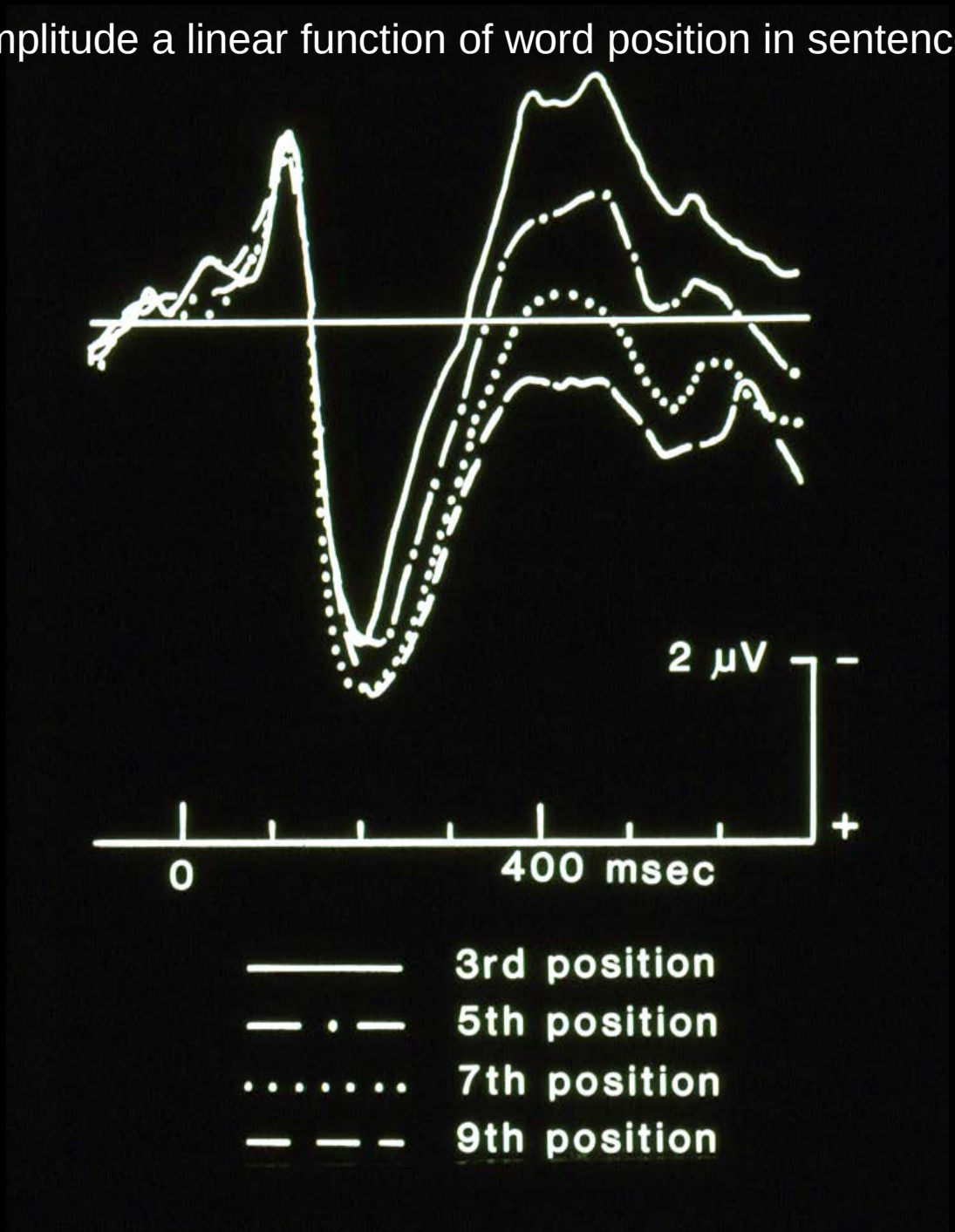
Since N400 is not a specific response to errors or violations, it might be a good way to examine language (and perhaps semantic processing) more generally.

N400 amplitude a linear function of word position in sentence



CONGRUENT

The tenants were evicted when they did not pay the last two month’s rent.
Most new drugs are tested on white lab rats.
It was supposed to bring seven years bad luck to break a mirror.

SYNTACTIC

He ran the half white car even thought he couldn’t name the raise.
The necklace pulled the certain cat and borrowed the spoon.
They married their uranium in store and cigarettes.

RANDOM

To prided the bury she room she of peanut the had china.
Into thumb cable male the effot his into group rowboat.
Every opened the gripped they stepping kind steel pine.

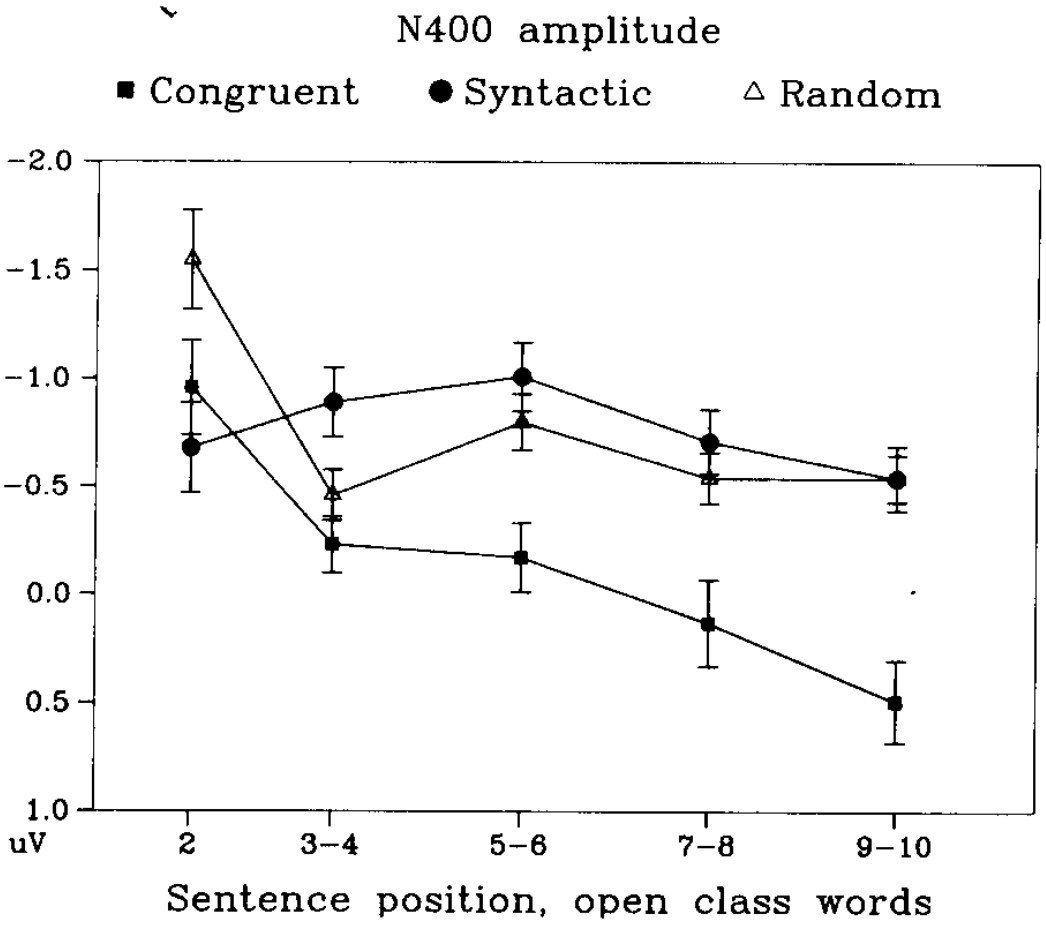


Figure 3. The mean voltage level between 300- and 500-msec post-stimulus (the N400 latency band) is plotted against word position. The ERP measure is collapsed across all of the scalp recording sites. The data here are for intermediate open-class words in the three sentence conditions.

Van Petten & Kutas

CLOSED CLASS WORDS

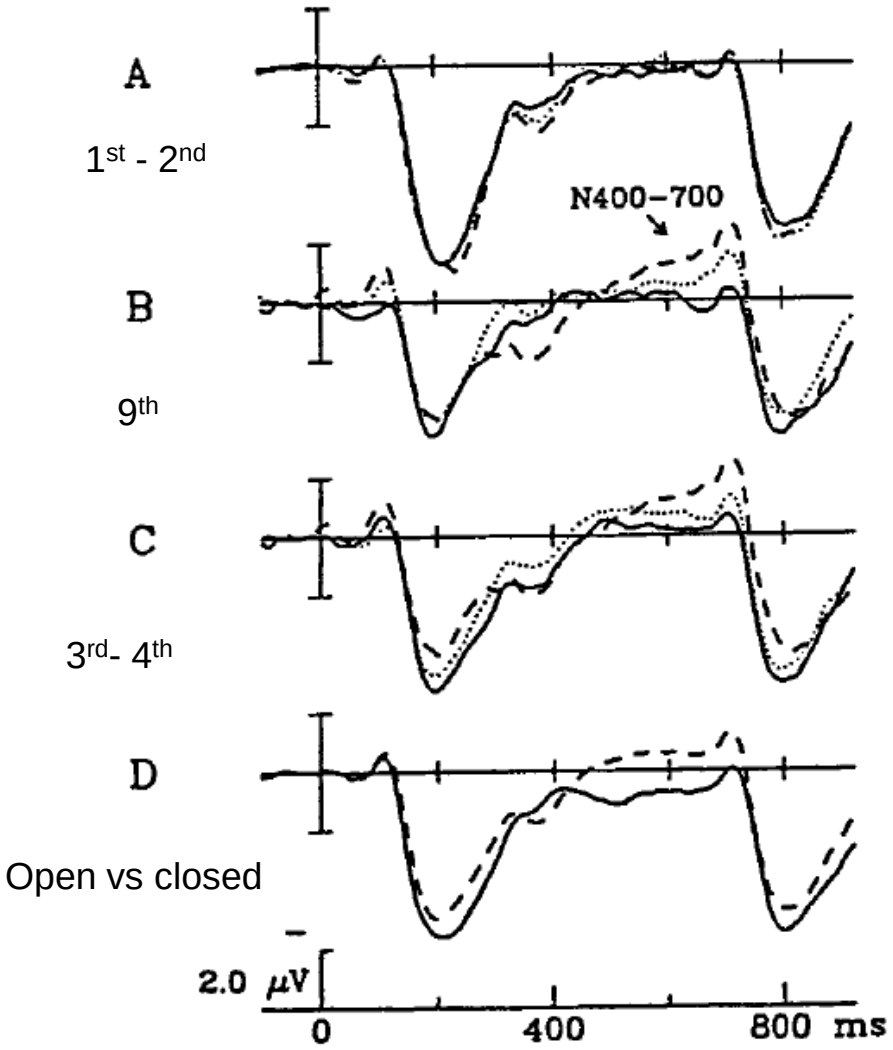
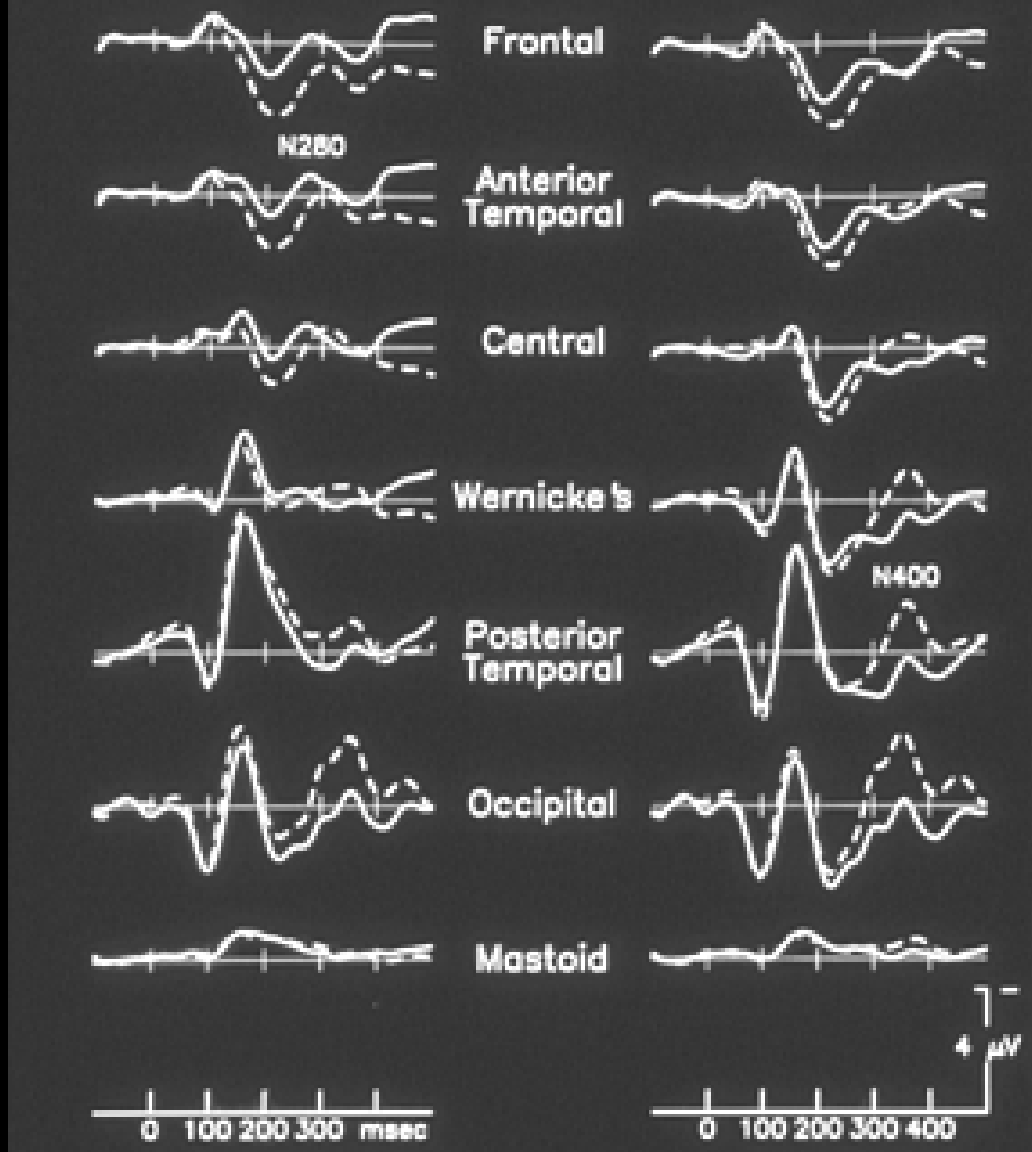


FIG. 10 (A) ERPs to closed-class words in the first and second ordinal positions of congruent sentences (*solid line*), syntactically structured but semantically anomalous sentences (*dotted line*), and random word strings (*dashed line*). (B) ERPs to closed-class words in the ninth and tenth positions of the same three conditions. showing the larger N400-700 in Congruent sentences. The Syntactic sentences appear to fall midway between the Congruent and Random conditions. but they were not statistically different from Random. (C) Closed-class words in the 3rd and 4th (*solid line*), 5th and 6th (*dotted line*), and 9th and 10th (*dashed line*) positions of Congruent sentences, showing the development of the N400-700 across the course of a sentence. (D) ERPs to all intermediate open (*solid line*) and closed (*dashed line*) class words from the congruent sentences. Data from Van Petten and Kutas (1991a).

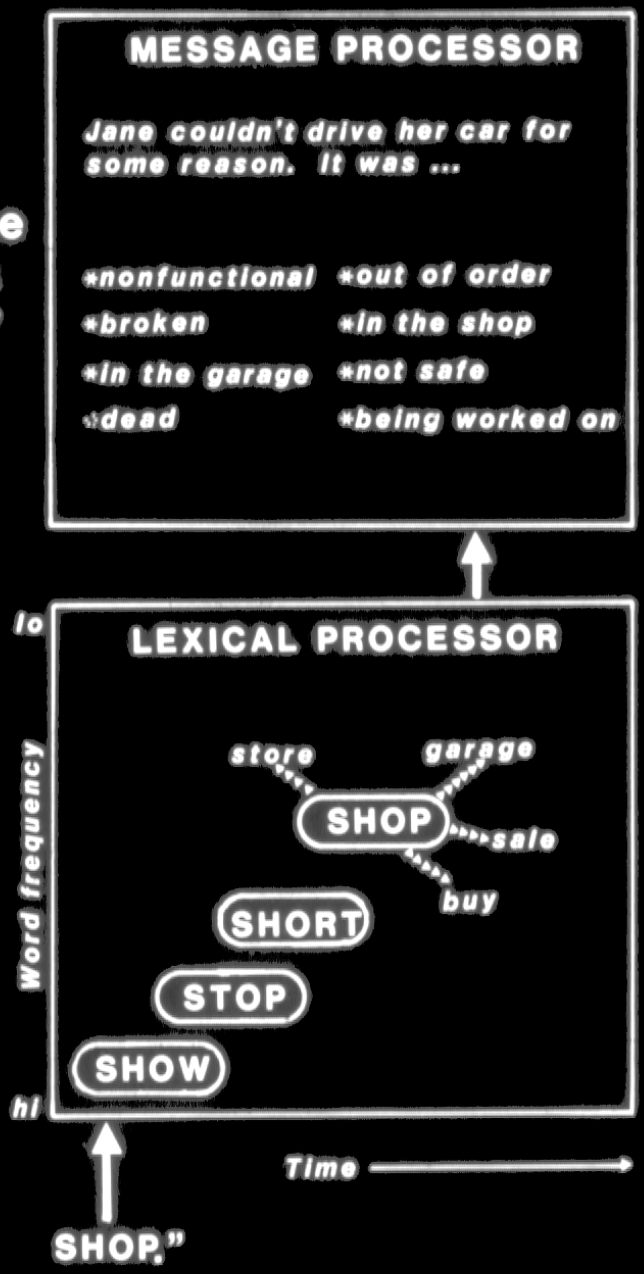
No word position effect on N400 for closed class items


Frontal
N280
Anterior Temporal
Central
Wernicke's
N400
Posterior Temporal
Occipital
Mastoid
4 μV
0 100 200 300 msec
0 100 200 300 400
Closed Class Words
Open Class Words

Constraints imposed by formal sentence structure alone were ineffective in influencing responses to open class words.

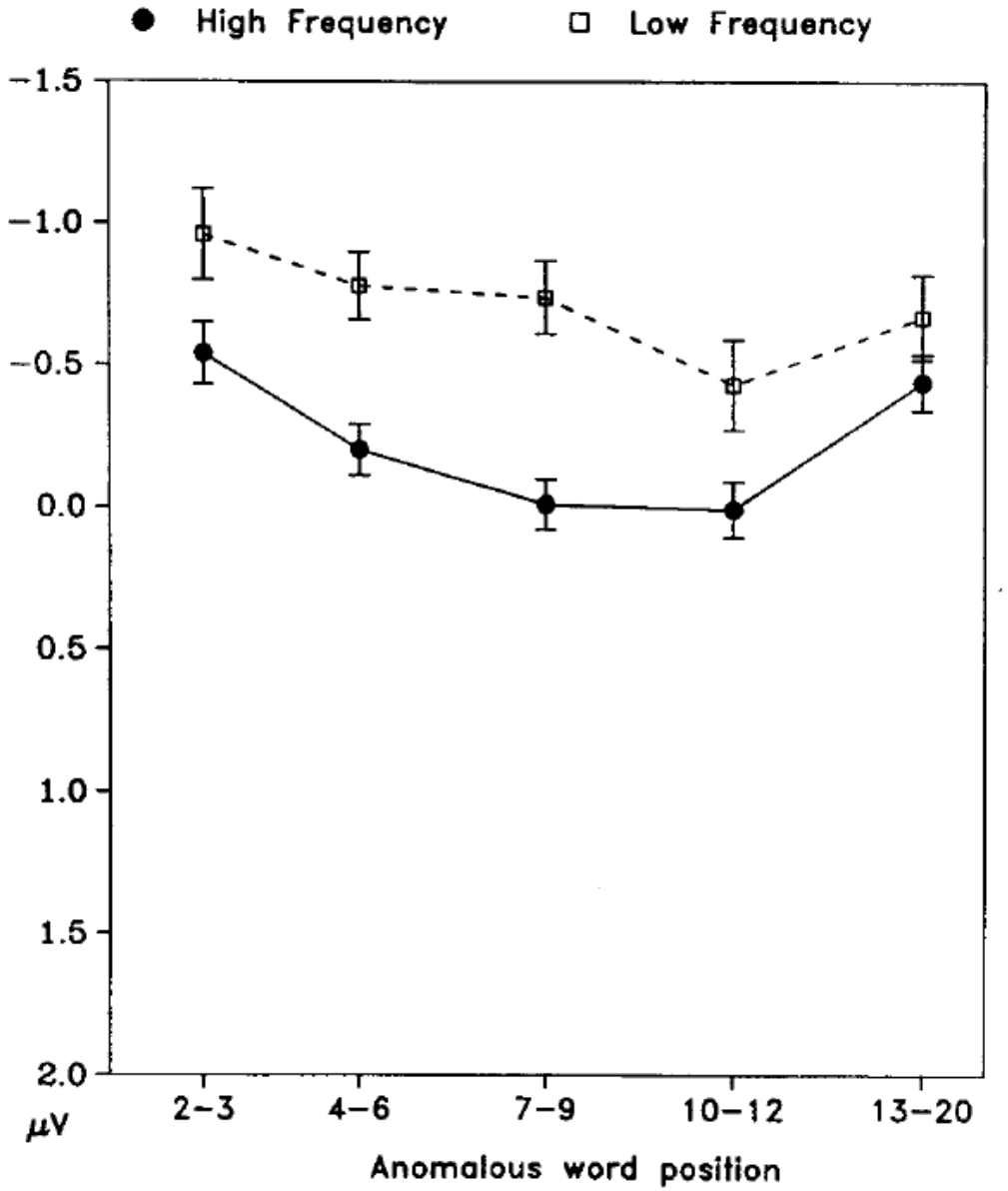
Semantic constraints imposed by these congruent sentences were cumulative. N400 word position effect reflects sentence level *semantic* contextual constraints.

"Jane had to take the bus to work because her car was...



in the SHOP."

No word position effect on N400 in anomalous (random word strings)



anomalous = random condition

Sentence type by frequency interaction on N400 amplitude

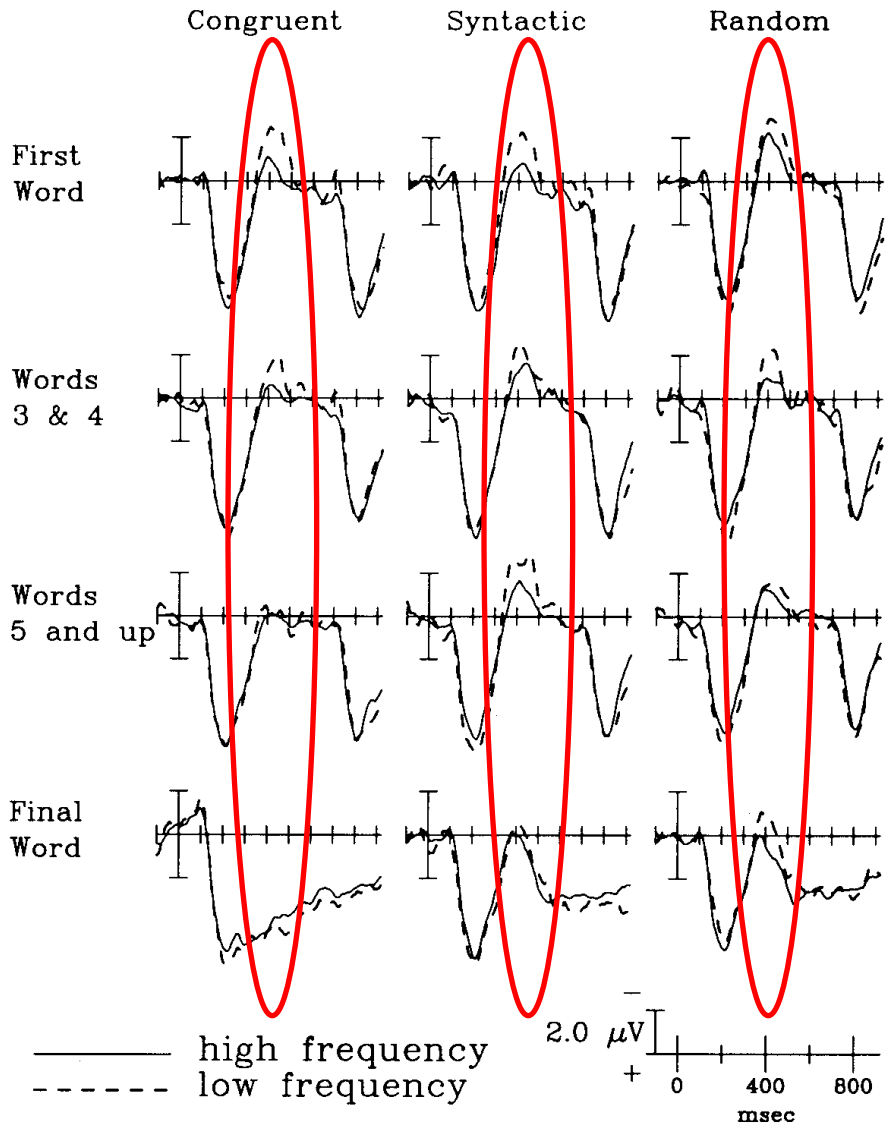
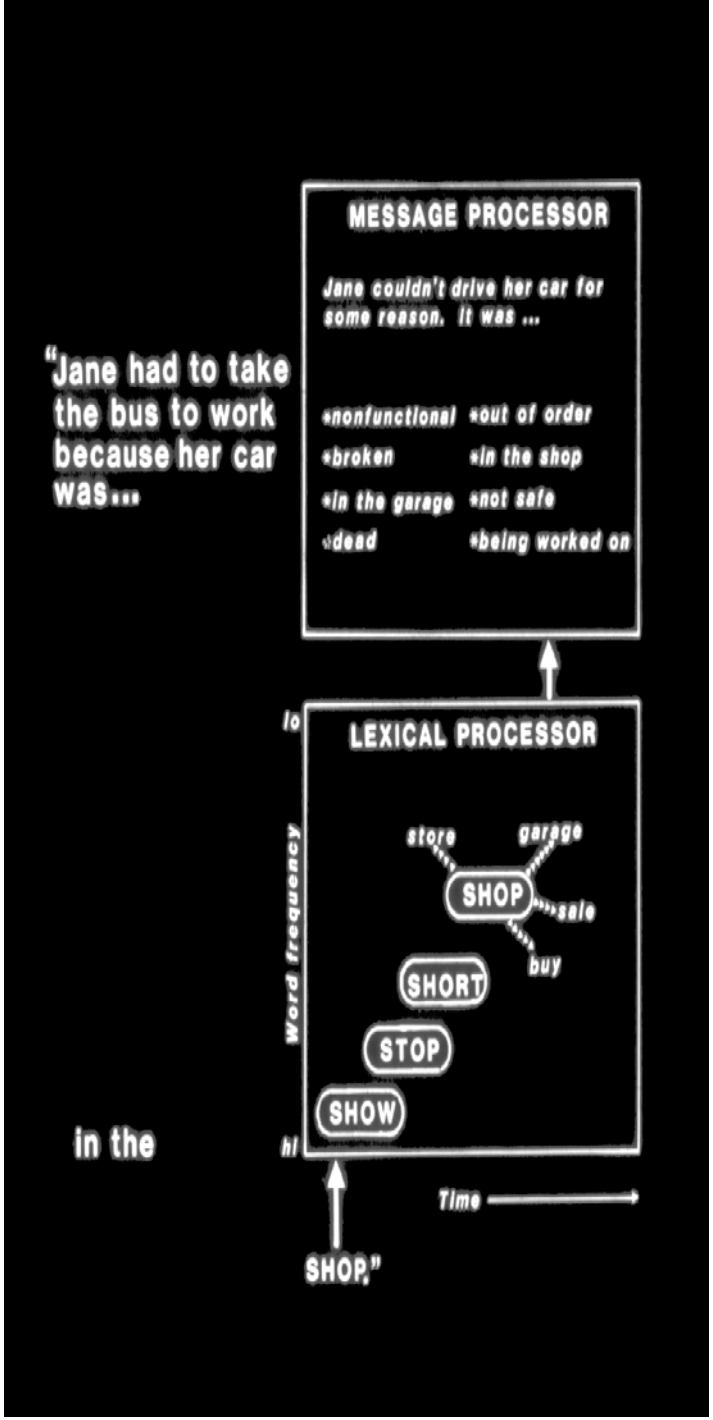
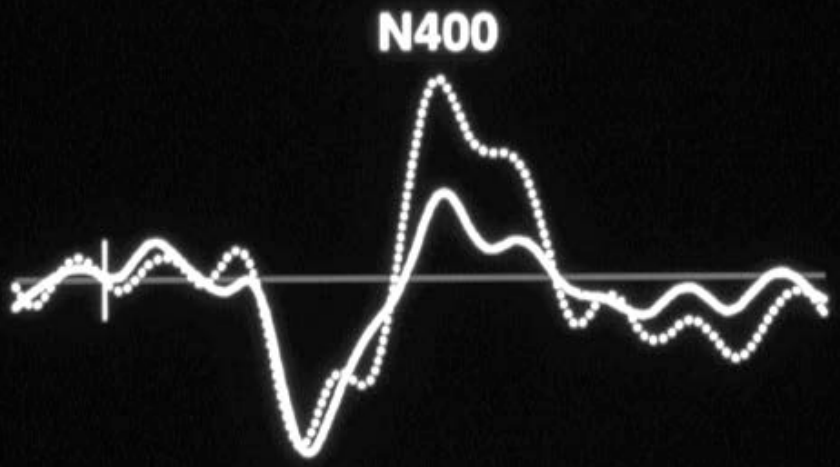


Figure 4. Grand average ERPs elicited at the central midline site (Cz) for high- and low-frequency open-class words broken down by sentence type and word position. *First Word* refers to the first open-class word of a sentence.

