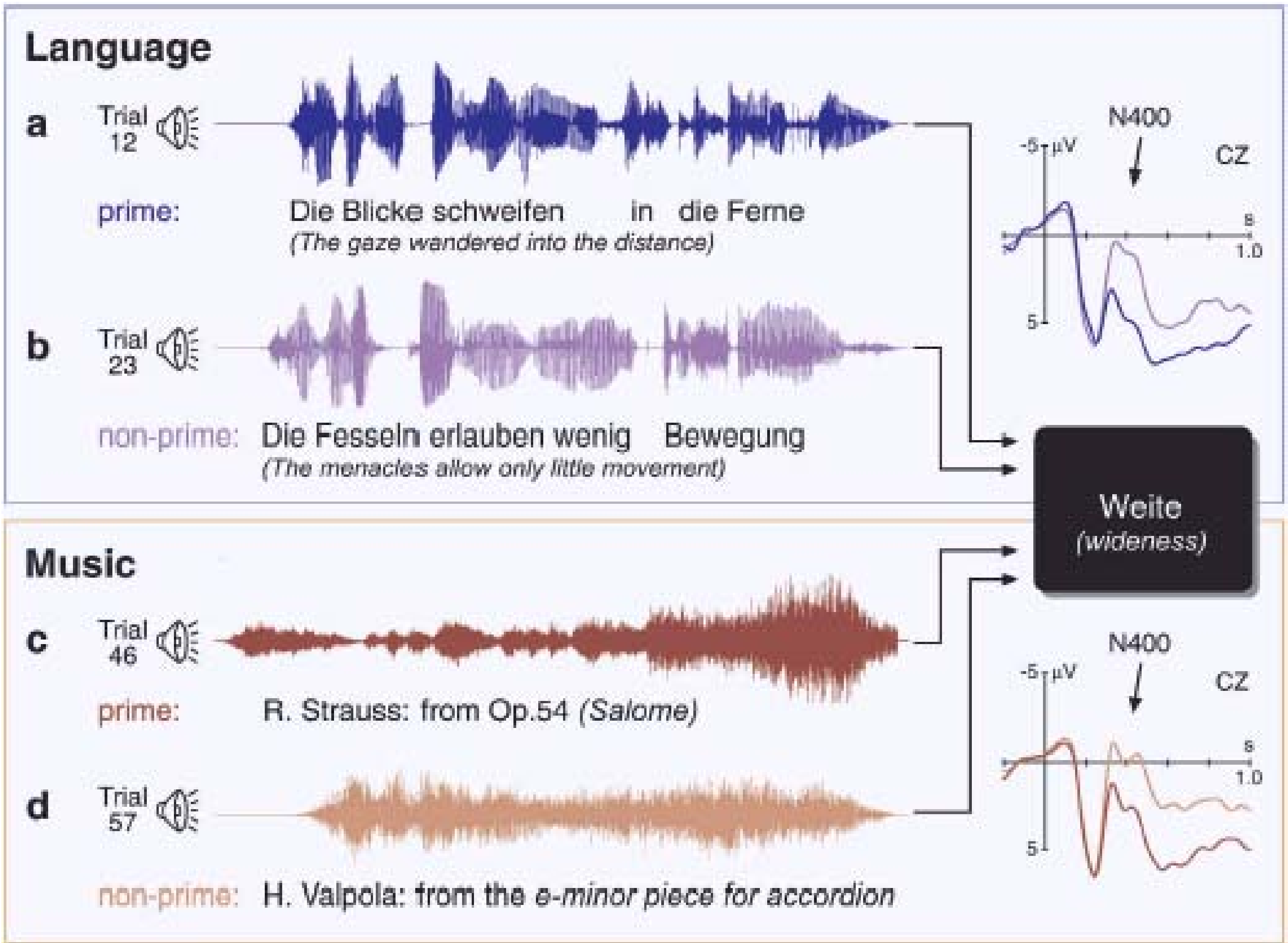
N5 vs. N400

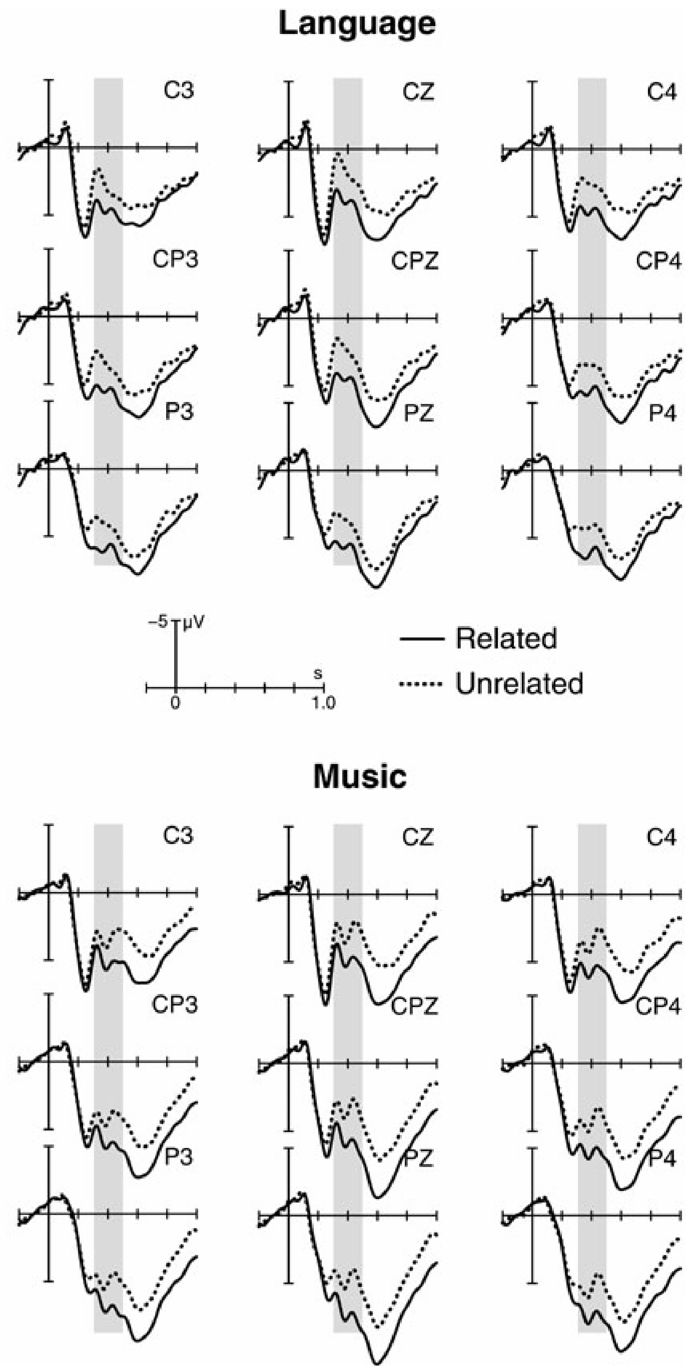
- Similar polarity
- Later latency
- Different scalp distribution
  - More anterior distribution
  - Reverses polarity at mastoids w/nose reference (consistent w/temporal lobe generator)
- Amplitude sensitive to integration demands
  - N400 semantic integration
  - N5 harmonic integration
- Has been suggested N5
  - reflects neural operations at least partly related to processing of musical meaning
  - involves processes that might also contribute to the generation of the N400

