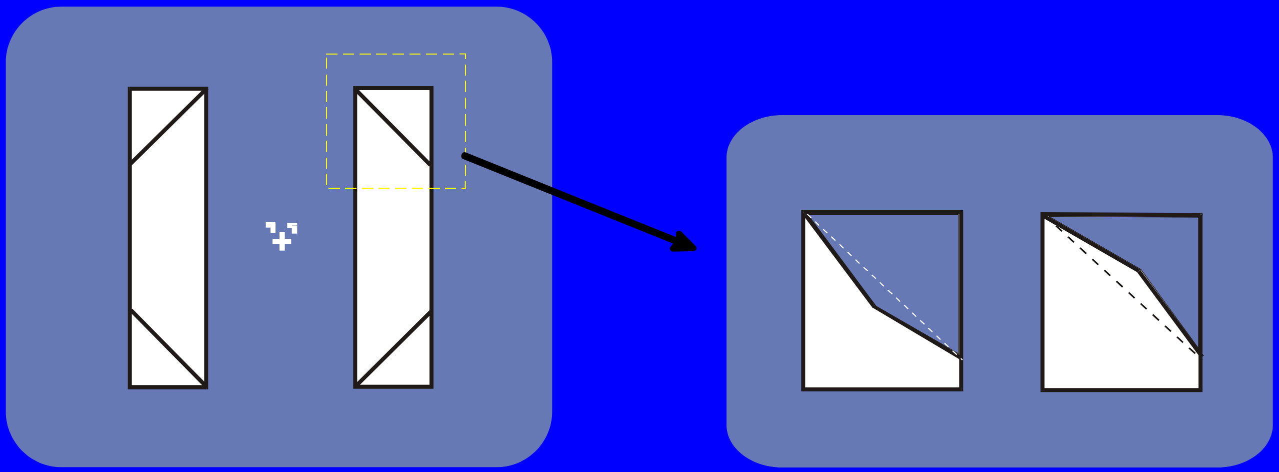
Some open questions

1. Do spatial and object-based attention use fundamentally different selection mechanisms at different levels of the visual pathways?

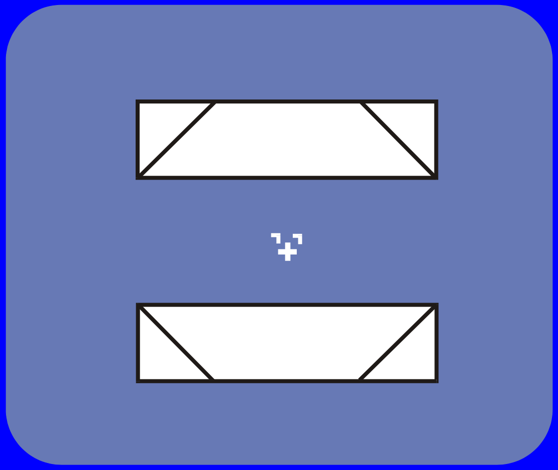
2. Or, does spatial attention tend to “spread” within object boundaries, selecting the entire object including all its parts?

Experimental Design



Vertical Bars

Standard Target



Horizontal Bars

Stimuli

--50 ms corner offsets

--Randomized sequence

--ISI’s 300-500 ms

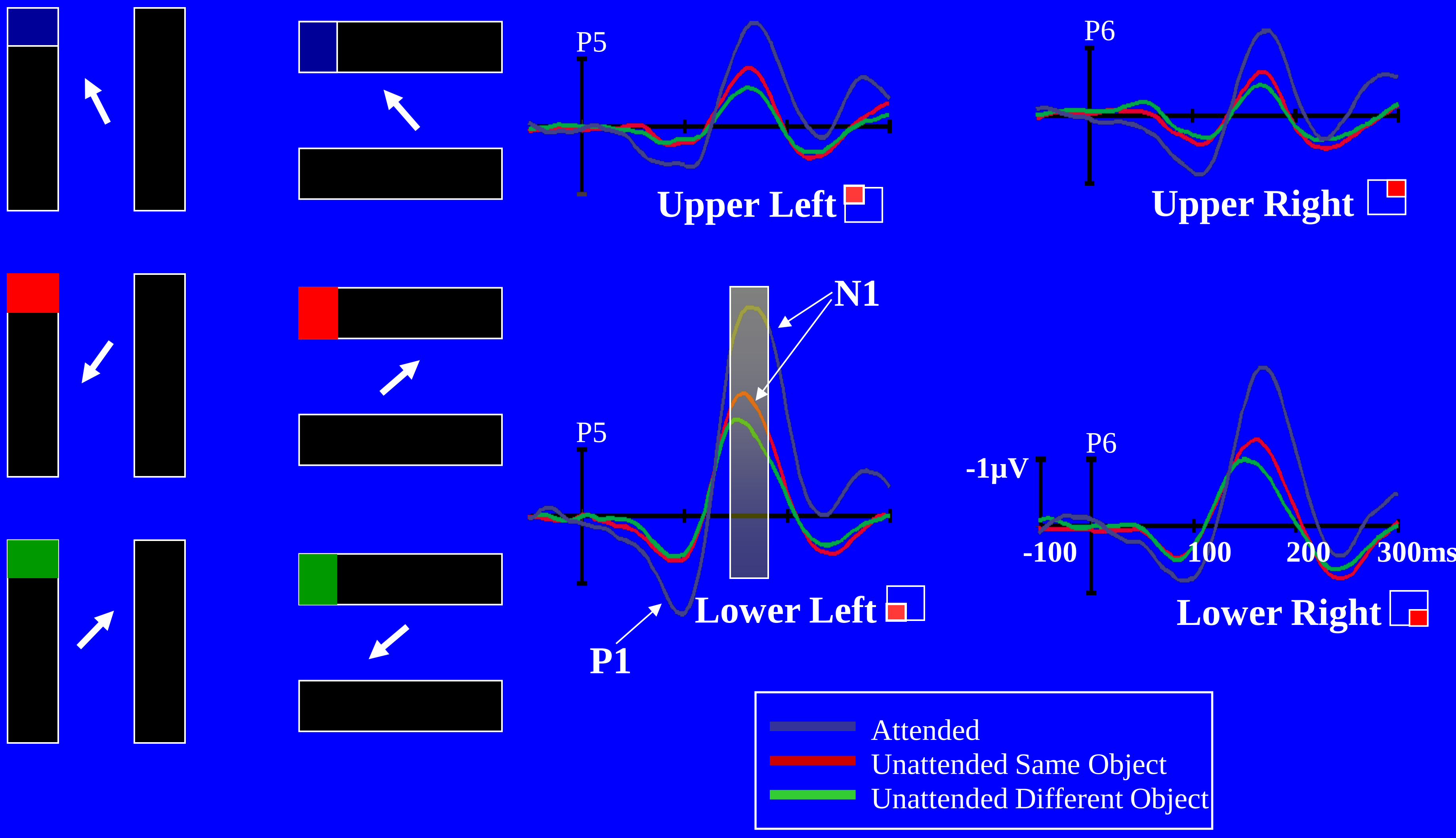
Conditions

--Bars either horizontal or vertical

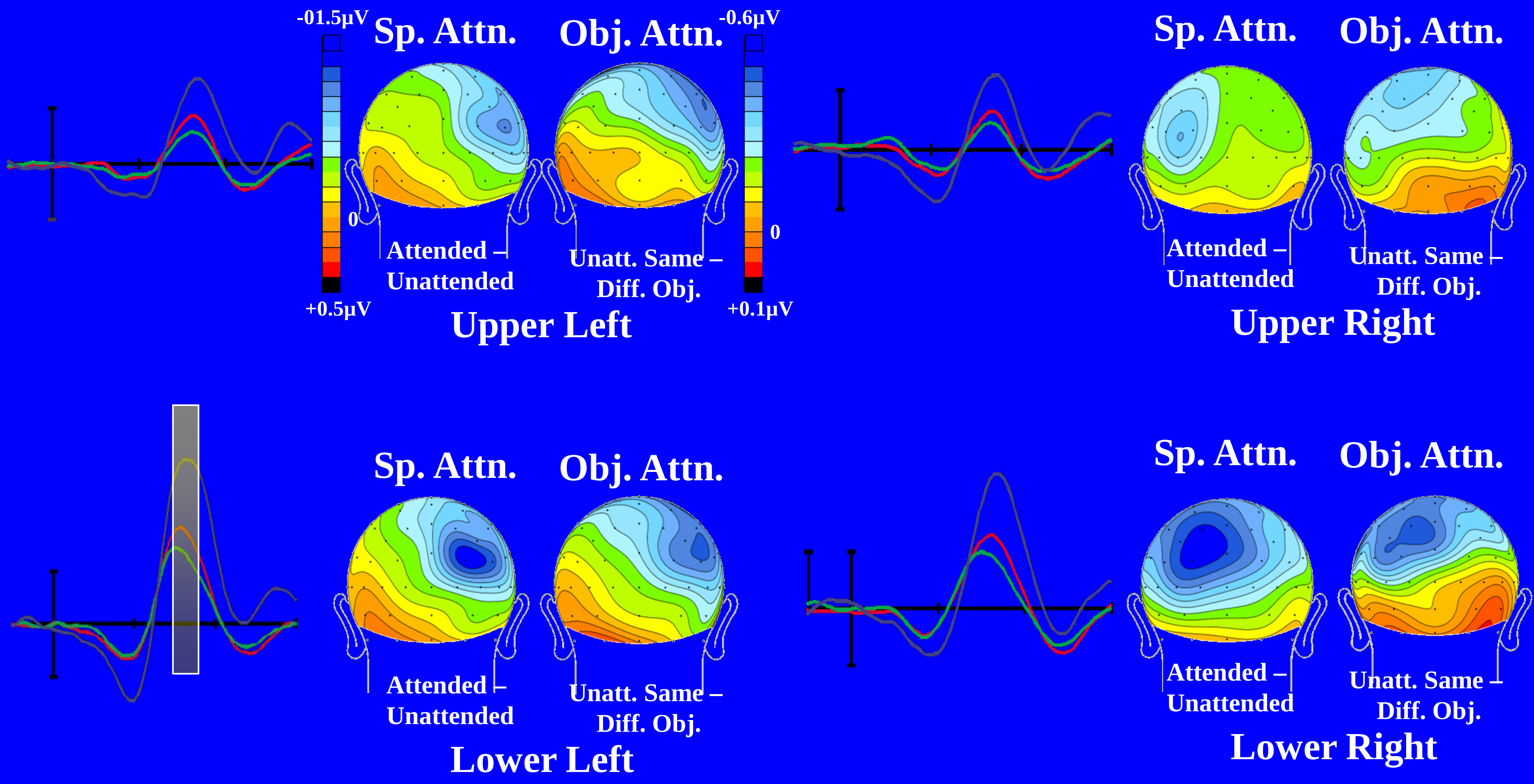
--Subject attends to one quadrant at a time, detecting occasional targets

--20 sec runs, attend UL/UR, LL/LR

Grand Averaged ERPs



N1 Spatial vs Object Attention



INFERENCES/CONCLUSIONS

1. Spatial attention to one part of an object results in facilitation of sensory processing of the entire object .

2. This object-based attention is evident within 140-180 ms of visual stimulus onset (as reflected in enhanced amplitude of N1 component).

3. Similarity of N1 scalp distributions suggest that spatial and object attention share a common mechanism (but P1 modulation is specific to spatial attention).

4. Spatial attention spreads within object boundaries, strengthening sensory representations of objects at or near the locus of attention; i.e., deployment of spatial attention to one part of an object results in a facilitation of sensory processing of the entire object, even if not relevant to the current task.

Some open questions

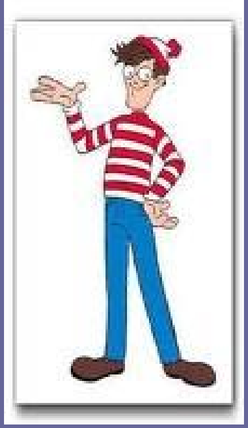
1. Do spatial and object-based attention use fundamentally different selection mechanisms at different levels of the visual pathways?

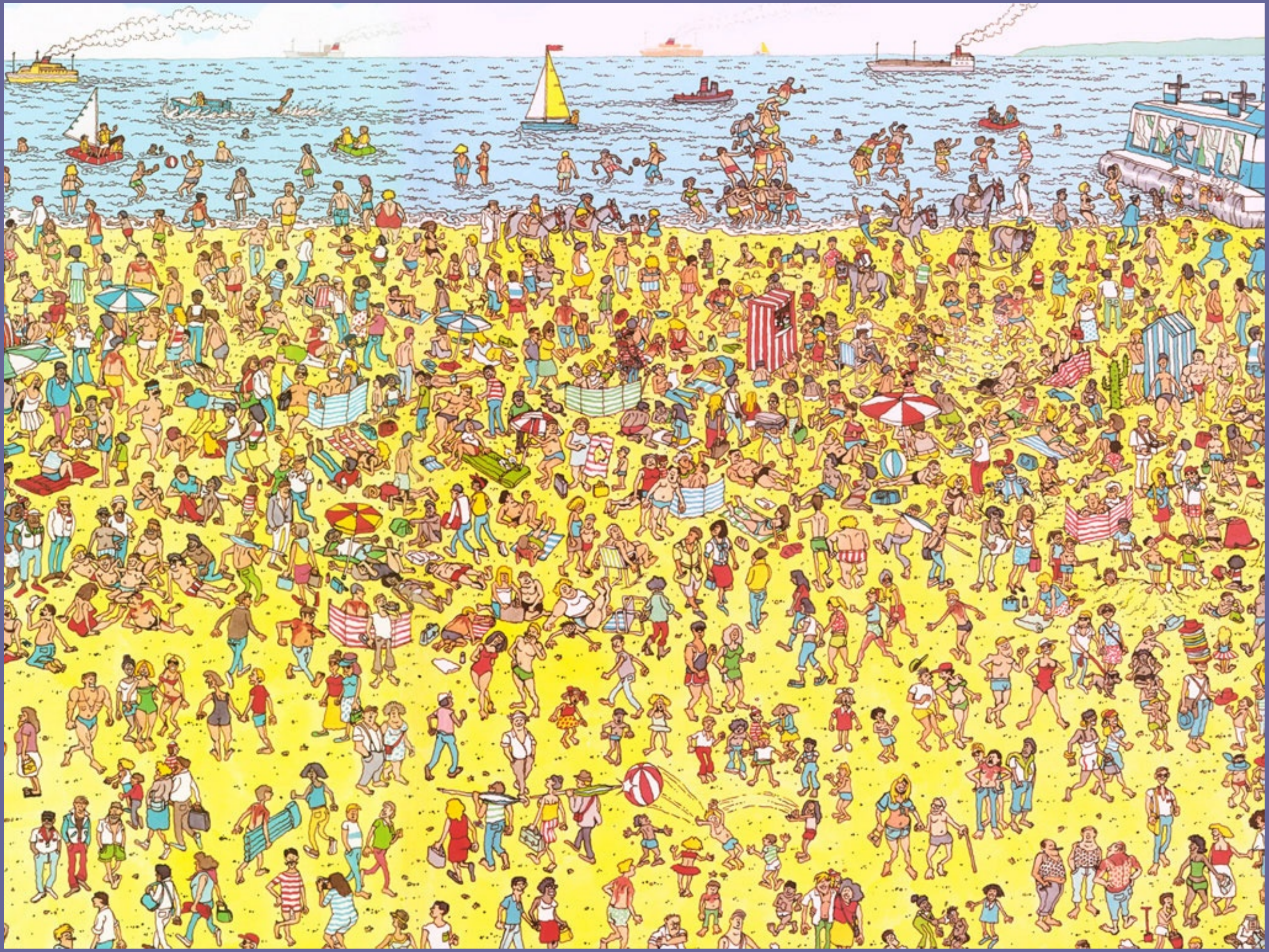
2. Or, does spatial attention tend to “spread” within object boundaries, selecting the entire object including all its parts?

Coming full circle: Results most consistent with 2nd hypothesis!!!

VISUAL SEARCH

We don't always know where the target is, must search!





VISUAL SEARCH PARADIGM

Find predefined target stimulus within an array of distractors

Examine ERPs to stimuli/probes at cued or uncued locations, as well as ERPs to search array.

Mechanisms of attention used spontaneously during visual search are basically the same as the mechanisms used when attention is directed by explicit instructions: i.e., P1 and N1, where P1 reflects suppressed processing at nontarget location, and N1 reflects enhanced processing at target location.

