Neural access to linguistic information: neurophysiological evidence using mismatch negativity

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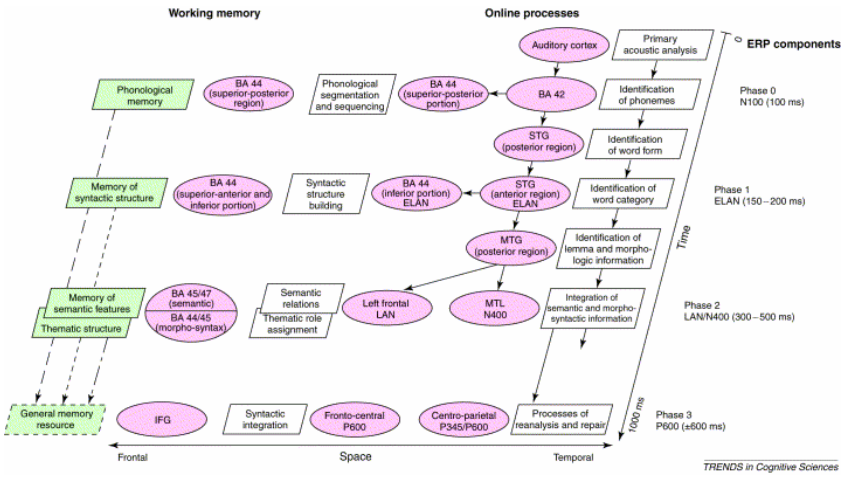
When and where do lexical, semantic and syntactic processes commence in the brain?

Leave the ‘where’ for now. What do we know about ‘when’?



Friederici, 2002

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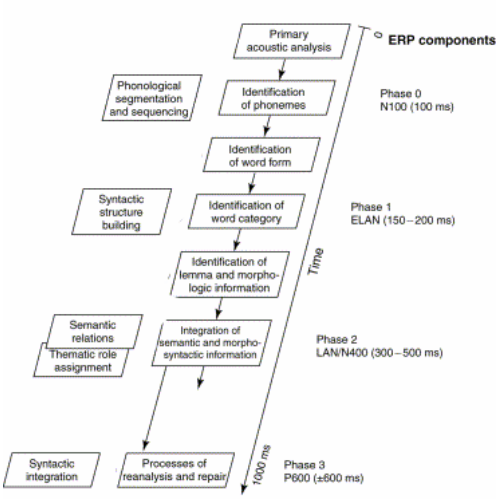

Classical ERP components and language processes			
Information type	**Topography**	**Delay (ms)**	**Component**
syntactic	Left anterior	100-250/500-700	ELAN/P600
semantic	Centro-parietal	300-500	N400
lexical	Centro-parietal	250-500	N350
Phonological		100-400	N100, N200
Acoustic		20-200	P20-N100

Behavioural/psycholinguistic evidence

- subjects can judge meaning and make reliable button-press *motor responses* to spoken words within 400-450 ms
- shadowing technique: subjects can repeat an incoming sentence almost immediately, at a latency of as little as 300 ms or less

=>the output must be initiated after the subjects have heard no more than 150 to 200 ms

Marslen-Wilson et al, 1975, 1985, 1987

Behavioural/psycholinguistic evidence

- Priming: specific semantic knowledge about an upcoming spoken word within 200 milliseconds after the acoustic signal allows for unique word identification

  Zwitserlood et al, 1989;Moss et al, 1997, Tyler et al, 2002

- Eye-tracking experiments: a range of psycholinguistic properties of words assessed within 200ms

  Sereno & Rayner, 2003

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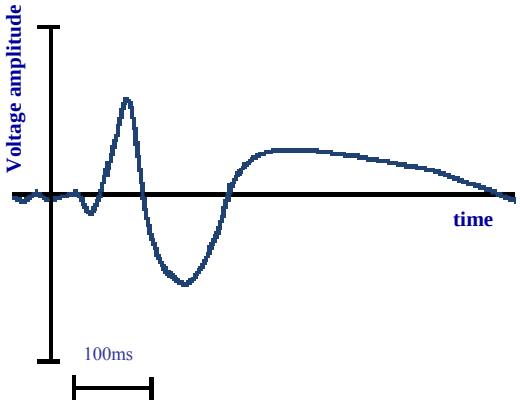
- Behavioural/psycholinguistic evidence speak in favour of early (within 200 ms) access to all (inlc. 'higher-order') information
- (Most) neurophysiological data advocate the sequential processing with semantic access at 350~400ms

- Are we getting the full picture?

Auditory responses



- "Obligatory" responses (P1, N1, P2)
- Other

Mismatch negativity (MMN) in brief

- cortical response to a rare (deviant) stimulus occasionally presented in a sequence of frequent (standard) stimuli

  -[st]----[st]----[st]----[st]----[***dev***]----[st]----[st]-
- Indicator of acoustic *change detection*
- *Automatic/pre-attentive* brain response

  (can be elicited without having subjects actively direct their attention toward stimuli)
- Registered electrically (EEG) and magnetically (MEG)

Näätänen et al., *Trends Neurosci.* 2001

Why MMN?