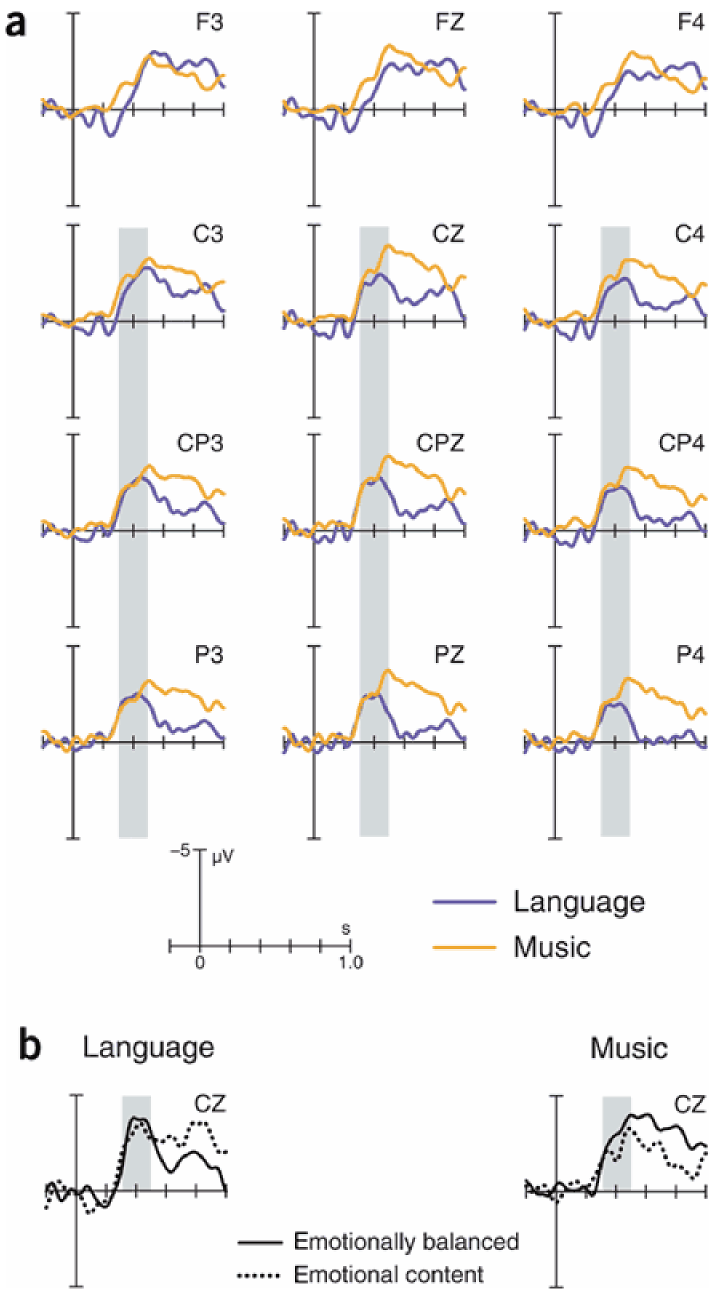
Musical Meaning

- Iconic meaning
  - Musical sounds that resemble sounds or qualities of objects
- Emotional meaning
  - Suggestion of a particular mood (happiness)
- Associative meaning
  - Extramusical associations (national anthem; “our” song)
- Musical tension
  - Via the combination of chords
- Musical resolution
  - Via the combination of chords

Koelsch et al. (2004)

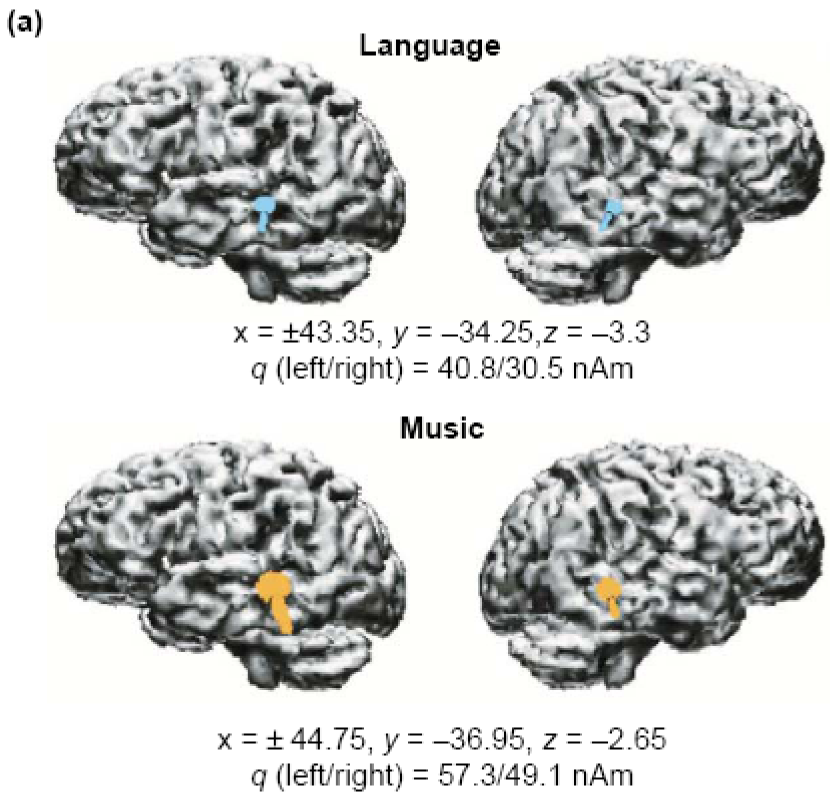



Language
C3
CZ
C4
CP3
CPZ
CP4
P3
PZ
P4
−5 μV
s
0
1.0
Related
Unrelated
Music
C3
CZ
C4
CP3
CPZ
CP4
P3
PZ
P4



- N400 effect similar for language and music (see difference waves)
  - Music conveys meaning
- N400 effect similar for abstract and concrete words (not shown)
  - Music conveys both abstract and concrete meaning
- N400 effect similar for emotional and non-emotional words
  - Musical meaning not limited to emotional information

Source Analysis of N400 Effects



- Same neural generators for music-primed words and language-primed words
- Bilateral posterior medial temporal gyrus (BA 21/37), near superior temporal sulcus

Environmental Sounds

- People derive meaning from auditory information in the environment
- When asked to identify a sound, people name the source of the sound rather than describing its acoustic characteristics (Ballas & Howard, 1987)

Words & Sounds

- Relationship between word and its referent are arbitrary while environmental sounds are causally related to their referents
- But many commonalities in processing of words and sounds
- Frequency effects
  - Commonly encountered words processed more quickly and accurately than rarely encountered words
  - Commonly encountered sounds processed more quickly and accurately than rarely encountered sounds
- Priming
  - DOCTOR-NURSE
  - Sound of explosion paired with sound of fuse burning

Materials

- Word – Sound
  - Related
    - "cat"
    - "cork"
  - Unrelated
    - "cat"
    - "cork"
- Sound – Word
  - Related
    - "cat"
    - "cork"
  - Unrelated
    - "cat"
    - "cork"

- 14 Animal Vocalizations
  - meow, bark, whinny
- 12 Nonspeech Human Sounds
  - sneeze, cough, gargle
- 3 Musical Instruments
  - piano
- 70 "Events"
  - helicoptor rotor, glass breaking, stream flowing, horses hooves striking pavement

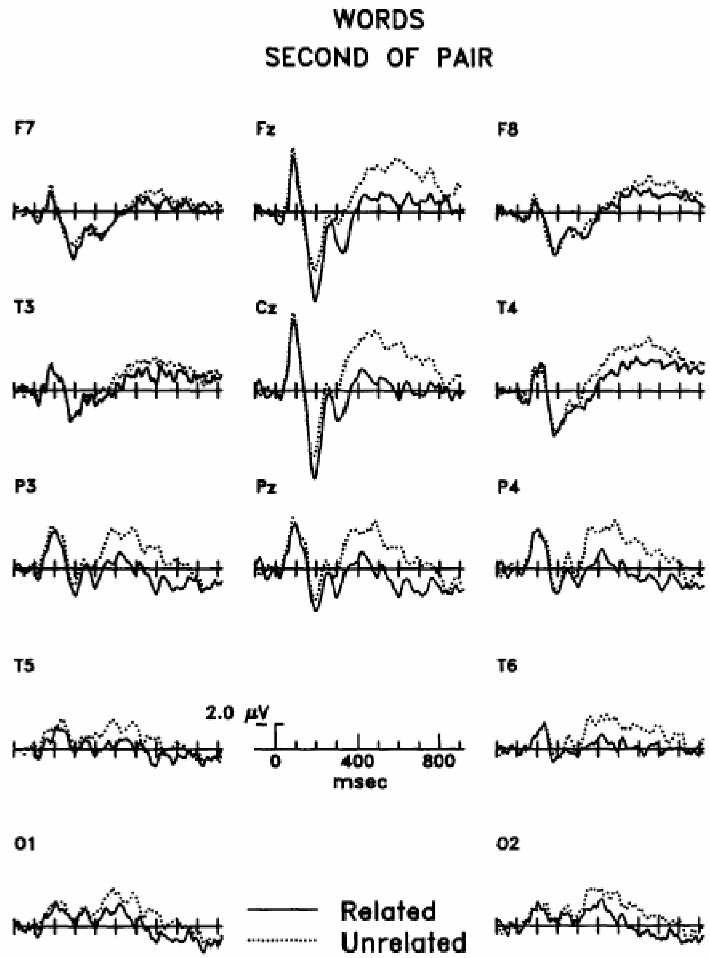


Fig. 2. Grand average ERPs elicited by words which were preceded by related or unrelated sounds.