VISUAL SEARCH PARADIGMS

Feature present

Feature absent

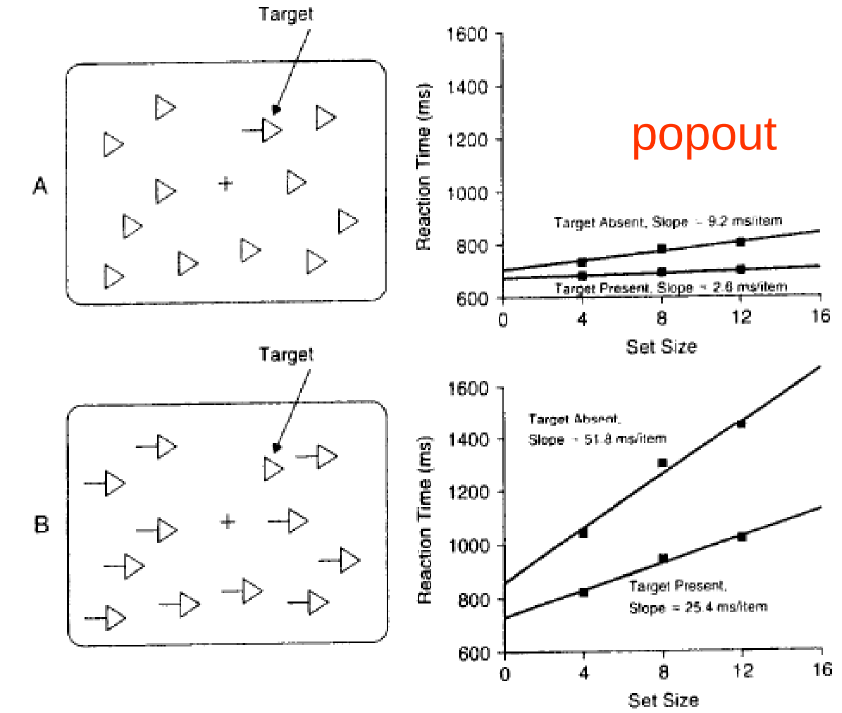
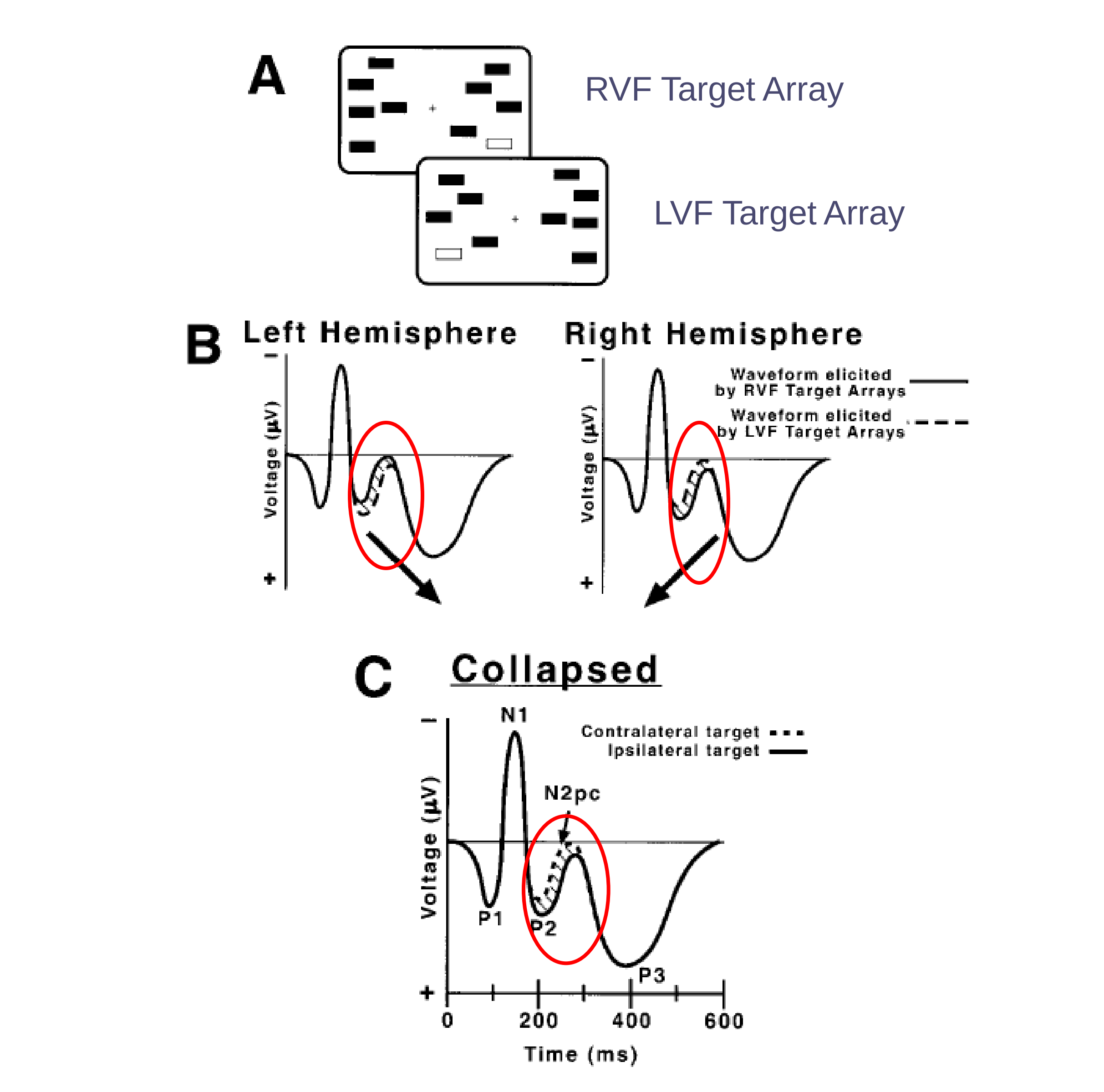
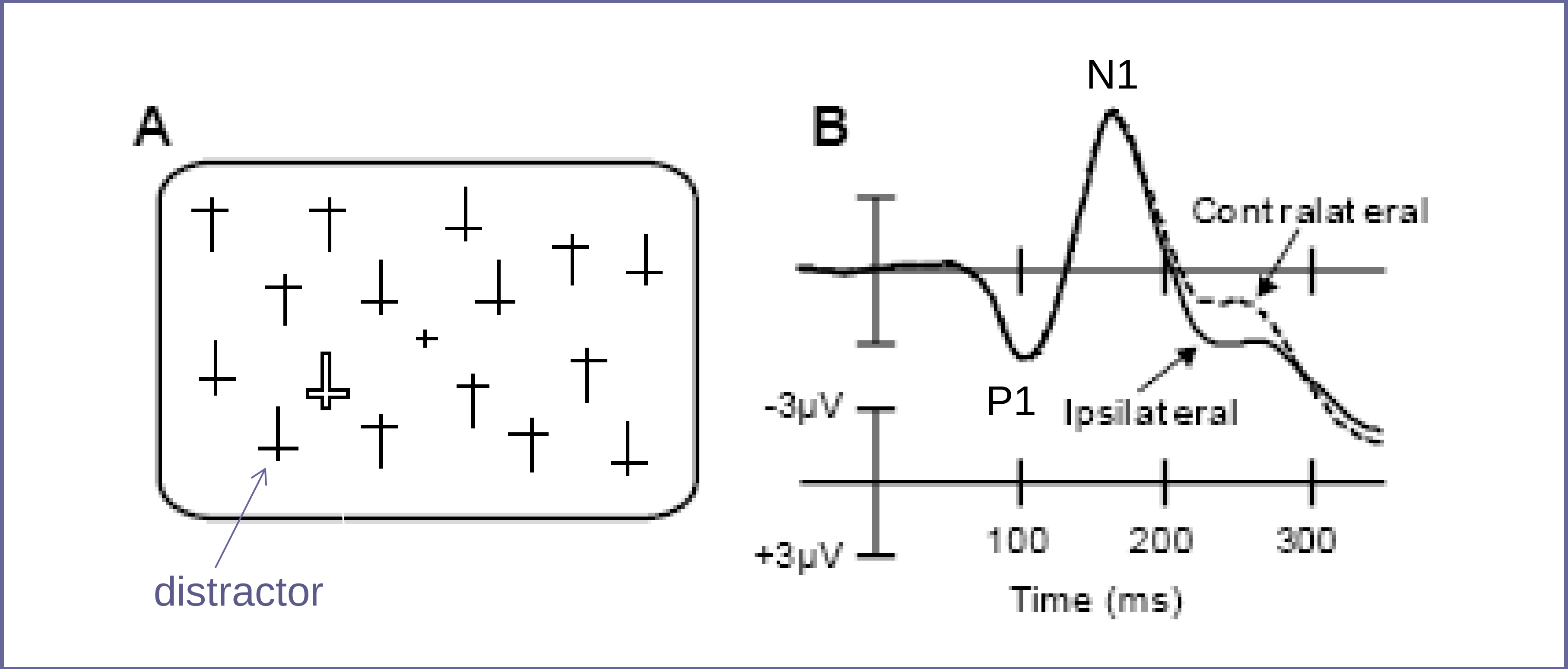


Figure 6.4 Visual search for feature presence and absence.
NOTE: (A) Example of a visual search task in which the target is defined by the presence of a simple feature and reaction times are not strongly influenced by the number of items in the stimulus array. (B) Example of a visual search task in which the target is defined by the absence of a feature and reaction times increase as a function of the number of items in the array.

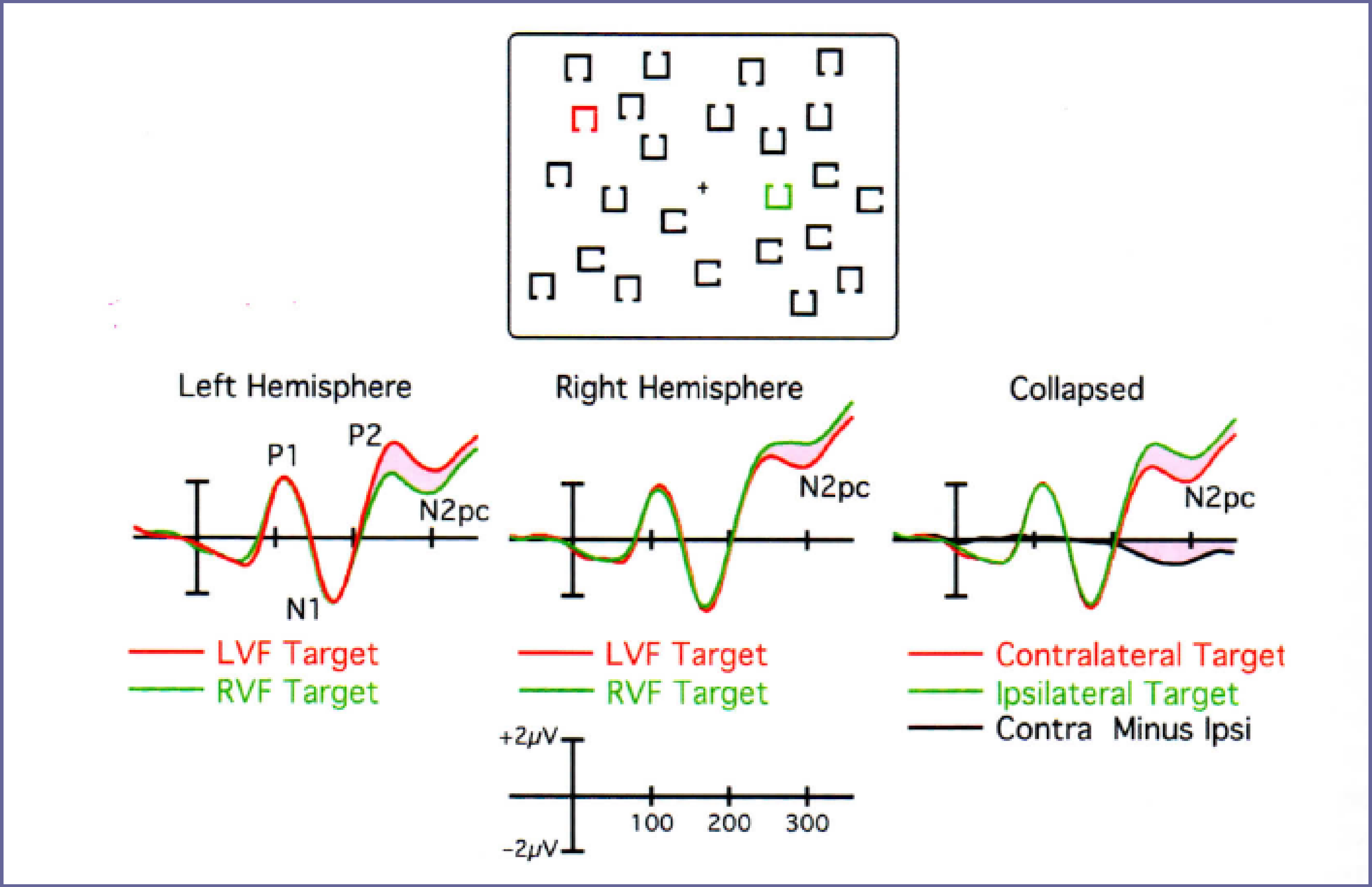

A
RVF Target Array
LVF Target Array
B
Left Hemisphere
Right Hemisphere
Voltage (µV)
Waveform elicited by RVF Target Arrays
Waveform elicited by LVF Target Arrays
C
Collapsed
N1
Contralateral target
Ipsilateral target
N2pc
P1
P2
P3
0
200
400
600
Time (ms)

N2pc – N2 posterior contralateral



Contralateral: L hem/R target + R hem/L target;
Ipsilateral: Lhem/L target + R hem/R target

N2pc component reflects the deployment of perceptual-level attention to minimize interference between the attended item and nearby distractors.



N2pc is difference between contralateral and ipsilateral ERP waveforms

Luck et al 2006

Some N2pc-related findings

1. N2pc component is absent for nontarget stimuli that can be rejected on the basis of preattentive feature information, but is present both for target stimuli and for nontarget stimuli that require careful scrutiny to be distinguished from the targets (Luck & Hillyard, 1994).

2. N2pc component is larger when distractors are near the target (Luck et al., 1997). There is no N2pc when there are no distractors (Luck & Hillyard, 1994).

3. N2pc component is larger for conjunction targets than for feature targets (Luck et al., 1997), and it can be completely eliminated for feature targets under some conditions (Luck & Ford, 1998).

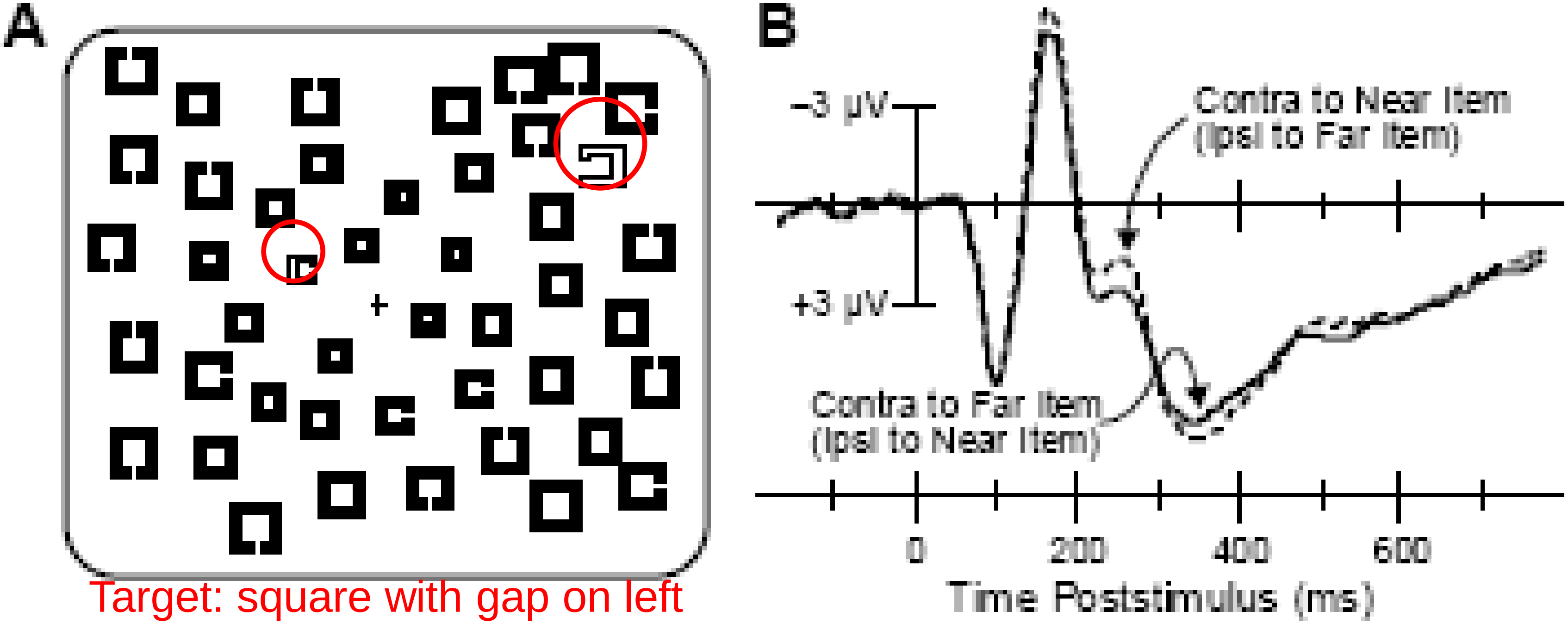
4. N2pc component appears to reflect the same attentional mechanism observed by Chelazzi and his colleagues in single-unit recordings (Chelazzi & Desimone, 1994; Chelazzi et al., 1993, 1998).