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Why MMN

- MMN is early
- MMN is ‘automatic’
- A response to individual item by definition
- A response to a change

MMN to speech

-enhanced to native language phonemes and syllables (e.g. Naatanen et al, Cheour et al, Alho et al, ...)

-sensitive to phonetic boundaries and
-sensitive to phonotactics (Dehaene-Lambertz et al)
-reflects audio-visual integration of speech (Colin et al)
-enhances with language learning / acquisition / rehabilitation (e.g. Cheour et al, Kujala et al, Winkler et al.)

=> reflects long-term memory traces for phonemes / syllables

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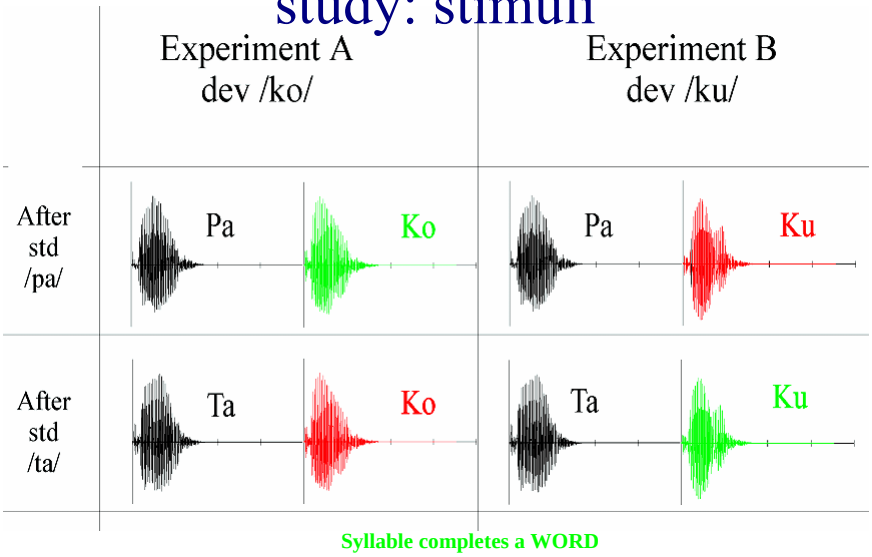
MEG words vs. pseudo-words study: stimuli



Syllable completes a WORD

Syllable completes a NON-WORD

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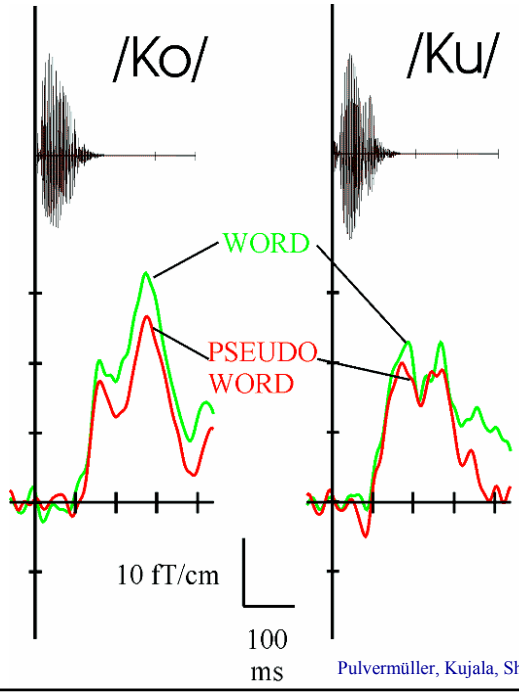
MEG results