Although word frequency is a lexical variable, human language processing system does not always respect the boundary between lexical and sentential processing. The data are inconsistent with hierarchical models of language processing that stipulate a purely bottom-up relationship between words and sentences. *(Van Petten, 1995)*



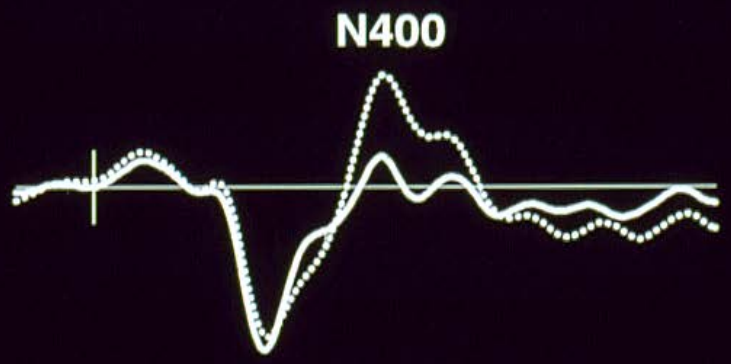
WORD FREQUENCY



Frequent

Less frequent

WORD REPETITION



Repeated

Unrepeated

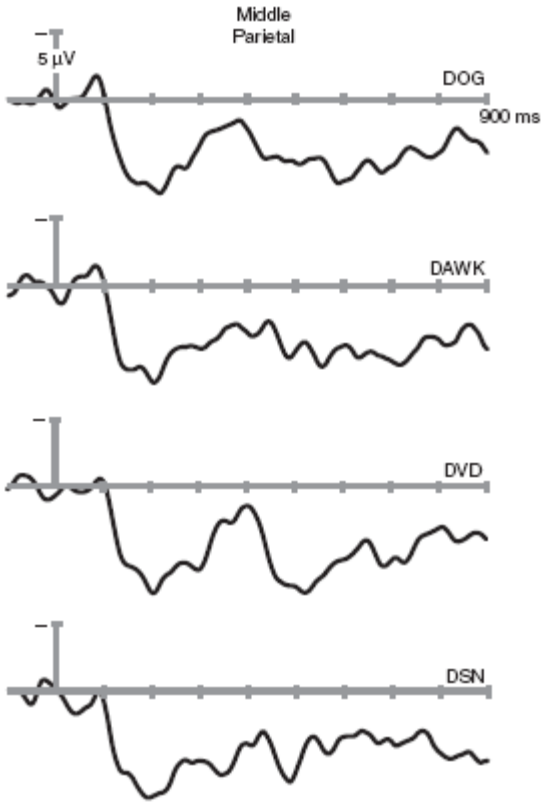


Figure 1. Example single item ERPs: Each ERP is an average of one EEG sweep over the middle parietal channel from each of 120 participants in response to a single item: the word DOG, the pseudoword DAWK, the acronym DVD, and the illegal string DSN. In this figure, as in all subsequent ones, negative is plotted up. These ERPs are unfiltered, which makes it evident that the signal-to-noise characteristics of the single item ERPs are satisfactory.

Laszlo & Federmeier, 2011

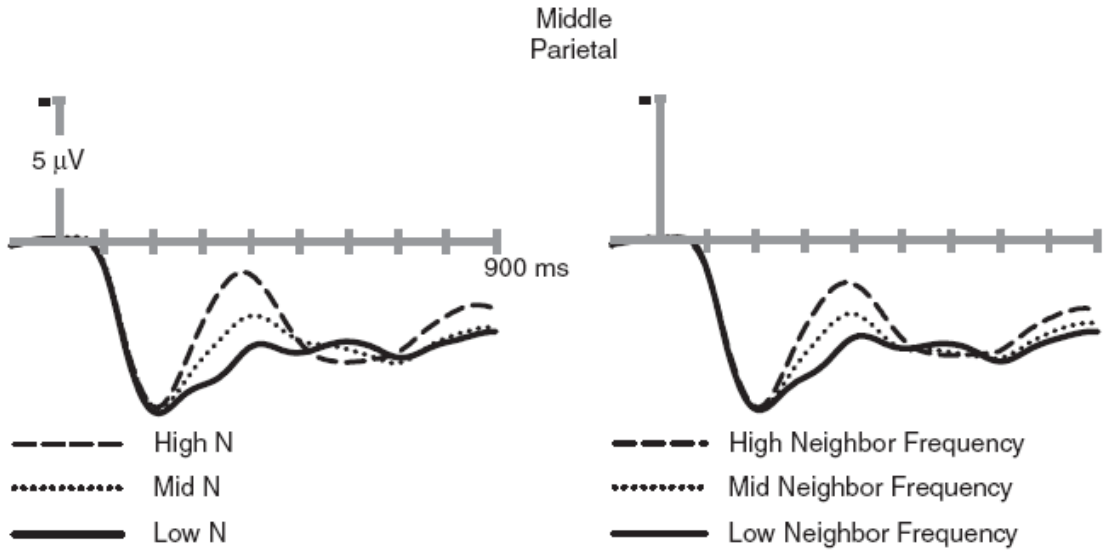


Figure 5. Effects of N and neighbor frequency: Left, grand average ERPs elicited in response to items with high, mid, or low orthographic neighborhood size (N). Right, grand average ERPs elicited in response to items with high, mid, or low neighbor frequency. All ERPs are from the middle parietal channel, and are averaged over both lexical and nonlexical items. In part because the two variables are highly inter-correlated, the effects are quite similar.

Laszlo & Federmeier, 2011

N400 amplitude is very sensitive to a word orthographic neighborhood density as well as neighbor frequency

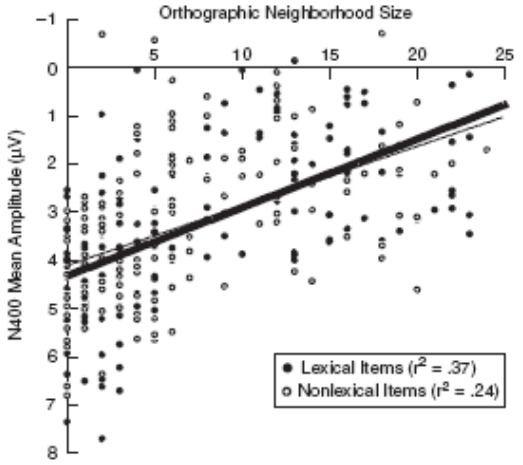


Figure 2. Equivalency of N effect across lexical types: Item N400 mean amplitude (250–450 ms) over the middle parietal channel is plotted against orthographic neighborhood for lexical items (filled circles) and nonlexical items (empty circles). Single regression trend lines for the relationship between N4 mean amplitude and N are also plotted for each item type. The function relating N400 amplitude to N is nearly identical for the two item types.

N400 is larger with larger orthographic neighborhood (30% variance)

N400 is larger with frequent (less frequent) orthographic neighbors

N400 is larger with greater number of lexical associates

N400 is larger with more frequent lexical associates

Semantic access does not serially follow a recognition process in which input has been mapped onto a single, stored representation.

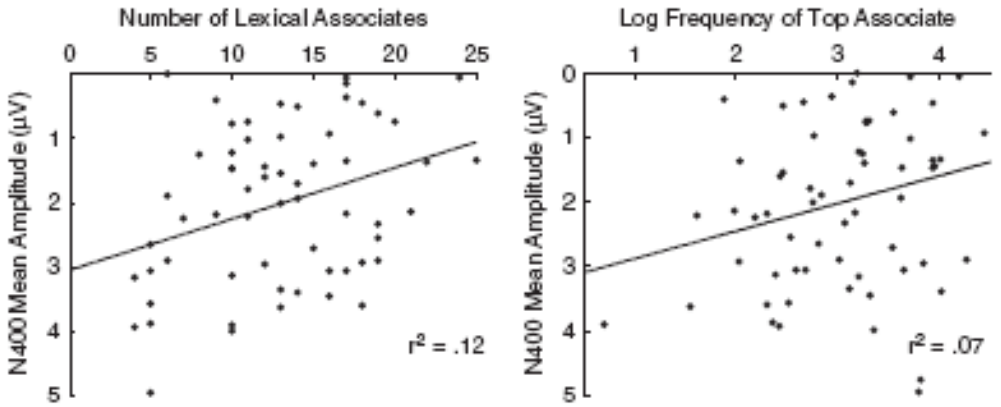


Figure 6. Effects of number and frequency of lexical associates: Left, a scatter plot showing the relationship of N400 mean amplitude (250–450 ms) and number of lexical associates at the single item level. Right, an identical scatter plot showing the relationship of N400 mean amplitude and log frequency of top lexical associate. Items with more lexical associates and items with more frequent lexical associates both elicit more negative N400s.

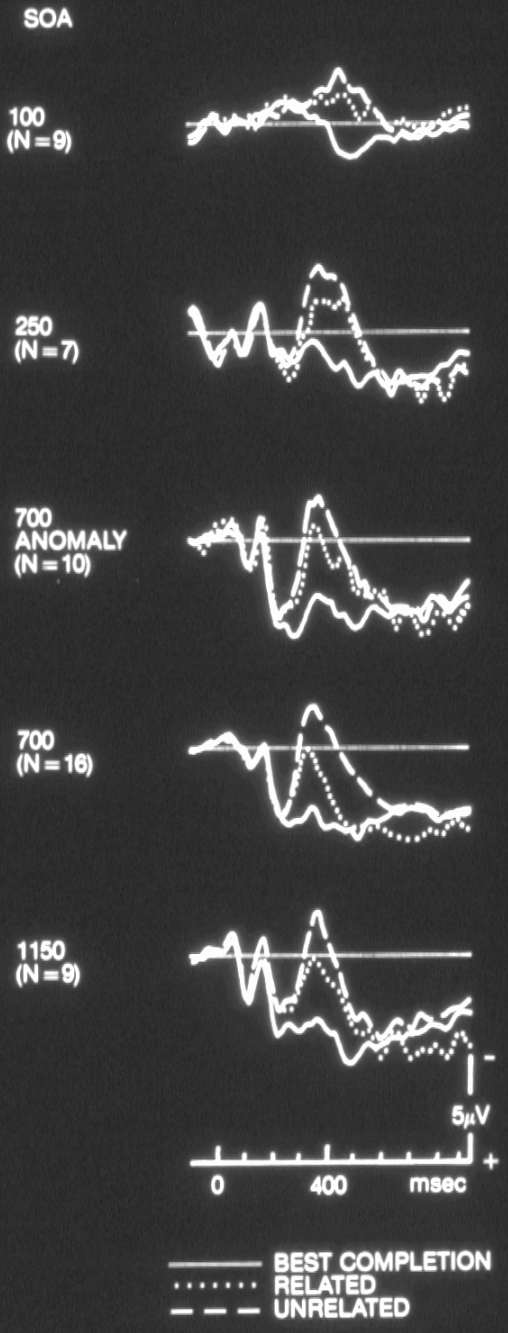
Laszlo & Federmeier 2011

N400 time window: when semantic information associated with a distributed set of co-activated representations comes online in parallel.

N400 represents activity taking place in the semantic level of representation before either orthographic or semantic layers in PDP models have settled.

N400 provides a temporally delimited “snapshot” of activity elicited by a given input in a distributed, cascaded, semantic system.

Laszlo & Federmeier, 2011


SOA
100
(N = 9)
250
(N = 7)
700
ANOMALY
(N = 10)
700
(N = 16)
1150
(N = 9)
-
5μV
+
0
400
msec
BEST COMPLETION
RELATED
UNRELATED

N400 paradigms

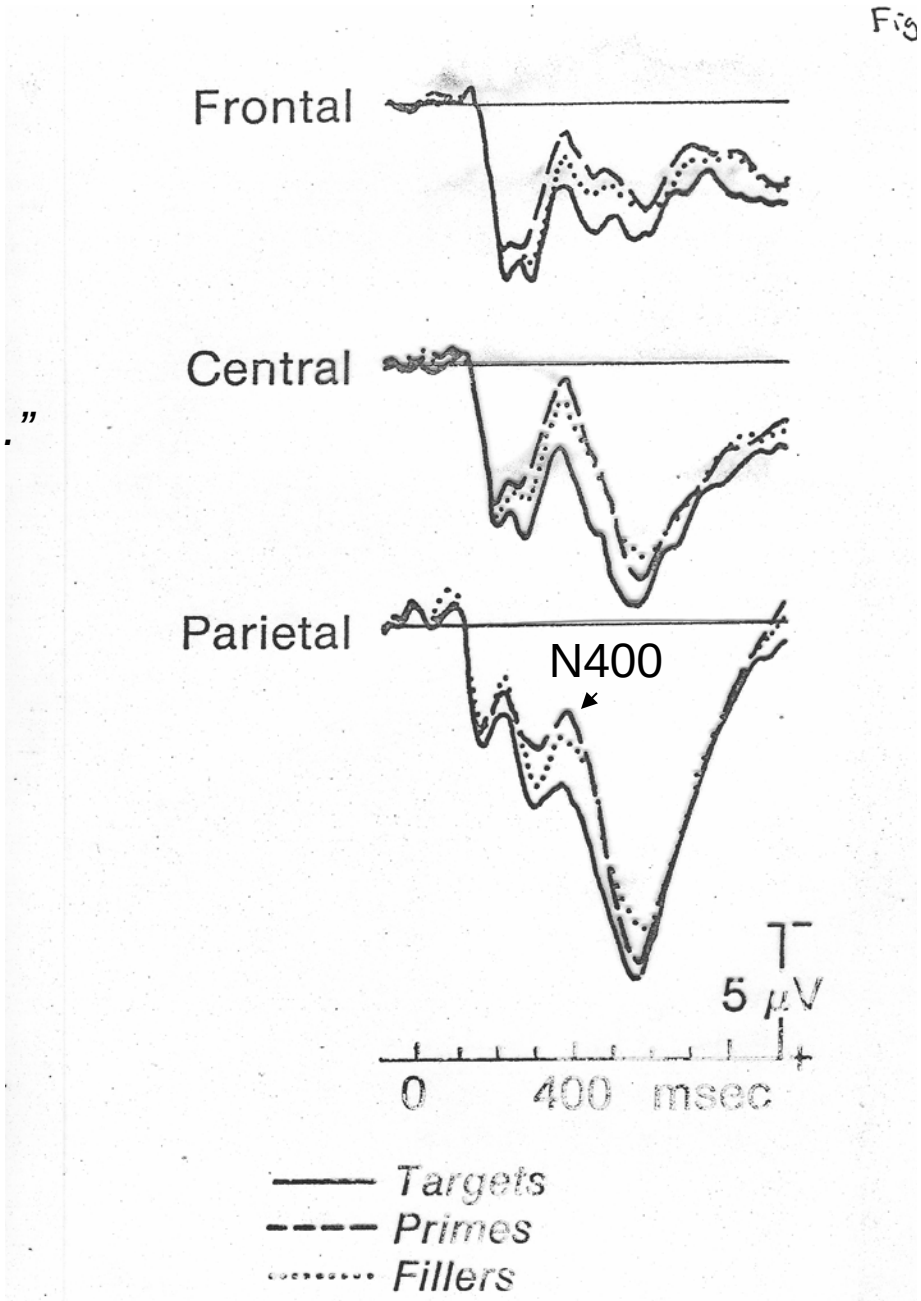
Sentence level expectancy manipulations

Sentence final – semantic anomalies, cloze probability
Sentence medial

Priming pardigm: word pair and word list
reading, listening, LDT, monitoring, masking

Lexical Decision Task

“dorf ..apple …table …chair…”

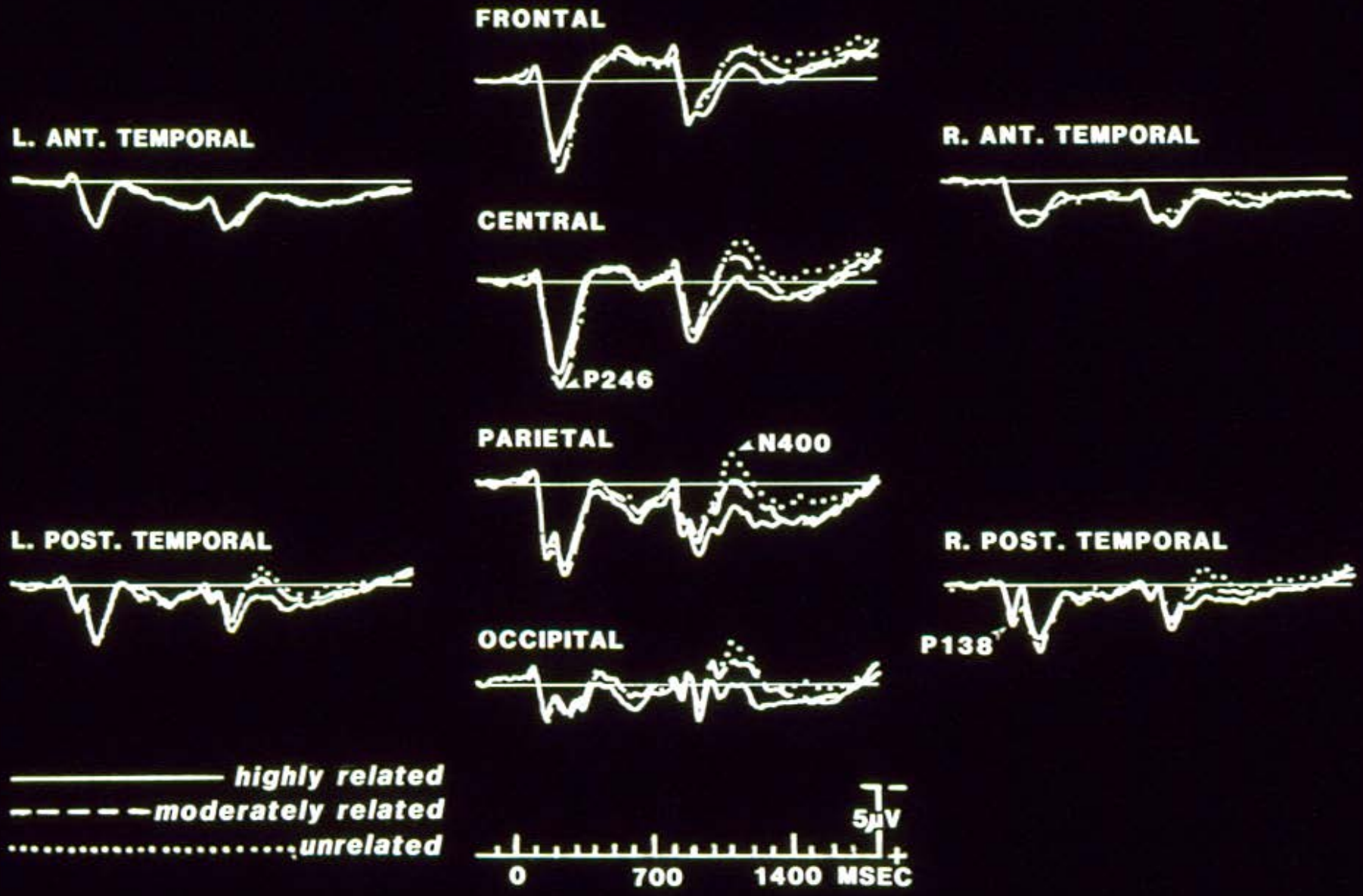


Bentin et al. 1985

LETTER SEARCH TASK

Strongly Related	Table	--	chair	b?
Weakly Related	Eat	--	chew	c?
Unrelated	Throw	--	think	k?

Letter Search Task



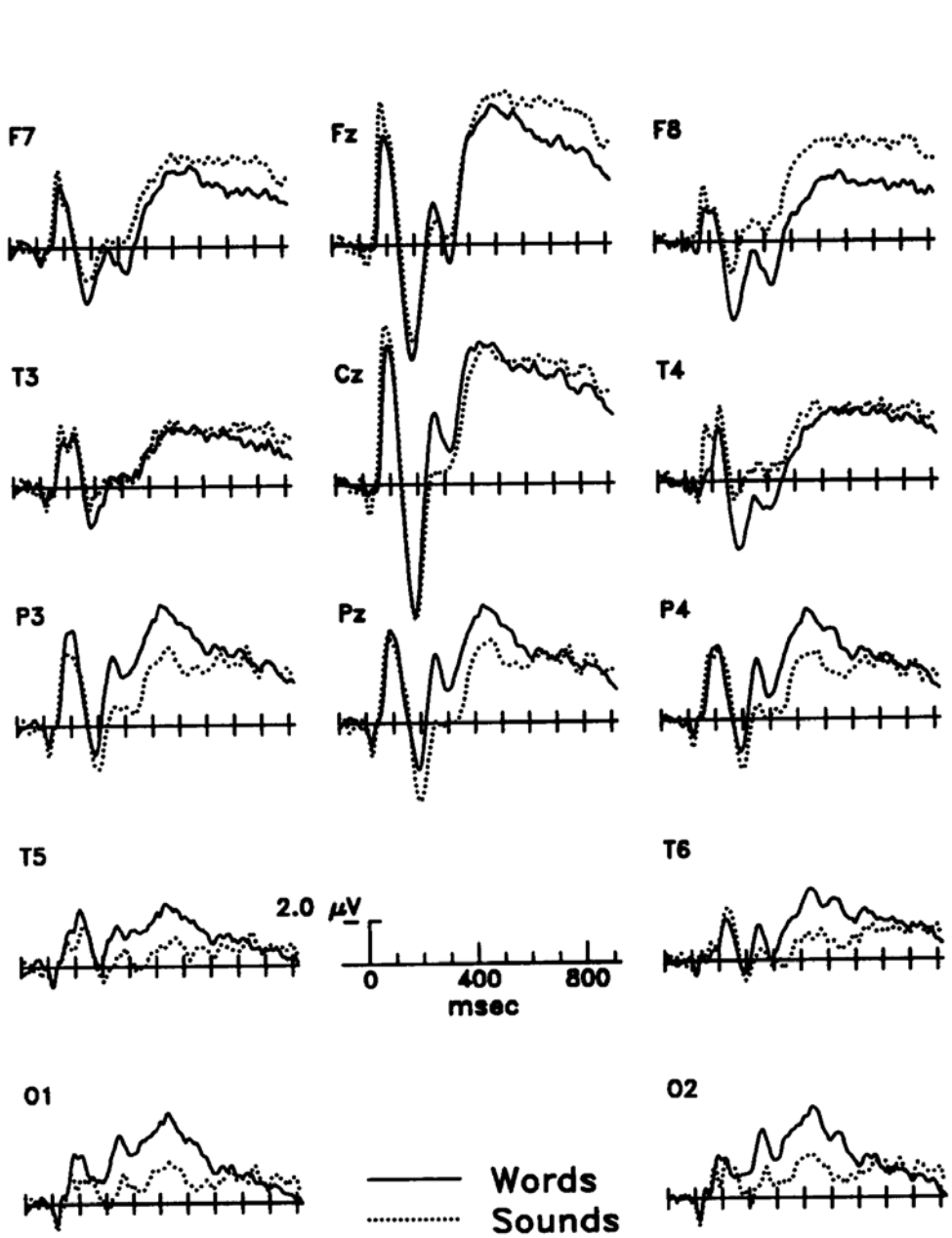


Fig. 1. Grand average ERPs elicited by words and sounds when they were the first member of a stimulus pair.