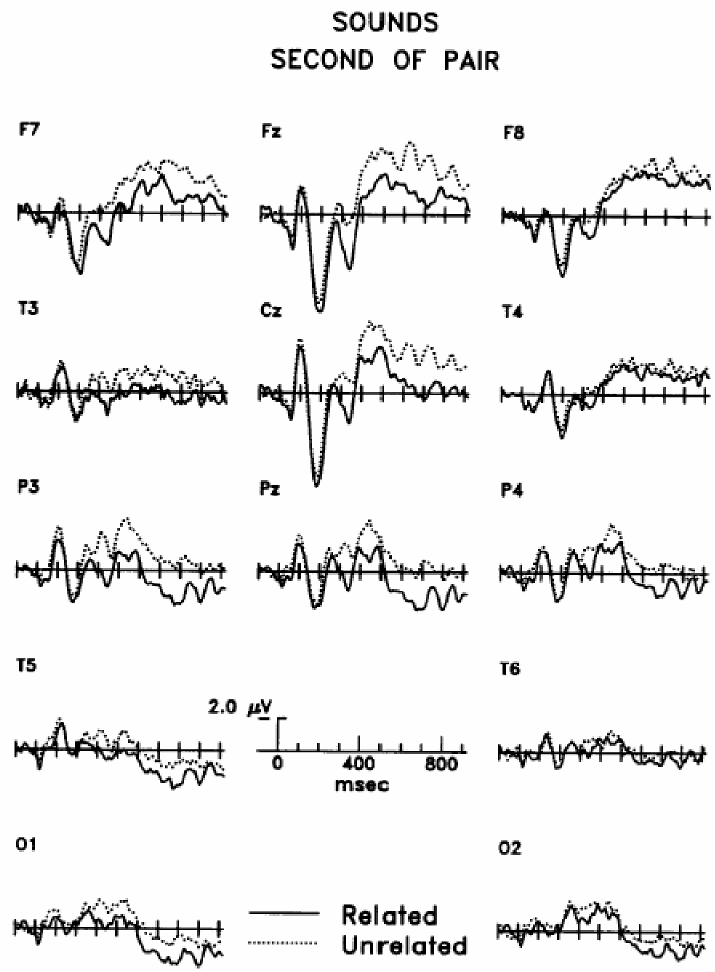


Fig. 3. Grand average ERPs elicited by sounds which were preceded by related or unrelated words.

Context Effects

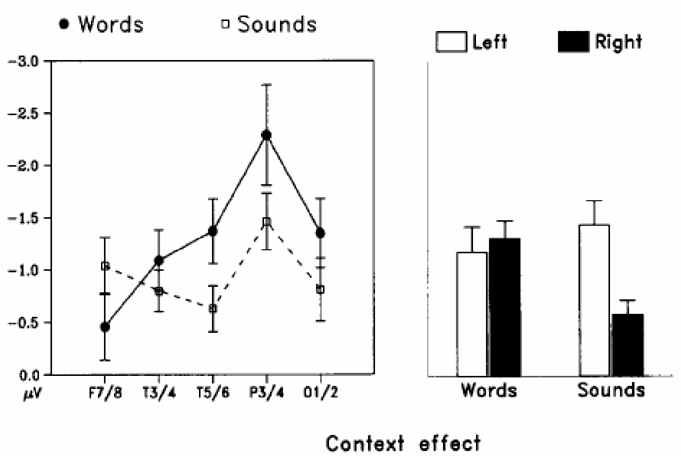


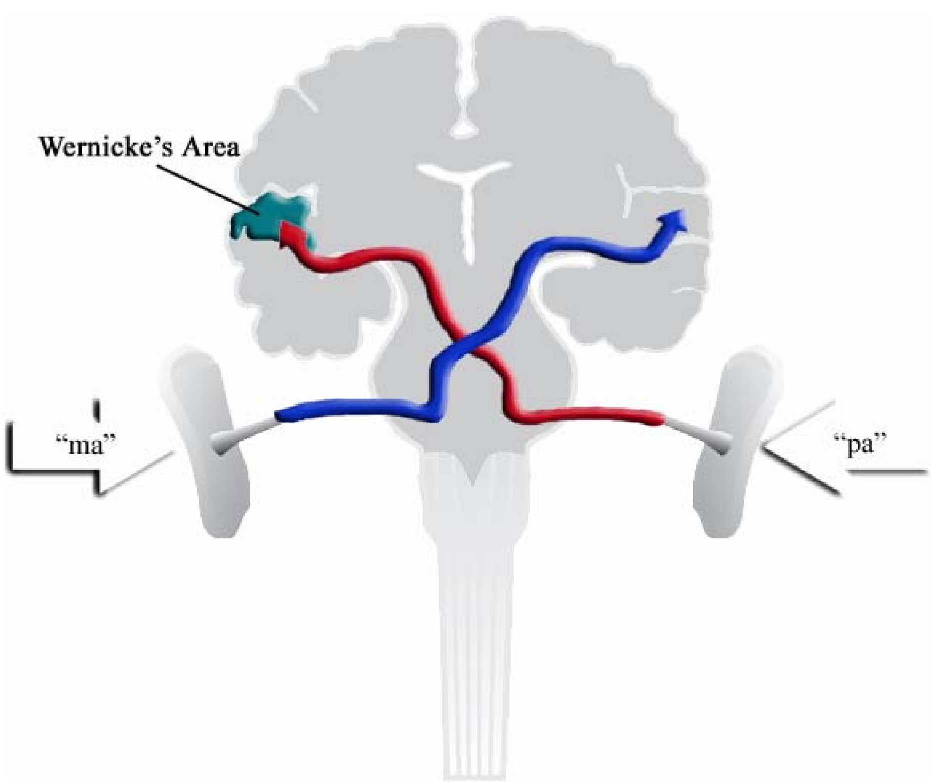
Fig. 4. Scalp distribution of the difference between related and unrelated items, quantified as the mean voltage from 300 to 700 msec after stimulus onset relative to a 100 msec pre-stimulus baseline. The left panel collapses across right and left recording sites to show distribution from the front to the back of the head (but note that some sites are further from the midline than others, T5/6 is lateral to T3/4). The right panel compares all recording sites over the right side of the head to all recording sites over the left side of the head. Error bars show standard error of the mean.

- N400 effect for words
  - largest over parietal scalp sites
  - slightly larger over RH
- N400 effect for sounds
  - largest over parietal sites but larger than word effect at frontal sites
  - larger over LH

Van Petten & Rheinfelder

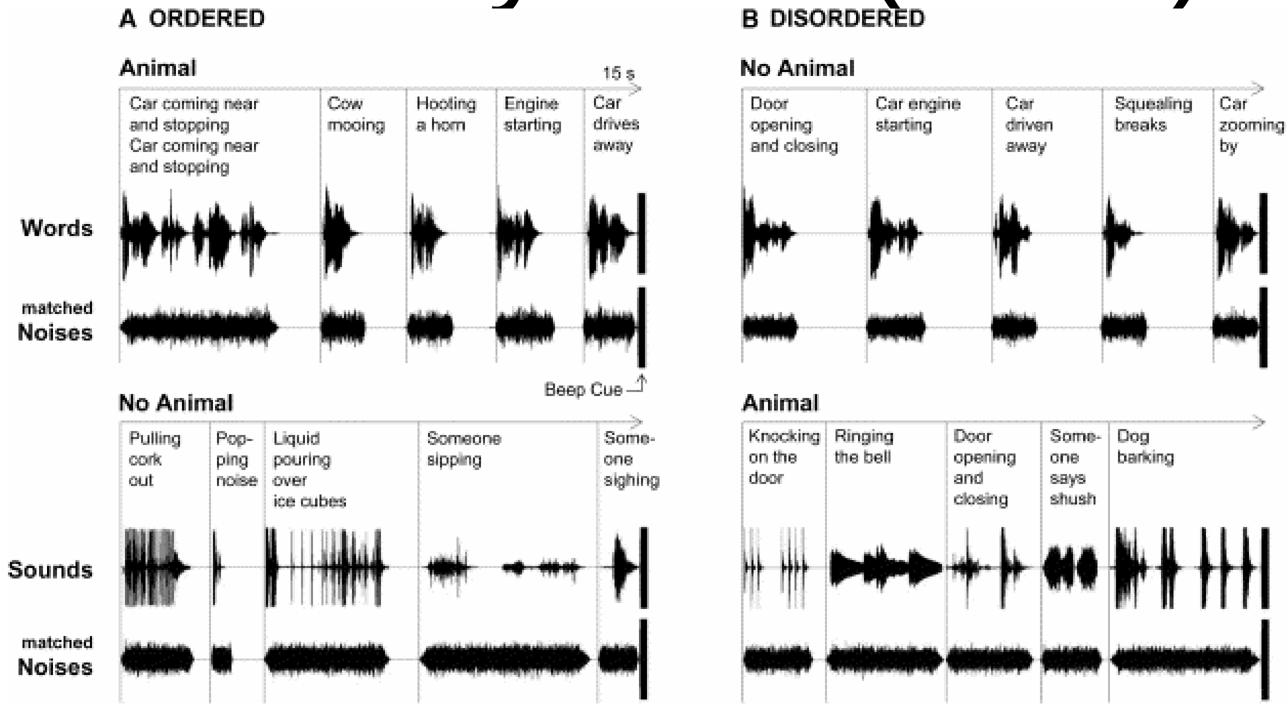
- Similarities in the brain response to contextually primed words and environmental sounds
- Different topography points to hemispheric differences in the specialization for processing meaningful verbal versus nonverbal acoustic information