One question addressed by N2pc measurements

Does attention shift from item to item (serial) or is it divided across the entire field or across all objects (parallel). In other words, how is attention allocated during visual search?

Each display has 2 potential targets (red items).

Lateral occipital recording site



Target: square with gap on left

Attention switched first to near item ~200 ms and then switched to far item ~100 ms later

Woodman & Luck 1999, 2003

N2pc generator based on MEG recording/source modeling

Early parietal source (180-200 ms)

Later occipital source (220-240 ms)

Hypothesis: ***parietal areas used to initiate shift of attention within search array. Focussing attention is implemented by extrastriate areas of occipital and inferior temporal cortex.***

Behavioral/Systems/Cognitive

Precision in Visual Working Memory Reaches a Stable Plateau When Individual Item Limits Are Exceeded

David E. Anderson, Edward K. Vogel, and Edward Awh
Department of Psychology, University of Oregon, Eugene, Oregon 97403

Multiple studies have demonstrated that resolution in working memory (WM) declines as the number of stored items increases. Discrete-resource models predict that this decline should reach a stable plateau at relatively small set sizes because item limits prevent additional information from being encoded into WM at larger set sizes. By contrast, flexible-resource models predict that the monotonic declines in precision will continue indefinitely as set size increases and resources are distributed without any fixed item limit. In the present work, we found that WM resolution exhibited monotonic declines until set size reached three items, after which resolution achieved a clear asymptote. Moreover, analyses of individual differences showed a strong correlation between each observer's item limit and the set size at which WM resolution achieved asymptote. These behavioral observations were corroborated by measurements of contralateral delay activity (CDA), an event-related potential waveform that tracks the number of items maintained during the delay period. CDA activity rose monotonically and achieved asymptote at a set size that predicted individual WM capacity. Moreover, this neural measure of on-line storage also predicted the set size at which mnemonic resolution reached a stable plateau for each observer. Thus, independent behavioral and neural measures of WM capacity support a clear prediction of discrete-resource models. Precision in visual WM reaches asymptote when individual item limits are exceeded.

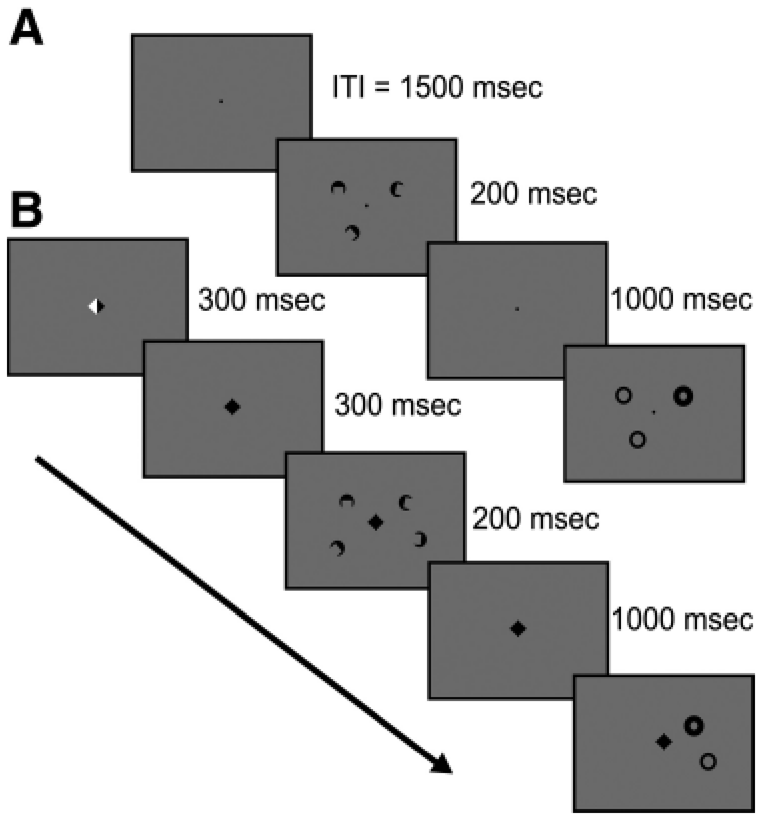
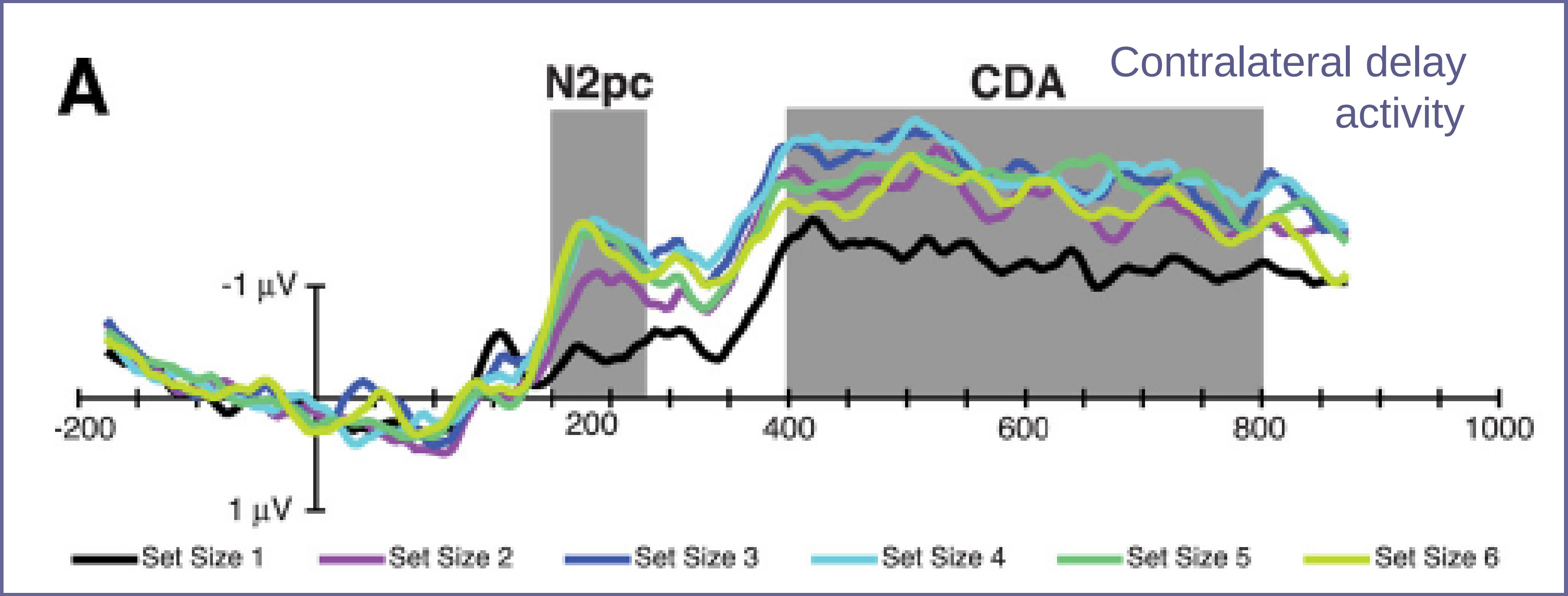


Figure 1. *A*, Visual working memory task used in experiment 1. Participants maintained fixation and were instructed to remember the orientations of all objects presented on the display. Set sizes used were one, two, three, four, six, and eight. After a short delay period, participants were probed to recall the orientation of one object presented in the memory display (demarcated with a thicker black ring). Participants responded by clicking on the location of the ring where they remembered the center of the gap being. *B*, ERP visual working memory task used in experiment 2. Participants were to attend to the hemifield indicated by one of two colored arrows (counterbalanced). Set sizes ranged from one to six. All other procedures were identical with those of experiment 1.


A
N2pc
CDA
Contralateral delay activity
-1 µV
1 µV
-200
200
400
600
800
1000
Set Size 1
Set Size 2
Set Size 3
Set Size 4
Set Size 5
Set Size 6

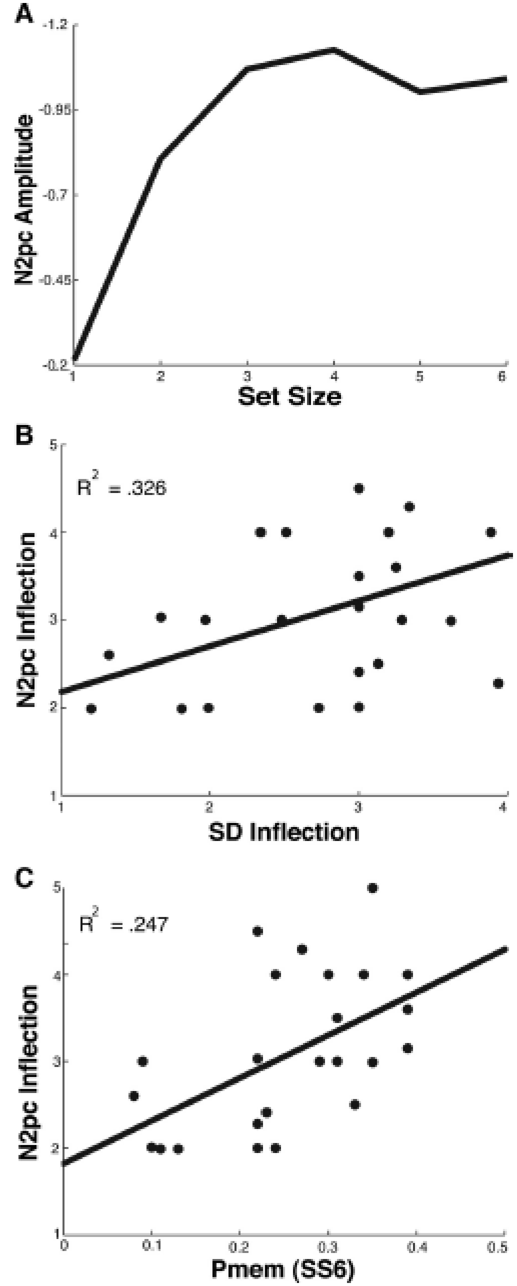


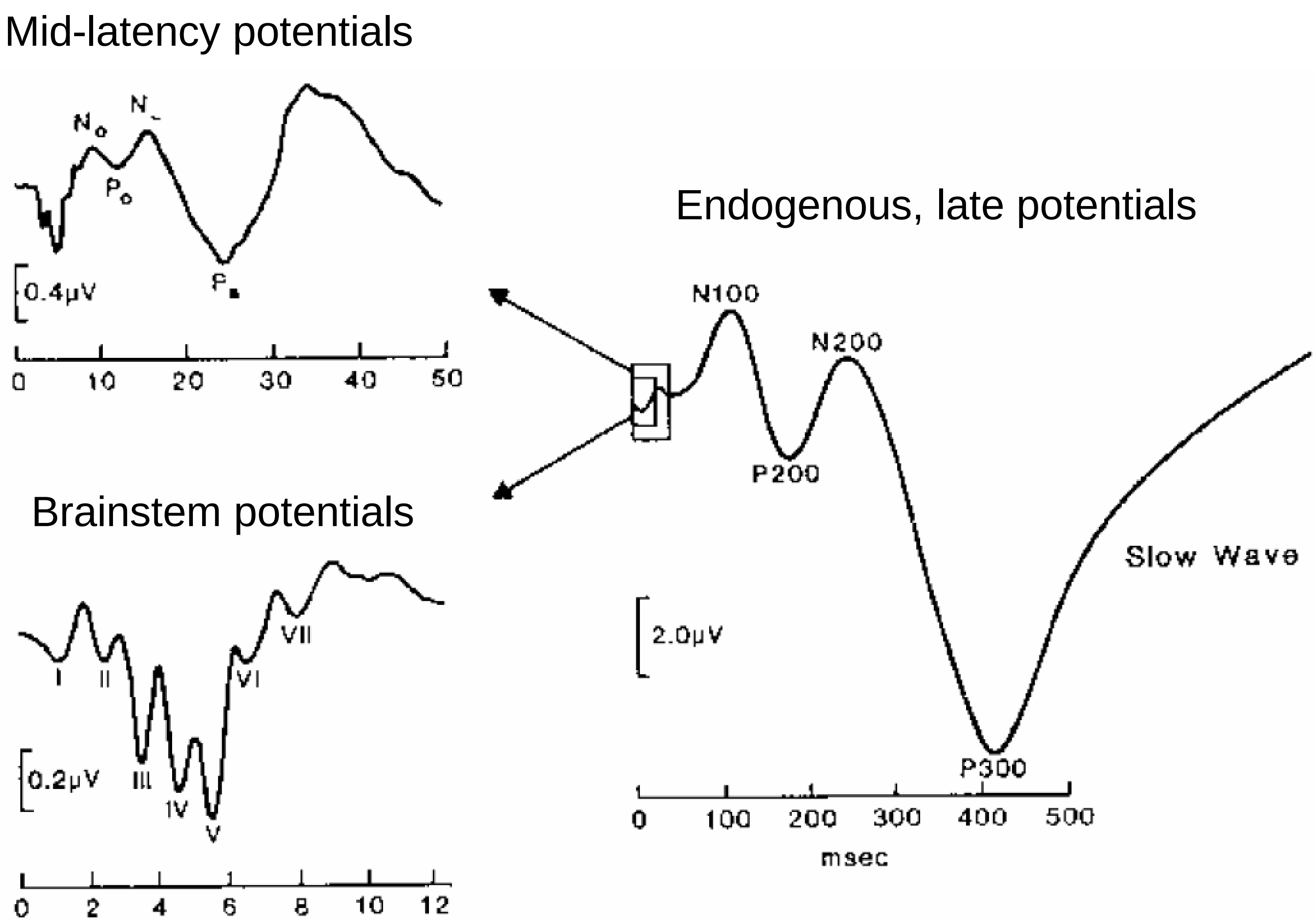
Figure 9. *A*, Plot of average N2pc amplitude for each set size. The inflection point in the N2pc by set size function was calculated for each observer, and this measure strongly predicted both asymptotes in precision (*B*) ($p < 0.01$) and individual capacity estimates (*C*) ($p < 0.01$).