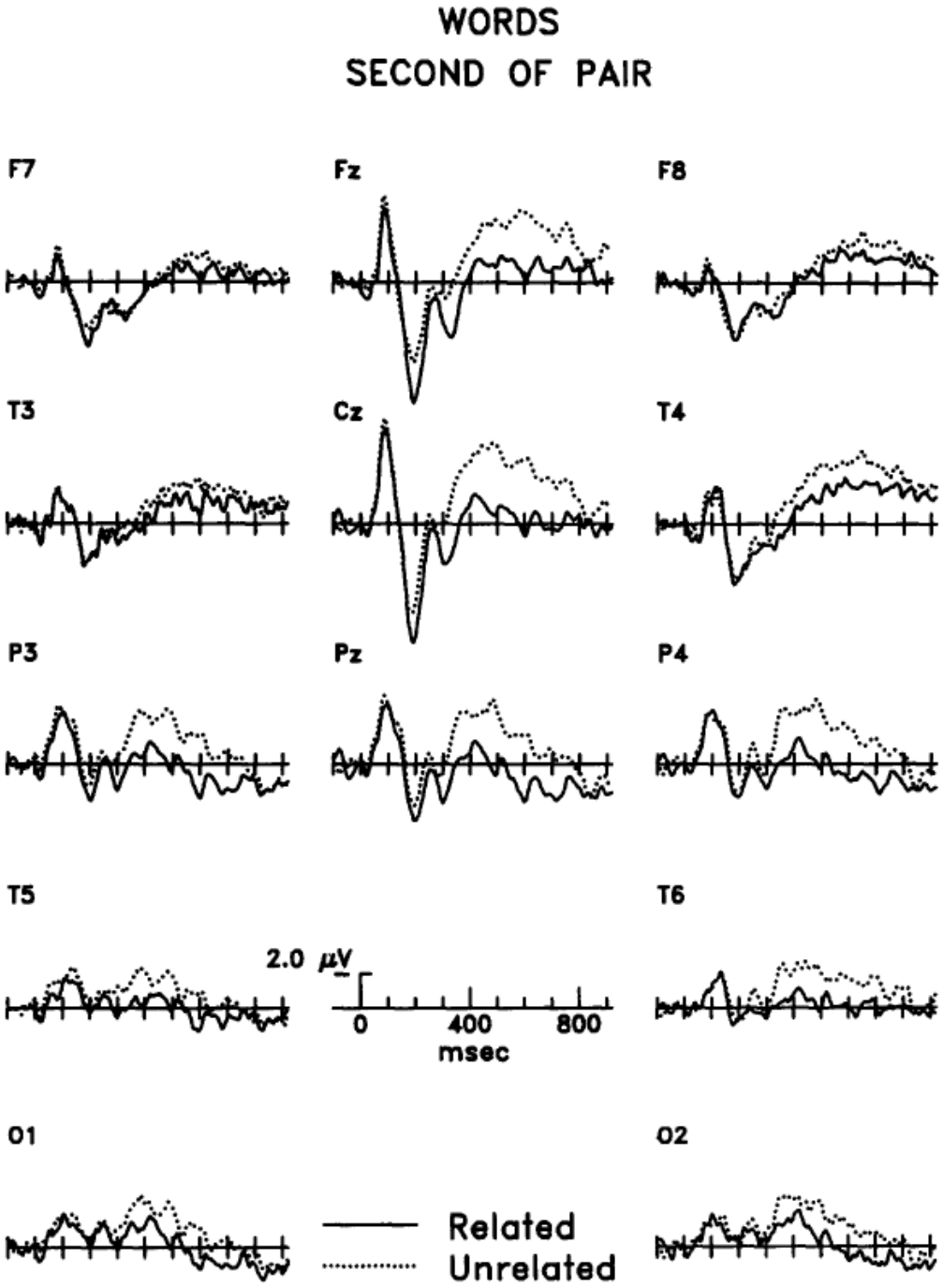


Fig. 2. Grand average ERPs elicited by words which were preceded by related or unrelated sounds.

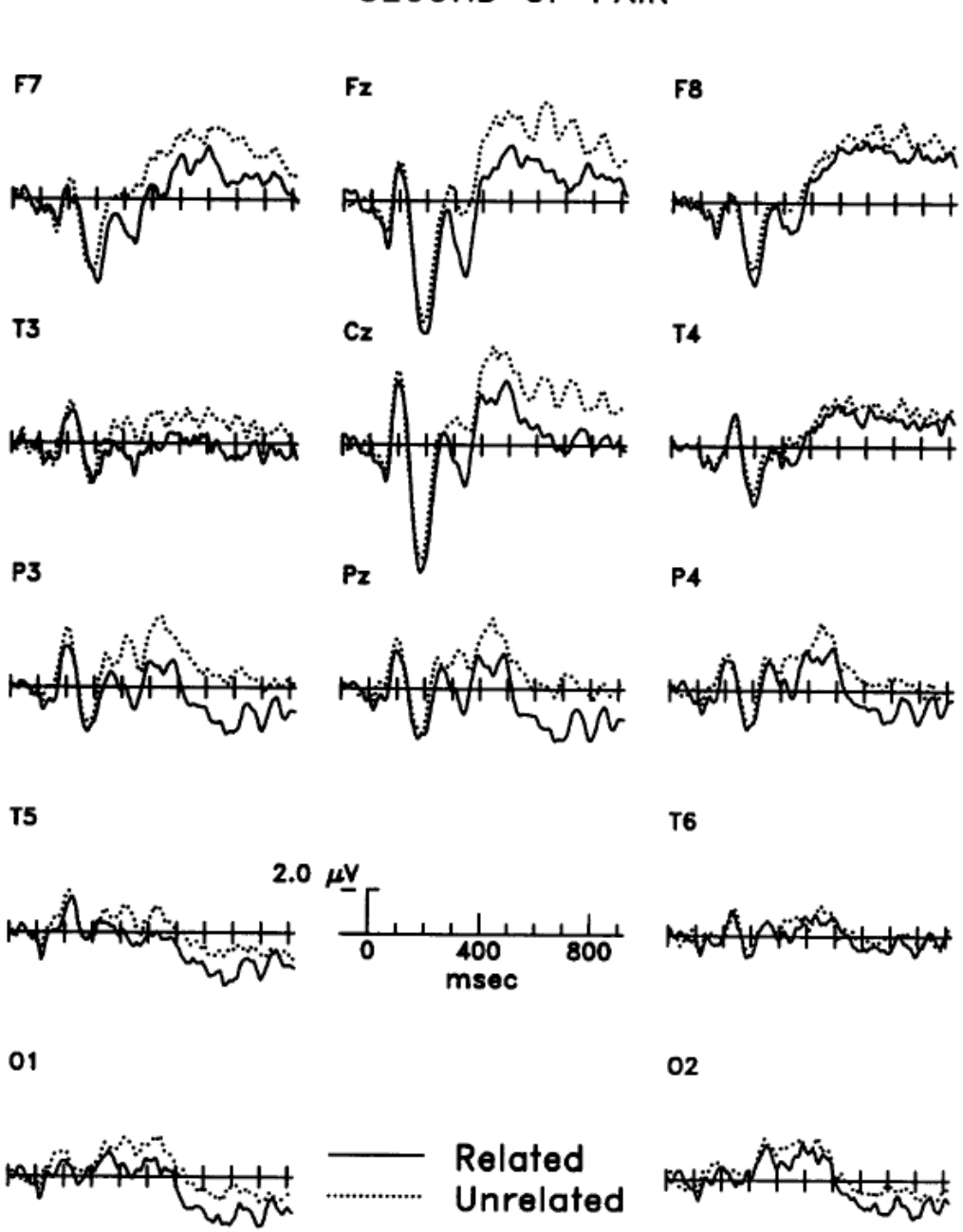


Fig. 3. Grand average ERPs elicited by sounds which were preceded by related or unrelated words.

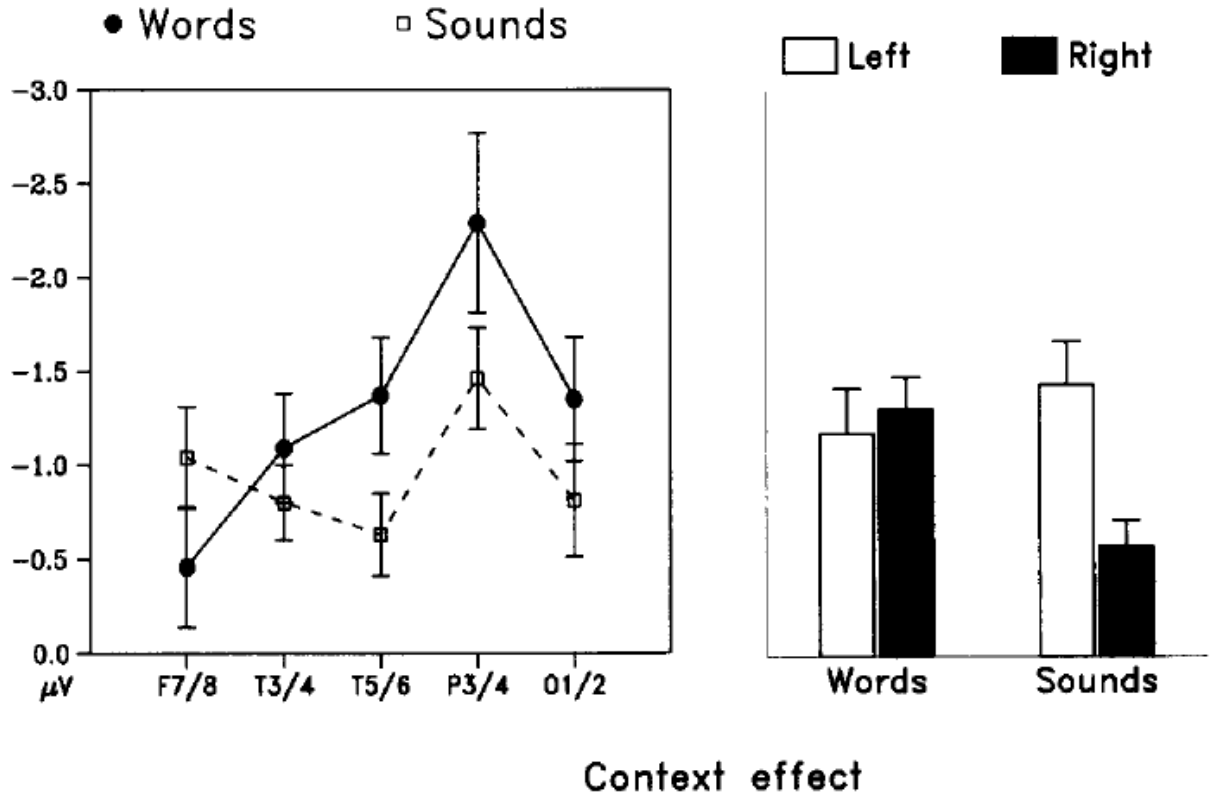


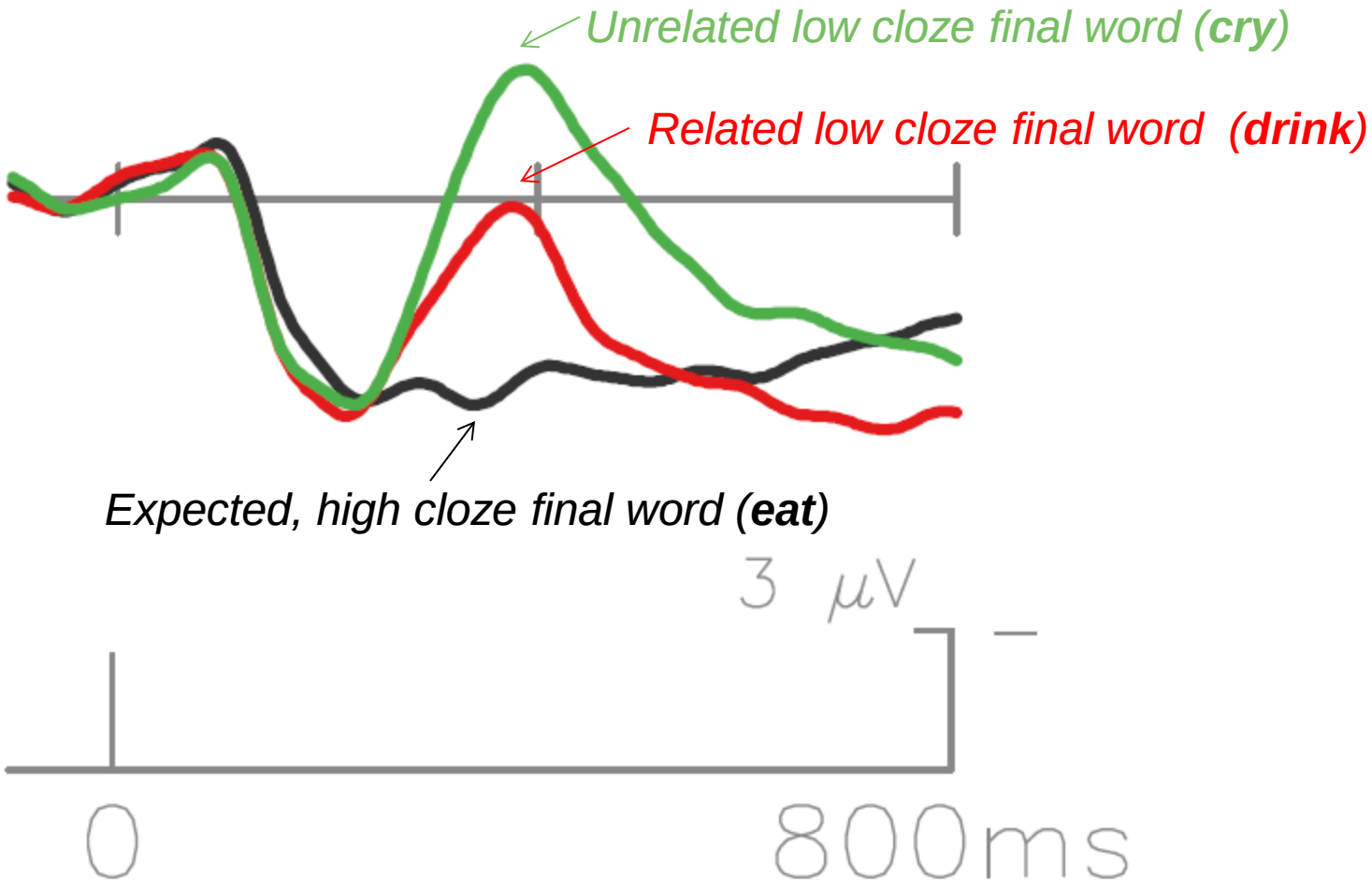
Fig. 4. Scalp distribution of the difference between related and unrelated items, quantified as the mean voltage from 300 to 700 msec after stimulus onset relative to a 100 msec pre-stimulus baseline. The left panel collapses across right and left recording sites to show distribution from the front to 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.

ERP context effects elicited by words and sounds were similar in general morphology, latency, and scalp distribution in the anterior-posterior dimension, but differed in lateral asymmetry. Van Petten and Rheinfelder view these results as consistent with the idea that the two context effects received differential contributions from the two cerebral hemispheres.

Importantly, these results show that ***conceptual relationships between spoken words and meaningful nonspeech sounds influence the processing of both words and sounds.***

WORD BY WORD READING

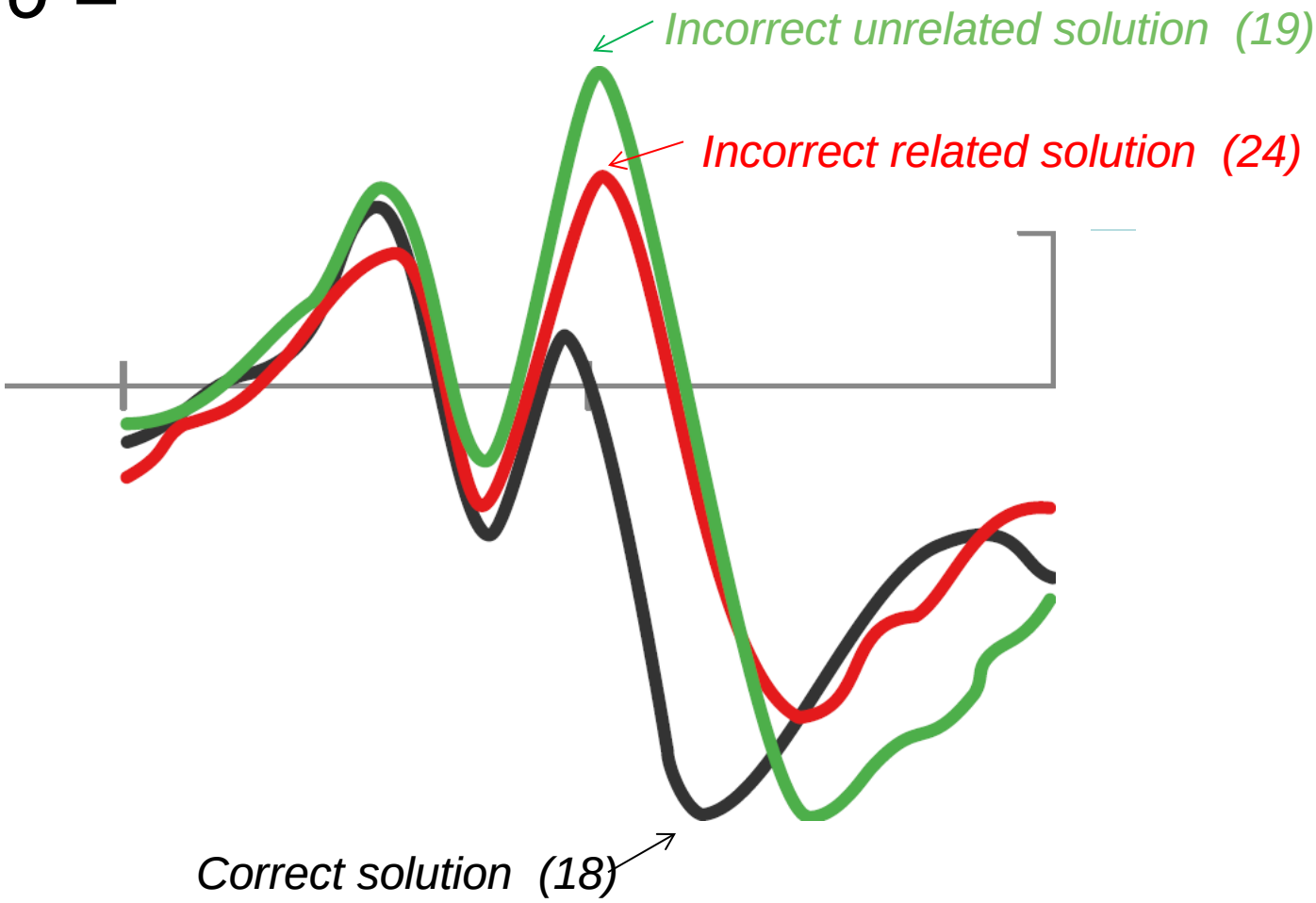
The pizza was too hot to …



Kutas, 1987

MULTIPLICATION

3 x 6 =



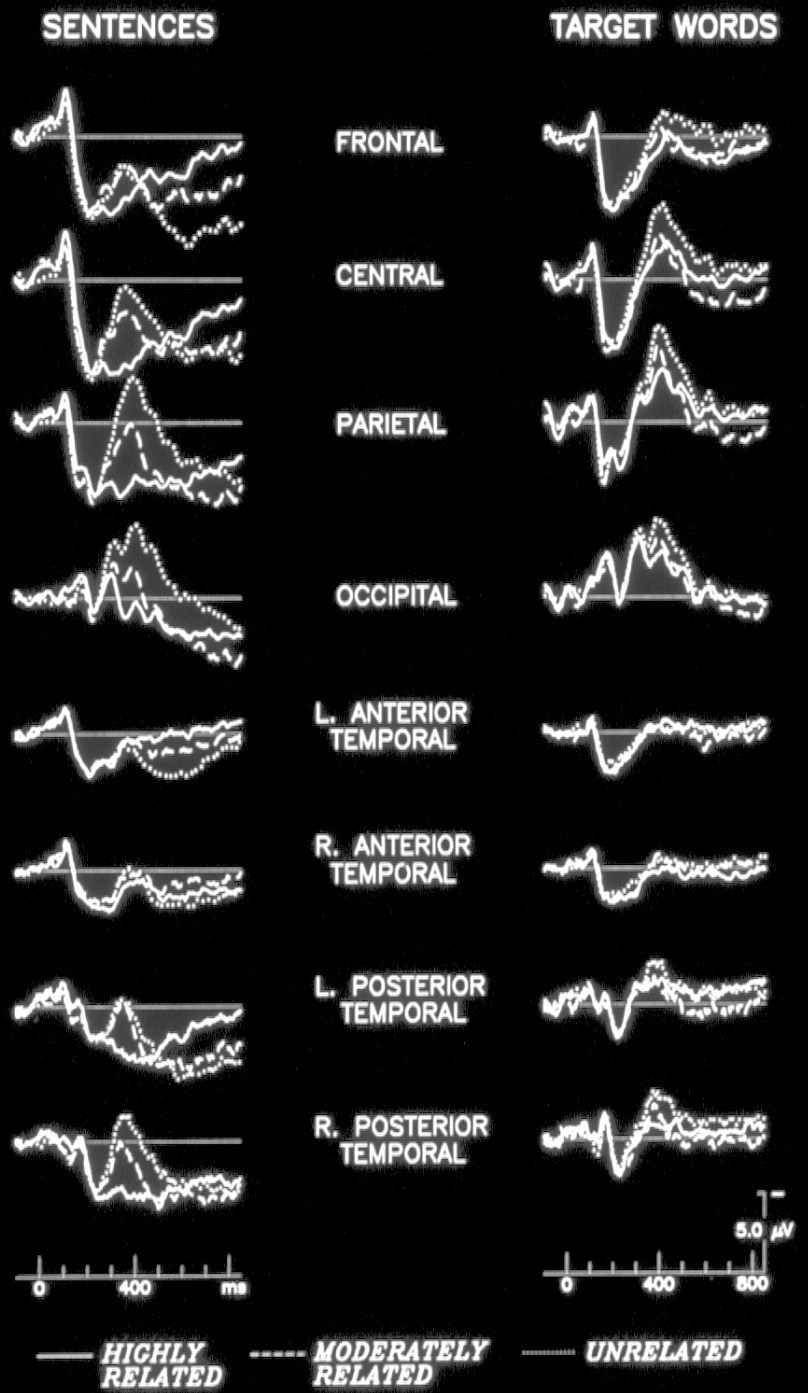
Nieddegen, Roesler & Jost, 1999

Both single words (lexical) and sentence context effects can lead to priming effects as seen in RT and N400 amplitude reduction.

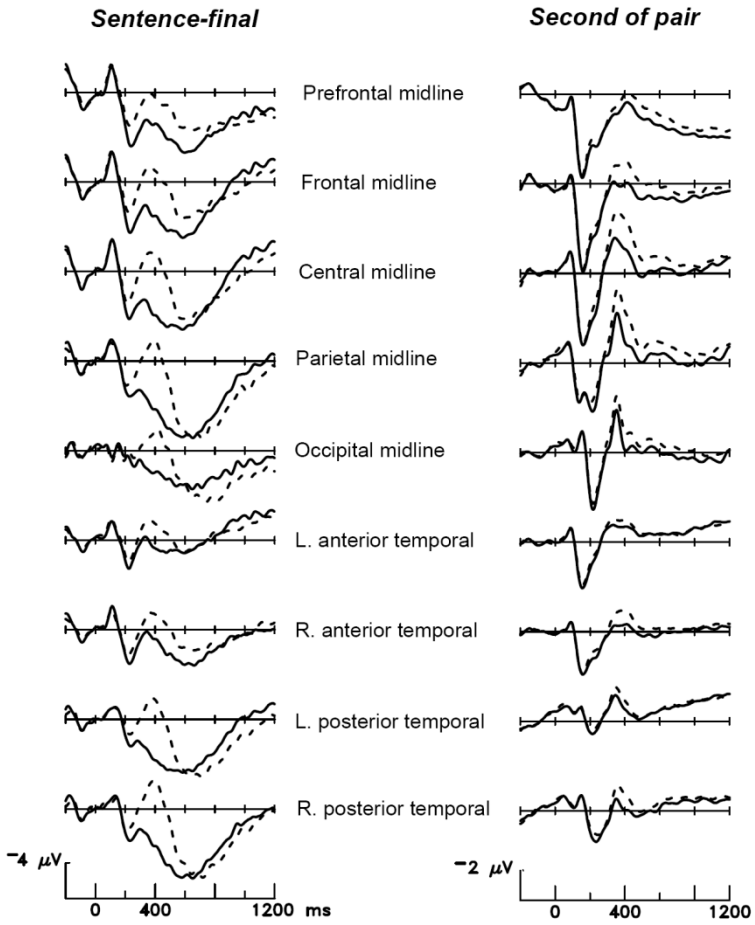
Two views on the relationship between semantic word priming and sentential priming:

1) They arise from qualitatively different mechanisms (e.g., lexical priming is due to fast acting, automatic spreading activation mechanism, sentence context effects are due to some other slower, more strategic mechanism).

2) They arise from similar if not identical mechanisms.


SENTENCES
TARGET WORDS
FRONTAL
CENTRAL
PARIETAL
OCCIPITAL
L. ANTERIOR TEMPORAL
R. ANTERIOR TEMPORAL
L. POSTERIOR TEMPORAL
R. POSTERIOR TEMPORAL
0
400
ms
5.0 μV
0
400
800
HIGHLY RELATED
MODERATELY RELATED
UNRELATED

Context effects: Words versus Sentences



Similar N400 effects for lexical context (word) and for sentence context, which argues against theories which propose qualitatively different processing mechanisms for word (low level) and sentence context (high level) effects that kick in one after the other.