Dichotic Listening



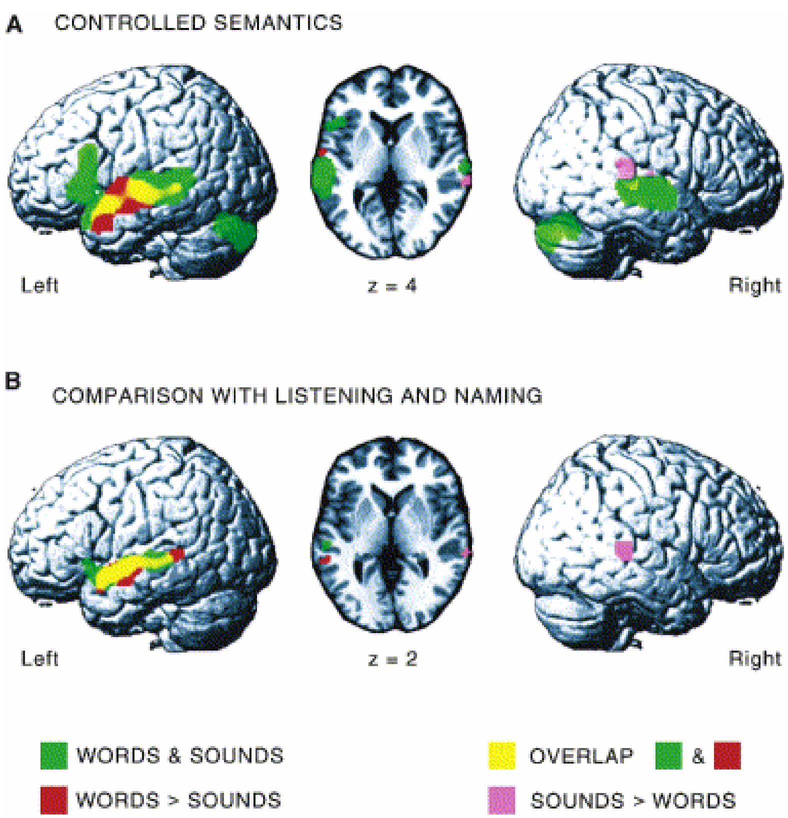
- Present different syllables to each ear simultaneously (e.g. ma-left, pa-right)
- Subject reports what he heard
- After 30 trials repeat presentations but swap left-right
- Right ear (LH) advantage for *speech sounds*
- Left ear (RH) advantage for *environmental sounds*

Thierry et al. (2003)



- Words & environmental sounds matched for content
- Digitally scrambled stimuli served as baseline, subtracted from each condition before comparison
- Easy Task: Animal vs. No Animal Judgment
- Difficult Task: Ordered vs. Disordered Judgment

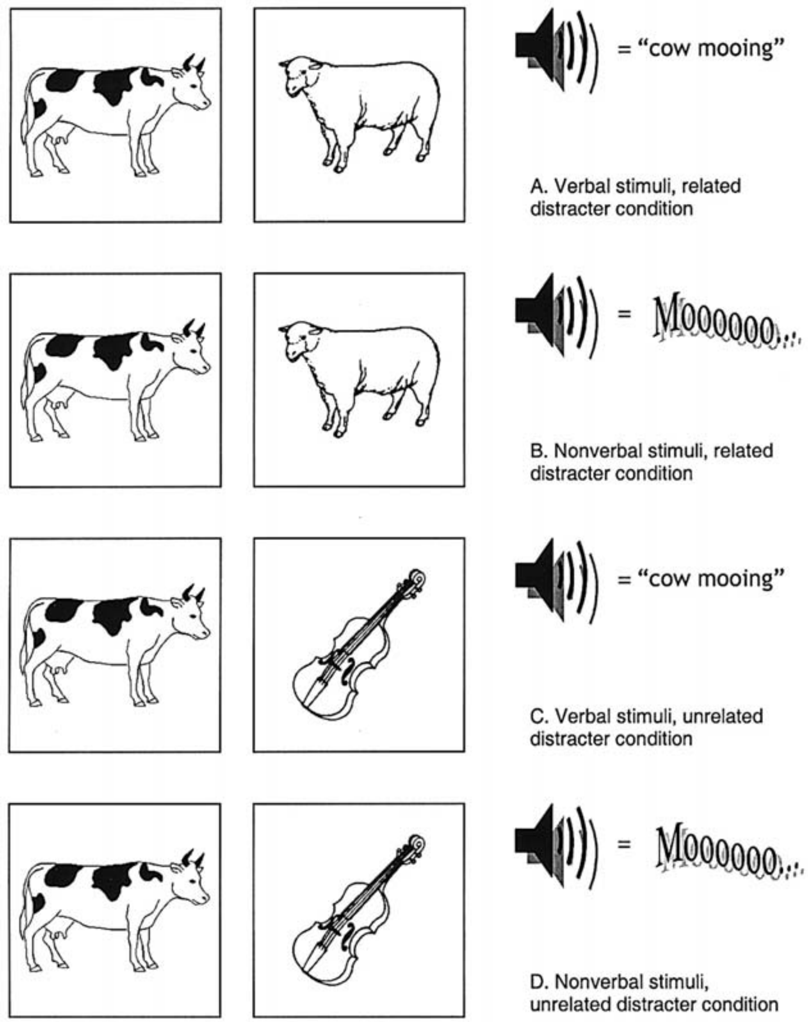
fMRI Activations



Thierry et al. (2003)

- Both words & sounds activate the left frontal lobe, and a large area in posterior superior temporal cortex bilaterally
- Words > Sounds in LH anterior temporal lobe regions
- Sounds > Words RH posterior temporal lobe
- Results do not depend on task – as long as it requires *semantic* analysis

Summary of the experimental design



Saygin, A. P. et al. Brain 2003 126:928-945; doi:10.1093/brain/awg082

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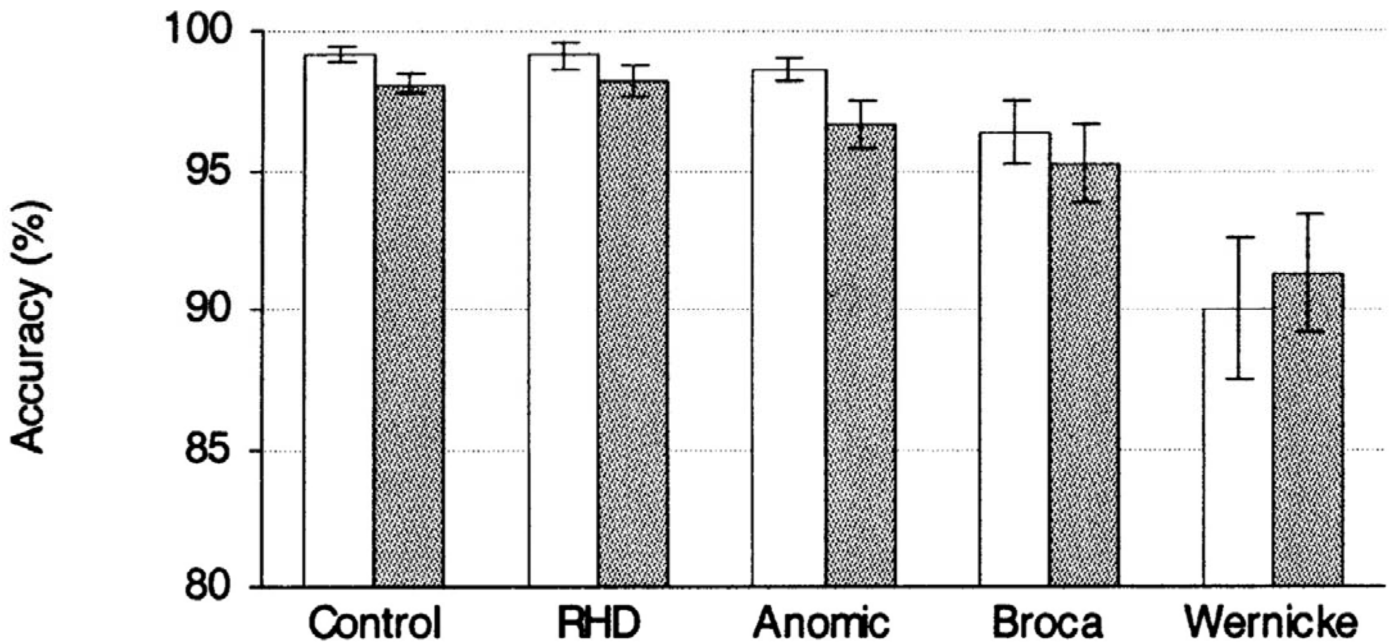
BRAIN
A journal of neurology