Dual/Multi-Task Paradigms

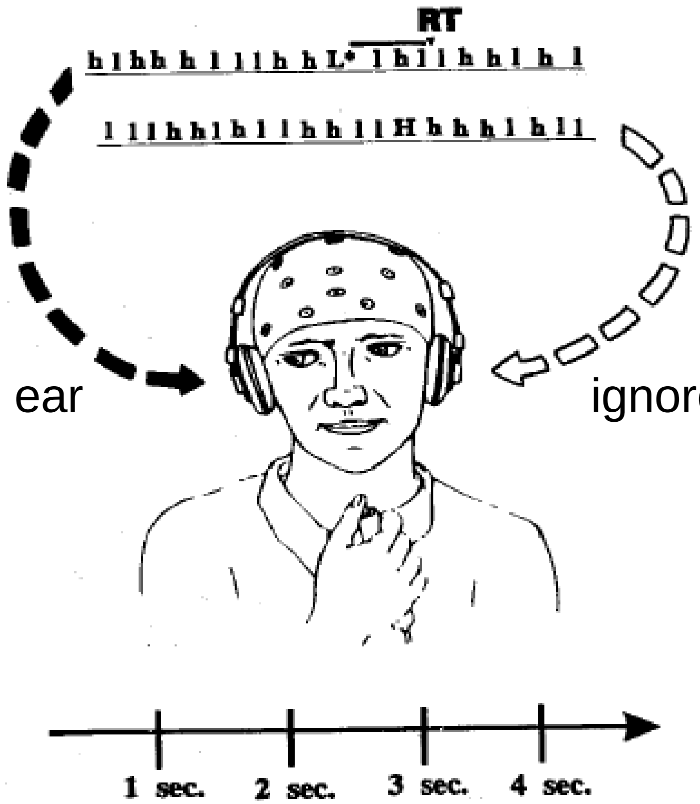
Psychological Refractory Period (PRP)
Attentional Blink Paradigm (AB)

Post-perceptual levels of processing after attention is directed to specific locations and/or objects

AUDITORY SELECTIVE ATTENTION



Filtering paradigm



attend right ear

ignore left ear

800 hz left ear
1500 hz right ear
250-1250 ms ISI
10% targets
 - 840 hz, 1560 hz
6 different orders

N1 attention effect

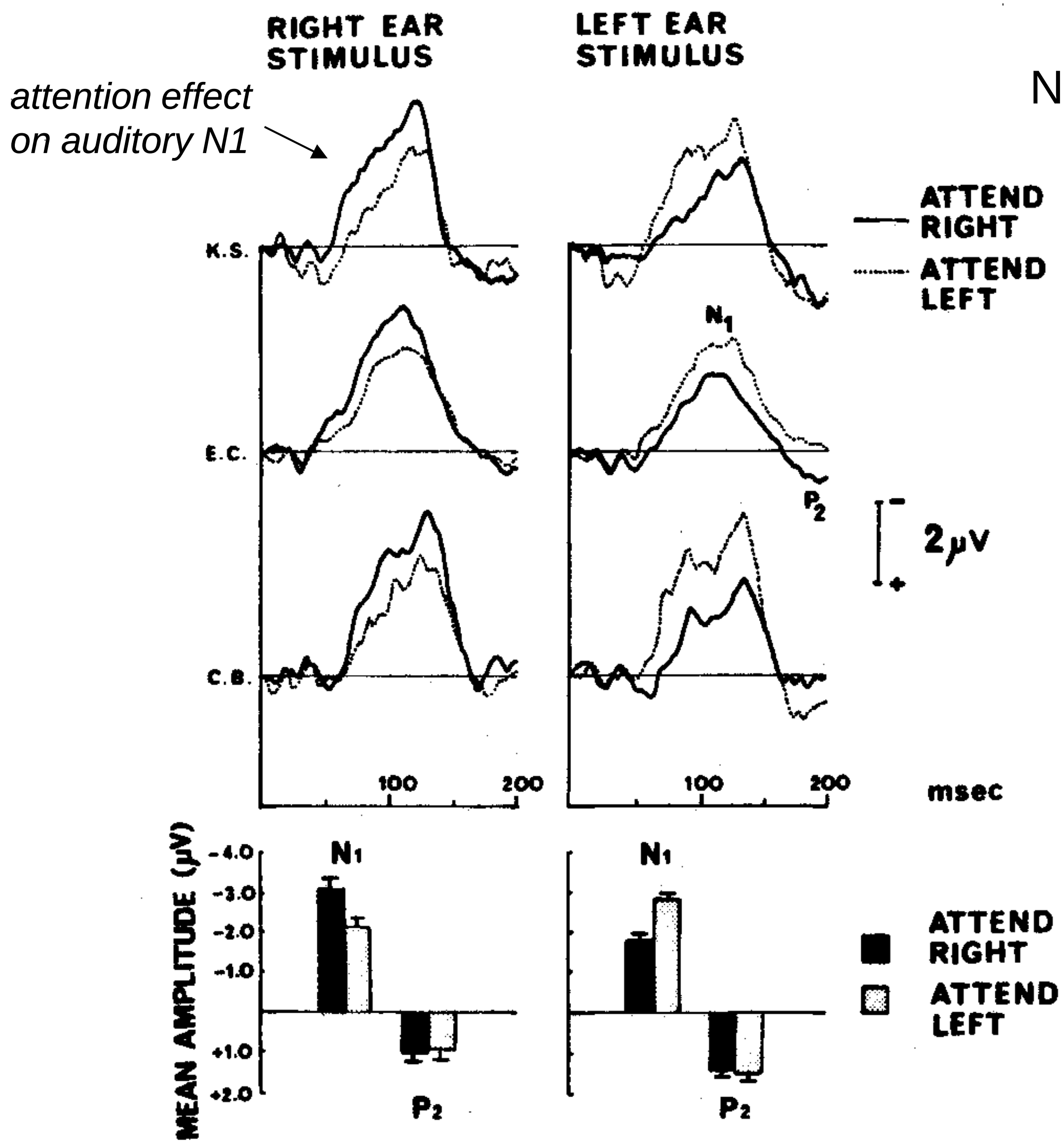
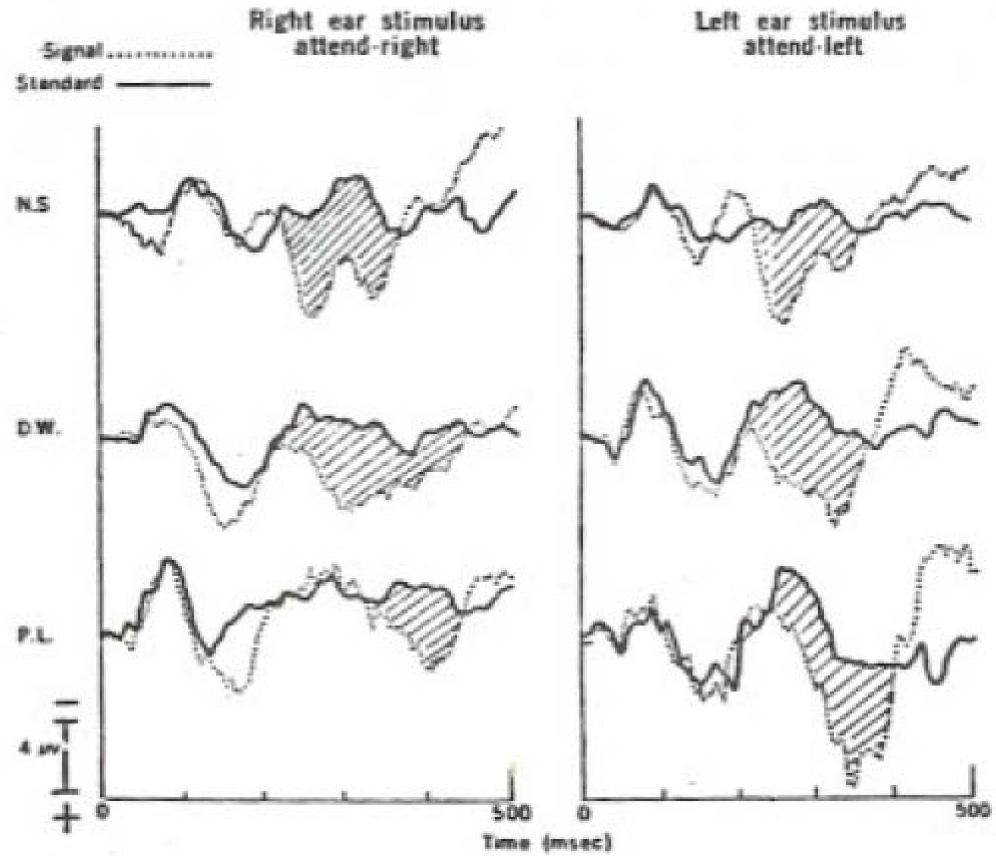


Fig. 8. Averaged ERPs to right ear tone pips (of 1500 Hz) and left ear tone pips (of 800 Hz) delivered in random order to three different subjects. In one condition, subjects attended to right ear tones (solid tracings) and in the other they listened to the left ear tones (dotted tracings). Vertex to mastoid recordings. Lower bar graphs show mean amplitudes (over ten subjects) of N_1 and P_2 components to tones in either ear as a function of direction of attention. From Hillyard *et al.* (1973).

Fig. 2. The P_3 component (shaded area) evoked by signal tone pips in the attended ear. The P_3 is absent in the evoked potential to the standard tone pips (solid tracings). Each tracing is the averaged response to 90 to 110 stimuli; the standard tones were selected at random from throughout the stimulus sequence. The data are from three subjects during both experiment 1 (D.W. and P.L.) and experiment 2 (N.S.).



N1 early phase: stimulus set; P3 late phase response set (further processing once stimulus is selected

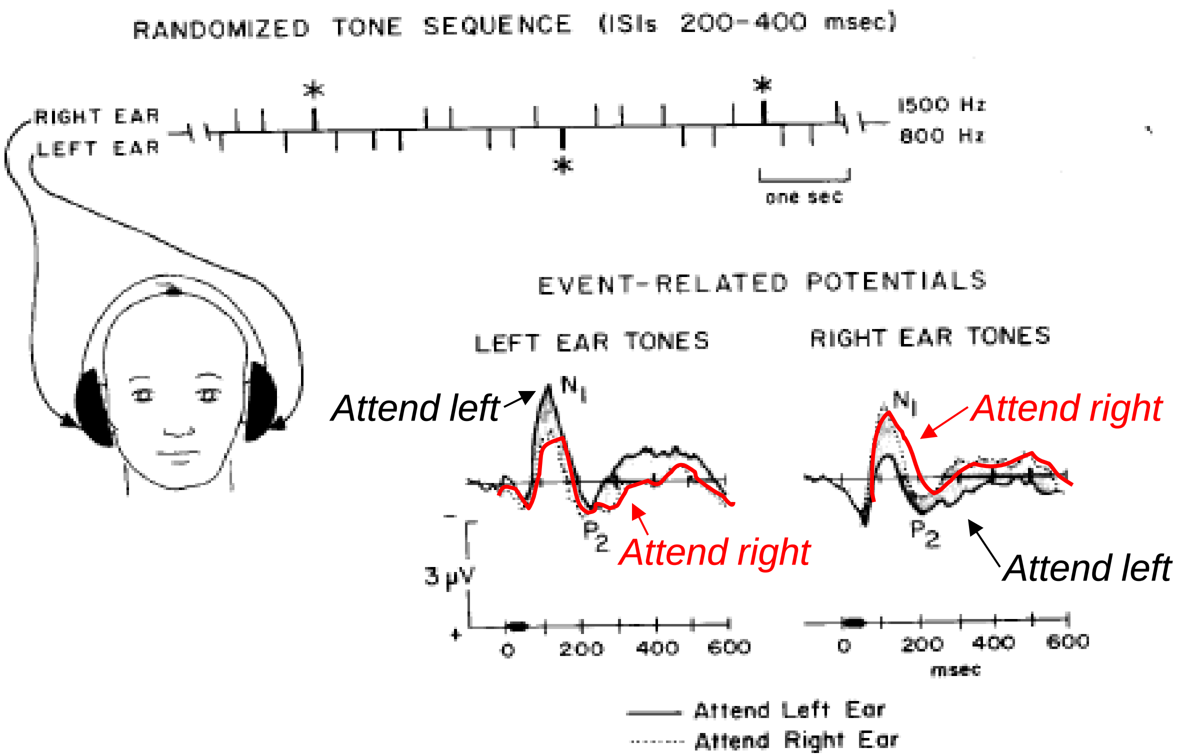


FIG. 2. Paradigm for demonstrating early ERP changes with channel selective attention. Randomized sequences of tones are delivered to the left (800 Hz) and right ears (1,500 Hz) at intervals shown on *upper axis*. *Asterisks* indicate "target" tones that subjects attempt to detect in one ear at a time. Grand average ERPs to tones in each ear are shown as a function of attend left and attend right conditions. The *shaded area* represents the difference waveform between the ERPs to attended and unattended tones and is called the N_d (negative difference) component.

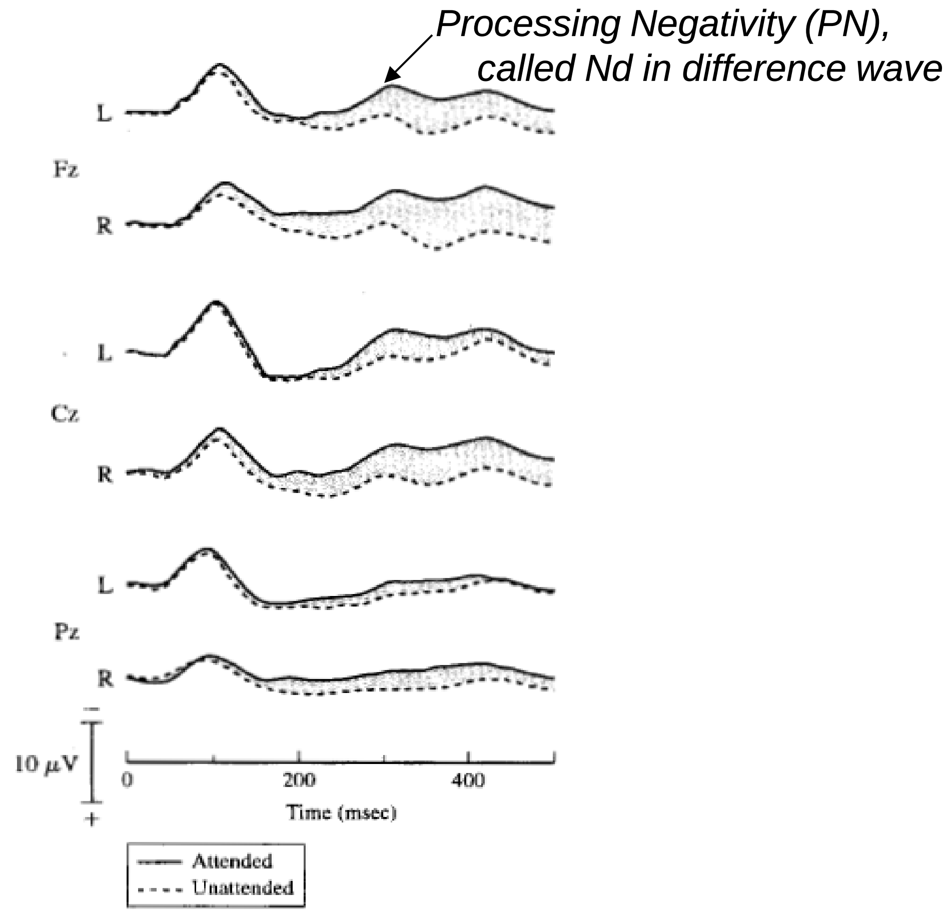


Figure 15.10 Grand-average ERPs at frontal (Fz), central (Cz), and parietal (Pz) midline scalp sites to left-ear (L) and right-ear (R) tones when attended and when the tones in the opposite ear were attended. The ERPs to attended tones are negatively displaced relative to the ERPs to unattended tones as the result of the processing negativity (hatched area) elicited by the attended tones.
SOURCE: Adapted from Näätänen and Michie (1979).

ERPs to Left Ear Tones

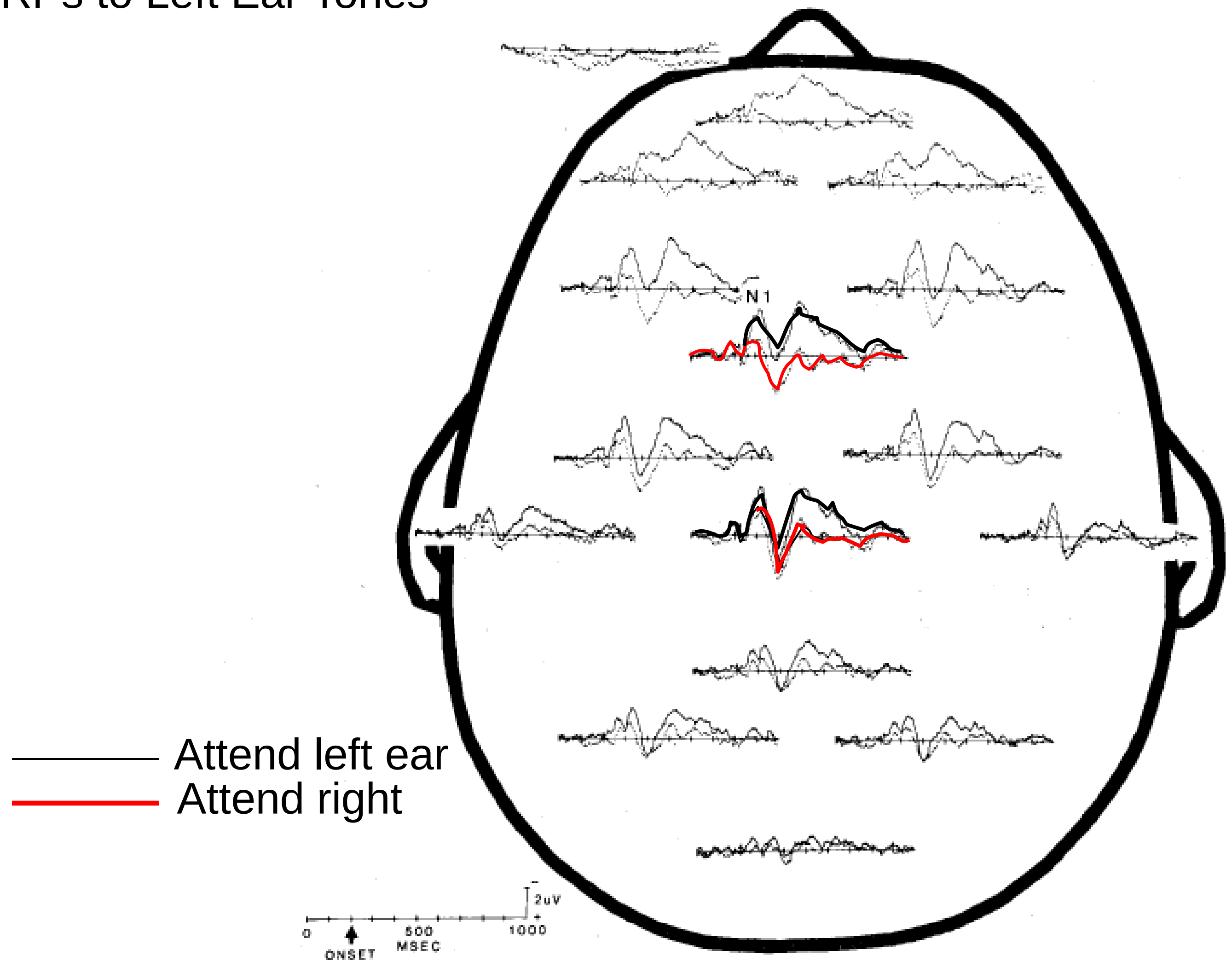
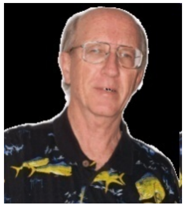


Fig. 1. Grand-mean ERPs produced during the first half of the experiment by tones presented to the left ear when subjects attended to left (solid line) and right ear (dashed line). The total analysis epoch is 998 msec including 200 msec of prestimulus activity. Tick marks indicate 100 msec intervals. The Nd wave is the difference between ERPs elicited by attended and ignored stimuli. Stimuli were 1300 Hz tones.