Pulvermüller, Kujala, Shtyrov et al. *NeuroImage* 2001

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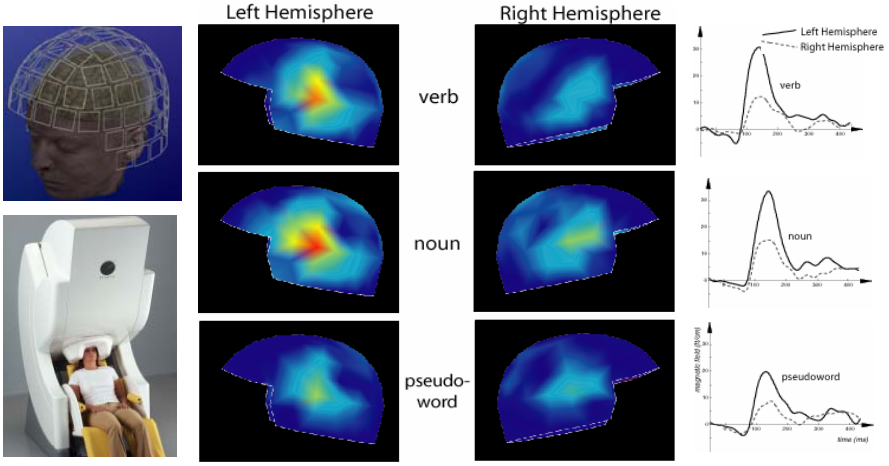
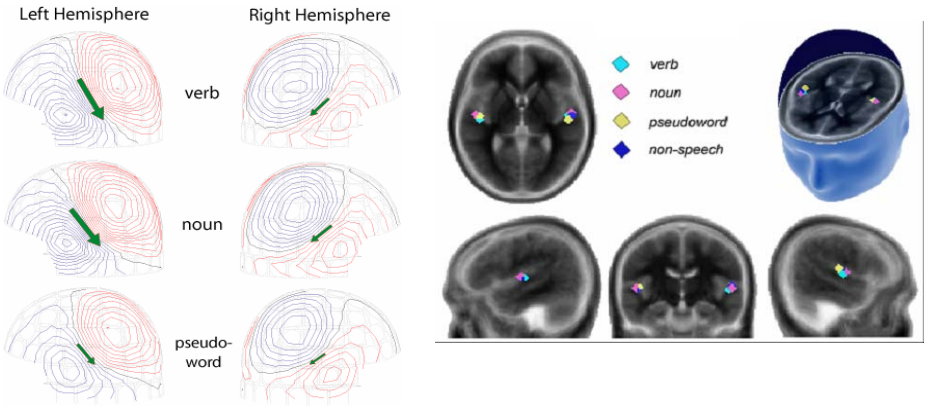
MEG to words and pseudowods



Shtyrov et al, *NeuroImage, 2005*



Left hemisphere, STG, ~150 ms

Shtyrov et al, *NeuroImage, 2005*

Word/pseudo-word MMN

- is enhanced in word contexts compared to pseudo-word context
- This is independent of the physical properties of the stimuli

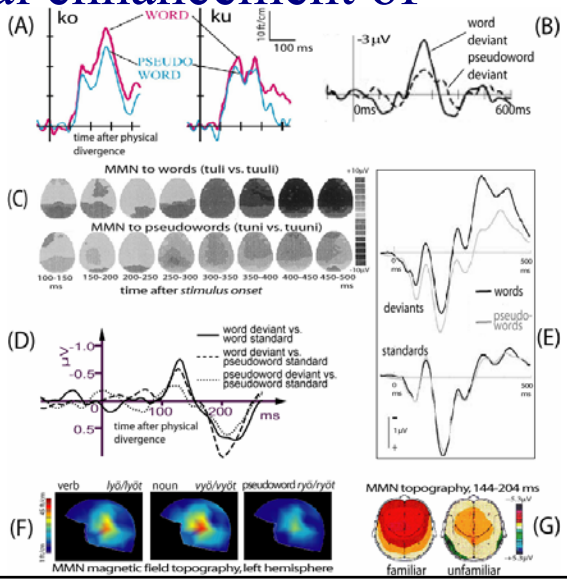
=> this enhanced response is best explained by activation of long term memory traces for words

=> present in ST cortex at <200 ms

=>An index of lexical access at this early latency

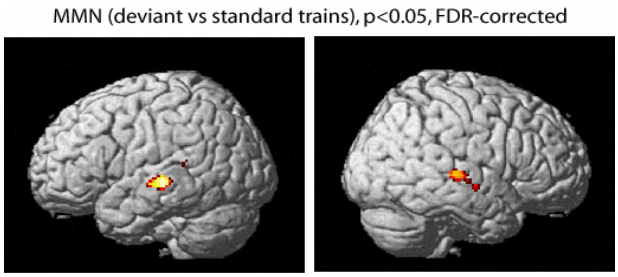
- Korpilahti et al, 2001 - young children, Finnish, EEG
- Pulvermuller et al, 2001 - adults, Finnish, EEG and MEG (2 studies - 2 sets of stimuli)
- Kujala A et al, 2002 - adults, Finnish, MEG
- Shtyrov et al, 2002 - adults, English
- Pettigrew et al, 2004 - adults, English
- Sittiprapaporn et al, 2003 - tonal contrasts in Thai word vs pseudowords
- Pulvermuller et al, 2004 - adults, Finnish, EEG
- Endrass et al, 2004, - adults, German
- Stimulus properties are essential!

'Representational negativity' (RN) - lexical enhancement of MMN



(A) Pulvermuller et al (2001). NeuroImage
(B) Pettigrew et al. (2004). Ear Hear
(C) Korpilahti et al. (2001).Brain and Lang
(D) Shtyrov, Y.et al. (2002). NeuroReport
(E) Endrass et al (2004). Eur J Neurosci
(F) Shtyrov et al. (2005) NeuroImage
(G) Sittiprapaporn et al (2004). Songk. J. Sci. Technol.