Accuracy depicted across verbal and nonverbal domains for all subject groups



	Control	RHD	Anomic	Broca	Wernicke
□ Verbal	99.2	99.1	98.6	96.3	90.0
▩ Nonverbal	98.1	98.2	96.7	95.2	91.3

Saygin, A. P. et al. Brain 2003 126:928-945; doi:10.1093/brain/awg082

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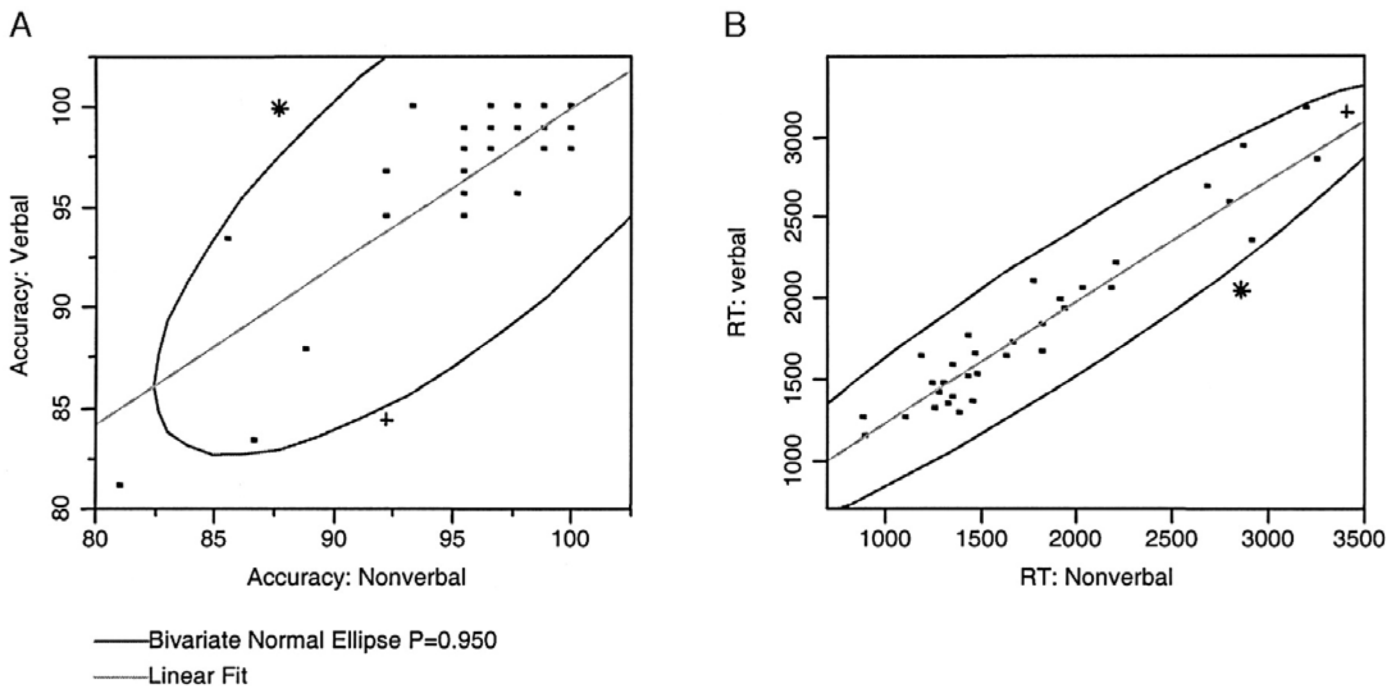
Correlation of performance in the verbal and nonverbal domains within the aphasic group for (A) accuracy and (B) reaction time



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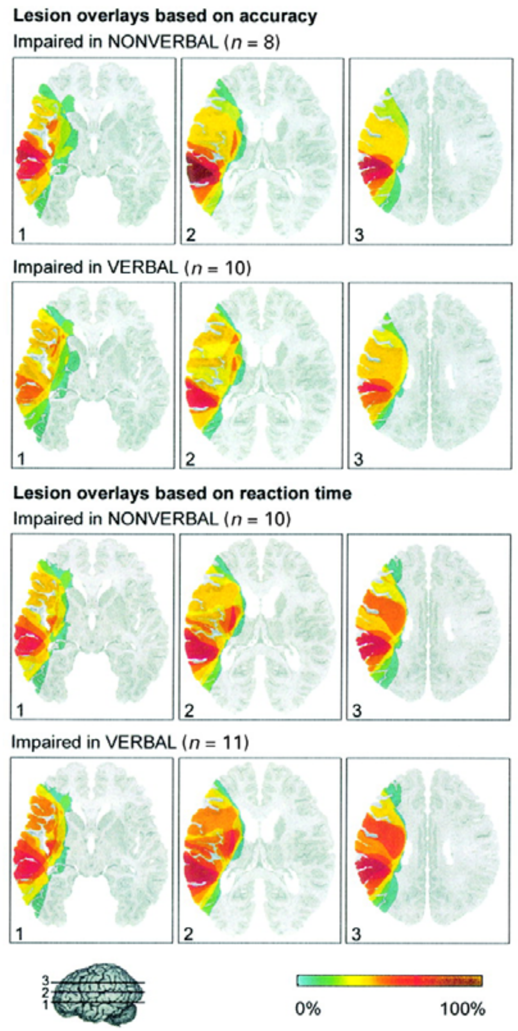
Lesion overlays for LHD patients who performed poorly in the nonverbal and verbal domains based on accuracy and reaction time



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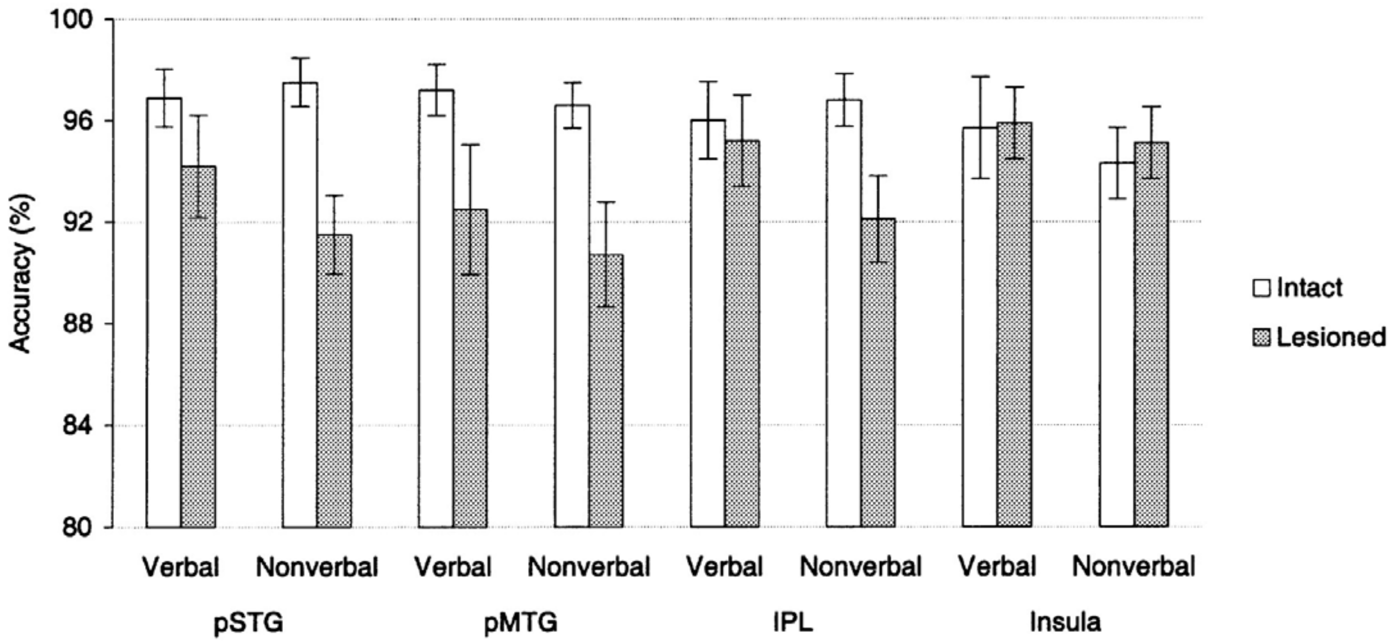
Summary of statistics on the regions of interest based on Fig