Views on Auditory Selective Attention Effects



Hillyard et al.: N1 amplitude modulation + Nd (negative difference): N1 reflects tonic facilitation of attended sensory channel.

Naatanen et al.: only Nd, attention based on comparison of each sensory input against memory representation of to be attended stimulus.

Major portion of auditory selective attention is endogenous Nd (which may overlap N1), but supratemporal N1 amplitude also may be modulated by attention in highly focused, fast rate conditions, so there seems to be (at least) two selective attention mechanisms in audition.

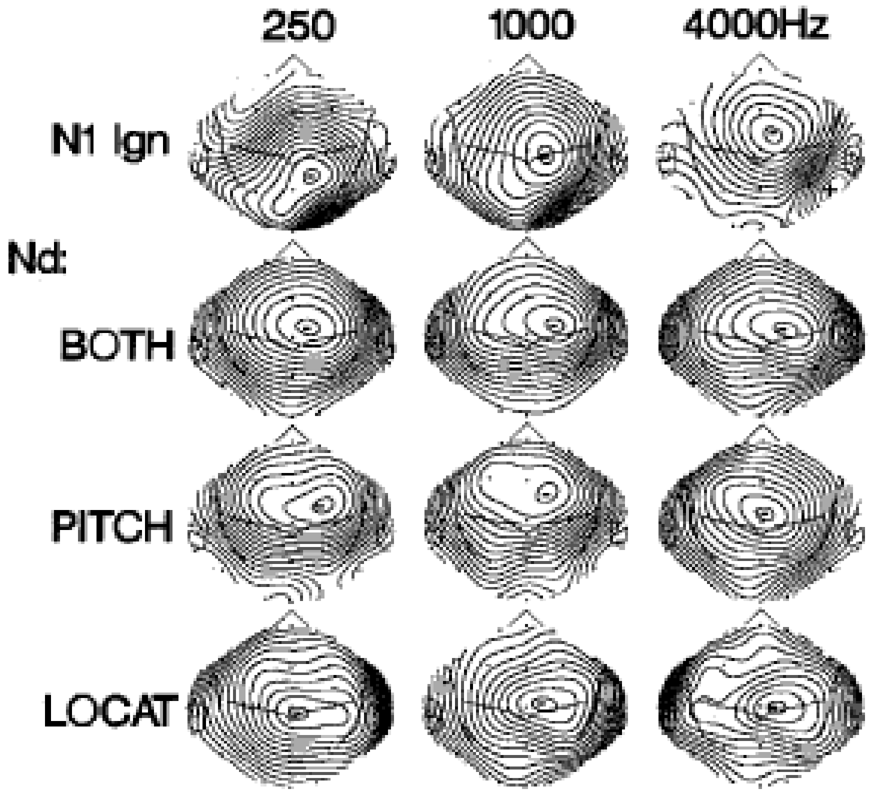


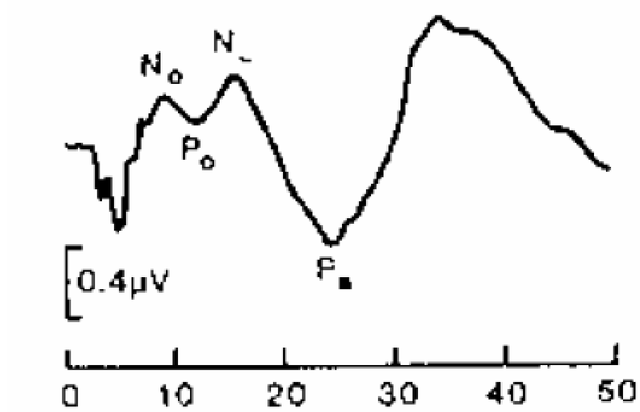
FIG. 2. ERP scalp distributions derived with spherical spline interpolation.[17] A. *N1 Ign*: Mean voltages of sensory ERPs evoked by nonattended tone bursts. Latency range 70–90 ms. B. *Nd. Both*: Distributions of Nd mean voltage from 130–150 ms to standard tones with both attended pitch and attended location features. C. *Pitch*: Distributions of Nd mean voltage from 130–150 ms to tones of attended pitch but nonattended location. D. *Locat*: Distributions of Nd mean voltage from 130–150 ms following tones of attended location but not attended pitch. Electrodes (dots) on the right were contralateral to the ear of stimulation. Contour lines are shown at 99% maximal voltage, and then at 6.25% steps through the total voltage range.

N1 distribution whether attended or not varies with pitch (i.e., tonotopic)

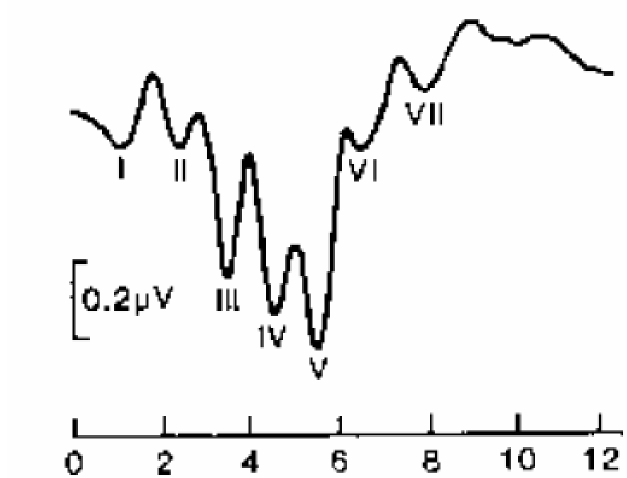
Nd distribution does NOT vary with pitch (i.e., not tonotopic).

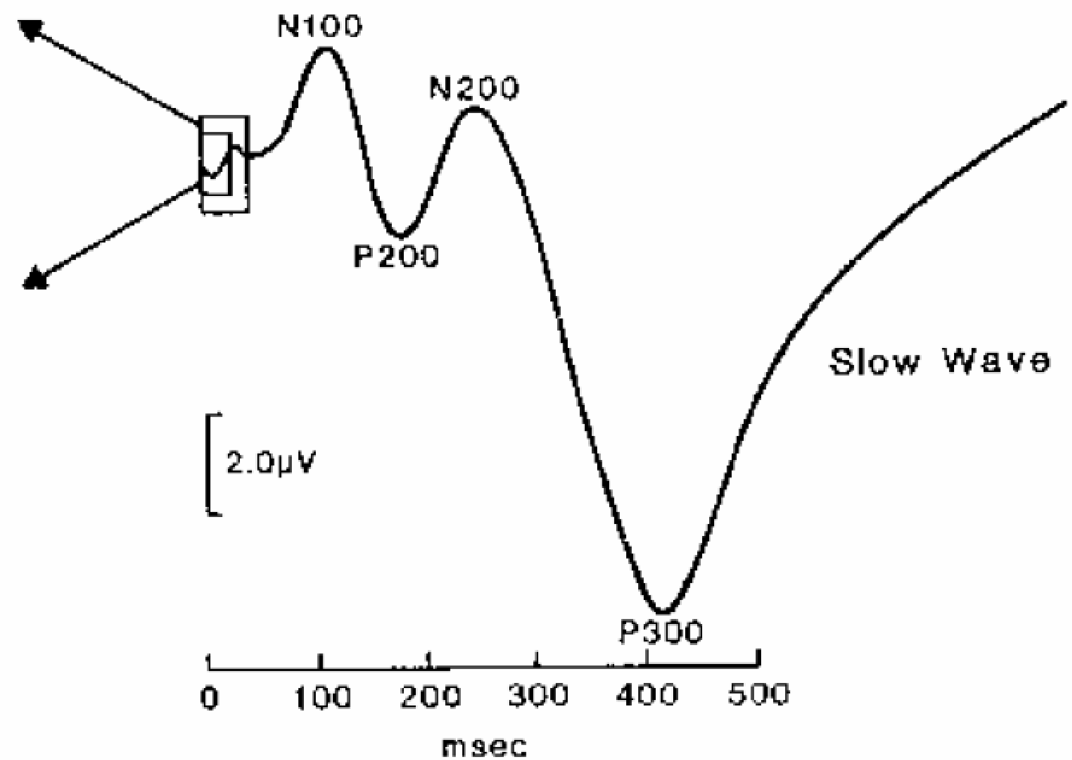
From lab of David Woods, Martinez

AUDITORY EVENT RELATED POTENTIALS



AUDITORY BRAINSTEM POTENTIALS





No reliable attention effects on ABR – auditory brainstem response

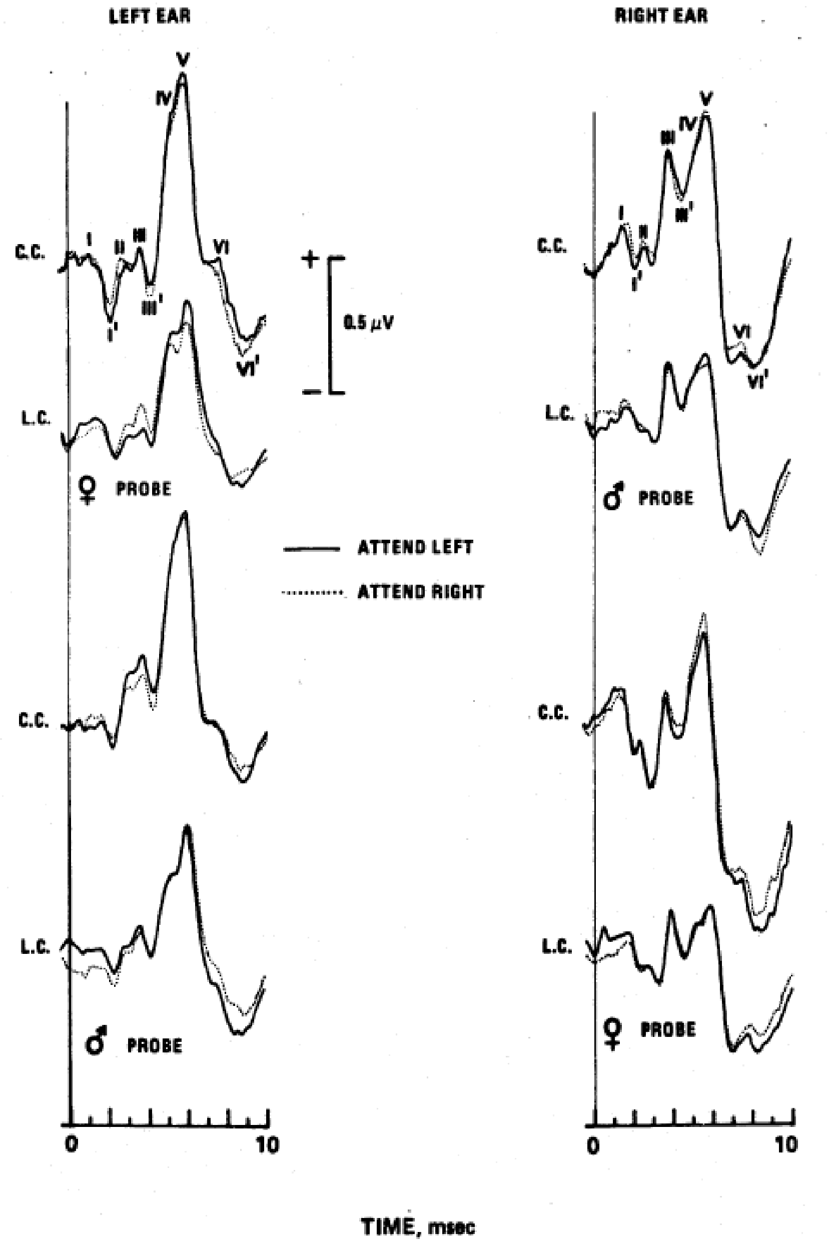
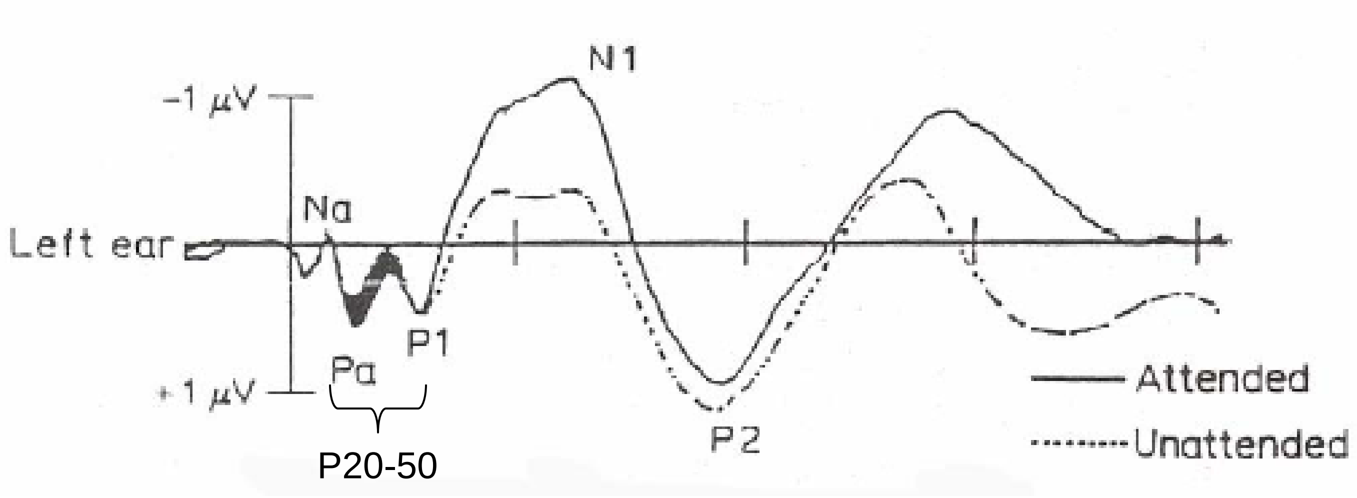


Fig. 1. Click-evoked BERs from two subjects (sisters C.C. and L.C.) during attention to left and right ear messages. Click probes were superimposed on female and male voices in left and right ears, respectively, in the top pairs of tracings; voices were reversed in lower tracings. N = 12,000 responses/average.