Lexical enhancement of MMN: fMRI



Word deviant vs pseudoword standards

Shtyrov et al. Cerebral Cortex, 2008

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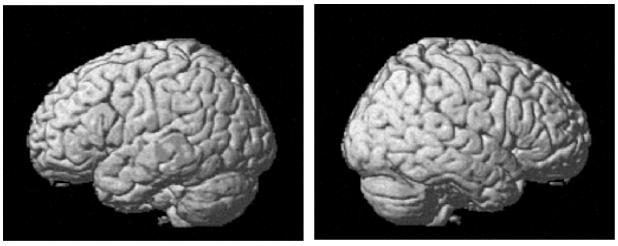
Lexical enhancement of MMN: fMRI



Pseudoword deviant vs word standards

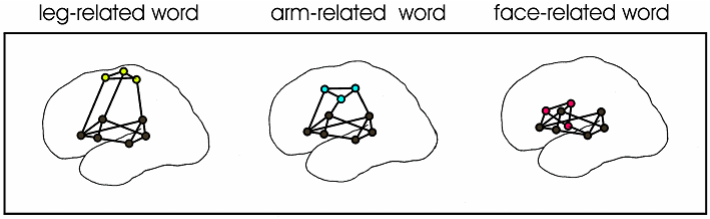
Shtyrov et al, Cerebral Cortex, 2008

- Early access to mental lexicon seems to be also a *neurophysiological* reality
- What about word storage of meaning per se, ie semantics

Action verbs in the brain

Examples: *lick, pick, kick*

- describe actions performed with the mouth, arm, or leg
- learnt in infancy in conjunction with actions
- have memory traces including neurones in sensorimotor cortex (somatotopy of action words)?

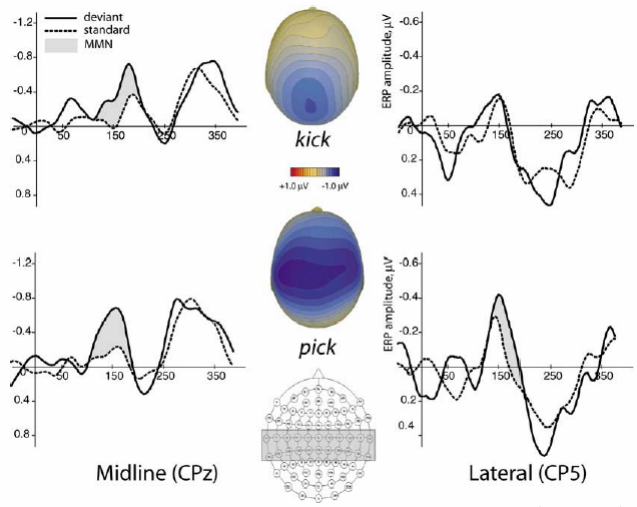


English action words (EEG)

- [pɪk] and [kɪk] presented as deviant auditory stimuli against pseudo-word standards
- differences between responses to the same stimuli as frequent deviants & repeated standards analysed
- cortical sources calculated using Minimum Norm Estimates (L2 norm)

Shtyrov et al, *Eur J Neurosci*, 2004

English action words, ERP



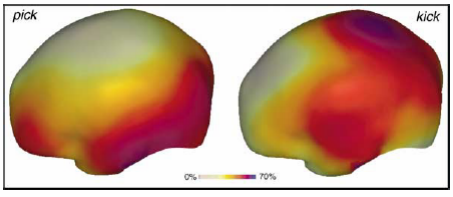
Shtyrov et al, *Eur J Neurosci*, 2004

English action words, ERP

- Atypical auditory activations: posterior to traditionally seen frontal negativity => sensory-motor involvement?
- Topography distinct for 2 action words mirroring somatotopy of body representation
- These differences peaking at 140-170 ms

Shtyrov et al, *Eur J Neurosci*, 2004

Minimum-Norm Current Estimates of MMN cortical sources (L2)



Shtyrov et al, *Eur J Neurosci*, 2004

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MMN to Finnish action words (MEG)

- [hotkɪ] (eat quickly) and [potkɪ] (kick) presented as deviant stimuli against pseudo-word standards
- cortical sources calculated using Minimum-Norm Current Estimates (L1 norm)