Table 1. *Examples of the four sentence types*

Type	Example
Congruent-associated Lexical & Sentential	When the **moon** is full it is hard to see many **stars** or the Milky Way.
Congruent-unassociated Sentential only	When the **insurance** investigators found that he'd been drinking they **refused** to pay the claim.
Anomalous-associated Lexical only	When the **moon** is rusted it is available to buy many **stars** or the Santa Ana.
Anomalous-unassociated None	When the **insurance** supplies explained that he'd been complaining they **refused** to speak the keys.

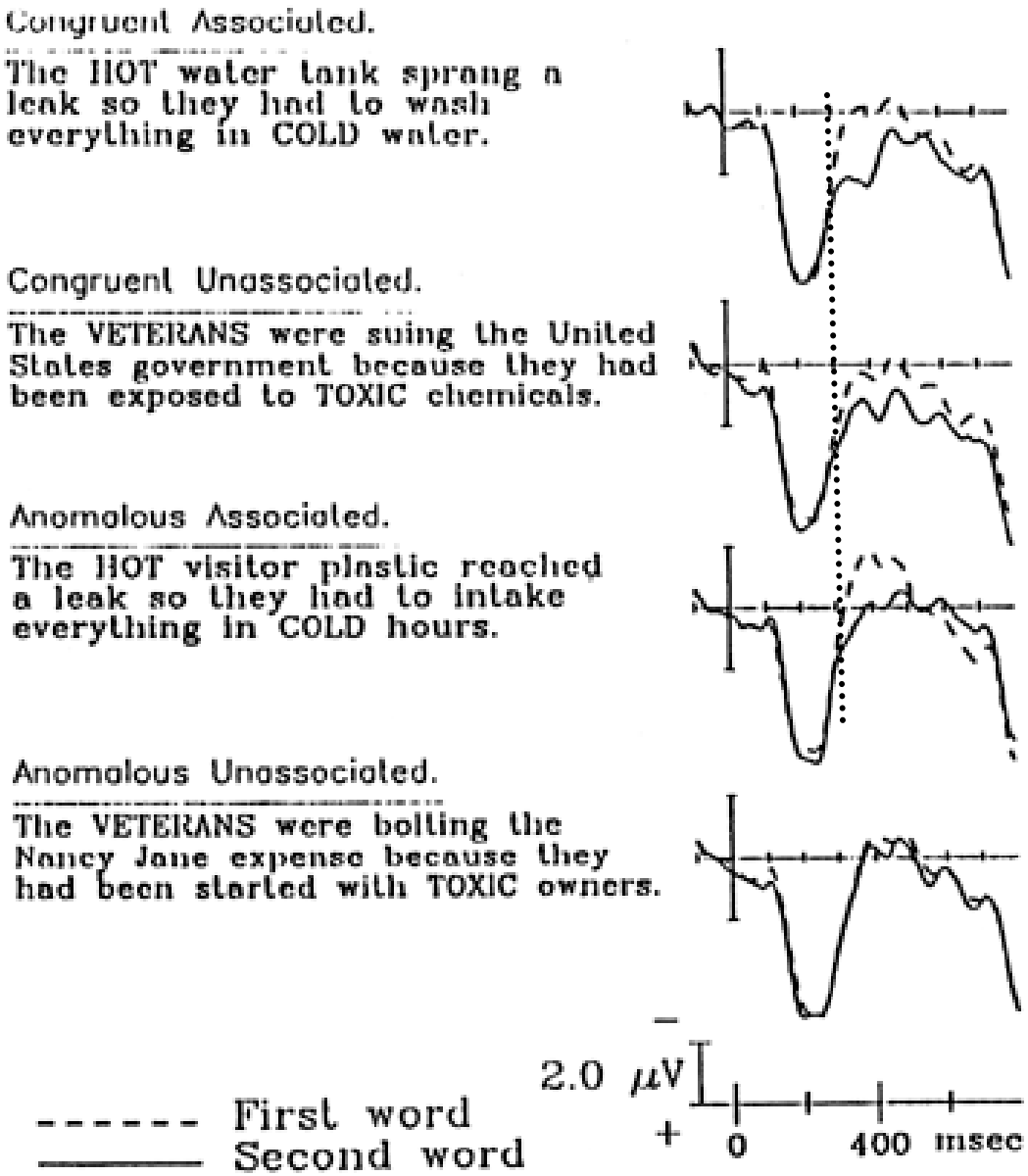
Note. The critical pairs of words are shown in bold.

Lexical & Sentential

Sentential only

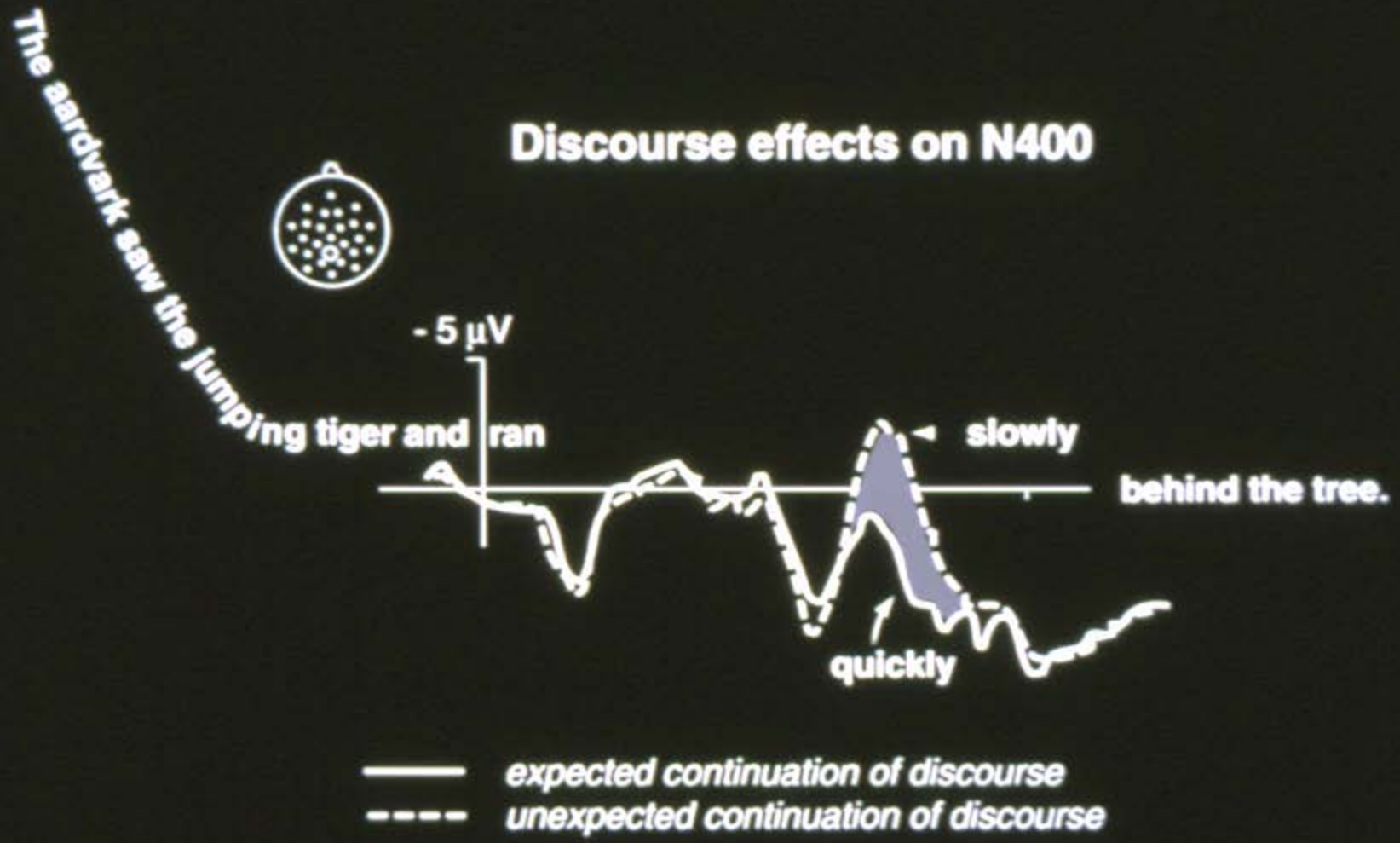
Lexical only

None



Onset latency of N400 effects in CU and AA conditions is the same, thus providing no evidence for a strictly lexical stage of semantic analysis that precedes sentence integration.

Discourse effects on N400



Van Berkum, Brown, & Hagoort

Can local semantic information be overruled by global contextual factors?

Hypothesis 1: Local semantic factors have a functional temporal precedence over global discourse context.

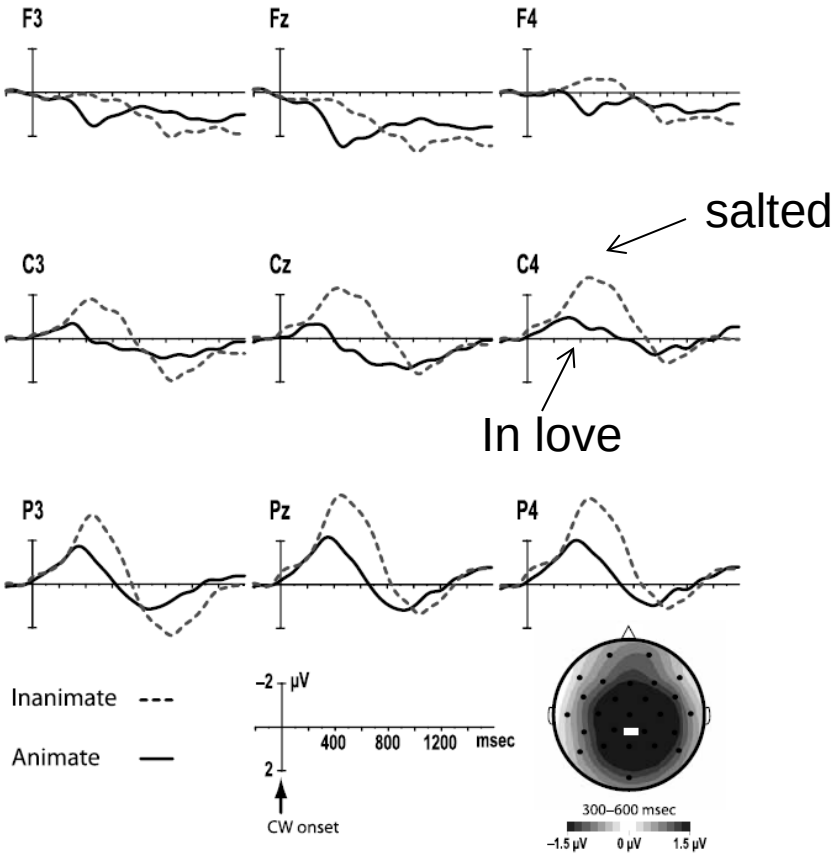
Hypothesis 2: Discourse level and local animacy constraints are simultaneously brought to bear on language comprehension in equivalent fashion.

Can context appropriateness outweigh the joint effects of animacy and real world plausibility?

Table 3. Example Story (Approximate Translation from Dutch)

A woman saw a dancing peanut who had a big smile on his face. The peanut was singing about a girl he had just met. And judging from the song, the peanut was totally crazy about her. The woman thought it was really cute to see the peanut singing and dancing like that. The peanut was *salted*/*in love*, and by the sound of it, this was definitely mutual. He was seeing a little almond.

A woman saw a dancing peanut who had a big smile on his face. The peanut was singing about a girl he had just met. And judging from the song, the peanut was totally crazy about her. The woman thought it was really cute to see the peanut singing and dancing like that. The peanut was ***salted/in love***, and by the sound of it, this was definitely mutual. He was seeing a little almond.



ERPs elicited by locally plausible but contextually inappropriate (salted) and locally anomalous but contextually appropriate predicates (in love). Predicates that were canonical for a particular object but inappropriate given the discourse context elicited an N400 effect compared to formally anomalous but contextually appropriate predicates*. (Nieuwland & van Berkum)*

Context appropriateness CAN outweigh joint effects of animacy and real world plausibility!

Role of context on word recognition in speech

Table 2
Sample Stimuli in Experiment 2

Cohort congruous/cohort incongruous/rhyme
It was a pleasant surprise to find that the car repair bill was only seventeen *dollars/dolphins/scholars.* Most marine mammals have some sort of legal protection, but fishermen continue to kill *dolphins/dollars/muffins.*
The referee got tired of the coach's behavior and gave his team a *penalty/pendulum/loyalty.* The visitor stared at the grandfather clock and seemed almost hypnotized by the swinging of the *pendulum/penalty/asylum.*
The movie was meant to be a horror flick, but the acting was so bad it was *funny/funnel/penny.* He spilled some of the oil onto the engine because he didn't have a *funnel/funny/tunnel.*
Instead of sending flowers, they asked everyone to make a donation to their favorite *charity/chariot/cavity.* The Roman general made his appearance in battle gear, with a white horse pulling his golden *chariot/charity/idiot.*
Sir Lancelot spared the man's life when he begged for *mercy/mermaid/fancy.* The old sailor kept a straight face as he told of his love affair with a beautiful *mermaid/mercy/grenade.*
Plain congruous
The mill worker caught his hand in a piece of machinery and was rushed to the *hospital.*
Plain incongruous
The gold medal winner from Brazil started out slow but took the lead in the second *bureau.*

Van Petten et al. 1999

N400 congruity effect: control

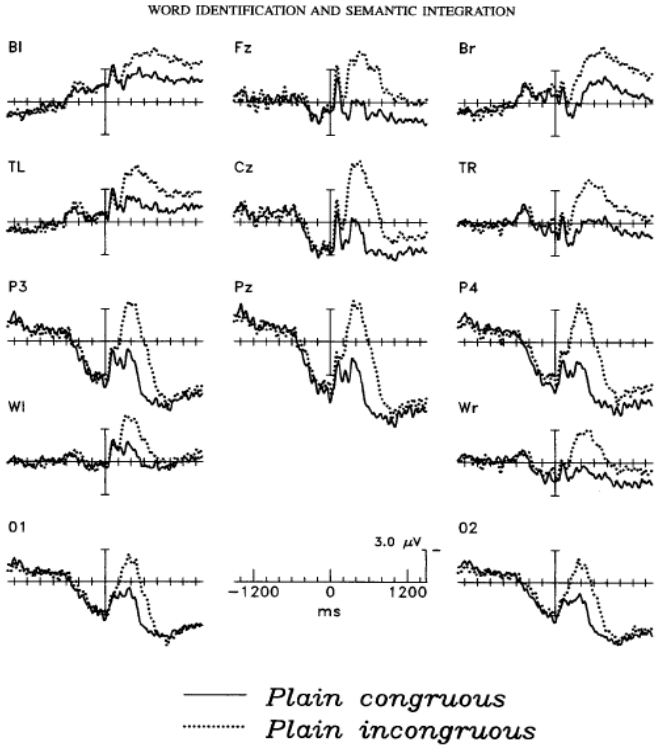
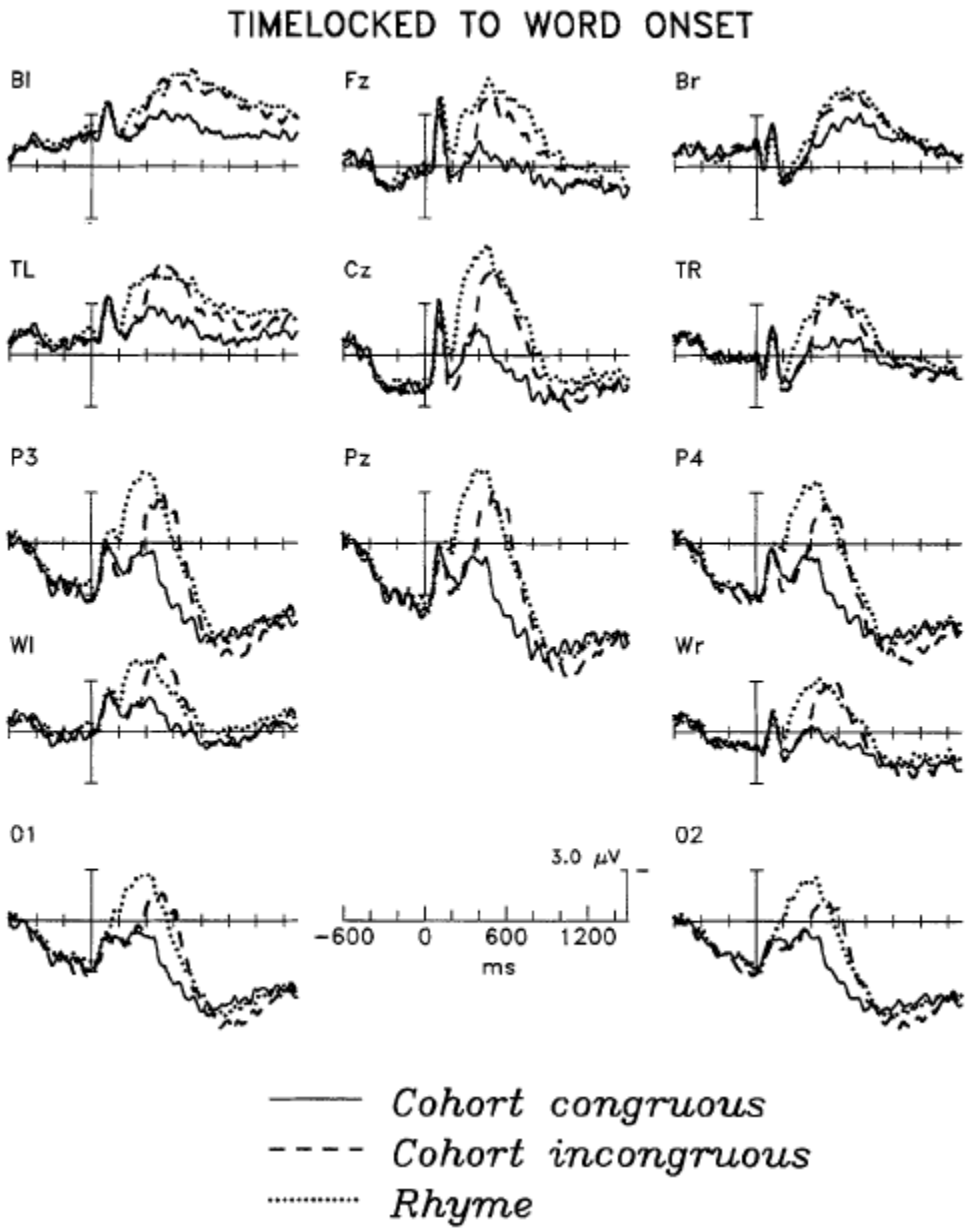


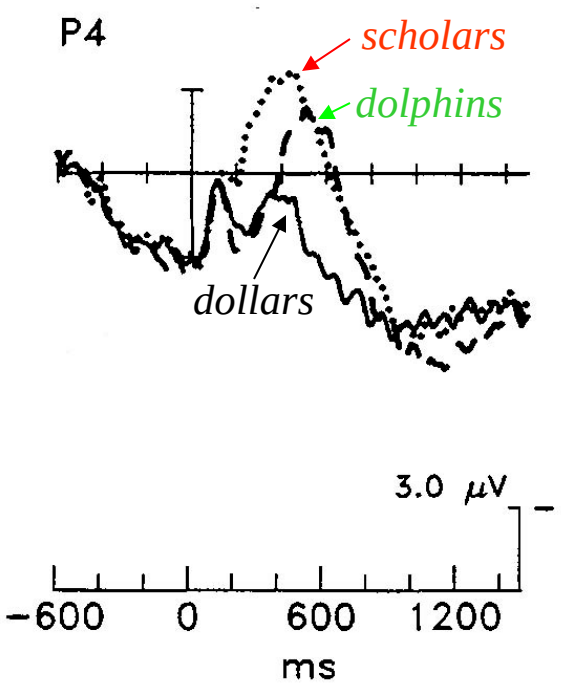
Figure 4. Grand average event-related potentials from 21 participants, elicited by the plain congruous and plain incongruous sentence-final words. Note that negative is plotted up in this and subsequent figures. Electrode sites on the left side of the head are shown in the left column, midline sites in the middle column, and right scalp sites in the right column. Top to bottom of the figure corresponds with anterior to posterior across the scalp. Time 0 is the onset of sentence-final words. "F" denotes frontal, "C" central, "P" parietal, and "O" occipital scalp sites. "B" ("Broca's") denotes scalp sites over inferior prefrontal brain regions, and "W" ("Wernicke's") scalp sites roughly over the temporal–parietal junction. "L" and odd numbers indicate the left side of the head; "R" and even numbers indicate the right side of the head.

Van Petten et al. 1999



Van Petten et al. 1999

It was a pleasant surprise to find that the car repair bill was only seventeen



———*Cohort congruous (dollars)*

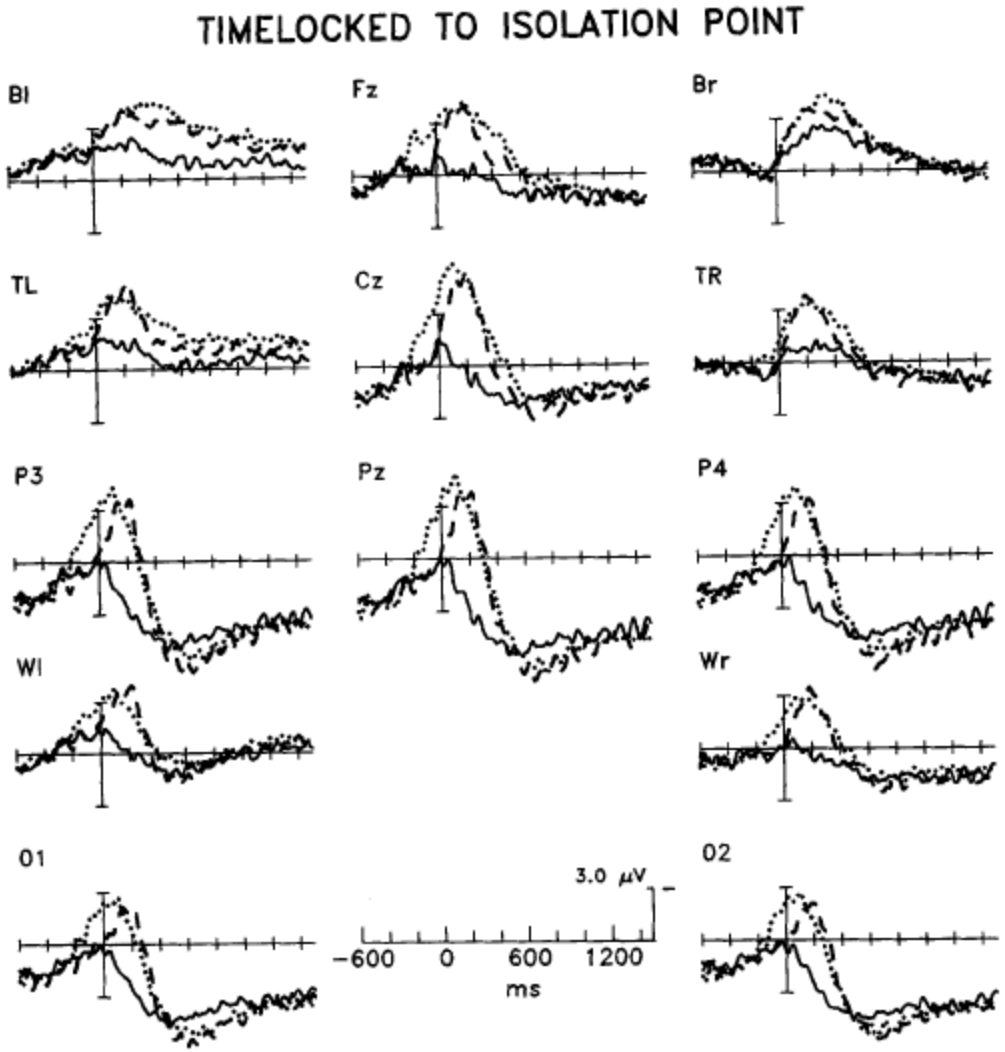
– – –*Cohort incongruous (dolphins)*

·····*Rhyme (scholars)*

Semantic integration starts before words are completely identified.