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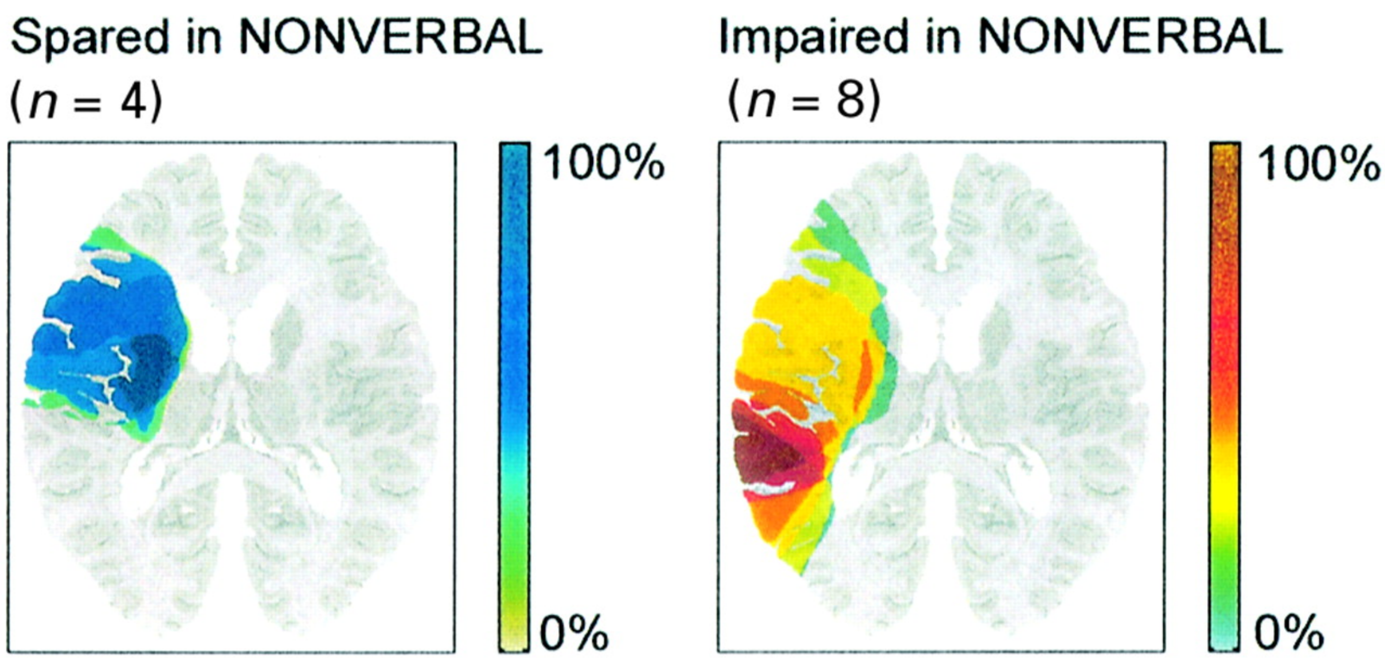
Lesion overlay on slice 2 depicting patients who are spared' in the nonverbal domain along with an overlay depicting patients who are impaired



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Saygin et al. (2002)

- LHD patients (especially Wernicke’s aphasics) impaired on both sound and word processing
- Impairments in environmental sound processing correlated with impairments on verbal processing
- Posterior MTG and Posterior STG contribute to performance in *both* word and sound processing
  - Brain areas that appear to be most crucial for environmental sound processing lie in and around classical Wernicke’s area!
- Inferior parietal lobule more important for sounds
- Aphasia not purely a linguistic deficit
  - Language utilizes brain areas important for processing the meaning of environmental sounds

Action- vs. Non-action- Related Sounds

- Understanding environmental sounds may depend on what kind of sound it is
- Given findings of audiovisual mirror neurons (right)
- Perhaps sounds associated with human action processed differently than non-action related sounds

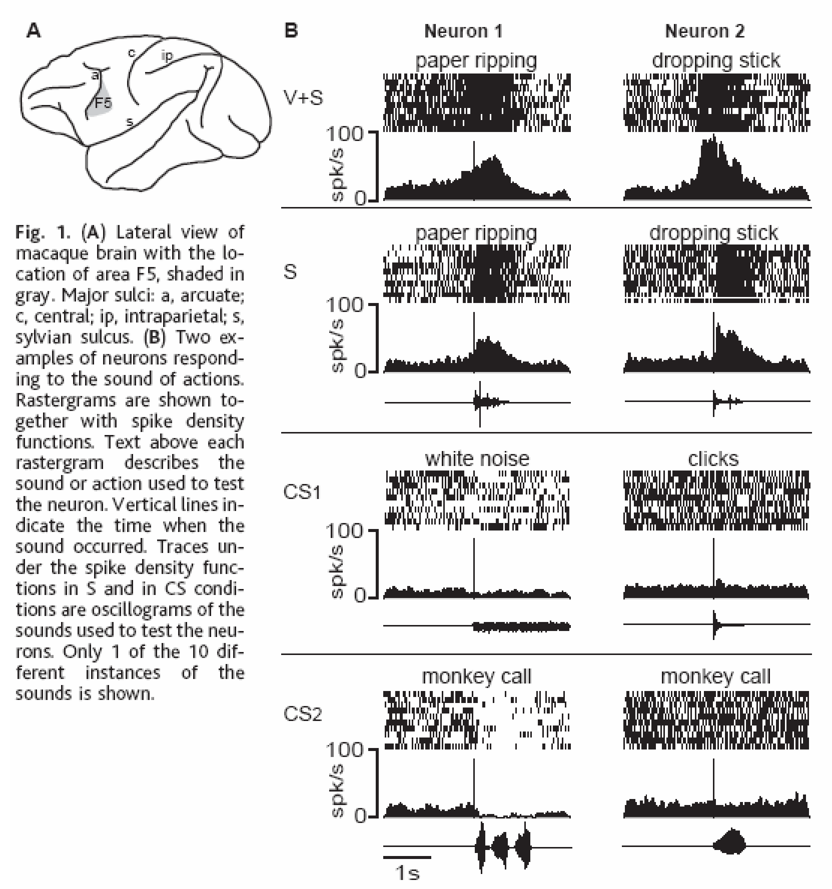
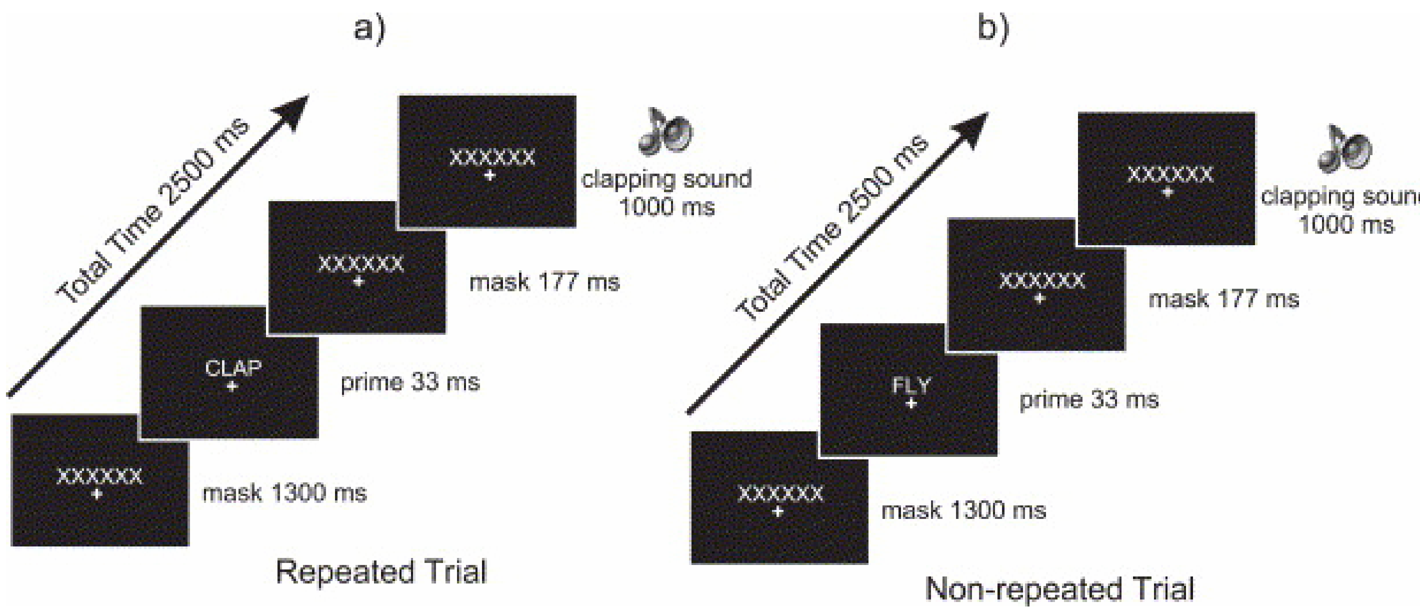
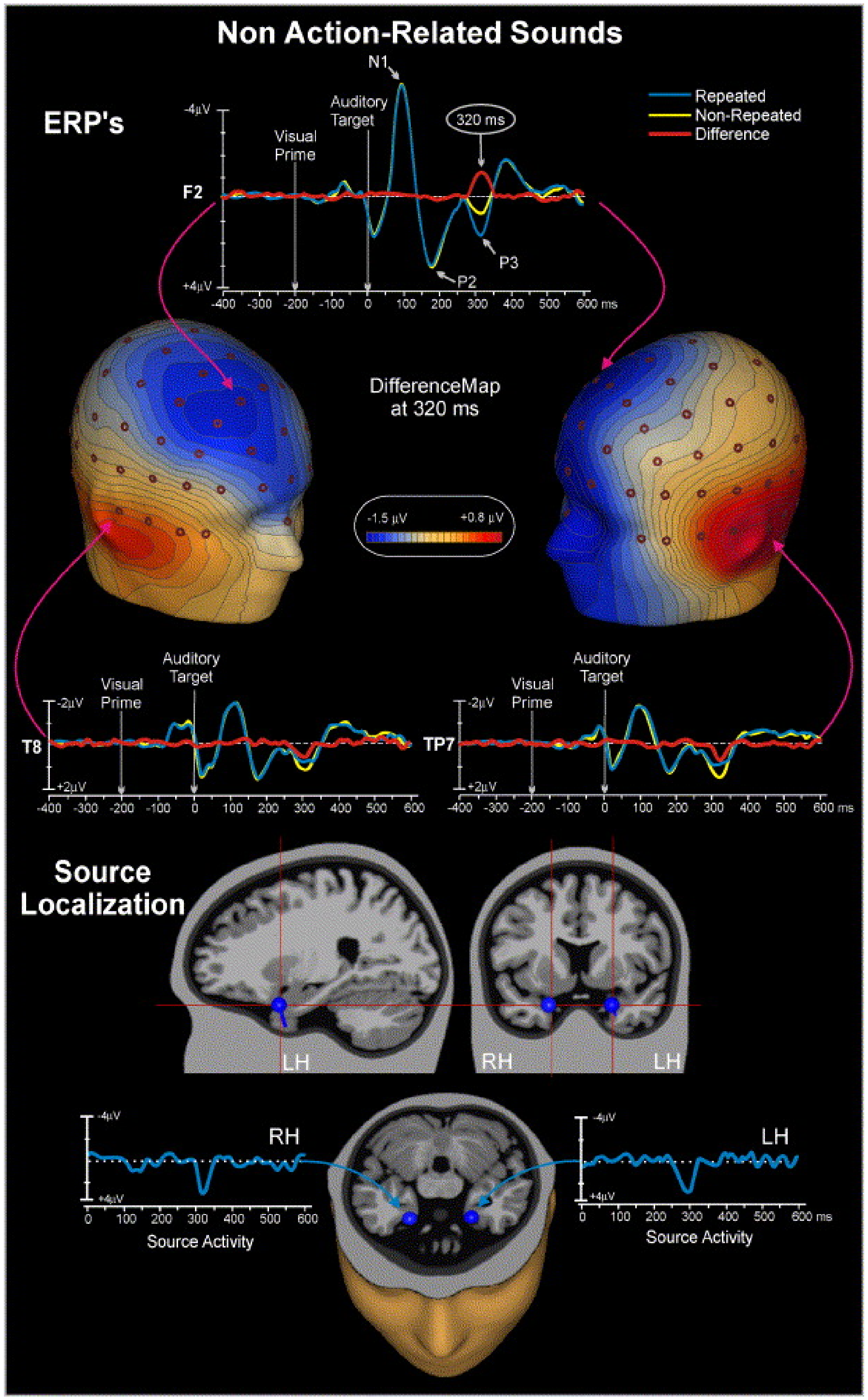