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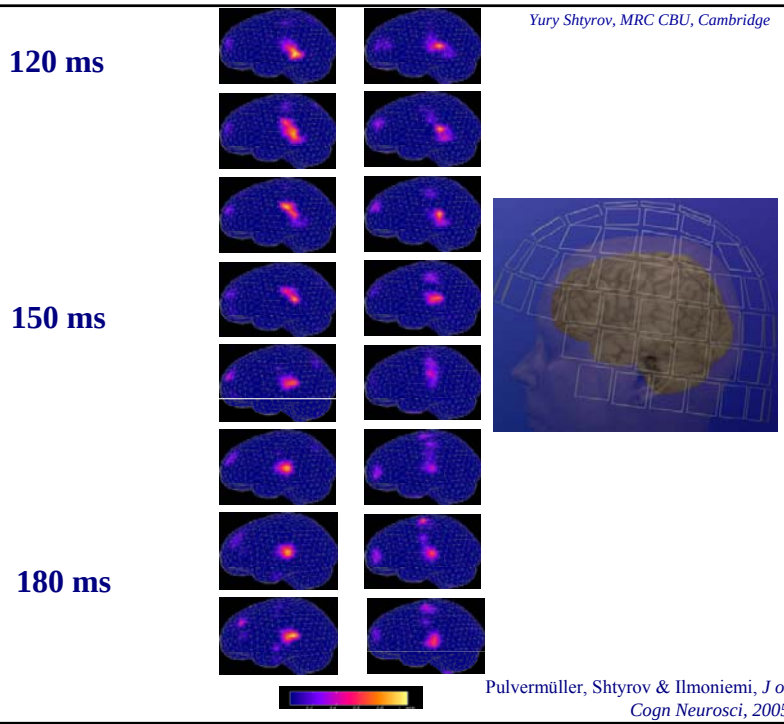

Pulvermüller, Shtyrov & Ilmoniemi, *J of Cogn Neurosci, 2005*

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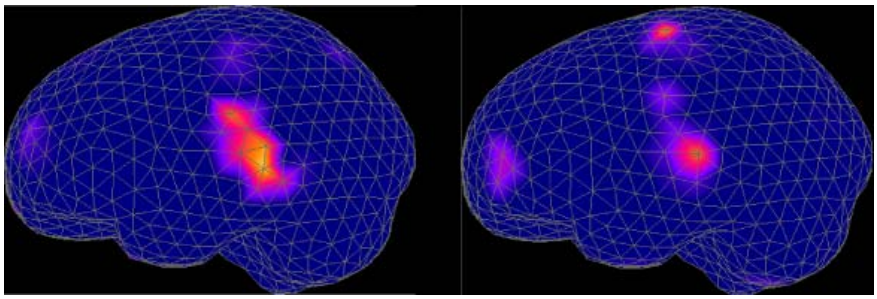
MNCE of cortical sources of MMNm *hotki* (eat) vs. *potki* (kick)



- 106 ms
- 137 ms, hotki (to eat)
- 158 ms, potki (to kick)

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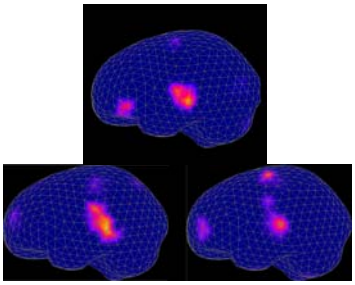
Aspect of words' referential semantics reflected in spatio-temporal pattern of MMN response at 120-180 ms

Visually presented action words exhibit similar dynamics at ~200 ms (Hauk et al, HBM, 2004)

Exact locations validated by fMRI (Hauk et al, Neuron, 2004) and shown to follow somatotopy of motor and premotor areas



- Lexical/semantic information related to individual words may be stored in the brain in the form of distributed memory traces/neuronal networks/neurone ensembles/Hebbian cell assemblies
- These encompass different areas, also outside the core language ones, and are formed as a result of associative learning, which strengthens the mutual connections
- This information is available/networks become active as early >100 ms
- What about a higher level of semantic processing, ie context integration?

Congruent/incongruent contexts in MMN design

- Minimal short word combinations/phrases (Finnish)
- The same words in either congruent or incongruent contexts and out of context
- Strict control over stimulus properties
- 306-channel MEG

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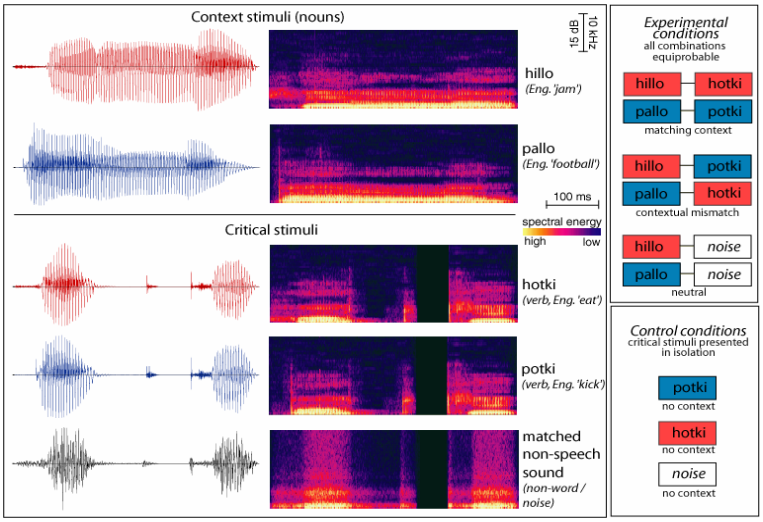
Congruent/incongruent contexts in MEG