Earliest auditory attention effect at scalp is P20-50



Woldorff & Hillyard

Magnetic auditory selective attention effects – M50, M100

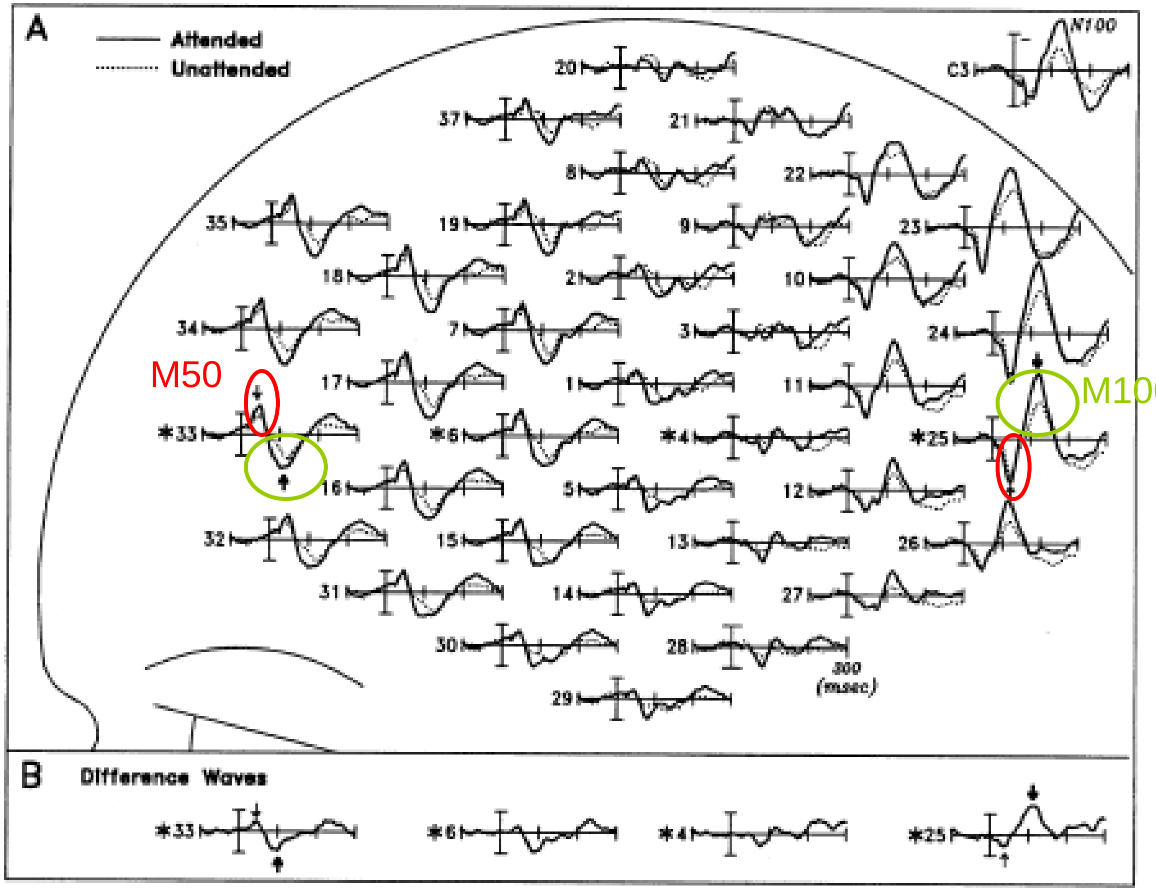


FIG. 1. (*A*) Grand-average waveforms (i.e., averaged across all seven subjects) of the event-related magnetic activity elicited by right-ear standard tones when they were attended versus when they were unattended, displayed at approximate locations of the magnetic sensors over the left hemisphere. At the upper right are the simultaneously recorded ERPs from the C3 site. Positive (upward) values for the magnetic activity indicate that the fields are directed out of the head, and negative values indicate inward-directed fields [calibration bars = ±20 femtotesla (fT)]. ERP scalp negativity is plotted upward [calibration bars = ±1 microvolt (μV)]. Large arrows mark the polarity-inverting M100 at sites 25 and 33; small arrows denote the polarity-inverting M50. (*B*) Grand-average attentional-difference waveforms (attended minus unattended ERFs) derived from the data in *A* for four sites (denoted with asterisks in *A*) in the anterior-to-posterior line across the array. Large and small arrows mark the polarity-inverting attention effects for M100 and M50, respectively.

MAGNETIC FIELD DISTRIBUTIONS

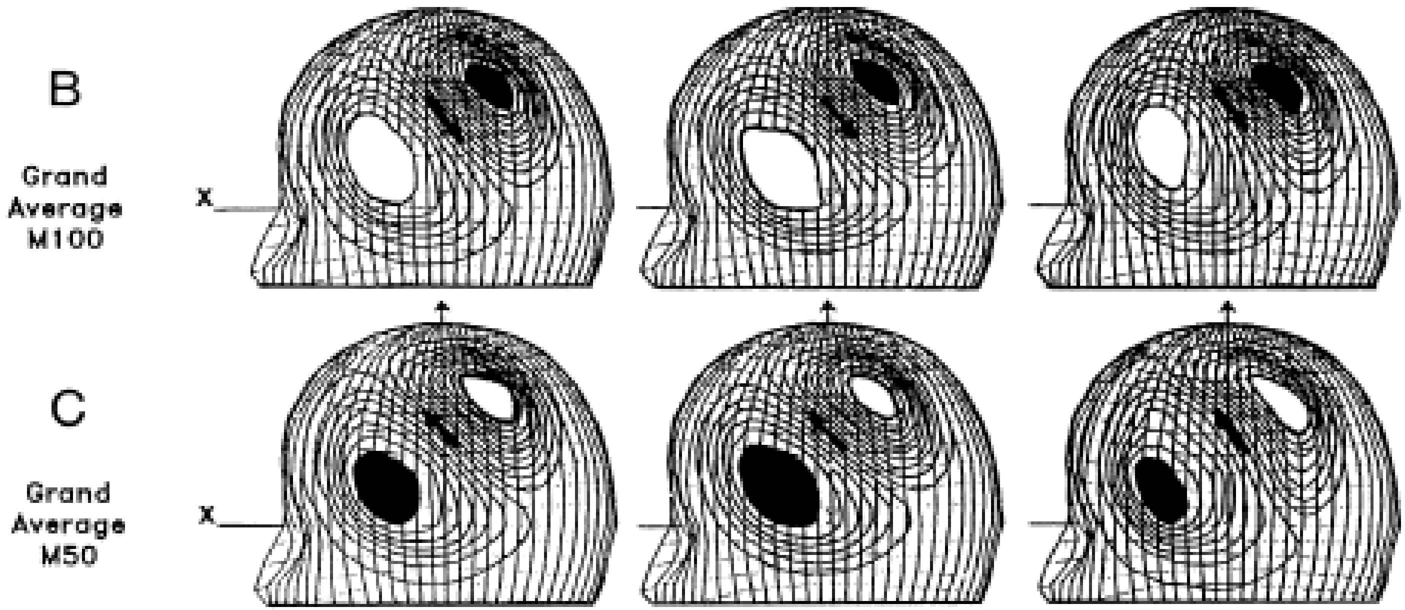


FIG. 2. Topographic plots (isocontour lines) showing magnetic field distributions for the M100 and the M50 (each individually scaled to emphasize distribution rather than absolute magnitude). (*A*) Field distributions at the peak of the M100 from a single subject for the attended response, the unattended response, and the attentional-difference wave (i.e., the subtracted difference between the attended and unattended responses). Note the dipolar field distribution, with a maximum (shaded dark) where the magnetic field lines are directed out of the head and a minimum (shaded light) where the magnetic field lines are directed into the head. The arrow indicates the direction of the single ECD source that would produce a set of fields that would best fit this distribution. Isocontour scales (differences between adjacent isocontour lines) are 12.4, 8.5, and 3.9 fT for the attended, unattended, and attentional-difference waves, respectively. (*B*) Corresponding field distributions for the M100 from the grand-averaged waveforms. Isocontour scales are 6.4, 3.7, and 2.9 fT for the attended, unattended, and attentional-difference waves, respectively. (*C*) Same as B for the M50. Isocontour scales are 4.8, 3.8, and 1.1 fT for the attended, unattended, and attentional-difference waves, respectively.

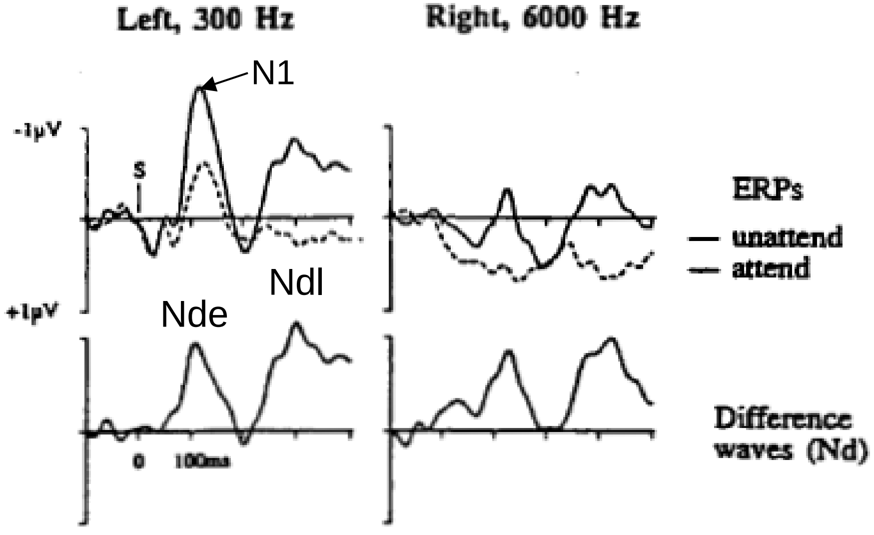
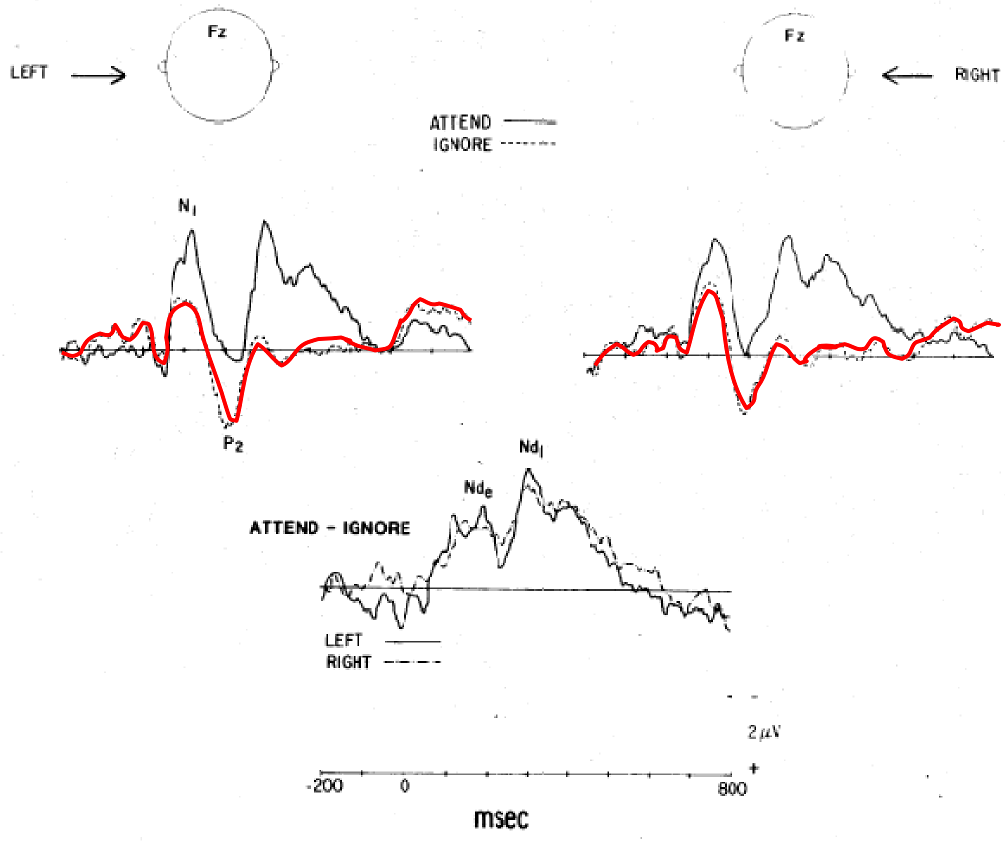


Figure 15.11 Grand-average ERPs at the central midline scalp site (Cz) to attended (solid line) and unattended (dashed line) tones delivered to the left (300 Hz) and right ear (6000 Hz) in a selective dichotic-listening study. Note the negative N1 deflection peaking at about 120 ms from stimulus onset. Bottom: Difference waves obtained by subtracting the ERPs to unattended tones from those to attended tones. These difference waves show an early effect of attention peaking at about 120 ms and a later effect peaking after 300 ms.
SOURCE: Adapted from Näätänen et al. (1992).

Nde – early, central distribution
Ndl -- late, more frontal distibution

Nd – negative difference consists of two subcomponents



Nd – negative difference consists of two subcomponents

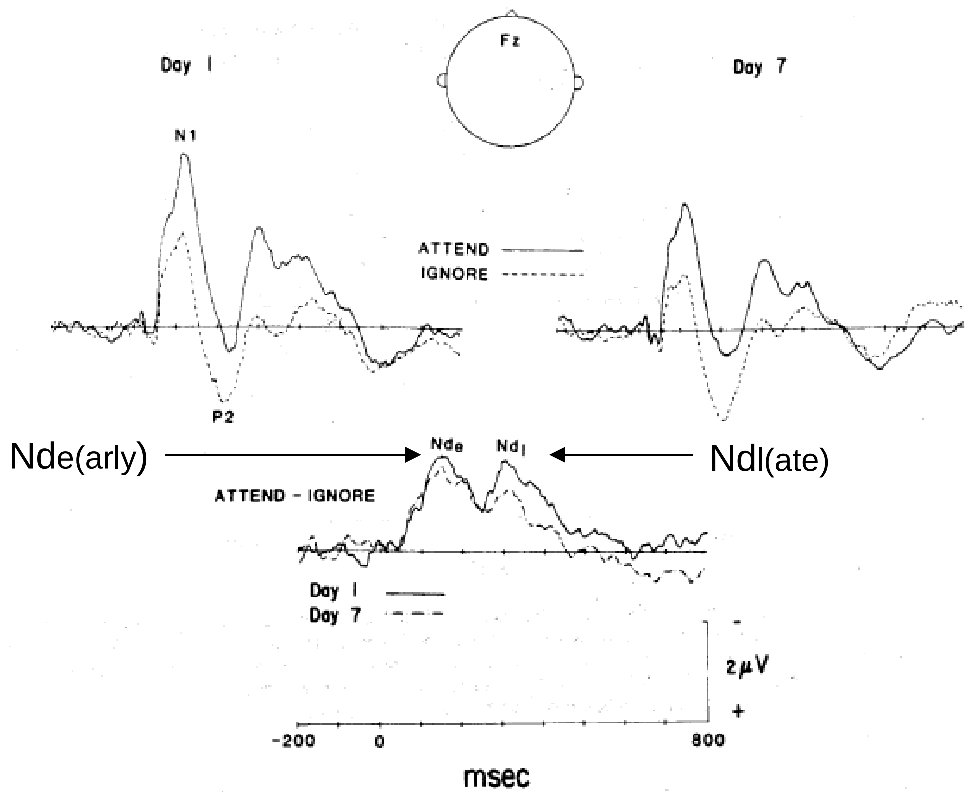


Fig. 13.4 Long-term habituation of ERPs recorded in a dichotic attention task. ERPs are shown from day 1 (left) and day 7 (right) of an experiment in which subjects performed for 1.5 hours per session in seven sessions at 1-week intervals. Grand mean ERPs at the Fz electrode are showed averaged over left- and right-ear stimuli. The Nd_e was reduced by about 10% over successive experimental sessions. The Nd_l was reduced by about 30%, and its duration was shortened by more than 60 msec.

SCALP TOPOGRAPHY OF N1, Nde, Ndl attention effects

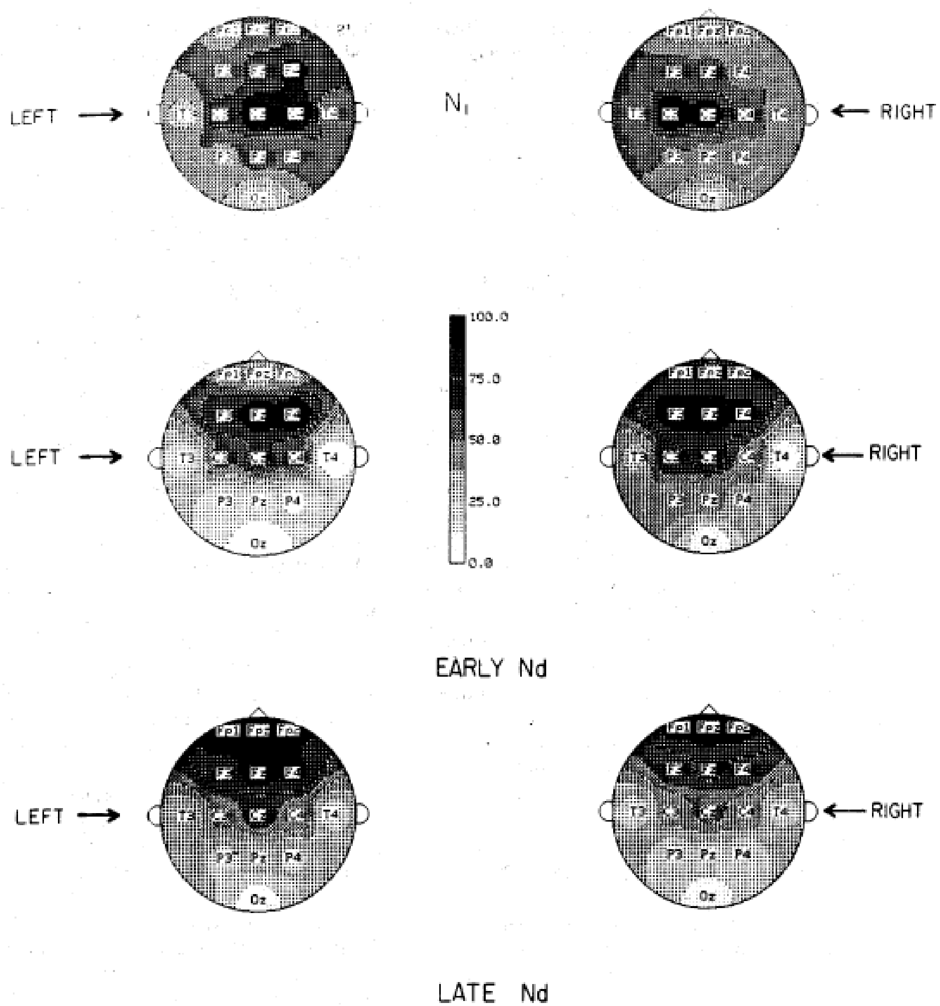


Fig. 13.5 Scalp distributions dissociate ERP components produced during selective attention tasks. Top: Scalp topography (in percent maximal amplitude) of mean voltages during the N1 latency range (90–130 msec) elicited by tones in the nonattended channel. Values are interpolated from 15 scalp electrode sites. Middle: Topography of the Nd_e recorded during the N1 (90–130 msec). The Nd was obtained by subtracting the ERPs in the nonattended channel from the ERPs produced by the same stimuli in the attended channel. Bottom: Topography of the Nd_l recorded during 300–400 msec poststimulus. Arrows show the ear of stimulation.