Van Petten et al. 1999

Semantic context has influence before word is uniquely identified



Van Petten et al. 1999

ENGLISH INDEFINITE ARTICLES (a, an)

Vowel-initial sound nouns	Consonant-initial sound nouns
an airplane	*a kite*
an eagle	*a robin*
an hour	*a watch*

The day was breezy so the boys went outside to fly…

a kite...

an airplane…

Because it frequently rains in London, Nigel always carries

an umbrella...

a newspaper…

ARTICLE AND NOUN CLOZE PROBABILITIES

Article cloze probability (0-.96); Noun cloze probability (0-1.0)

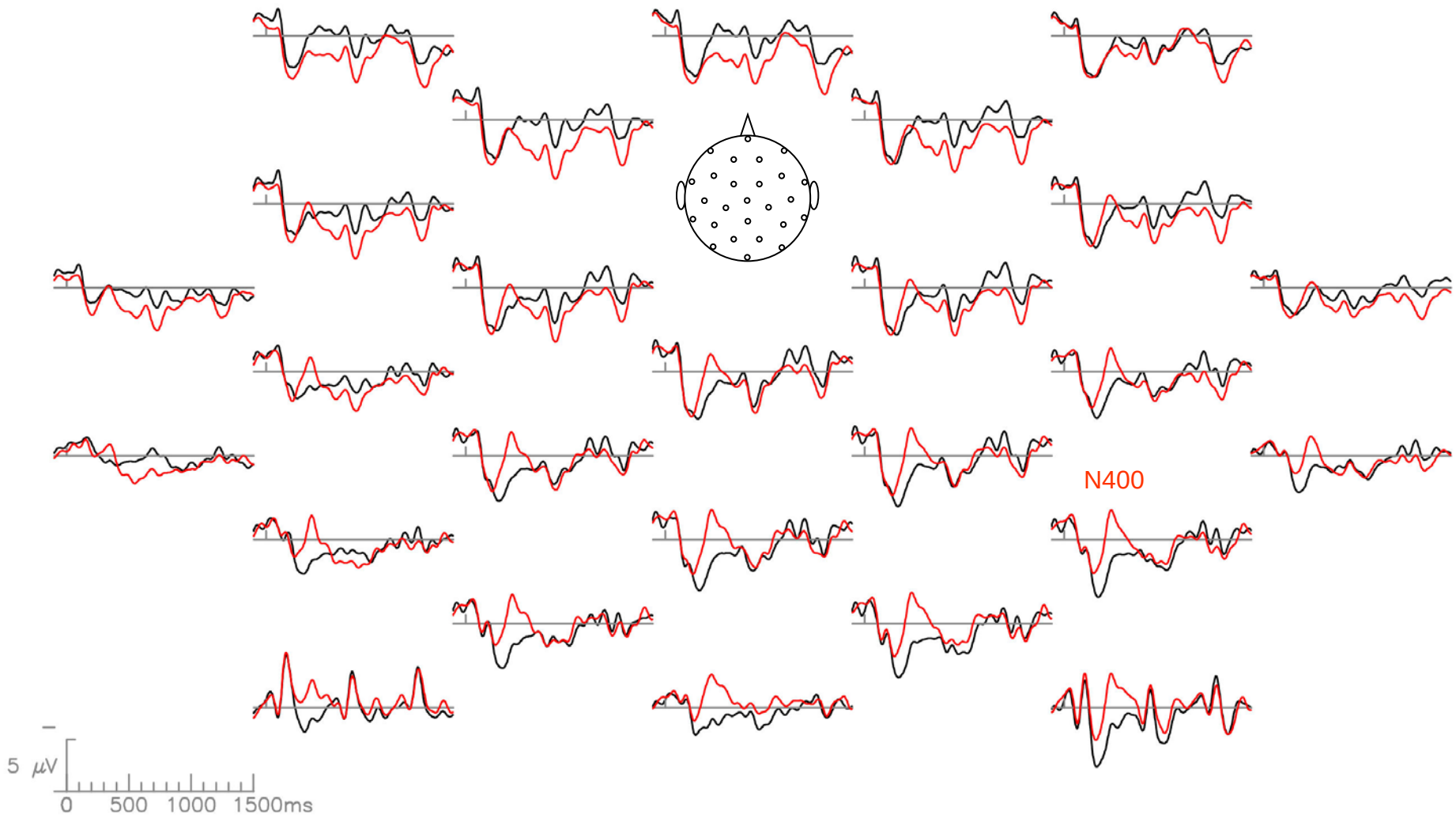
The day was breezy so the boy went outside to fly a kite in the park. (a=.86, kite=.89)

Older children often have a harder time than younger children dealing with the loss of a parent who has cared for them (a=.62, parent=.38)

When the representative retired in the middle of his term, the state was forced to hold an election in his district (an=.55, election=.73)

The group had been brainstorming all day but they still didn't have an idea for their project (an=.46, idea=.50)

Marie wanted to sample a tiny bit of the sauce so she daintily dipped a finger into the pot (a=.21 , finger=.16)



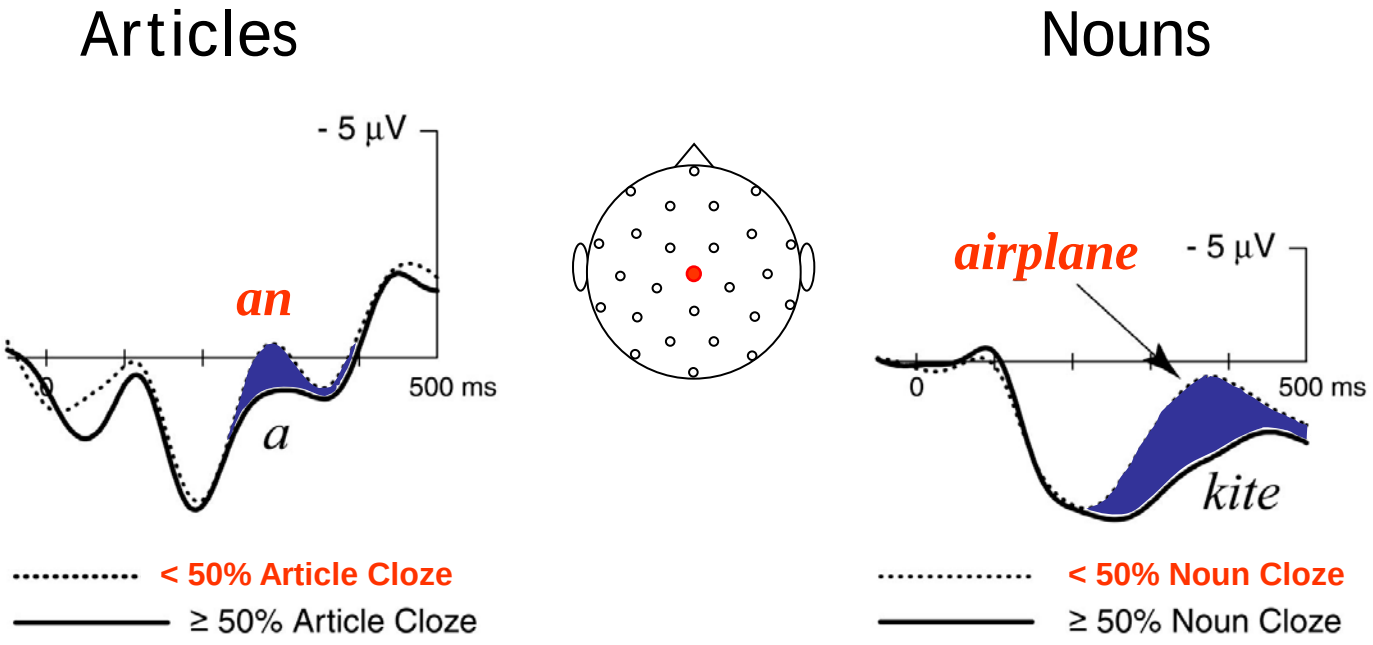
Because it frequently rains in London, Nigel always carries...

——— ***Expected AN Nouns*** *(e.g., an* ***umbrella****)*

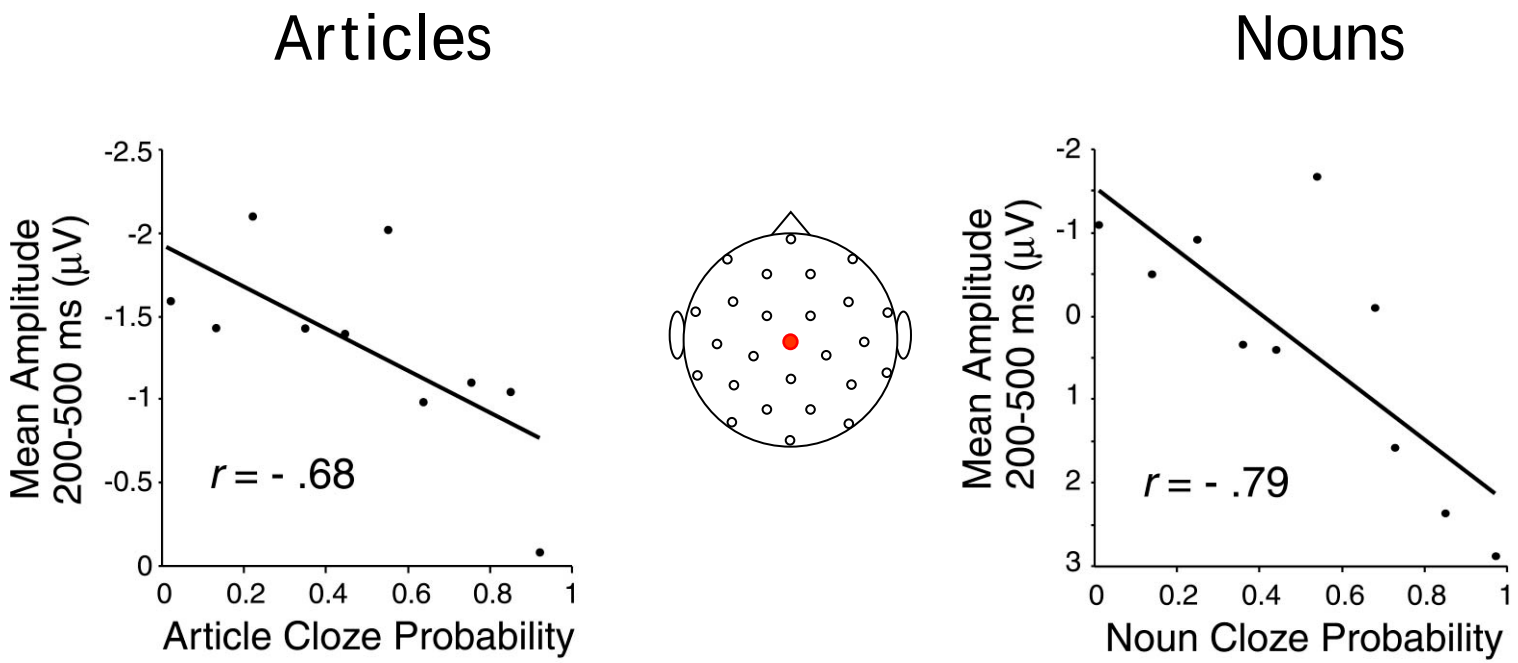
——— ***Unexpected A Nouns*** *(e.g., a* ***newspaper****)*

ERPs by median split on cloze probabilities

e.g., The day was breezy so the boy went outside to fly…

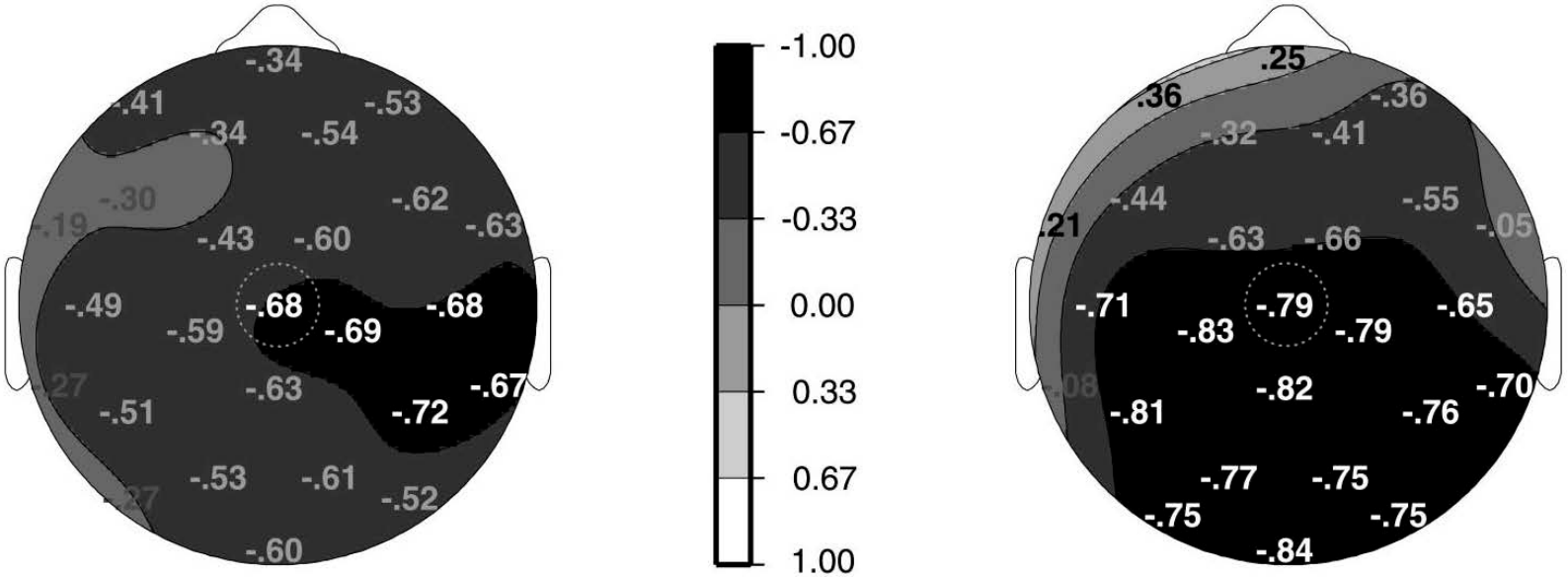


Correlations between N400 amplitude and offline cloze probabilities

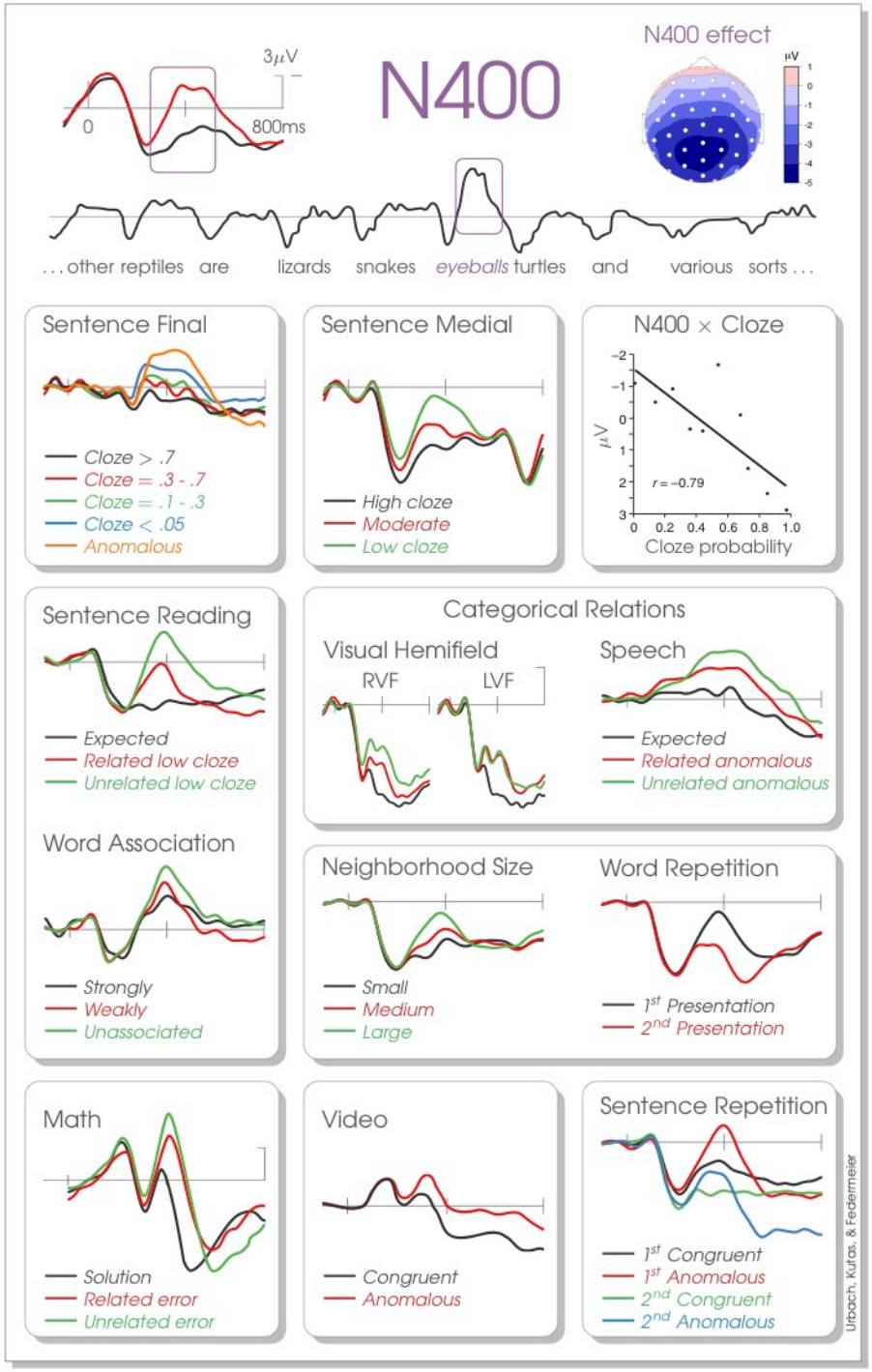


Correlations between N400 amplitude and cloze probabilities at all recording sites

Articles



Nouns



N400 data ...

(a) point to a distributed, multimodal, bi-hemispheric comprehension system that is simultaneously open to linguistic and non-linguistic influences, which often interact;

(b) suggest that access to meaning is a natural part of the stimulus-elicited processing stream, not dependent on an information state such as "recognition", and thus open to all stimuli in all task conditions (unless the feed-forward stream has been suppressed by selective attention);

(c) have shown that comprehension is largely non-serial, at least partially incremental, predictive, flexible, and context-dependent;

(d) have been instrumental in blurring the line between long-honored dichotomies such as prelexical versus postlexical, automatic versus controlled, and literal versus nonliteral processing, among others.

Functional Significance of N400

N400 amplitude is a **general index of the ease or difficulty of retrieving stored conceptual knowledge associated with a word (or any potentially meaningful item).** Depends on:

- Representation of eliciting item itself
- + Contextually activated knowledge (broadly construed)

N400 reflects stimulus-induced semantic activity in LTM. As such, the N400 response to a given input can be used as a tool to assess semantic memory states, with the amount of N400 reduction (relative to a control condition) revealing how much of the information normally elicited by that stimulus is already active.

Alternative: N400 amplitude is an Index of **contextual integration**: This view emphasizes the importance of the fit between the eliciting item and context-based information, currently held in working memory. (Hagoort's unification theory)

Neural Generators of N400

- ERPs from patients with brain damage (split-brain, right hemisphere damage, Wernicke's and Broca's aphasics, temporal lobectomy, frontal); Intracranial Recording (in epileptics); MEG; fMRI

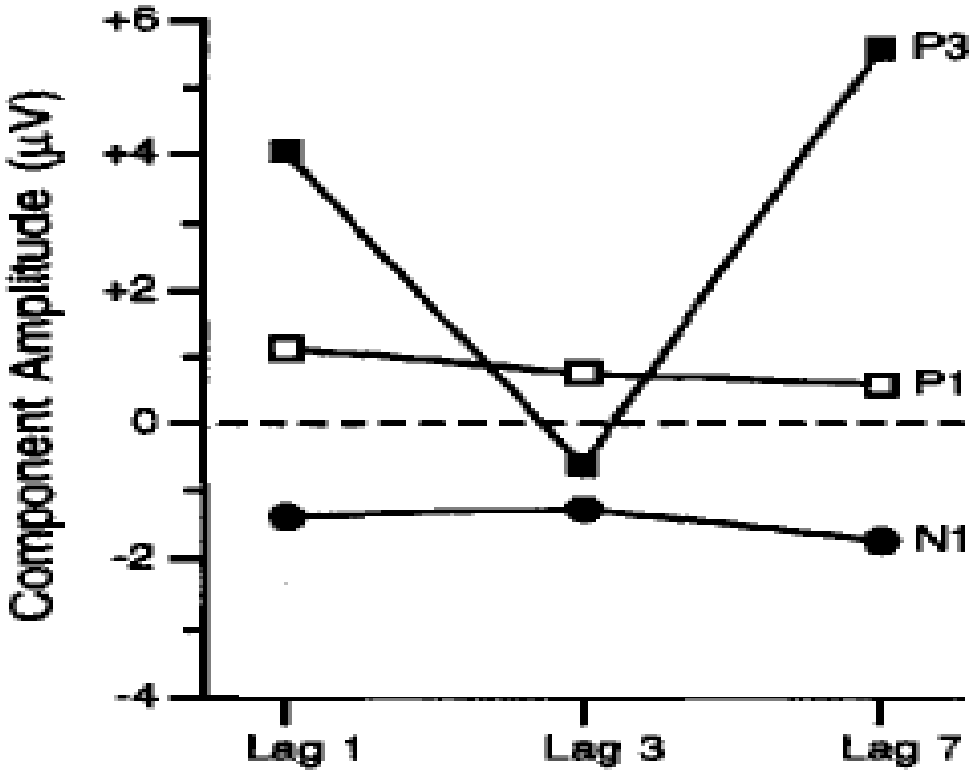
Recordings from patients with brain damage, intracranial recordings, and MEG (magnetoencephalographic) data implicate a (probably large portion of) the left temporal lobe as the largest source of the N400 semantic context effect, with a substantial but lesser contribution from the right temporal lobe (Van Petten & Luka, 2006). Also, some evidence for contribution from/involvement of left inferior frontal cortex (selection).

Taken together findings suggest N400 arises from a highly distributed brain network that includes higher-level perceptual areas and multimodal processing and storage areas, perhaps critically in the medial and anterior temporal lobe.

Using N400 to answer non-language question: The Locus of the Attentional Blink (AB)

Somewhere between sensory processing (normal sensory components and consolidation into working memory (suppressed P3b). Is a word that is blinked analyzed for semantic content (i.e., does it elicit an N400 that is modulated by semantic relationships)?

Summary: ERP components and attentional blink



Attentional blink operates at post-perceptual stages, but before or during the consolidation into working memory

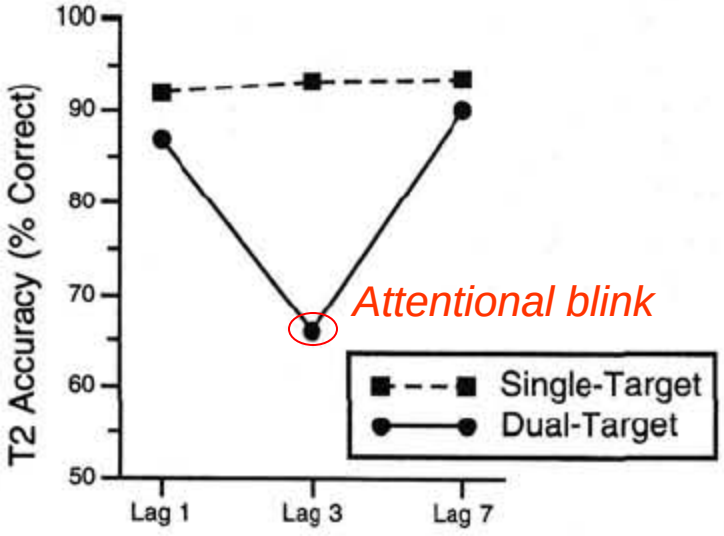
ATTENTIONAL BLINK

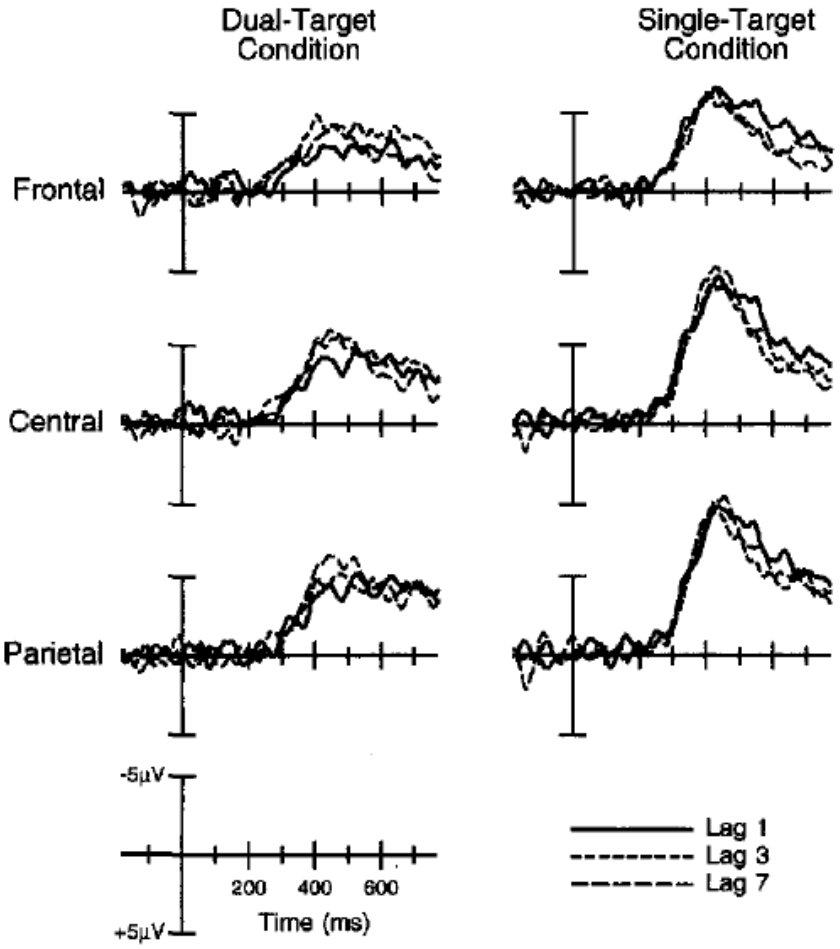
Stimulus Type	Time (ms)	Related Trial	Unrelated Trial	
Context Word	1000	SHOE	PICKLE	
Blank	1000			
Distractor	83	PNVCSZP	KDSWPVZ	
Distractor	83	GRSDPKN	VNMCPKL	
Distractor	83	BVCPLMS	FDPMCNV	
Distractor	83	DSPWTFR	VPMTDZM	
Distractor	83	RLDJHGK	HJDLGFP	
Distractor	83	SPLDJMF	DFPLJKH	
T1	83	7777777	8888888	← FIRST TARGET
Distractor	83	WDPTBNF	GHJDMVT	
Distractor	83	SCDPVBF	HDVCBNM	
T2	83	XFOOPXX	XROPEXX	← SECOND TARGET
Distractor	83	FDLNLKB	NMCVPHJ	
Distractor	83	DLJJCNW	DCVPBJM	
Distractor	83	WPSCDSN	PCNBVLK	
Distractor	83	DPWVCPB	NPMTVDK	
Distractor	83	CBNDPNJ	BRTFPMF	
Distractor	83	RTPMVBC	JLSDCDK	
Distractor	83	TWSCLMN	LKSDVCP	
Distractor	83	LJVBCMH	DKKHNVP	
Distractor	83	RMVCPKL	WKLDMZP	
Distractor	83	DPNMNVZ	CPNHVGB	
Blank	1000			
Response Cue	2000	?	?	
Blank	2000			