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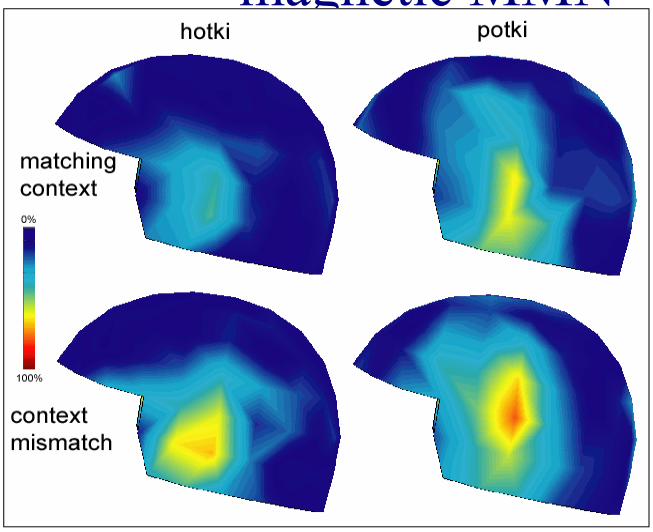
Congruent/incongruent contexts: magnetic MMN



Increased response in the LH for the same words in incongruent context as opposed to OK context early in the course of acoustic stimulation

Shtyrov et al. Journal of Cogn Neurosci, 2007

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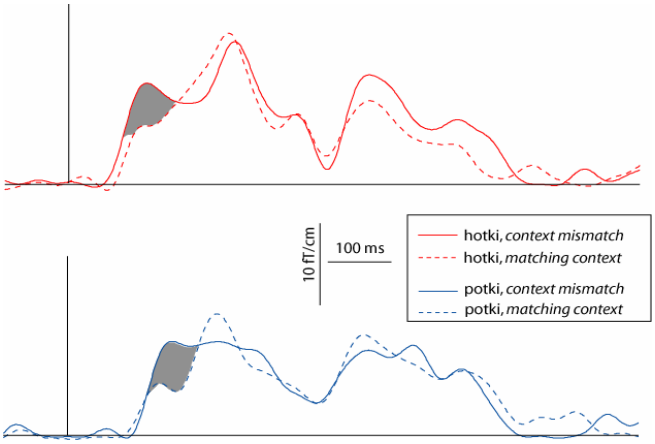
MMNm to congruent/incongruent contexts



Increased response in the LH for the same words in incongruent context as opposed to OK context

Maximal over left temporal and inferior frontal areas

Reaching maximum statistical significance over at 100-140 ms

Shtyrov et al. Journal of Cogn Neurosci, 2007

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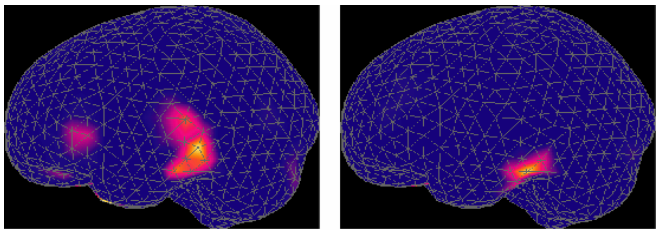
Congruent/incongruent contexts in MEG



incongruent **congruent**

Increased response in the LH for the same words in incongruent context as opposed to OK context

Maximal over left temporal and inferior frontal areas

Reaching maximum statistical significance over IF areas at 100-140

Shtyrov et al. Journal of Cogn Neurosci, 2007

- Hauk et al, 2004: distinct spatio-temporal patterns of activations at ~200ms for words of different semantic categories
- Penolazzi et al, 2007: congruency/cloze probability effects ~120-180 ms
- Moscoso del Prado Martin et al, 2005: ERP differentiating between words related to different visual properties (colour, form) as early as 160ms.
- Hinojosa et al, 2004: ERPs peaking near 200 ms when the subjects were asked to perform visual semantic detection task, and marginal effects of context on word recognition
- Sereno, 2003: marginal effects of context on word recognition at 130-190 ms
- Ortigue et al, 2004: visually presented words of emotional valence could already elicit responses distinct from control stimuli at 100-140 ms
- Skrandies et al, 1998, 2003: words of different semantic classes (with varying affective parameters) produce diverging patterns of electrophysiological activity as early as 80-130 ms

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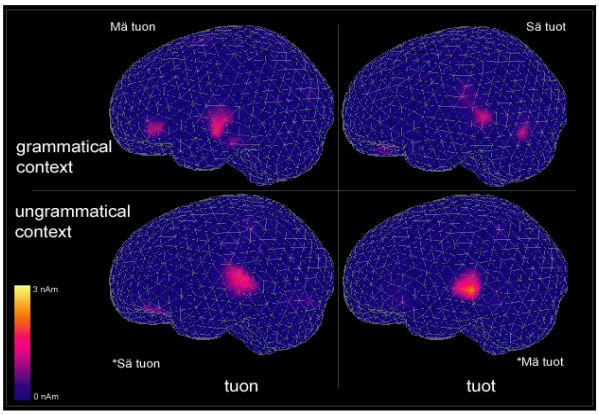
- The earliest brain processes of semantic context integration may occur as early as at ~120 ms after the onset of spoken words in the left interior frontal and superior temporal cortex
- It is approximately the same time as the lexical, and phonological effects seen in the MMN
- Syntax?...