N1, fronto-central, broad spread
contralateral to stimulated ear

Nde: Early Nd, more frontal than N1
bilaterally symmetric

Ndl: Late Nd, frontopolar
bilaterally symmetric

Attended ERP minus Unattended ERP

In difference ERP (attended minus unattended), attention related Nd

Nde **–** negative difference early (~50 ms+), reflects early processing negativity (PN)
rapid analysis of physical features of initial portion of stimulus for further processing
reduced with dorsolateral prefrontal damage

Ndl **–** negative difference late (200-500 ms onset, 1000 ms duration), reflects later PN
more frontal distribution than either N1 or early Nd
further processing of attended stimulus after initial selection or, rehearsal and maintenance of attentional trace
reduced with parietal and temporal damage

Distributional and functional differences indicate that N1, Nde and Ndl are distinct.

ATTENTION AND AUDITORY EVENT RELATED POTENTIAL SUMMARY

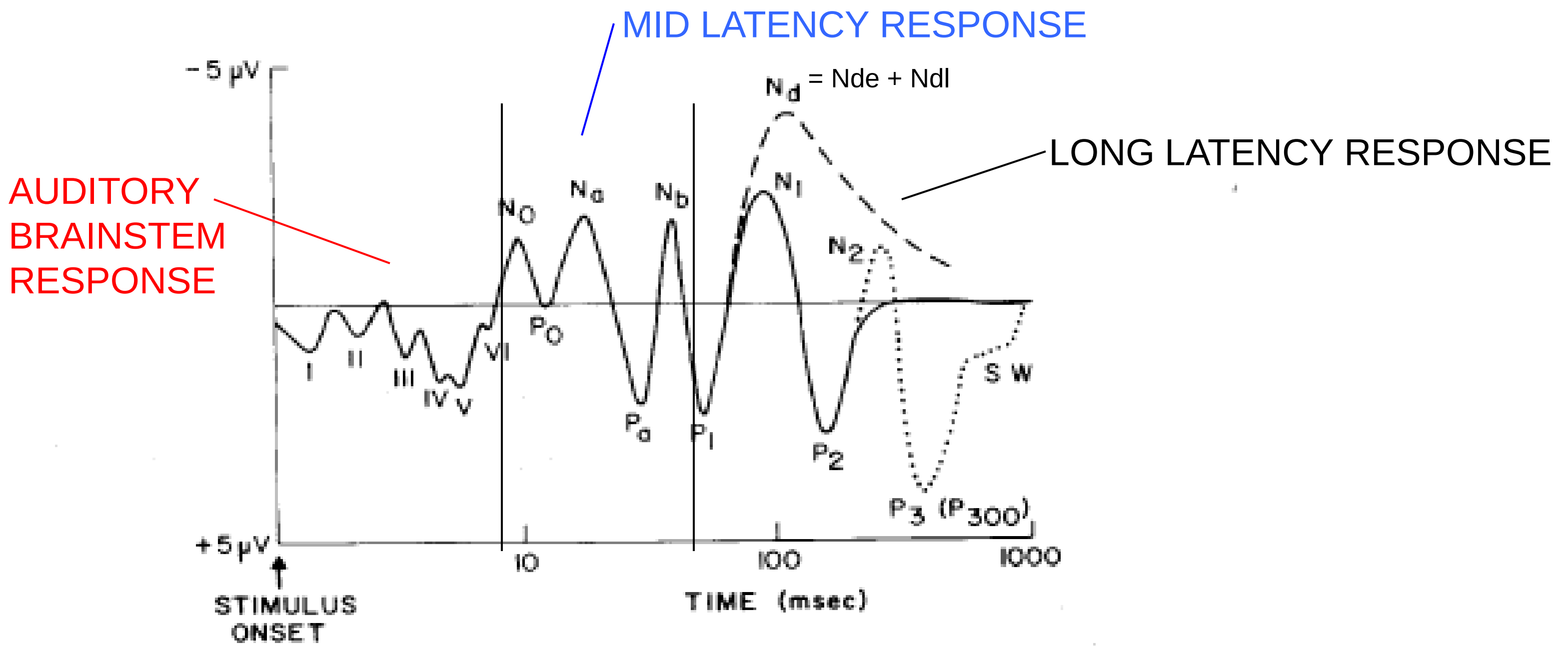


FIG. 1. Idealized waveform of auditory event-related potential in man, showing brainstem (waves I–VI), mid-latency and long-latency components observable in most subjects. The *solid tracing* represents the "exogenous" or evoked components, while the *dashed* and *dotted lines* show different endogenous components associated with specific modes of processing.

No reliable attention effect on ABR/BER

Earliest attention effect: P20-50 generated in supratemporal cortex

N1 amplitude enhanced, Processing Negativity (PN)

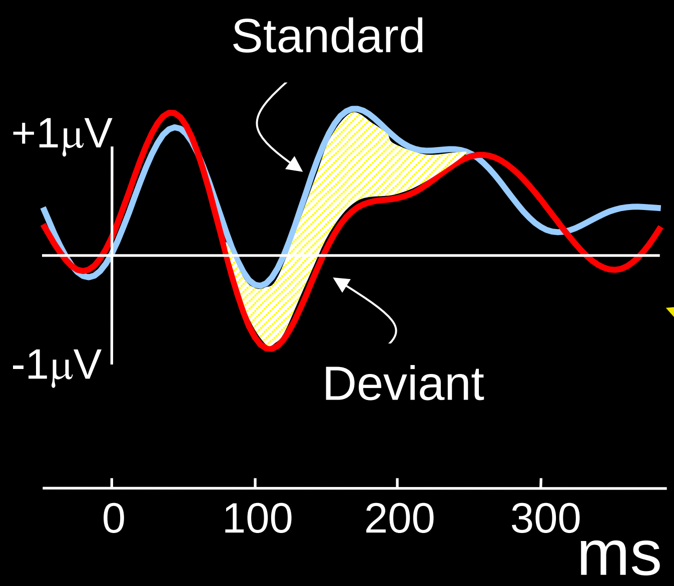
Nde – negative difference early, reflecting early processing negativity

Ndl – negative difference late, reflecting later processing negativity

Basic Mismatch Negativity (MMN) paradigm

- Present a series of sounds with some regularity
- Infrequently break the rule
- Have the subject do something else
  (e.g. read a book, play a video game)
- Compare electrical potentials elicited by the standard and deviant stimuli

Mismatch Negativity – Index of Automatic Change Detection



Beep… Beep… Beep… Boop… Beep… Beep… Beep… Boop…

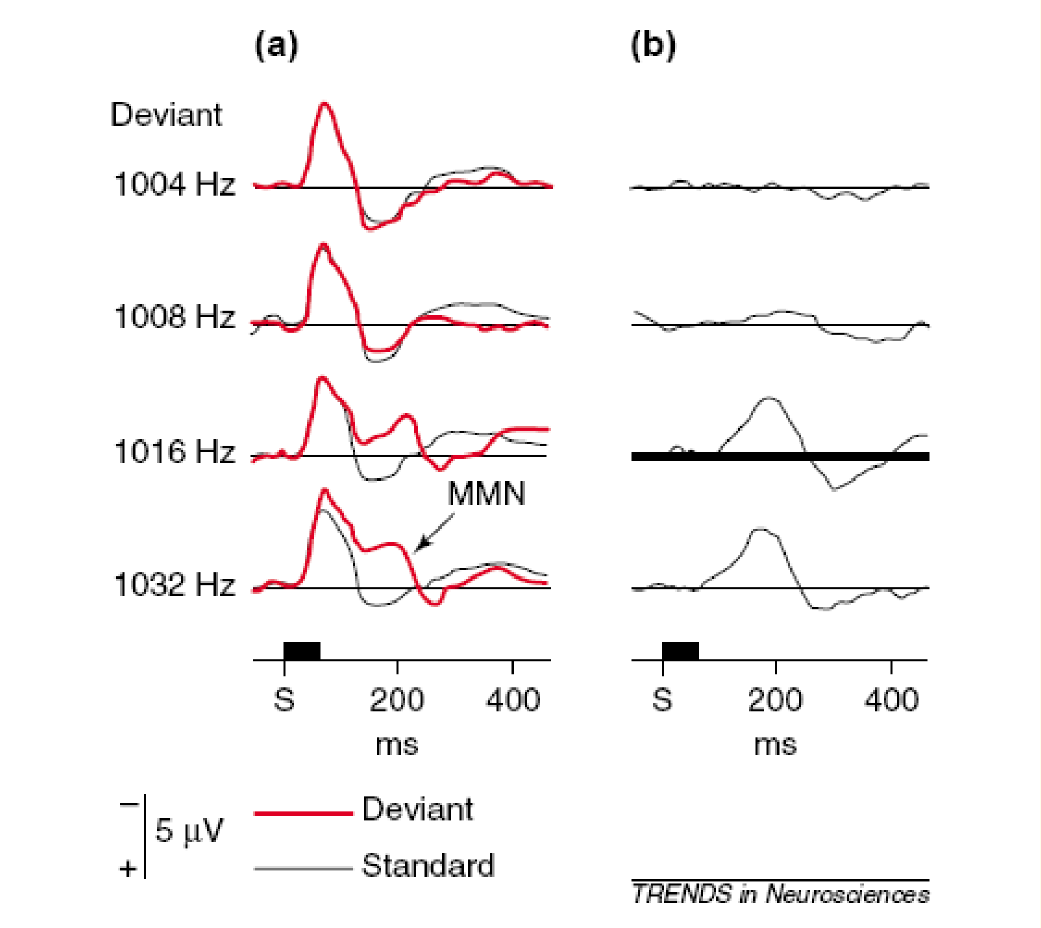


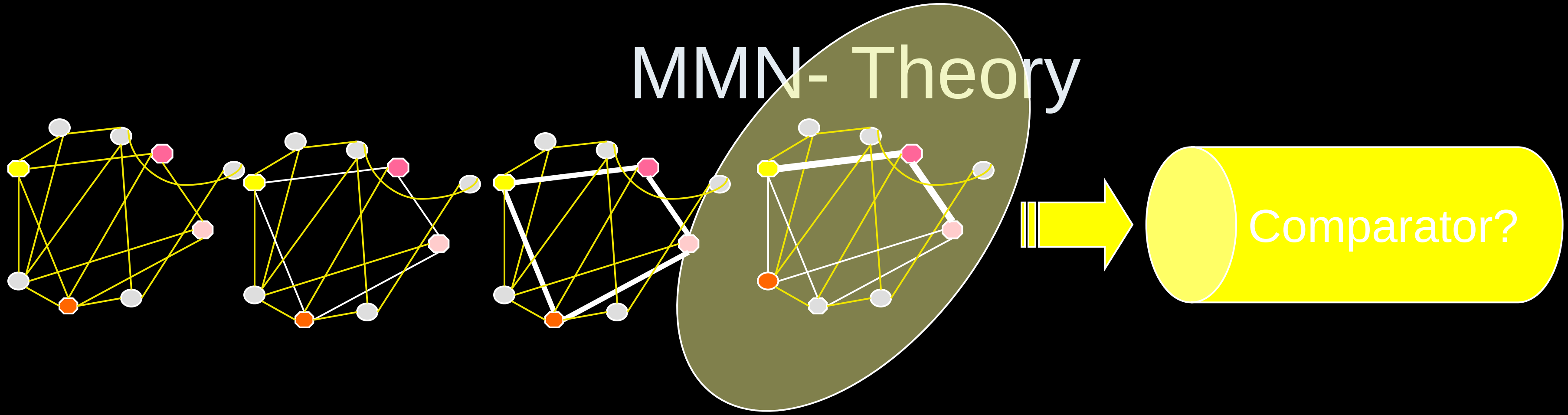
Fig. I. (a) Frontal (Fz) event-related potentials (ERPs) (averaged across subjects) to randomized 1000 Hz standard (80%, black line) and to deviant (20%, red line) stimuli of different frequencies (as indicated on the left side). (b) The difference-waves obtained by subtracting the standard stimulus ERP from that of the deviant stimulus for the different deviant stimuli are shown. Subjects were reading a book. Adapted, with permission, from Ref. b.

The Mismatch Negativity (MMN)

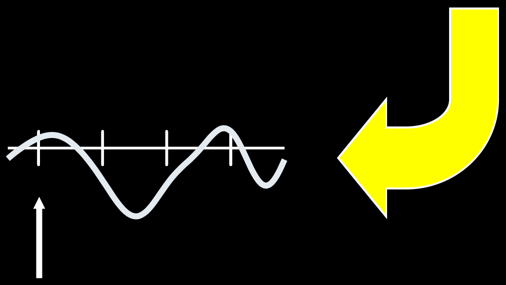
- Probe index of sound representation, echoic short term memory
- Pre-attentive, non-intentional; i.e., does not require attention or response (seen in babies, sleep, coma)

Change detection between new auditory input and representation in auditory sensory memory

MMN- Theory



- Sensory memory traces
- Formed by as few as 3 events
- Last for up to 10 seconds
- NMDA dependent (LTP)
- Deviance detected in 100ms – 300 ms
- Automatic & pre-attentive



MMN reflects pre-attentive change detection process: mismatch between new auditory input and representation stored in auditory sensory memory.

What information is coded in sensory memory?

- Sound Frequency
- Duration
- Intensity
- Location
- Timbre
- Phonetic content
- Temporal order
- Frequency change direction
- ???

Simple physical featuress, phonetic content, temporal order, etc.!

MMN is Sensitive to 'Abstract' features

H-L H-L H-L **L-H** H-L H-L **L-H** H-L

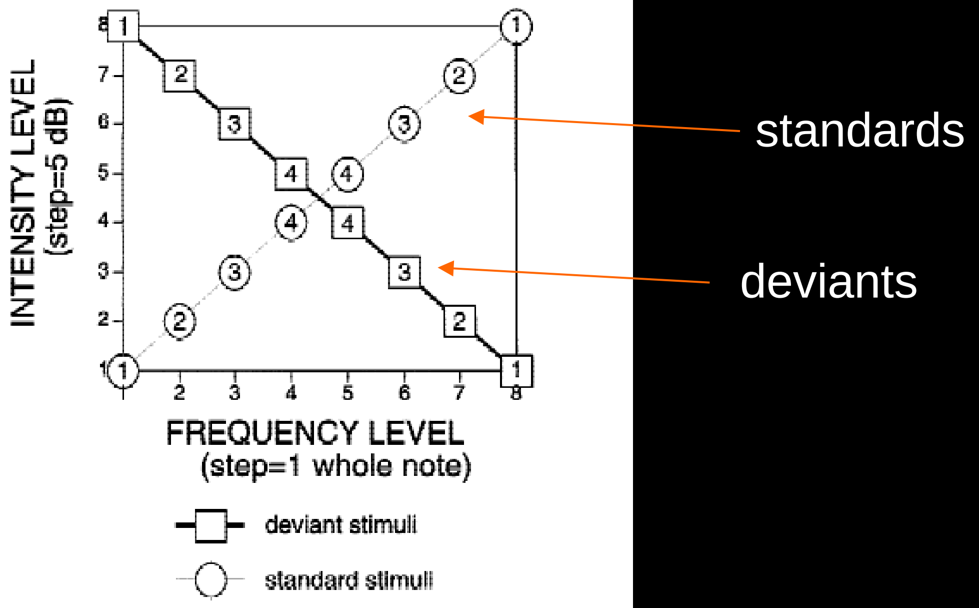


Figure 1. A schematic illustration of the stimuli used in Experiment 1. The frequencies and intensities of the stimuli varied on eight equiprobable frequency levels (*x* axis) and eight equiprobable intensity levels (*y* axis). The frequencies and intensities of the standard stimuli (circles on the thin diagonal line) followed an abstract linear rule "the higher the frequency, the louder the intensity," so that there were eight equiprobable standard conjunctions for frequency and intensity (i.e., F_1I_1, F_2I_2, . . . F_8I_8). In contrast, the deviant stimuli (squares on the thick diagonal line) obeyed the reverse rule. For half of the subjects, the rules for standard and deviant stimuli were reversed. The numbers inside the circles and squares refer to the four different stimulus positions in the standard and deviant "rules," proceeding from the corners of the frequency-intensity space towards its center. Position 1 refers to the stimuli in the extreme corners and Position 4 to the stimuli nearest to the center.