Vogel, Luck, Shapiro, 1998

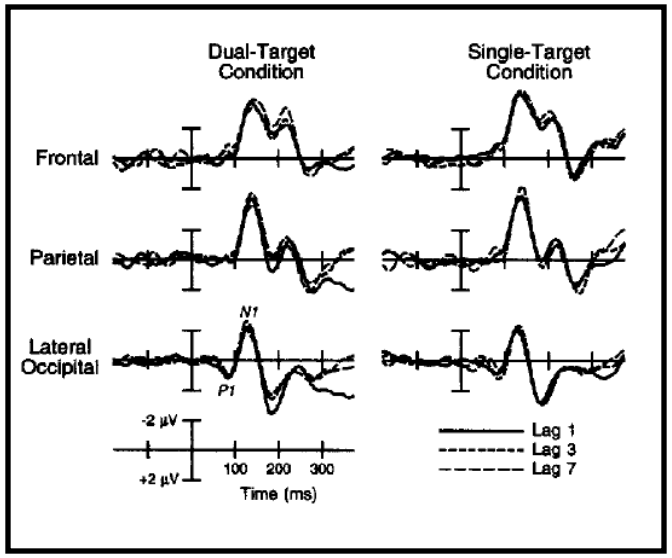
Attentional Blink

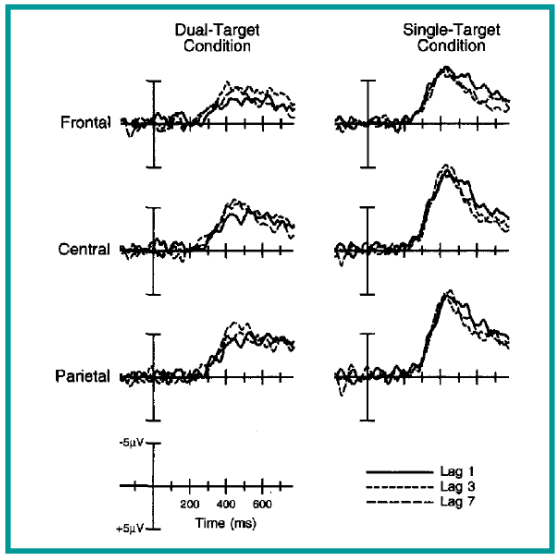
N400 effect (unrelated-related)

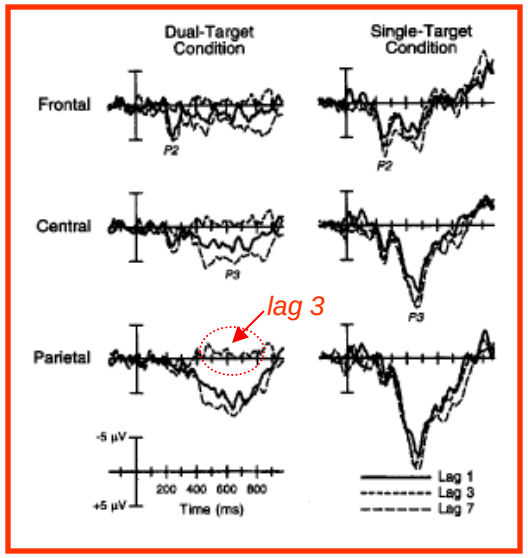


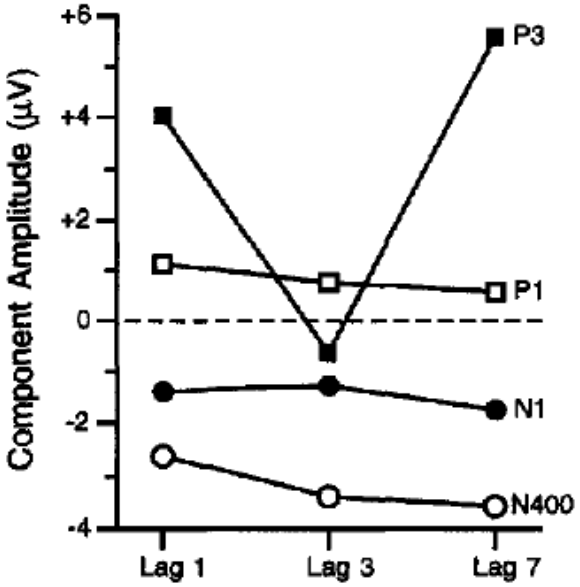


Vogel, Luck, Shapiro (1998)









P300 suppressed during AB

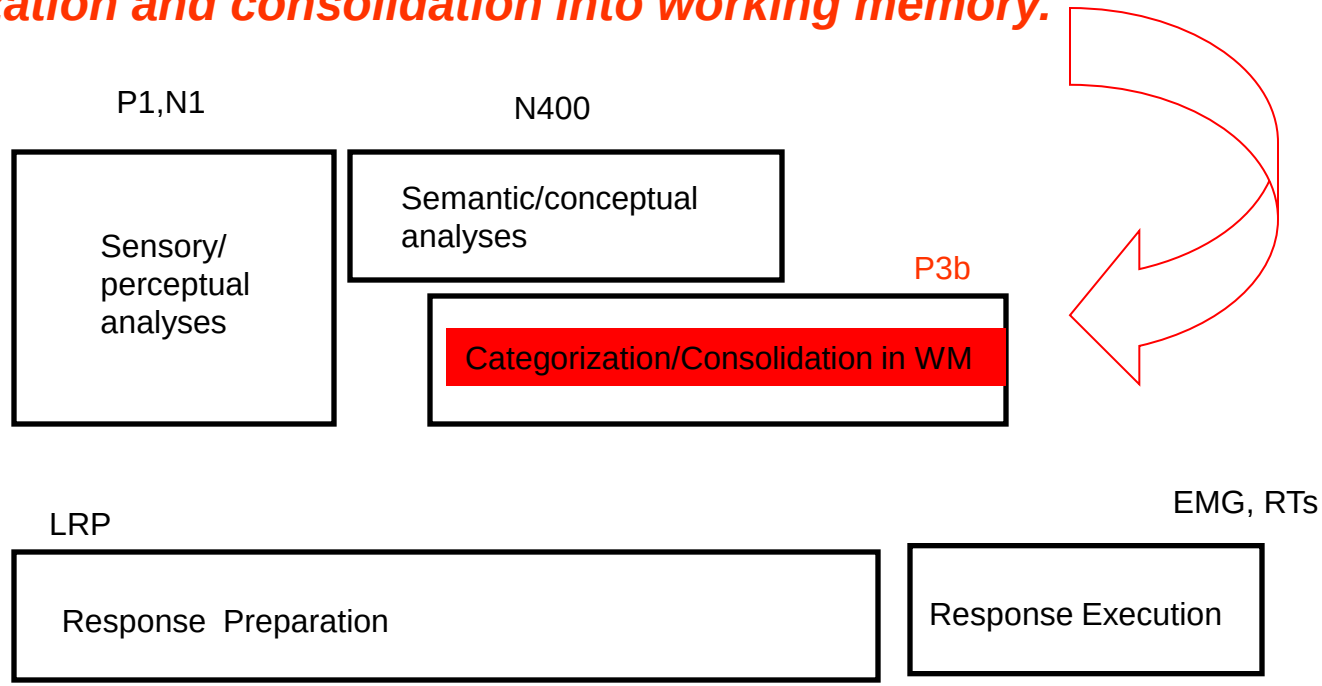
sensory P1 unaffected during AB

sensory N1 unaffected during AB

N400 unaffected during AB

ATTENTIONAL BLINK

Temporal locus of synaptic computations leading to attentional blink phenomena is coincident with processes involved in stimulus categorization and consolidation into working memory.



Using N400 to test alternative theories of how sentences are parsed…
how to figure out syntactic relations between words in a sentence.

Examine *wh*-sentences: Which customer

Subject?
Object?

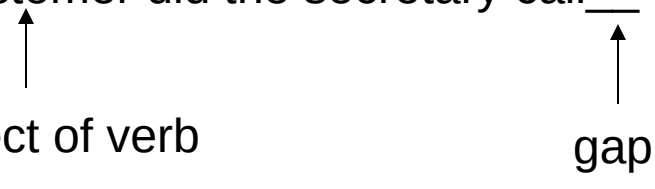
Using N400 to test alternative theories of how sentences are parsed…
how to figure out syntactic relations between words in a sentence.

Examine *wh*-sentences: Which customer did

Object, but of what?

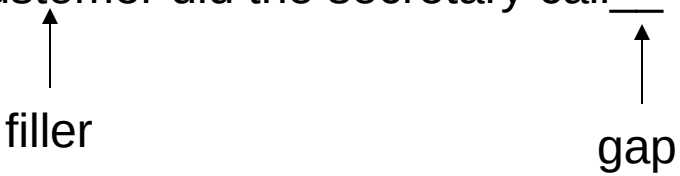
Using N400 to test alternative theories of how sentences are parsed…

Examine *wh*-sentences: Which customer did the secretary call__



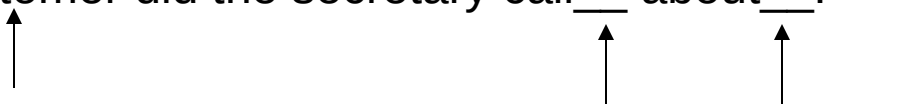
Using N400 to test alternative theories of how sentences are parsed…

Examine *wh*-sentences: Which customer did the secretary call__

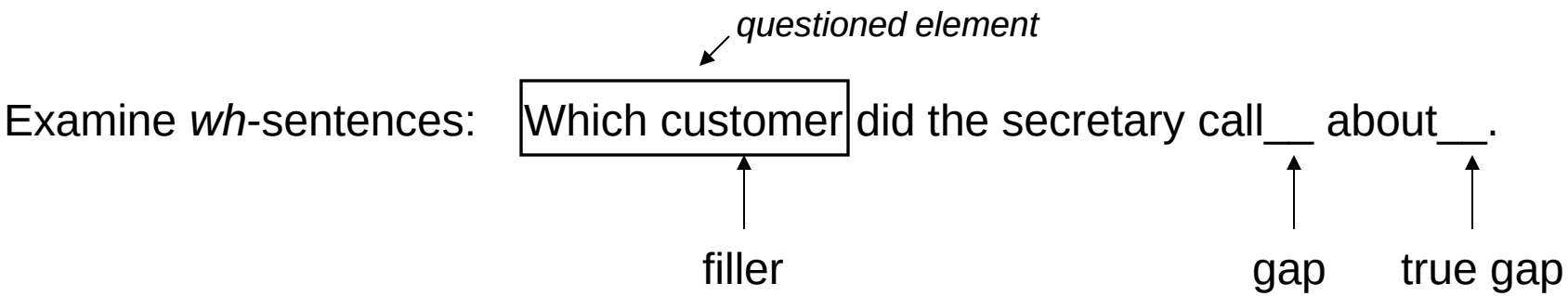


Using N400 to test alternative theories of how sentences are parsed…

Examine *wh*-sentences: Which customer did the secretary call__ about__.



Using N400 to test alternative theories of how sentences are parsed…



First resort strategy: put the filler in the first available gap.
Last resort strategy: wait for unambiguous information about the true gap before placing filler.

CONTROL SENTENCES

The businessman knew whether the secretary called the customer…
The businessman knew whether the secretary called the article … N400

EXPERIMENTAL SENTENCES: FILLER-GAP

The businessman knew which customer the secretary called __…
The businessman knew which article the secretary called __

PREDICTED OUTCOMES:

If first resort strategy is correct,

The businessman knew which customer the secretary called __…
The businessman knew which article the secretary called __(N400)

If last resort strategy is correct,

The businessman knew which customer the secretary called __…
The businessman knew which article the secretary called __...

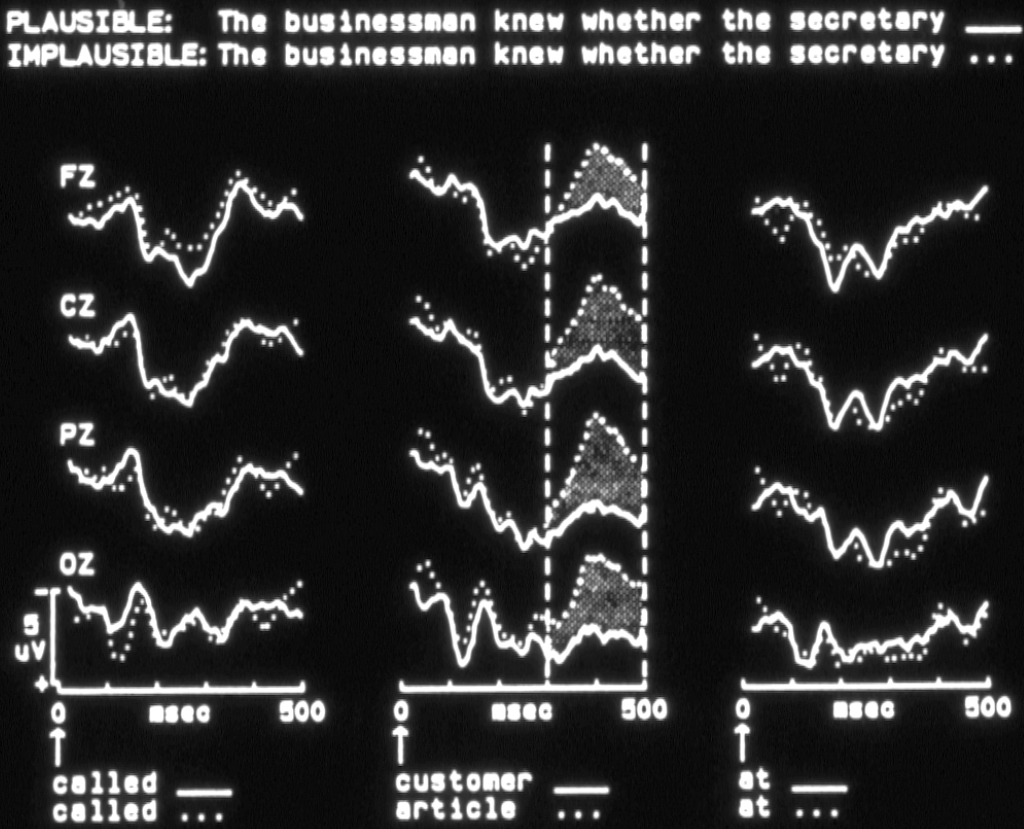


Fig. 1. Mean EP waveforms (32 subjects) for plausible and implausible control sentences. Solid lines represent the plausible condition and dotted lines the implausible condition. At the top of the figure appear the portions of the sentences preceding the words whose responses are shown, which appear under each panel. The word *the* was presented between *called* and *article* or *customer*, but its response is not shown here. Vertical dashed lines at 300 and 500 msec in the middle panels indicate the 200-msec range across which N400 was quantified. The shading indicates the plausible–implausible differences found.

Garnsey, Tanenhaus & Chapman, J. Psycholinguistic Res. 18(1): 51, 1989.

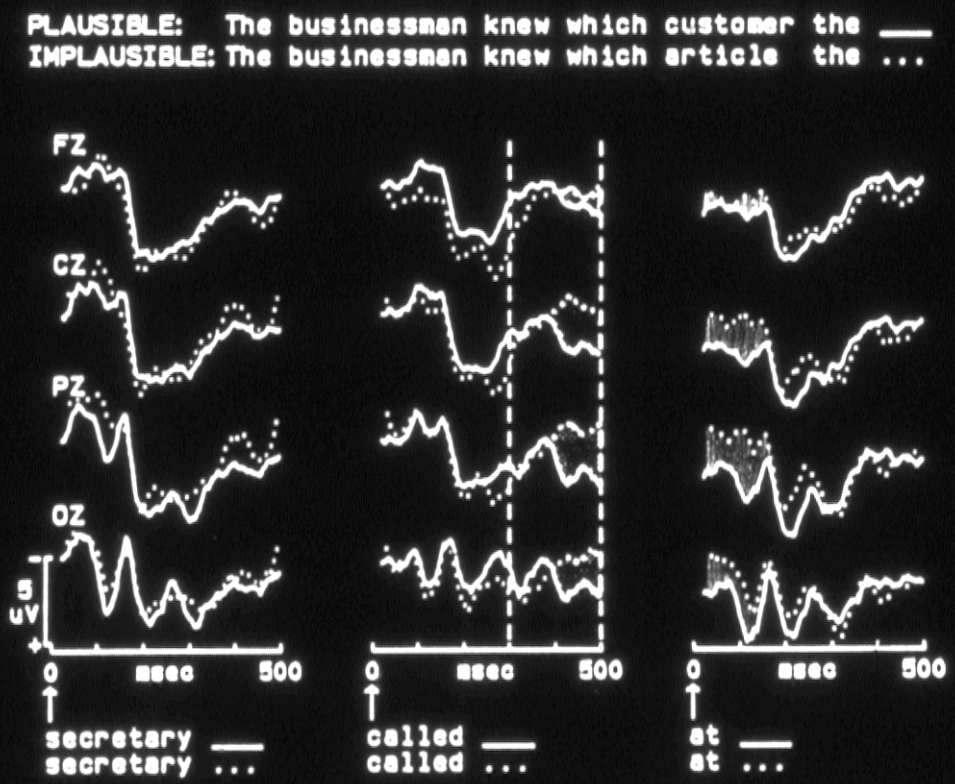
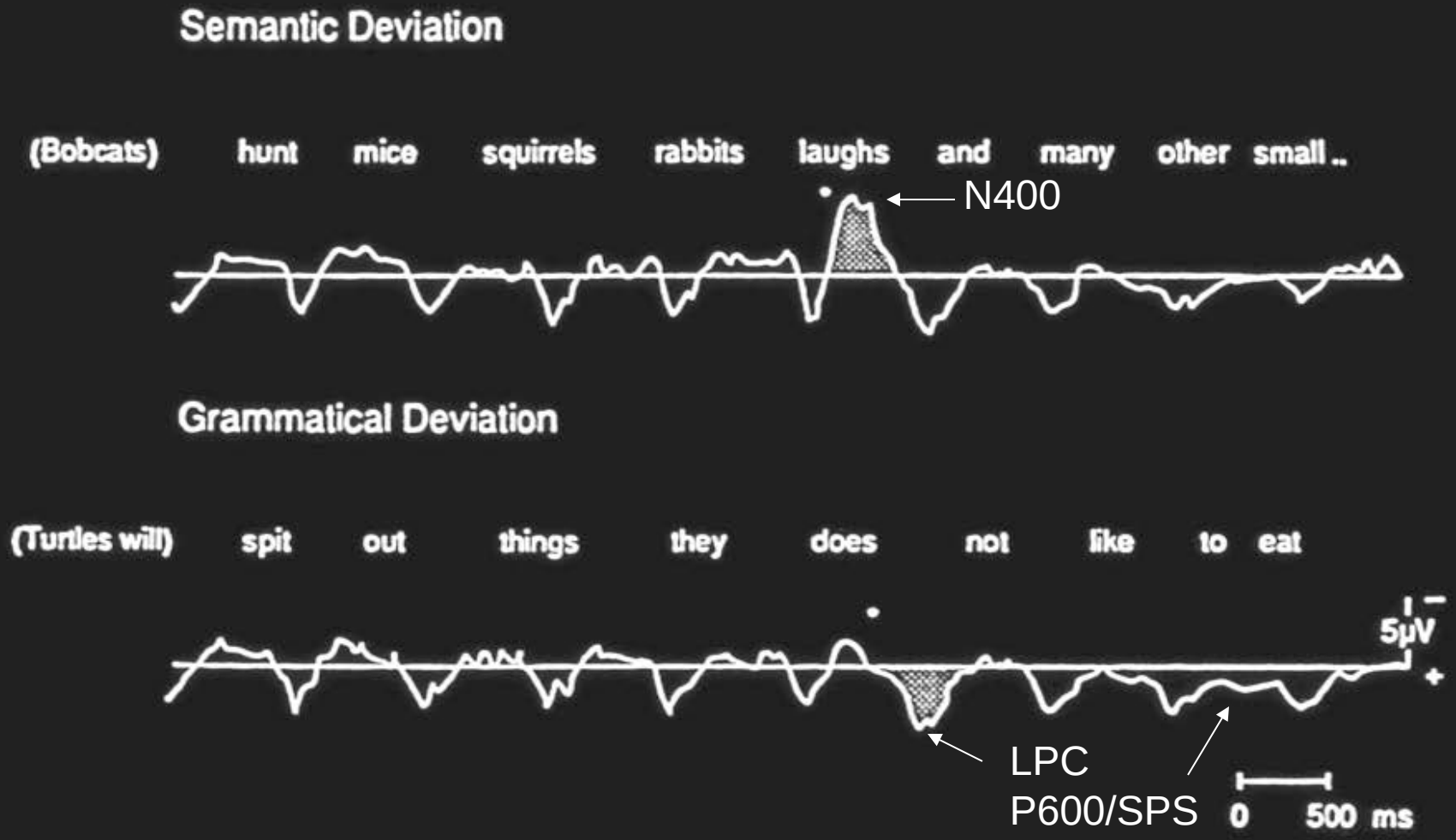


Fig. 2. Mean EP waveforms (32 subjects) for plausible and implausible filler-gap sentences. Solid lines represent the plausible condition and dotted lines the implausible condition. At the top of the figure appear the portions of the sentences preceding the words whose responses are shown, which appear under each panel. Vertical dashed lines at 300 and 500 msec in the middle panels indicate the 200-msec range across which N400 was quantified. The shading indicates the plausible–implausible differences found.


Semantic Deviation
(Bobcats) hunt mice squirrels rabbits laughs and many other small ..
N400
Grammatical Deviation
(Turtles will) spit out things they does not like to eat
5μV
LPC
P600/SPS
0 500 ms

P600 aka Syntactic Positive Shift (SPS)

In most cases (though many still need to be tested), lexico-semantic violations and grammatical violations elicit qualitatively different ERP componentry (see semantic P600 to complicate this division).

The little boy would only eat one chair ➔ N400 to chair vs carrot

The little boy would only eat one carrots. ➔ P600 to carrots vs carrot

The broker persuaded …

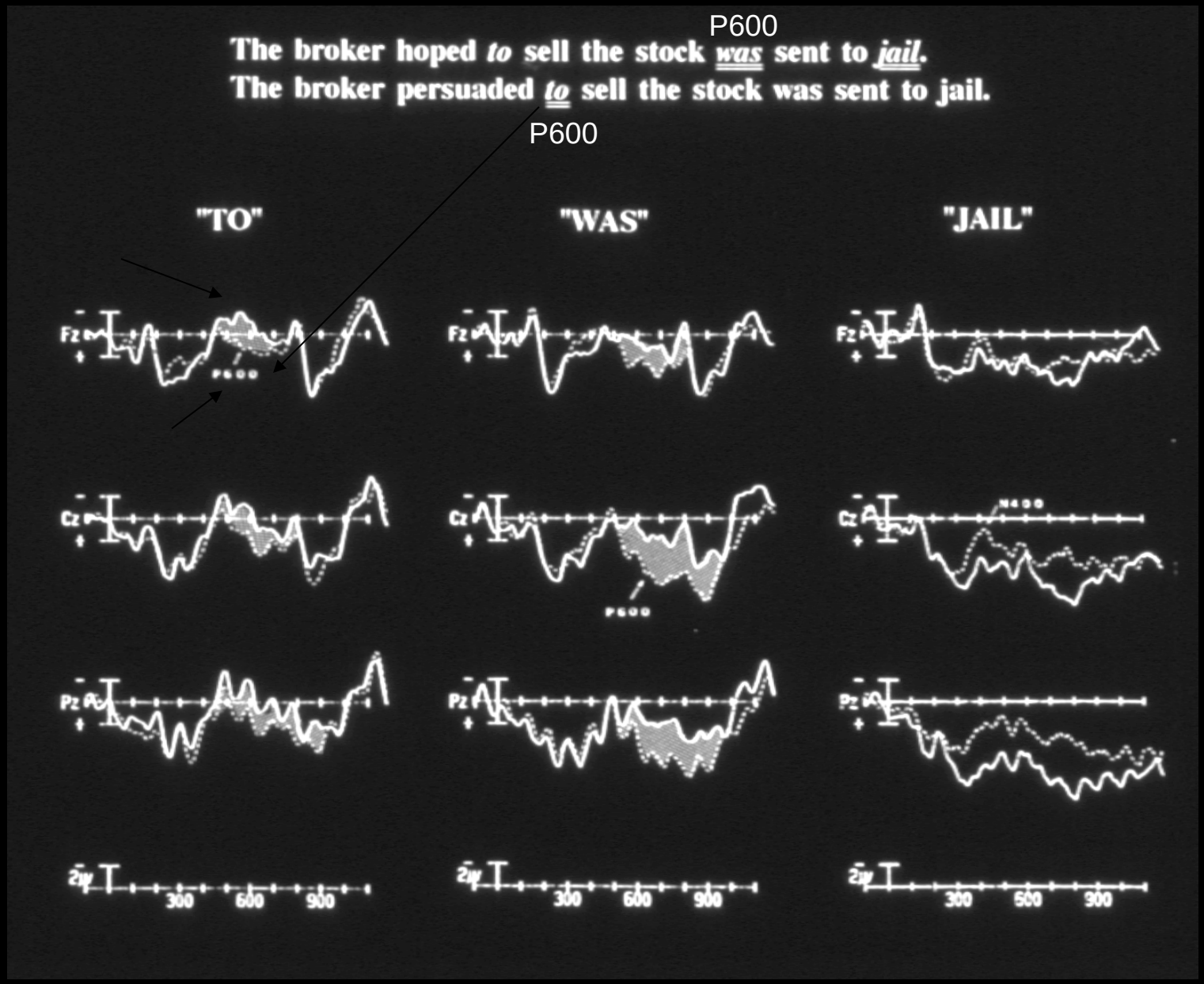
^ locus of temporary syntactic ambiguity

The broker persuaded the investor to ….
or
The broker (who was) persuaded to sell the stock hoped

2 possible interpretations: active vs passivized reduced relative clause

1. The broker hoped ***to*** sell the stock ***was*** sent to jail.
2. The broker persuaded ***to*** sell the stock ***was*** sent to jail.