Syntax, MEG

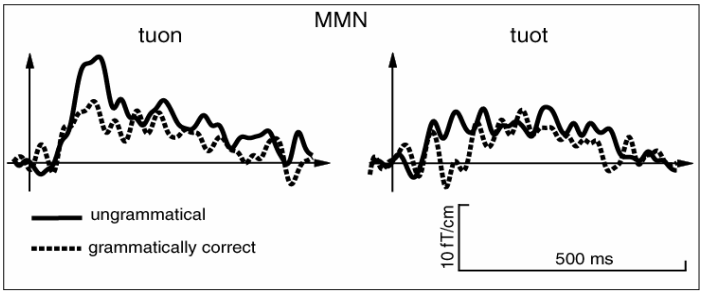
- activation of distributed cortical sources spread out ***over the left temporal cortex***. This activation was significantly ***stronger for the syntactically incorrect than for correct phrases*** ($p<0.011$).
- no effects of context or suffix
- no differences between conditions in the right hemisphere.



Shtyrov *et al*, *J Cogn Neurosci*, 2003

MEG syntax

- ~200 ms
- No late shifts which could be related to P3 or P600 components



Shtyrov *et al*, *J Cogn Neurosci*, 2003

MMN to syntactic errors:

Shtyrov & Pulvermuller, 2003, MEG

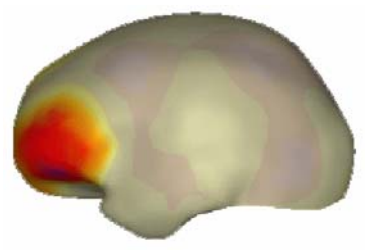
Pulvermuller & Shtyrov, 2003, 2008, EEG

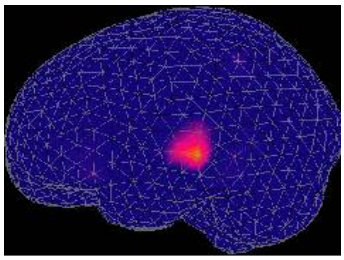
Menning et al, 2005, MEG

Hasting et al, 2007, 2008, EEG

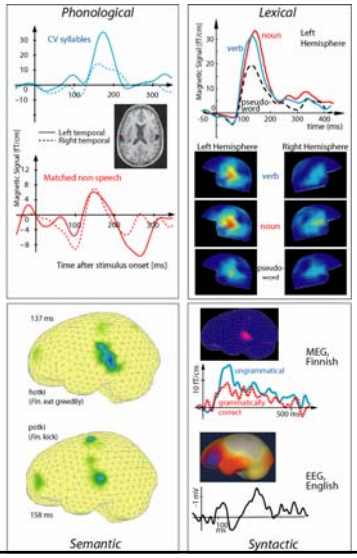
Pulvermuller & Assadolahi, MEG

English, Finnish, German, French





Language in the brain: a totally new picture



Time course of linguistic information access

according to MMN studies

Information type	Cortical sources	Latency (ms)
Syntactic	Left inferior frontal and superior temporal	*100-250 130-280
Semantic	Left inferior to superior fronto-central	*120-180 170-210
Lexical	Left inferior frontal and superior temporal	*130-150 160-190
Phonological	Left superior temporal	100-200
Acoustic	Superior temporal and right frontal	90-170

Early language automaticity?

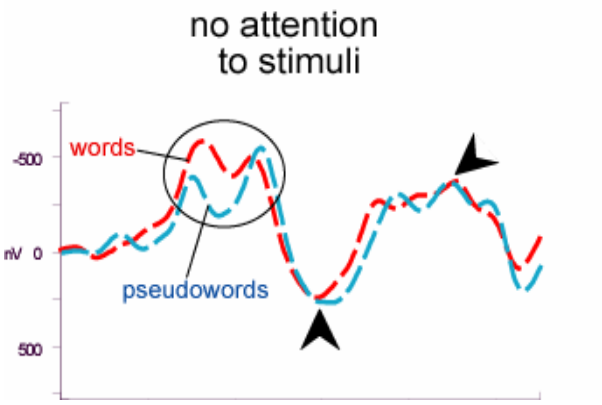
- Linguistic MMNs elicited outside the focus of attention -> taken as a sign of early automaticity
- Traditional MMN distraction is passive -> is is really attention-free?
- More rigid distraction paradigm needed to validate the automaticity claims

Early language automaticity?