Abstract rule: the higher the frequency, the louder the intensity

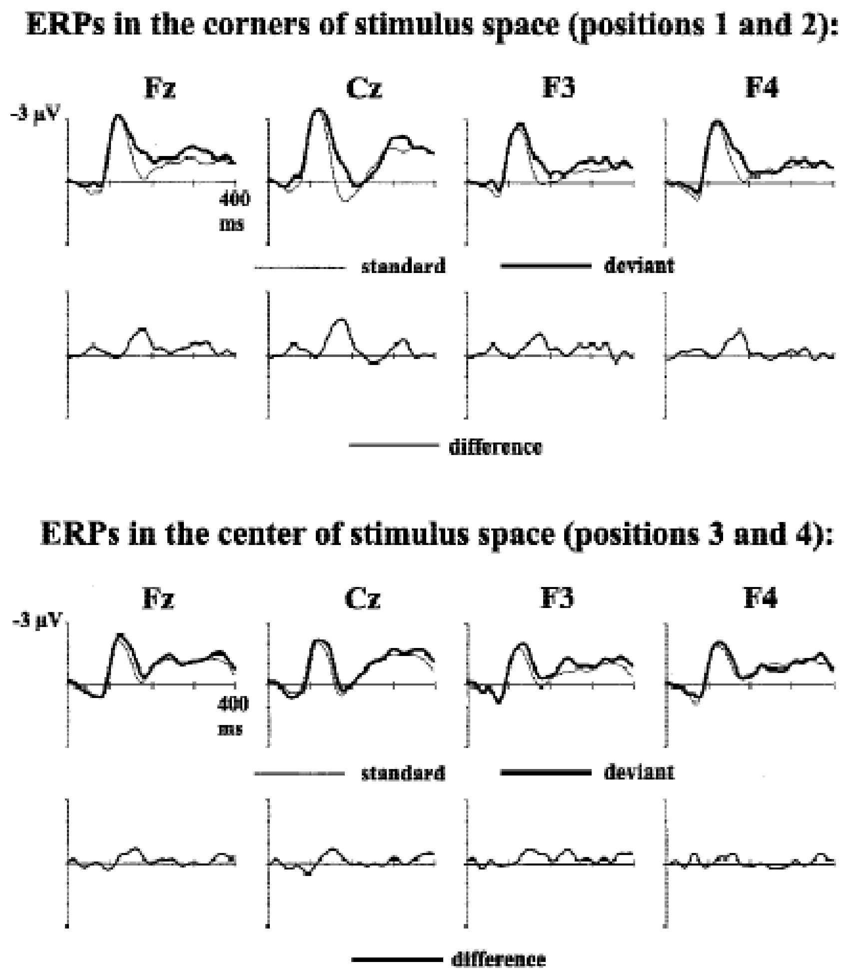
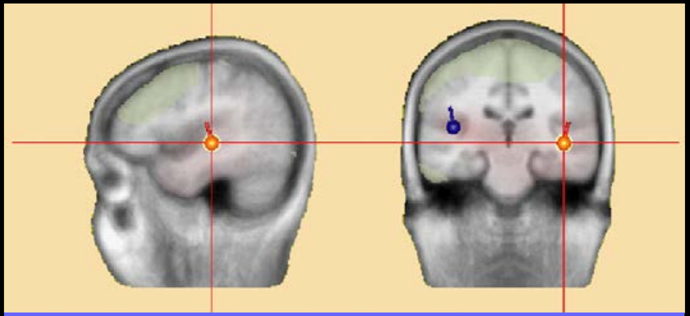


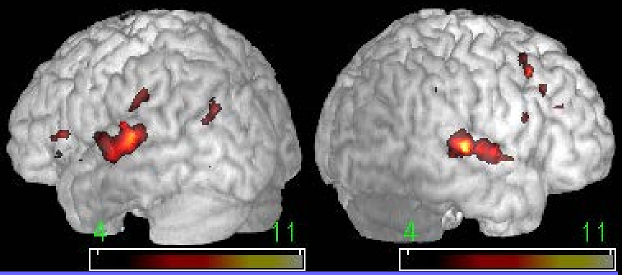
Figure 5. The ERPs to standards and deviants and the corresponding difference waveforms separately for the stimuli in the corners (top panel; Positions 1 and 2 averaged together) and in the center (bottom panel; Positions 3 and 4 averaged together) of the frequency-intensity space ($N = 14$).

Preattentive auditory processing can detect complex relationships between stimulus features.

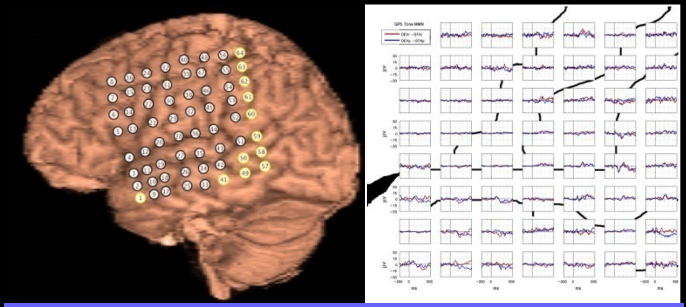
Multiple sources of evidence support a temporal generator of the MMN (near auditory cortex)



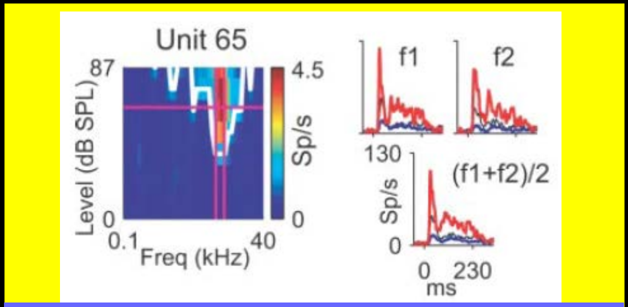
Inverse Solutions



PET and FMRI



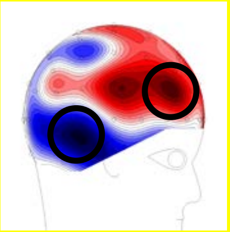
Implanted Electrodes



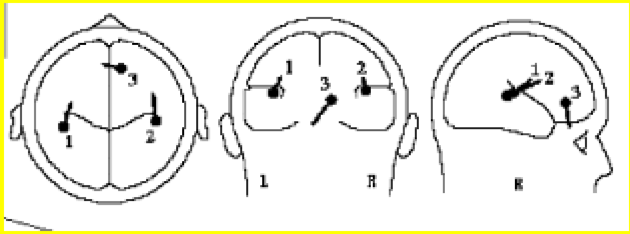
Recordings in Animals

Less robust evidence for a frontal generator of the MMN

- **<u>EEG-CSD</u> ! –**
  - **frontal sinks in addition to temporal sink-sources.**
  - **[But: intracranial sources not determined]**
- **<u>MEG</u> dipole modeling –**
  - **[NO, maybe wrong orientation]**
- **<u>EEG inverse solutions</u> –**
  - **Rt IFG, Left ACC, Right ACC**
  - **[But: Frontal dipoles add very little to the solution, if any!]**



CSD

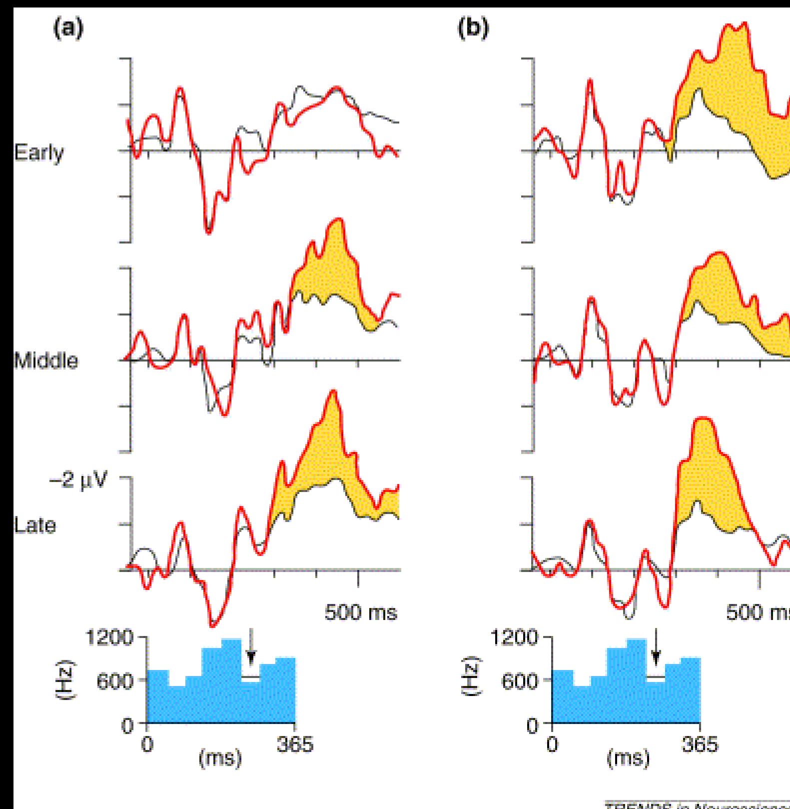


Inverse Solutions

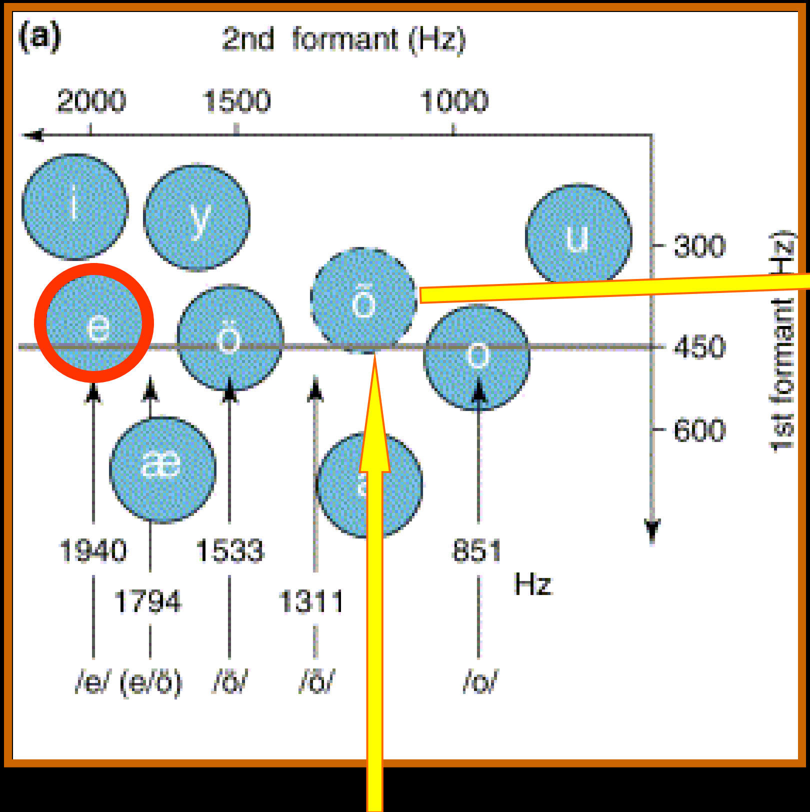
MMN is not only sensitive index of short term echoic memory but also longer term perceptual learning

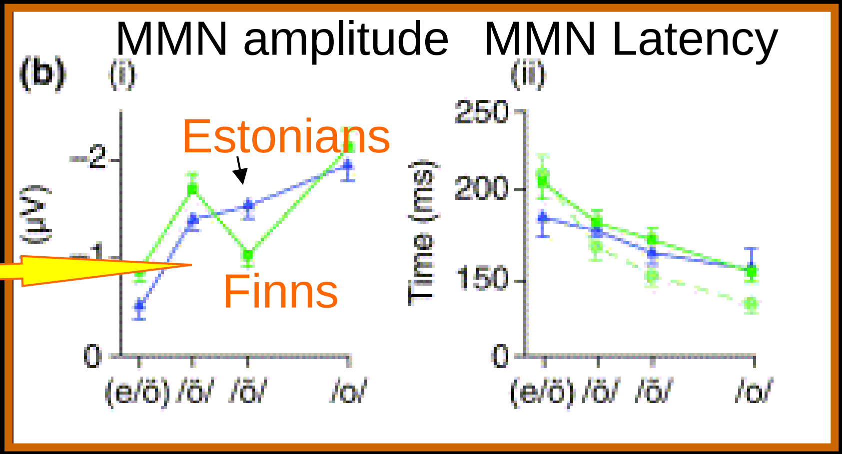
1
2

1
1
1
1
1
2
1



MMN is Sensitive to Categorical Knowledge





Estonian prototype, does not exist in Finnish

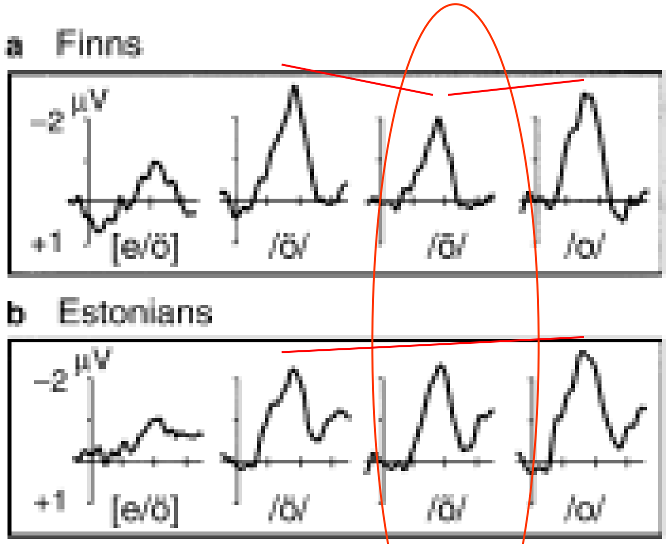


Figure 3 The amplitude of the mismatch negativity (MMN; frontal Fz electrode; grand-average deviant-standard difference waveforms) reflects the language-specific phoneme categories of the Finnish and Estonian languages. Note that the MMN amplitude for the deviant /õ/, a non-prototype in Finnish, is clearly smaller than that for the adjacent prototype deviants with Finnish subjects (**a**) but not with Estonian subjects (**b**) for whom /õ/ was a prototype.

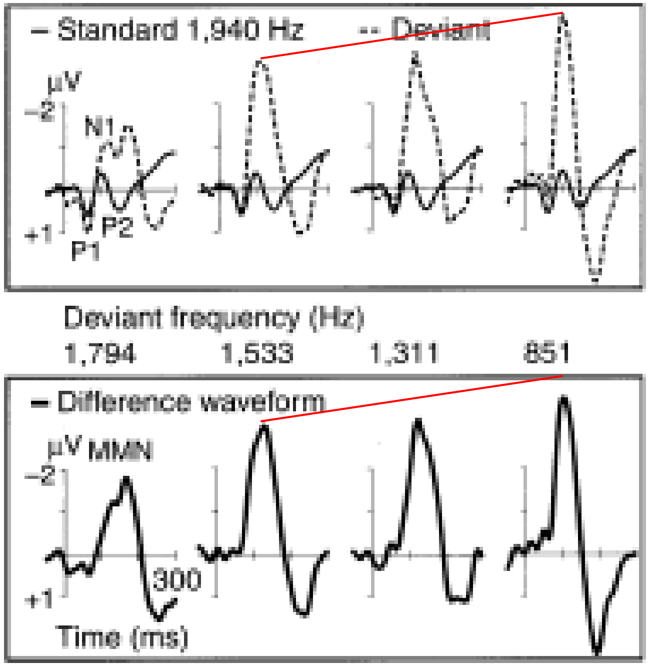


Figure 2 Top, the electric response (from the frontal Fz electrode; grand-average waveforms of Finnish subjects) to the standard sinusoidal tone of 1,940 Hz (solid line; equal to the F2 of /e/ used as the standard stimulus in the present phoneme experiments) and to deviant sinusoidal tones of 1,794, 1,533, 1,311 and 851 Hz (broken line; equal to the F2 of the deviant stimuli [e/ö], /ö/, /õ/, and /o/, respectively). The standard-stimulus response shows relatively small P1, N1 and P2 deflections[6]. The negative displacement of the deviant-stimulus response relative to the standard-stimulus response is caused by the mismatch negativity (MMN), which can be seen by subtracting the standard-stimulus trace from that for the deviant stimulus (bottom). MMN steadily increases in amplitude with the increasing magnitude of frequency change.

Speech sounds are stored as perceptual patterns in auditory cortex.

Language experience can influence auditory processing very very early – certainly within 100 ms!