Osterhout & Holcomb, 1992


P600
The broker hoped to sell the stock was sent to jail.
The broker persuaded to sell the stock was sent to jail.
P600
"TO"
"WAS"
"JAIL"
Fz
Cz
Pz
P600
N400
2μv
300
600
900

1. *Het verwende kind gooit het speelgoed op de grond.* (*The spoilt child throws the toys on the floor.*)
2. **Het verwende kind gooien het speelgoed op de grond.* (*The spoilt child throw the toys on the floor.*)

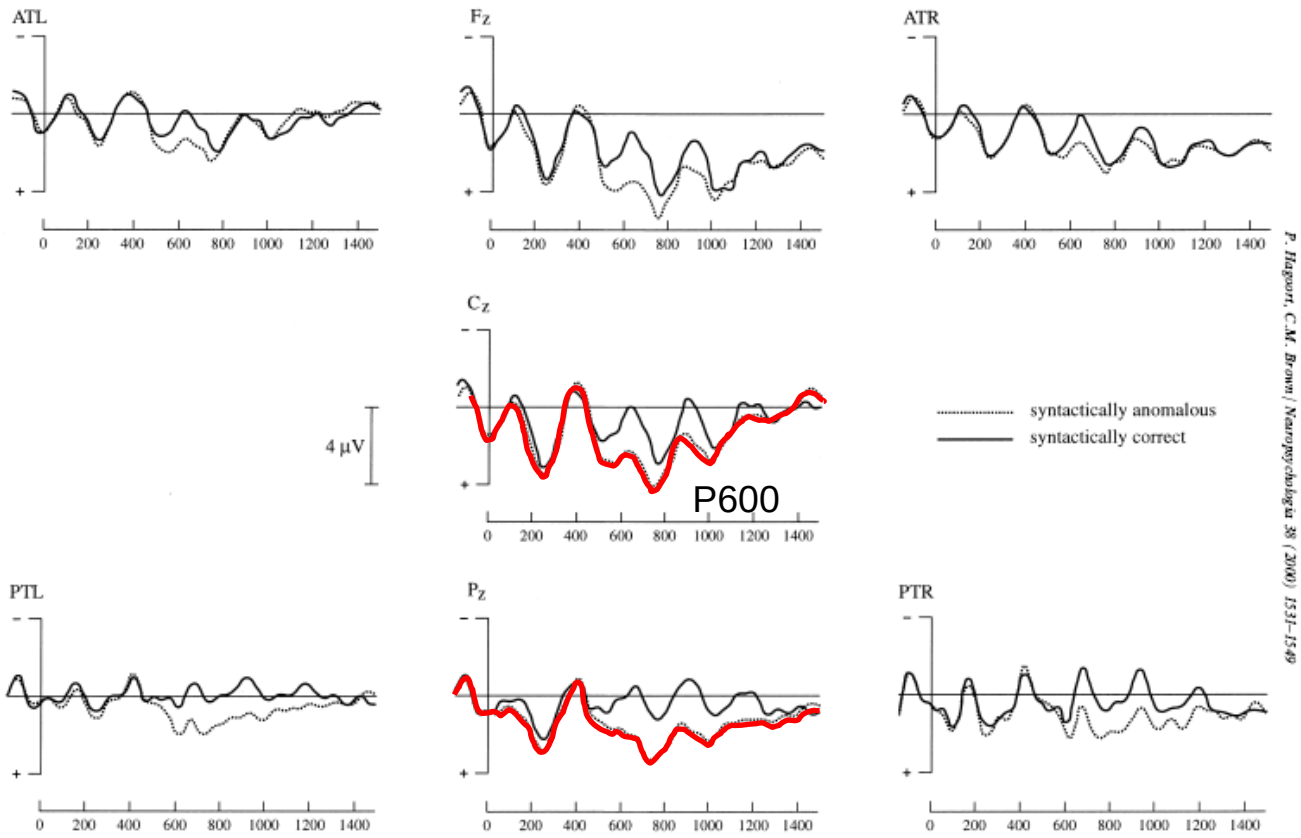


Fig. 1. Agreement condition, RSVP: Grand average ERPs (across all subjects and items), from 7 scalp sites, for the grammatically correct and incorrect critical words (CW). The onset of the CW is at zero milliseconds. The waveforms display the ERPs to the CW and the four following words. The time axis is in milliseconds. Each plot represents approximately 931 trials. Negativity is plotted upwards in this and all following figures.

P. Hagoort, C.M. Brown / Neuropsychologia 38 (2000) 1531–1549

WORD ORDER VIOLATION IN WRITTEN DUTCH

5. *De echtgenoot schrikt van de nogal emotionele reactie van zijn vrouw. (The husband [is startled] by the rather emotional response of his wife.)*
6. **De echtgenoot schrikt van de emotionele nogal reactie van zijn vrouw. (The husband [is startled] by the emotional rather response of his wife.)*

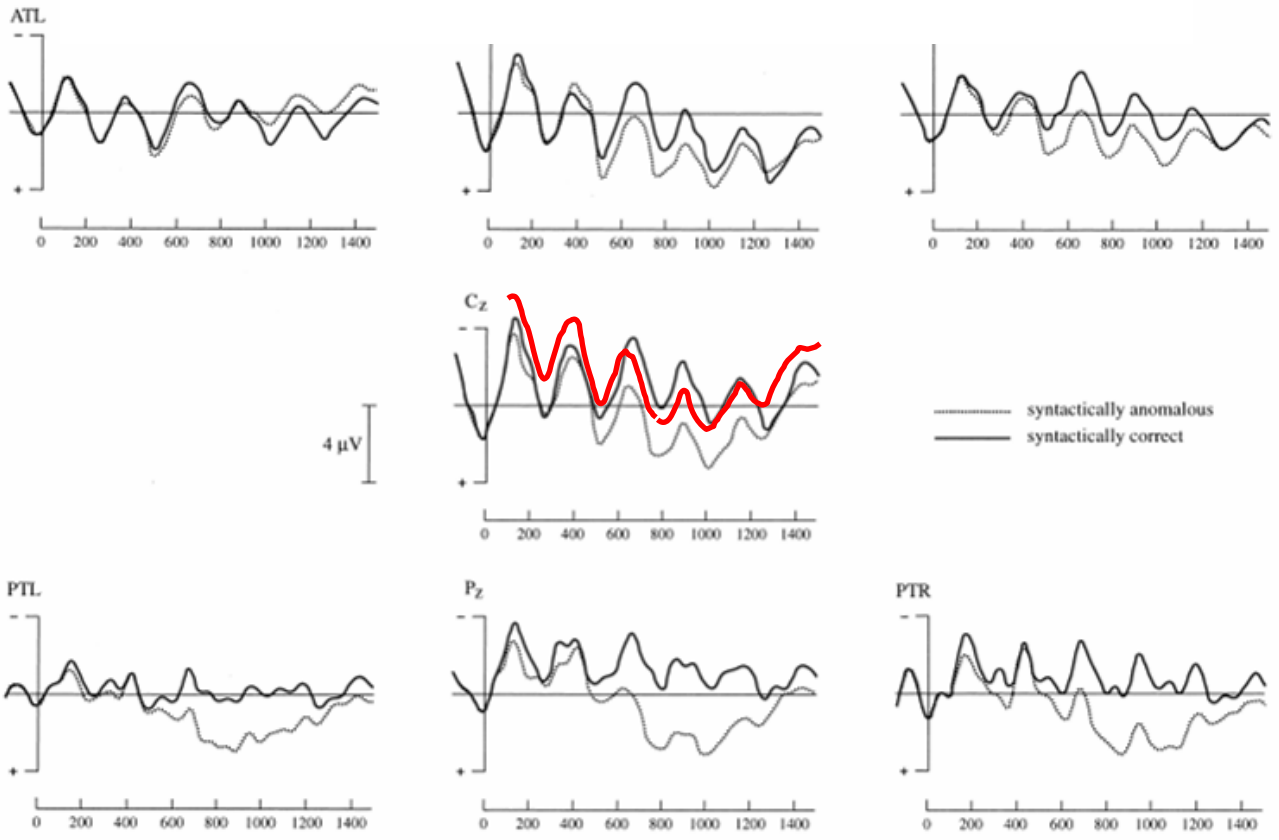
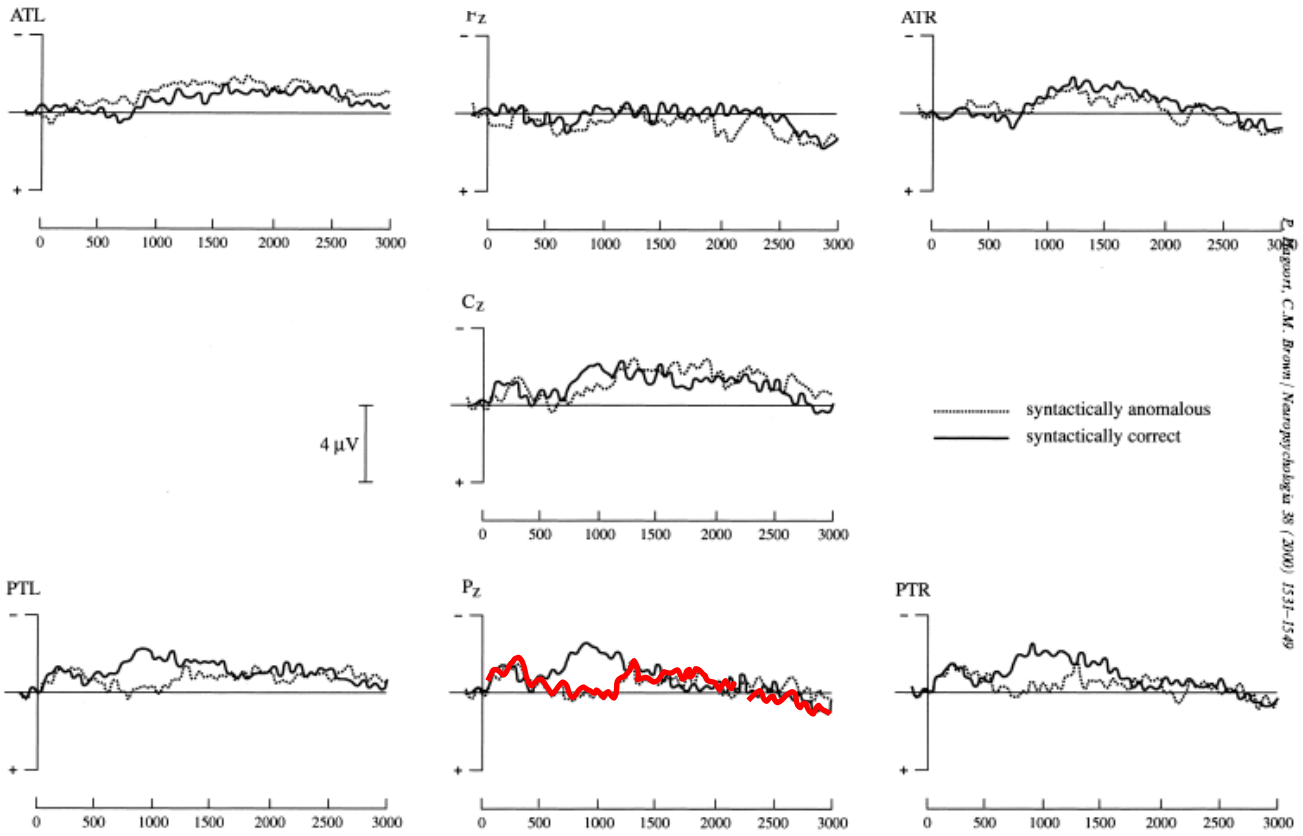


Fig. 5. Phrase structure condition, RSVP: Grand average ERPs (across all subjects and items), from 7 scalp sites, for the grammatically correct and incorrect critical words (CW). The onset of the CW is at zero milliseconds. The waveforms display the ERPs to the CW and the four following words. The time axis is in milliseconds. Each plot represents approximately 931 trials.

P. Hagoort, C.M. Brown / Neuropsychologia 38 (2000) 1531–1549

VERB NUMBER VIOLATION IN SPOKEN DUTCH

1. *Het verwende kind gooit het speelgoed op de grond. (The spoilt child throws the toys on the floor.)*
2. **Het verwende kind gooien het speelgoed op de grond. (The spoilt child throw the toys on the floor.)*



P. Hagoort, C.M. Brown / Neuropsychologia 38 (2000) 1531–1549

Fig. 7. Agreement condition, connected speech: Grand average ERPs (across all subjects and items), from 7 scalp sites, for the grammatically correct and incorrect critical words (CW). The onset of the CW is at zero milliseconds. The time axis is in milliseconds. Each plot represents approximately 786 trials.

WORD ORDER VIOLATION IN SPOKEN DUTCH

5. *De echtgenoot schrikt van de nogal emotionele reactie van zijn vrouw. (The husband [is startled] by the rather emotional response of his wife.)*
6. **De echtgenoot schrikt van de emotionele nogal reactie van zijn vrouw. (The husband [is startled] by the emotional rather response of his wife.)*

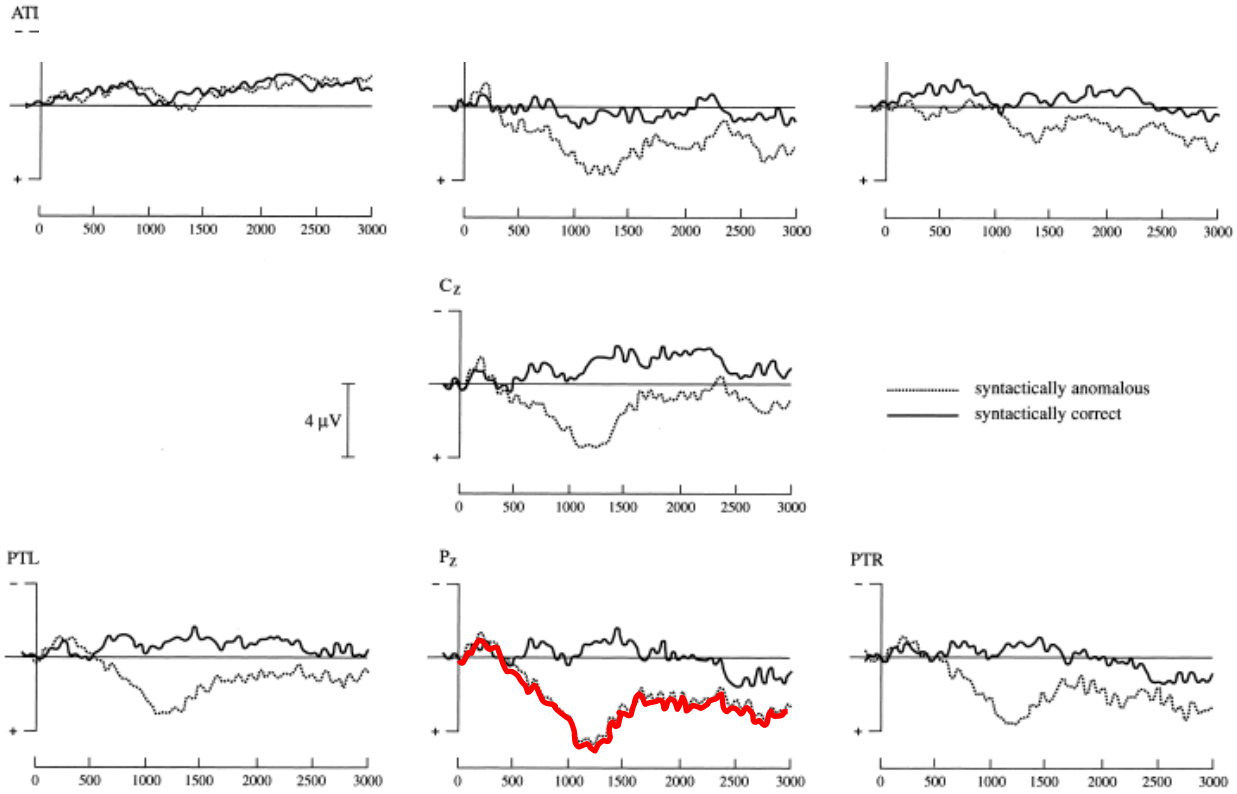
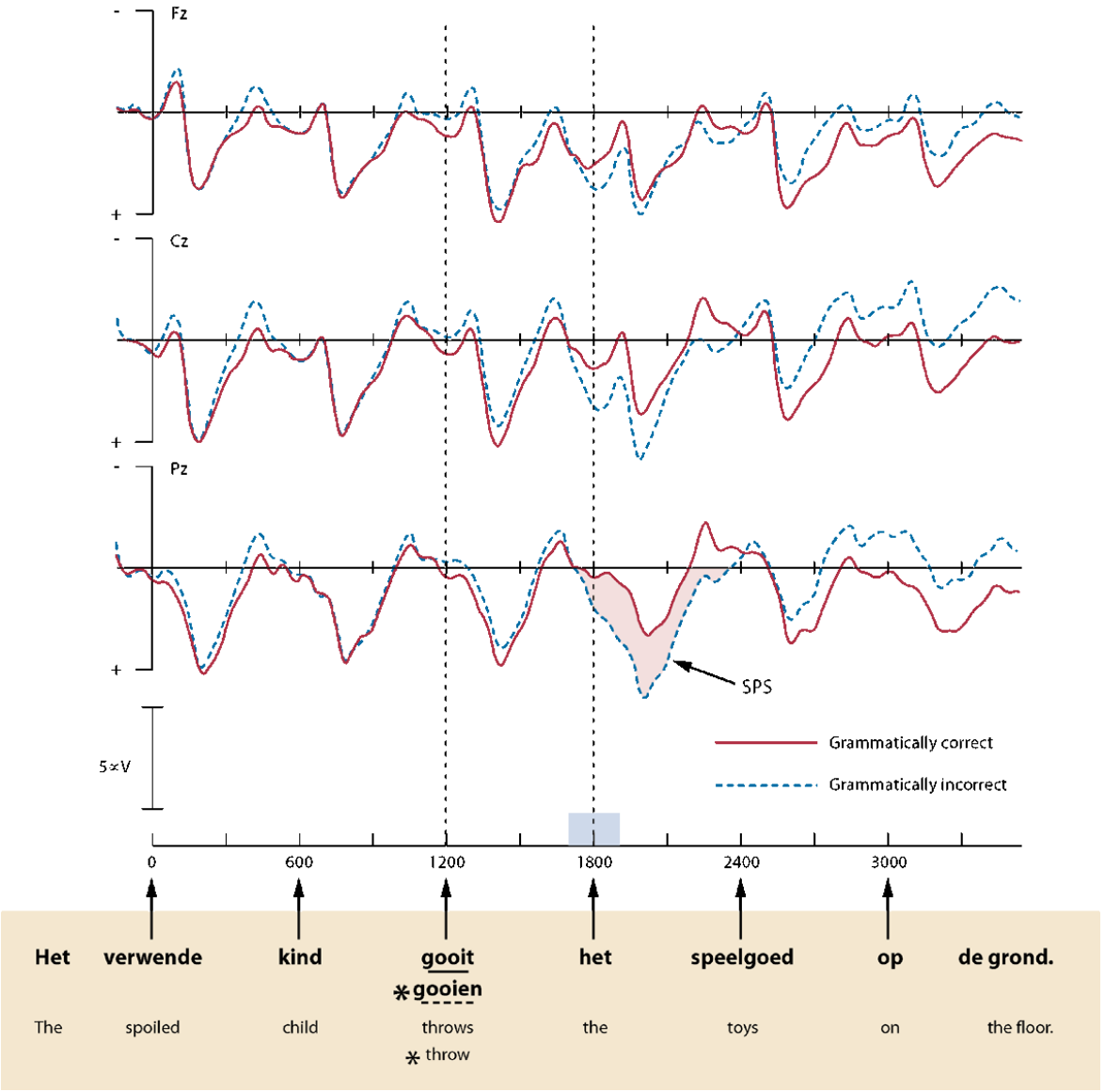


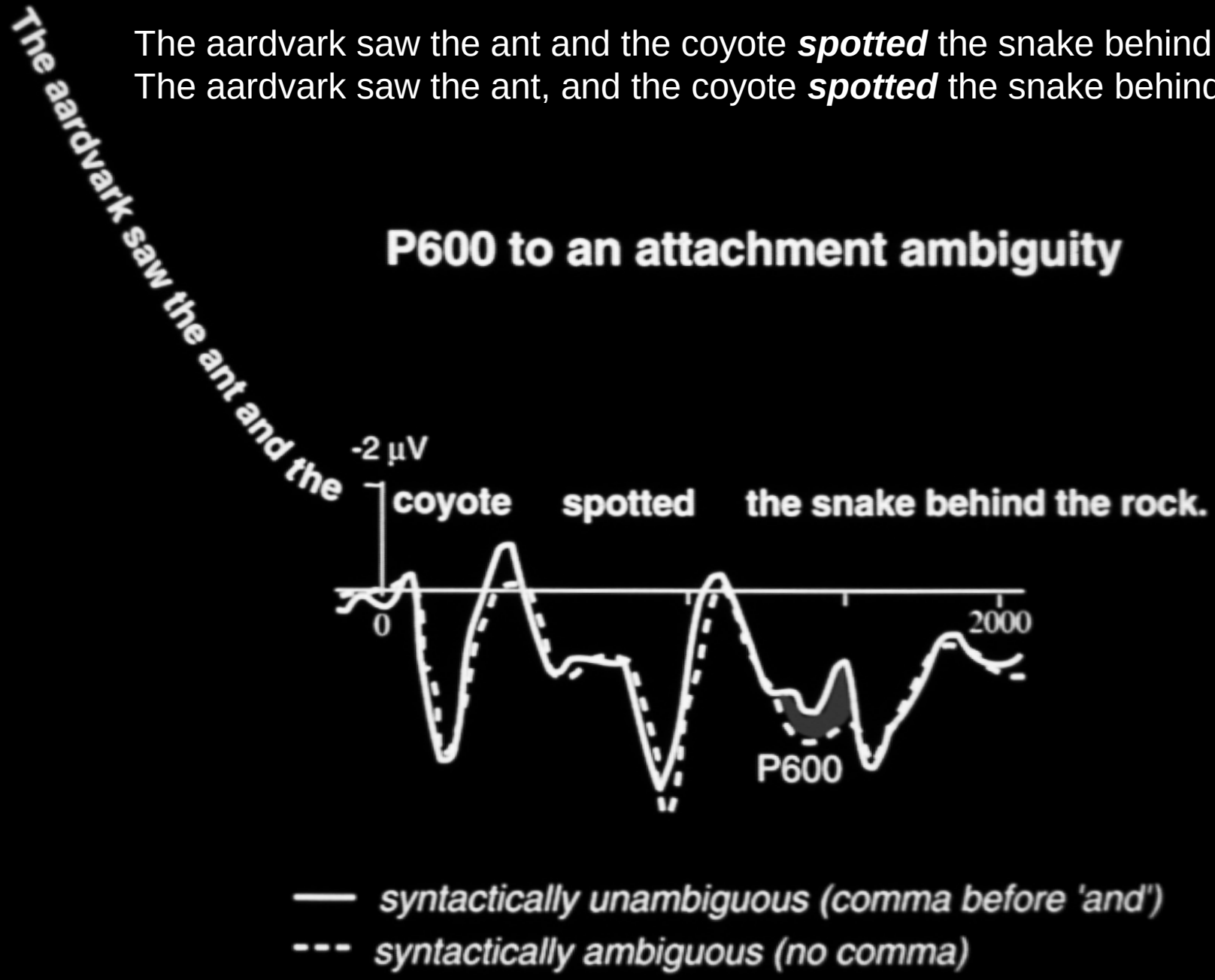
Fig. 9. Phrase structure condition, connected speech: Grand average ERPs (across all subjects and items), from 7 scalp sites, for the grammatically correct and incorrect critical words (CW). The onset of the CW is at zero milliseconds. The time axis is in milliseconds. Each plot represents approximately 786 trials.

P. Hagoort, C.M. Brown / Neuropsychologia 38 (2000) 1531–1549

P600: The P600 is a large positive component elicited by words after a syntactic violation, although it is not unique to violations.

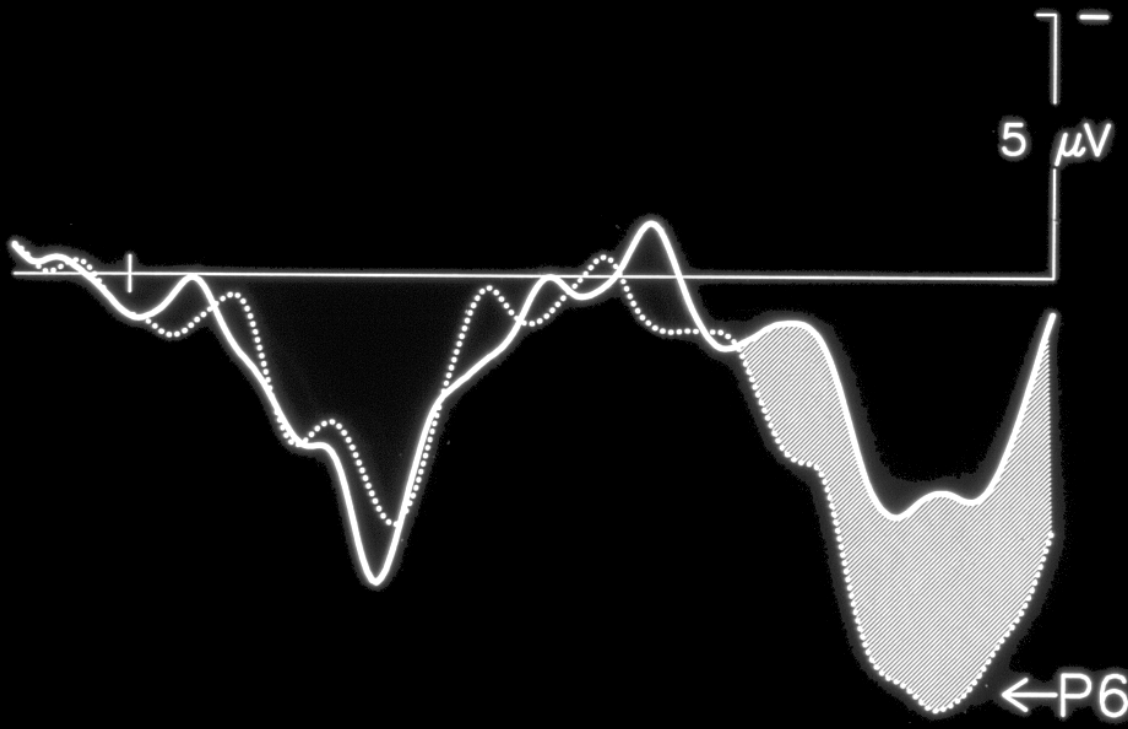


The aardvark saw the ant and the coyote ***spotted*** the snake behind the rock.
The aardvark saw the ant, and the coyote ***spotted*** the snake behind the rock.



Charles doesn't shave because ..... *him
——— he

tends to cut himself.



——— *Grammatical* ..... *Ungrammatical*

P600 sensitive to syntactic complexity within sentences that do not contain any structural violation – i.e., sentence well formed but syntactically more difficult or less preferred; e.g. those containing a syntactic ambiguity. But even without syntactic ambiguity can see P600 ..