An EEG study:

- Subjects ignore the stimuli or do a stimulus-related task
- MMNs elicited by a group of words & pseudowords matched phonologically

Language and Attention



Lexical MMN enhancement
~120ms

(Shtyrov *et al.*, *submitted*)

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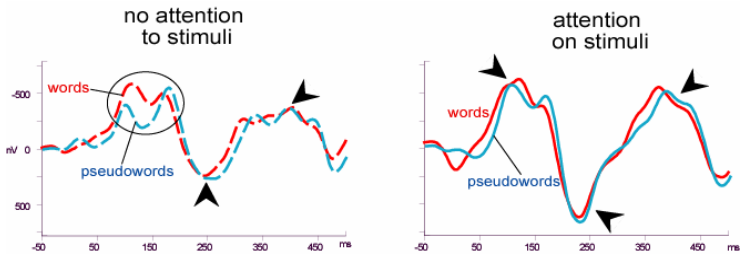
Language and Attention

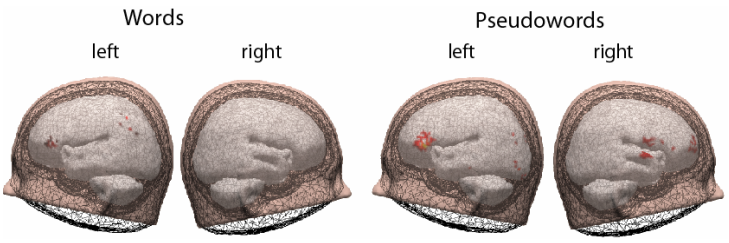
(Shtyrov *et al.*, *submitted*)

Language and Attention



(Shtyrov *et al.*, *submitted*)

Language and Attention



(Shtyrov *et al.*, *submitted*)

Language and Attention

•Early word-elicited MMNs not affected by attention

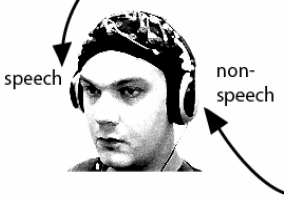
->lexical access up to 140 ms may indeed be automatic

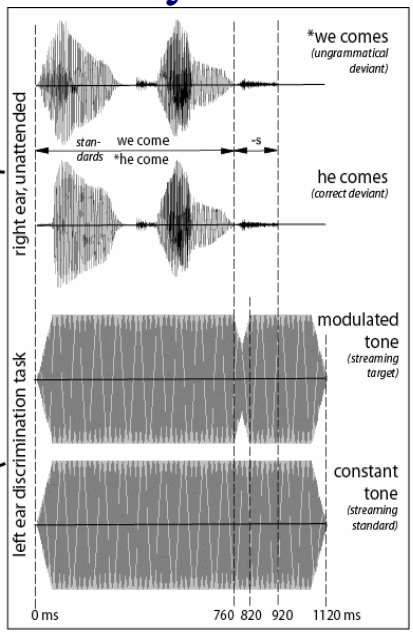
•Attention effects accumulate at later times and are predominantly modulated by left perisylvian areas

(Shtyrov *et al*., *submitted*)

Syntax automaticity

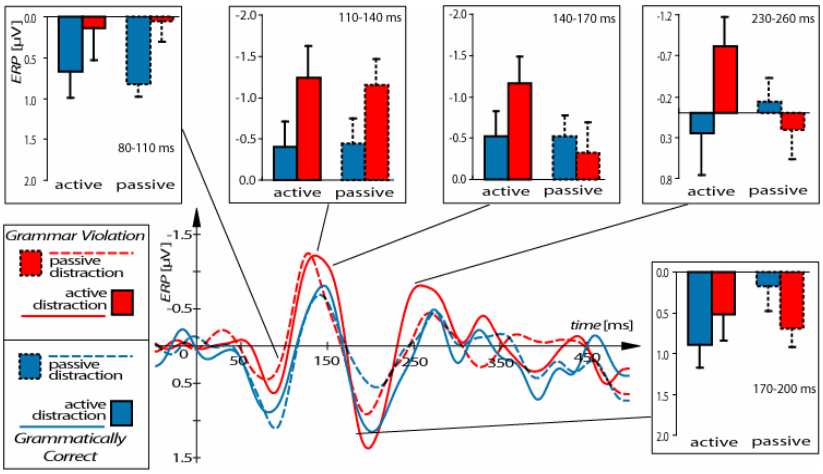
• Strong distraction: streaming task in contralateral ear





Pulvermuller et al, Brain & Lang 2008

Syntax automaticity



- Encapsulated early syntax? (here before 140ms)
- Attention kicks in later *Pulvermuller et al, Brain & Lang 2008*

Conclusions

- Lexical, semantic, and syntactic processes can be traced to commence in the brain well before 200 ms
- These early processes seem to take place near-simultaneiously, possibly in parallel
- They can take place out side the focus of attention, and may be, at their earlier stages, automatic

With many thanks to...

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Gabriele Holz
Anna Hasting
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et al.…