Fig. 1. (A) Lateral view of macaque brain with the location of area F5, shaded in gray. Major sulci: a, arcuate; c, central; ip, intraparietal; s, sylvian sulcus. (B) Two examples of neurons responding to the sound of actions. Rastergrams are shown together with spike density functions. Text above each rastergram describes the sound or action used to test the neuron. Vertical lines indicate the time when the sound occurred. Traces under the spike density functions in S and in CS conditions are oscillograms of the sounds used to test the neurons. Only 1 of the 10 different instances of the sounds is shown.

Pizzamiglio and colleagues (2005)

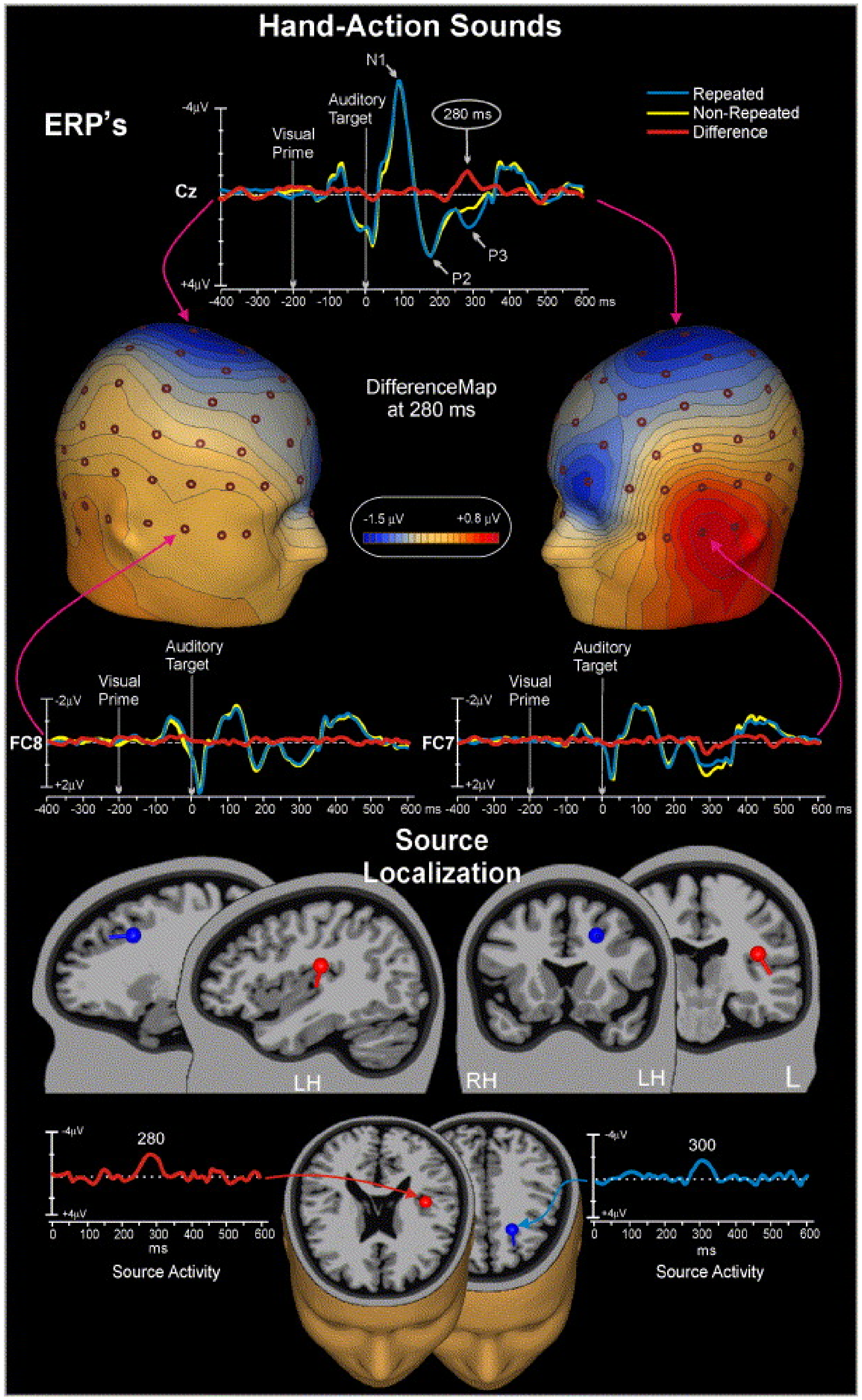
- Use masked priming paradigm to prime different kinds of sounds
  - Human hands (clapping, ringing a bell)
  - Human mouth (whistling, laughing)
  - Non-Action sounds (water boiling, rain, siren, fly buzzing)
- Subjects do not consciously perceive the prime word, but processing of primed sounds facilitated relative to preceded by unrelated word
- Brain areas affected by priming participate in the processing of the relevant sorts of sounds





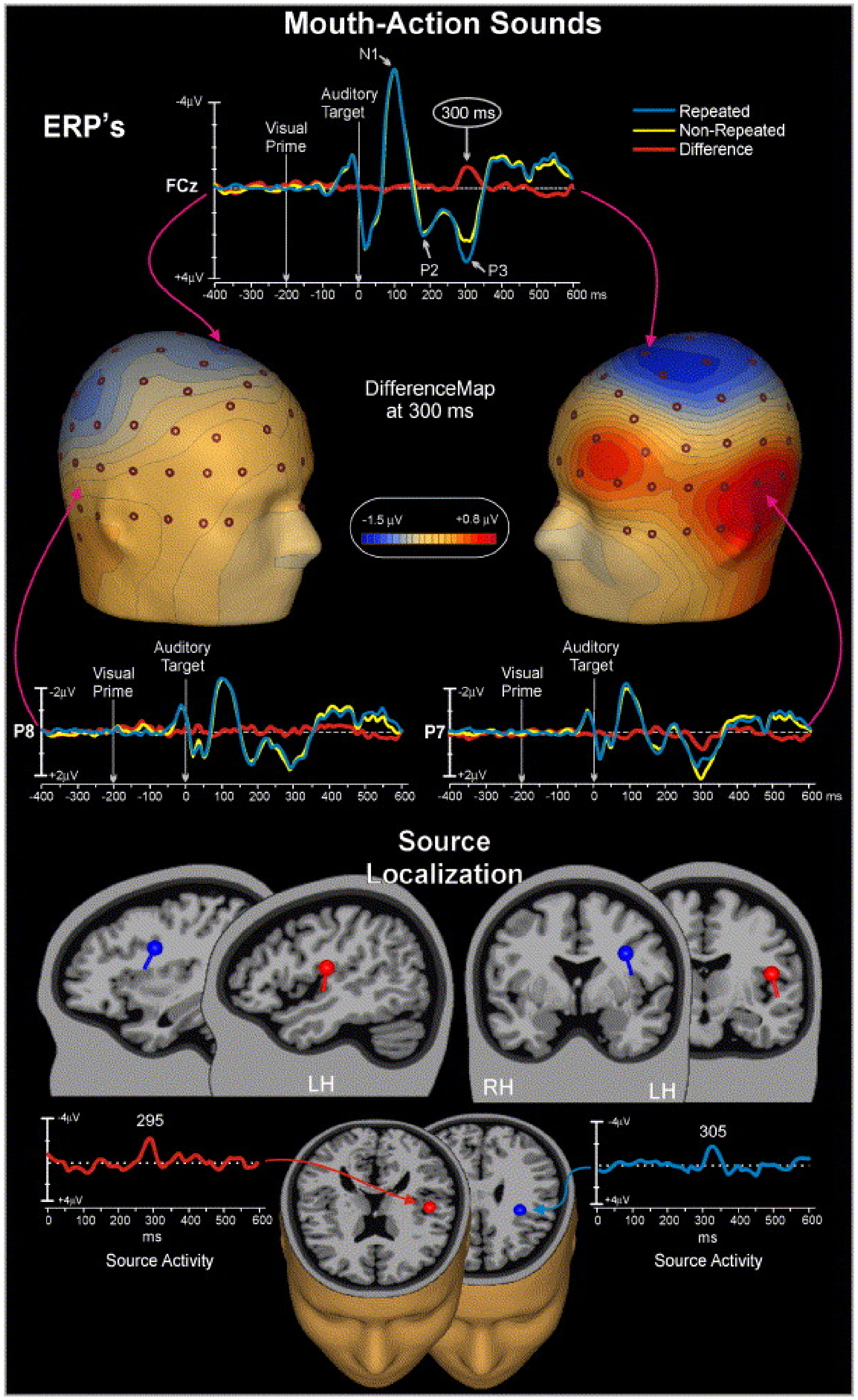
Non-Action-Related Sounds

- ERPs
  - Non-primed yellow
  - Primed blue
  - Non-repeated minus repeated red
- Difference wave is frontocentral negativity and temporoparietal positivity
- Source localization suggests symmetrical generators in each of the temporal poles



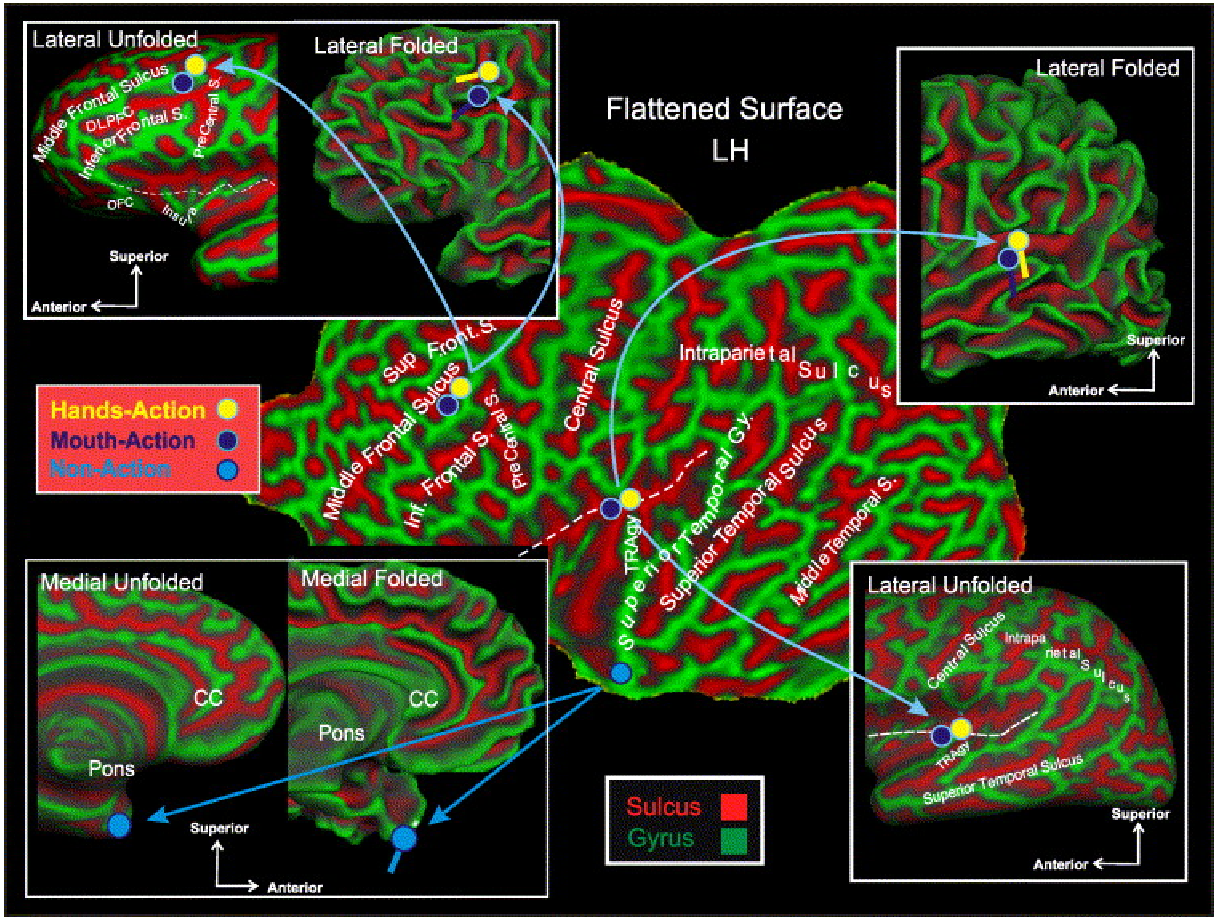
Hand-Action Sounds

- ERPs
  - Primed: blue
  - Unprimed: yellow
  - Unprimed minus primed: red
- Difference wave negative over central sites and positive over left temporofrontal sites
- Dipoles localized to LH STS and left pre-motor cortex



Mouth-Action Sounds

- ERPs
  - Primed: blue
  - Unprimed: yellow
  - Unprimed minus primed: red
- Difference wave frontocentral negativity and left temporoparietal positivity
- Dipoles localized to LH STS and left premotor cortex



- 1st dipole between Sylvian fissure and insula
  - Hand sounds (orange) more “posterior, lateral & ventral” than mouth sounds consistent with somatotopic mapping of biological motion stimuli
- 2nd dipole in premotor cortex near middle frontal sulcus
  - Mouth sounds more “lateral, ventral, and a little more anterior” than hand sounds consistent with somatotopic mapping of premotor cortex
- Non-Action sounds in temporal poles (RH not shown)