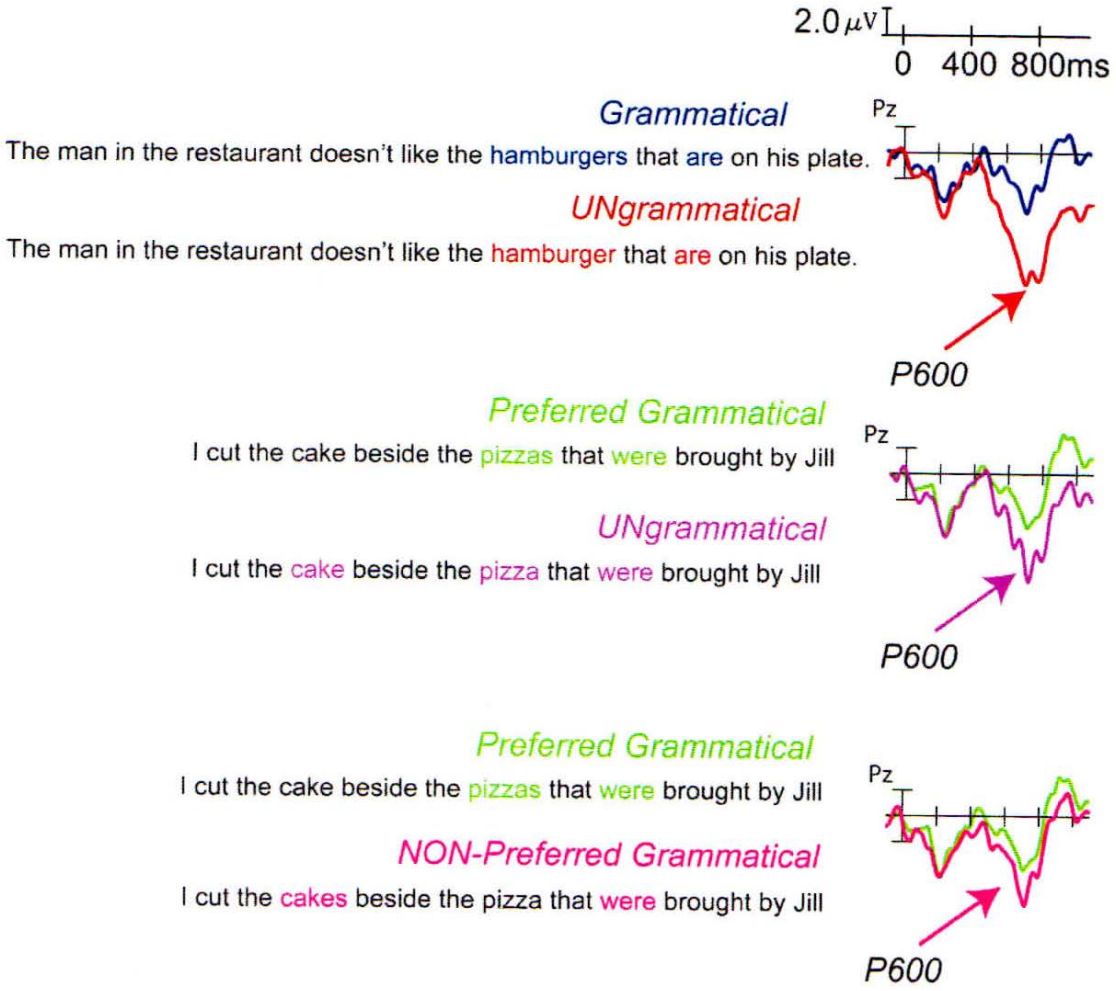


Fig. 15.17 P600 effects are also found to grammatical but less preferred syntactic continuations of sentences. In the top panel, the typical P600 effect to ungrammatical continuations is shown; when a verb and a noun do not agree in number (i.e., ". . . the

P600

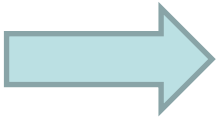
P600 has been observed in response to a wide variety of violation types, including

- subject-verb agreement,
- verb inflection,
- case inflection,
- phrase structure, and
- higher-level syntactic AS WELL AS NON-VIOLATIONS, e.g., in syntactically well-formed sentences with a non-preferred structure (e.g., garden path sentences) or with relatively complex syntactic structures, such as those with embedded long distance dependencies.

P600

Broad range of syntactic anomalies
Phrase structure violations
Number agreement violations
Gender and case marking agreement
Verb tense violations
Subcategorizationviolation
Violations of subjacency

Violations even in nonsensical sentences
The boiled watering can smokes/smoke the telephone in the cat.



P600 to violations of different types of structure
Music
Mathematical rules
Abstract sequences

Index process of structure building quite generally

Not limited to outrigiht structural violations

VIEWS ON FUNCTIONAL SIGNIFICANCE OF P600

P6 = P3b component, a more general purpose response to low probability target events often associated with some form of categorization and/or binary decision.

Alternatively, it indexes
(1) the inability of the parser to assign the preferred structure to the input
(2) a late, controlled (as opposed to automatic) process of syntactic re-analysis or repair once a syntactic error has been detected in a multi-stage parsing model,
(3) syntactic integration difficulty
(4) any kind of linguistic parsing difficulty (semantic, morphosyntactic, or orthographic).

Specific views on functional significance of P600

Role for P600 in processes of syntactic analysis and reanalysis or repair

Cost of reprocessing necessary when initial parse is disconfirmed (Osterhout)

Difficulty of syntactic integration (Kaan)

Third and final stage of of syntactic reanalysis when info from initial 2 stages cannot be reconciled *early phase structure building; semantic/verb argument info activation (Friederici)

Unification view of P600, index amt of time required to unify syntactic frames info one phrasal configuration. P600 more frontal when syntactic preferences are not met, and more posterior for outright syntactic violations

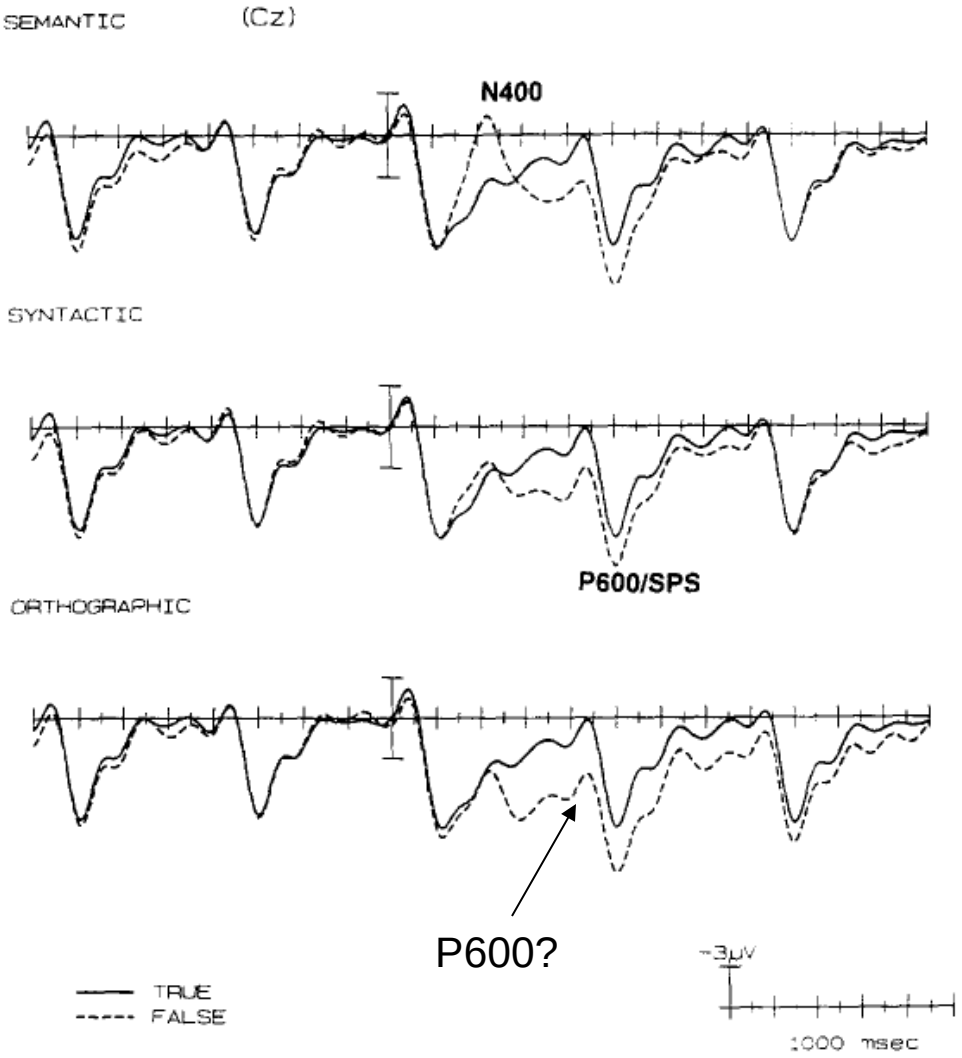


Fig. 4. Grand average ERPs with an extended epoch including the effects of the two words before and the two words after the critical word for the Cz electrode site.

(5)	Der Junge schlägt den Hund *The kid beats the dog*	Singular - match
(6)	* Der Mann trinken das Bier *The man drink the beer*	Singular - mismatch
(7)	Viele Passagiere zahlen die Fahrkarten *Many passengers pay the tickets*	Plural - match
(8)	* Manche Lehrer bestraft die Schüler *Some teachers punishes the students*	Plural - mismatch

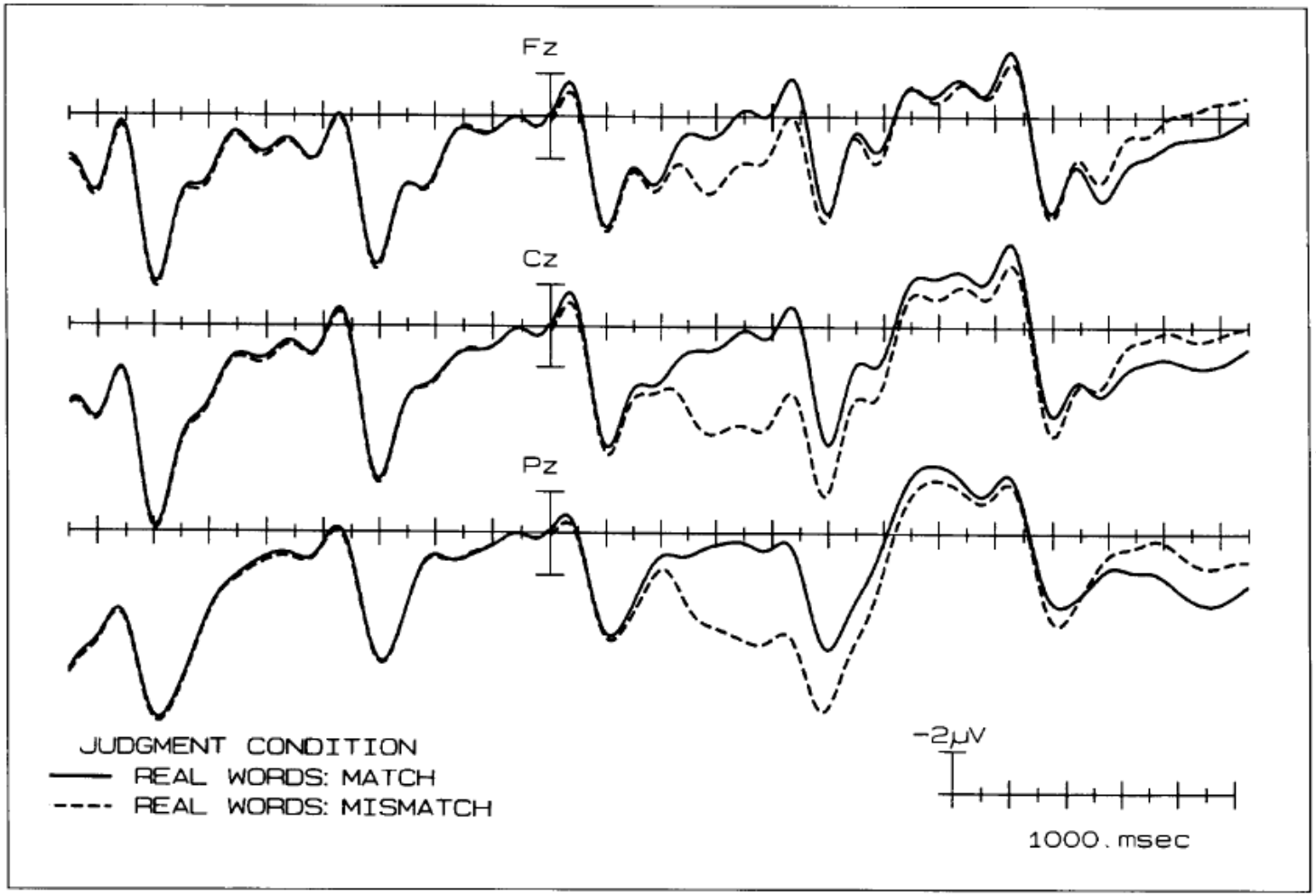


Figure 4. ERPs over the entire sentence from the real-word experiment with judgment instructions. The vertical line marks the onset of the verb. The preceding words (denominator, noun/subject) occur at −1600 and −800 msec, the two words following the verb at 800 and 1600 msec. The mismatching verb gives rise to a long-lasting positivity beginning at about 400 msec and extending into the waveform of the following word. For this effect a parietal maximum is apparent.

(1)	Der Kruke plötzt den Schruck	Singular -
	A flurk nerches the minch	match
(2)	* Das Klenck frunen den Wech	Singular -
	A mizzel quanch the plurr	mismatch
(3)	Viele Wenken donzen den Tend	Plural -
	Many fluzzies brin the chink	match
(4)	* Manche Verzinker trögelt den Blotz	Plural -
	Some globbies higgles the vlinch	mismatch

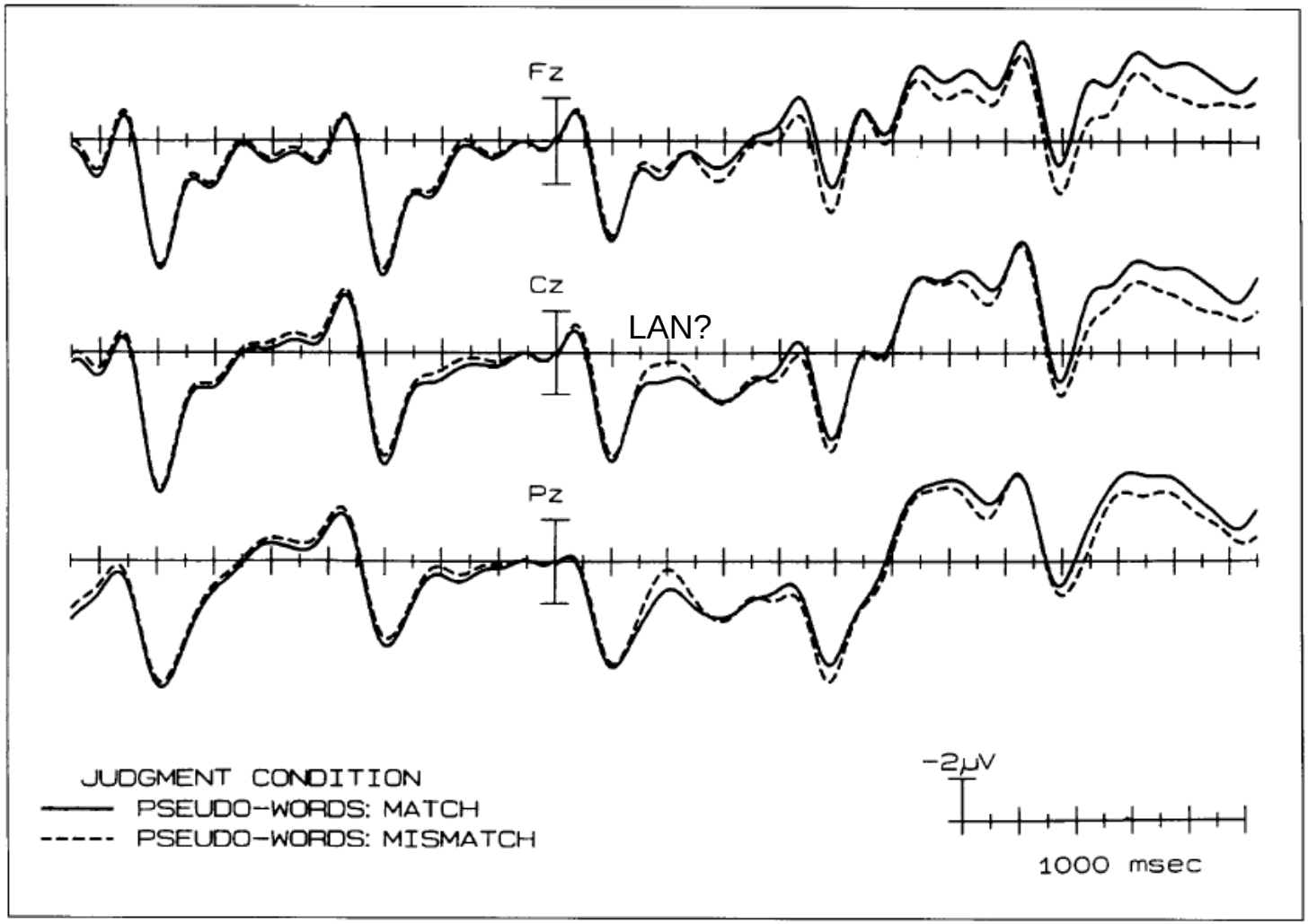
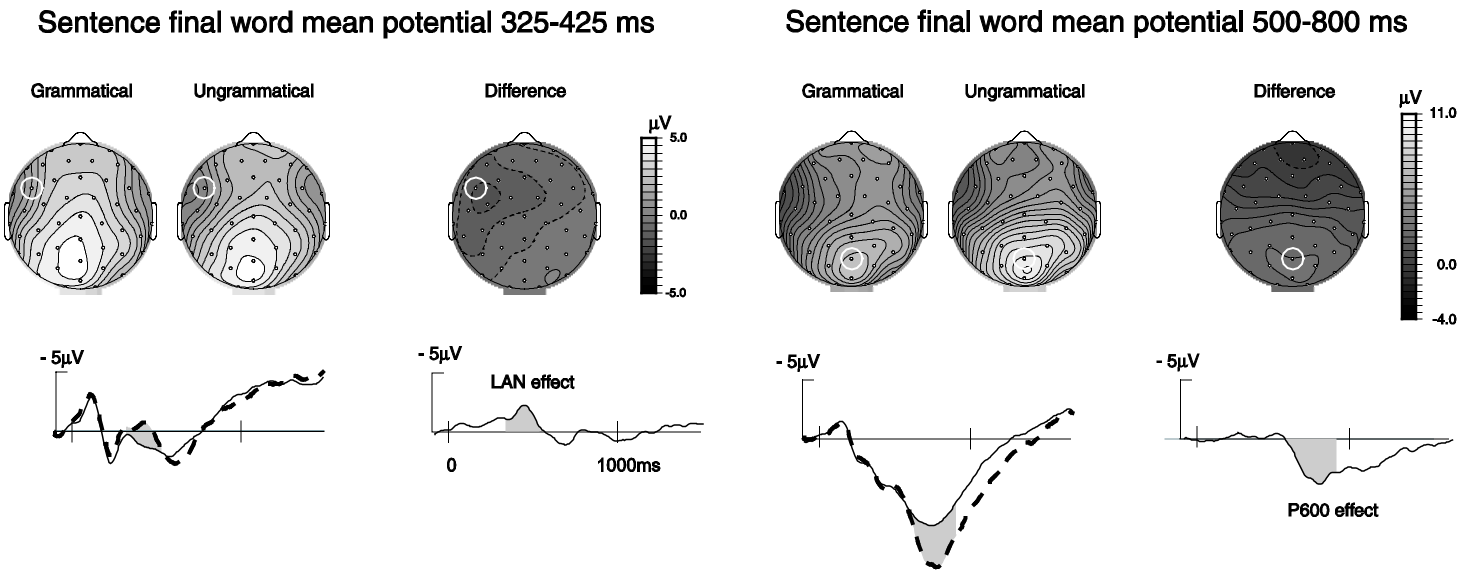


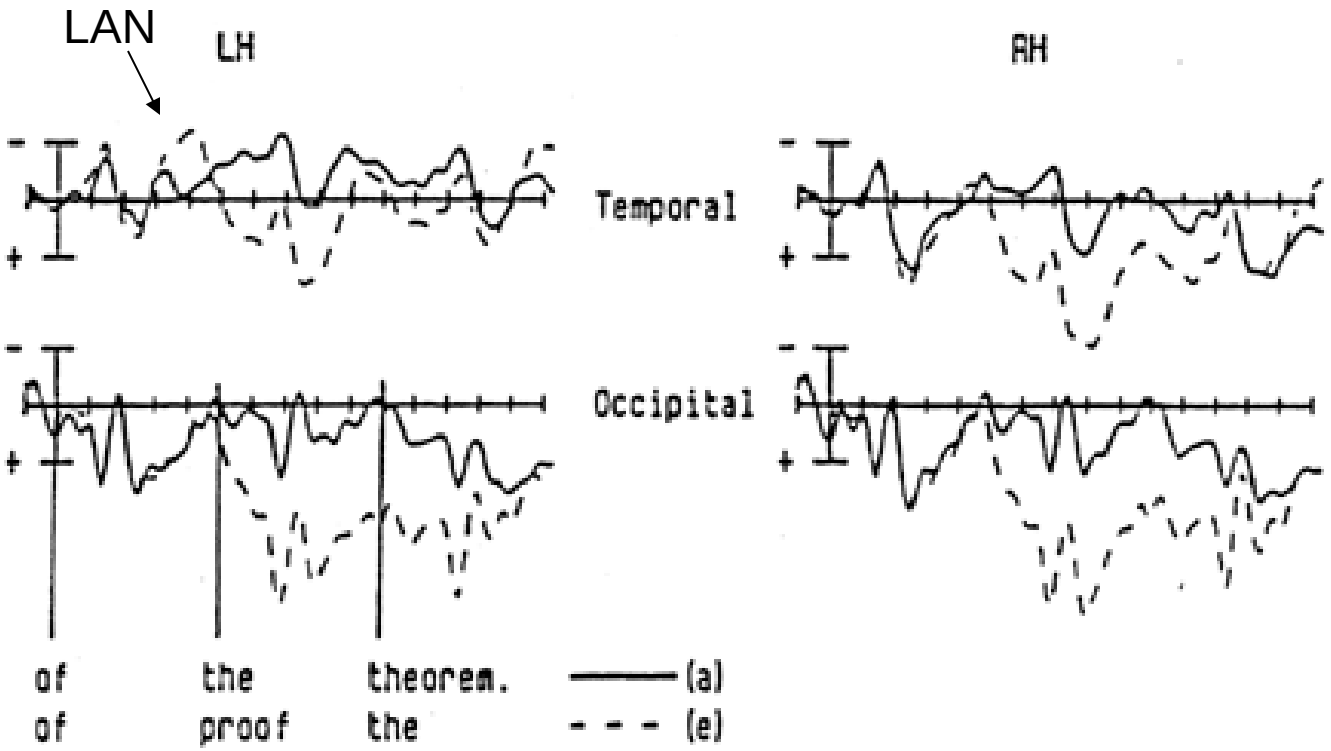
Figure 3. ERPs over the entire sentence from the pseudo-word experiment with judgment instructions. The vertical line marks the onset of the pseudo-verb. The preceding words (denominator, pseudo-noun/subject) occur at −1600 and −800 msec, the two words following the verb at 800 and 1600 msec. As in the experiment with memory instructions, mismatching pseudo-verbs are characterized by a more negative waveform beginning at approximately 180 msec. This effect is not as prolonged as in the experiment with memory instructions (see also Fig. 5).



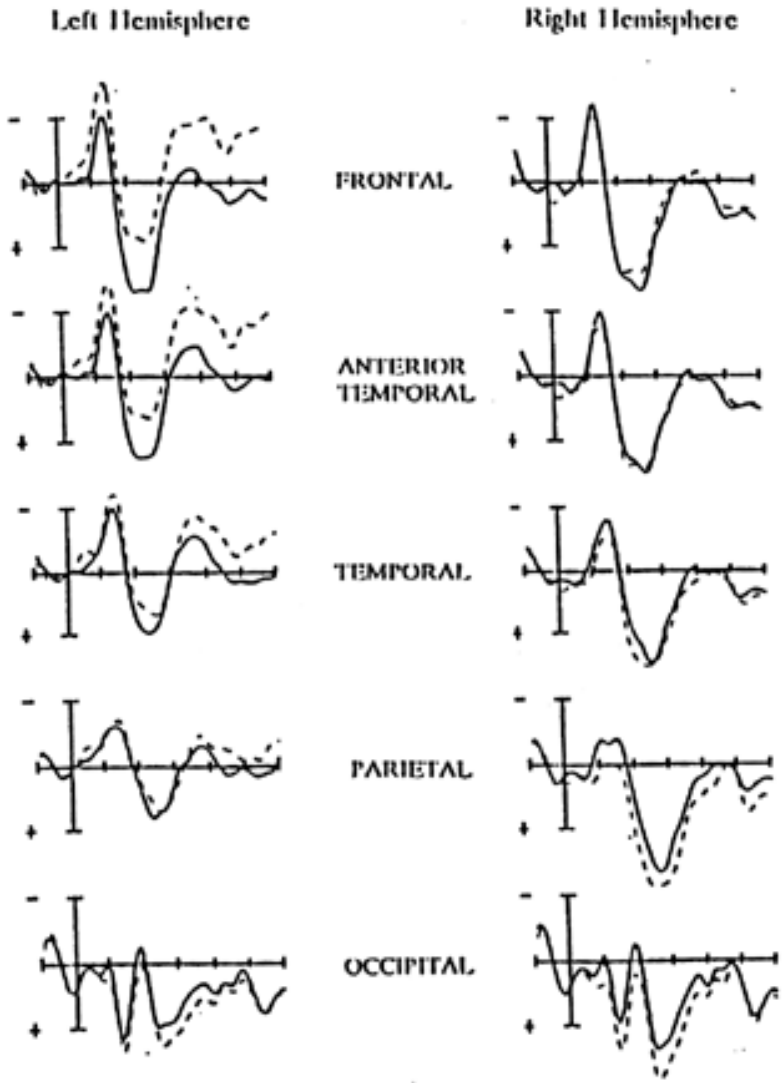
GRAMMATICAL SENTENCES: Once a month she goes to the theater with me.

UNGRAMMATICAL SENTENCES: Once a month she goes to the theater with I.

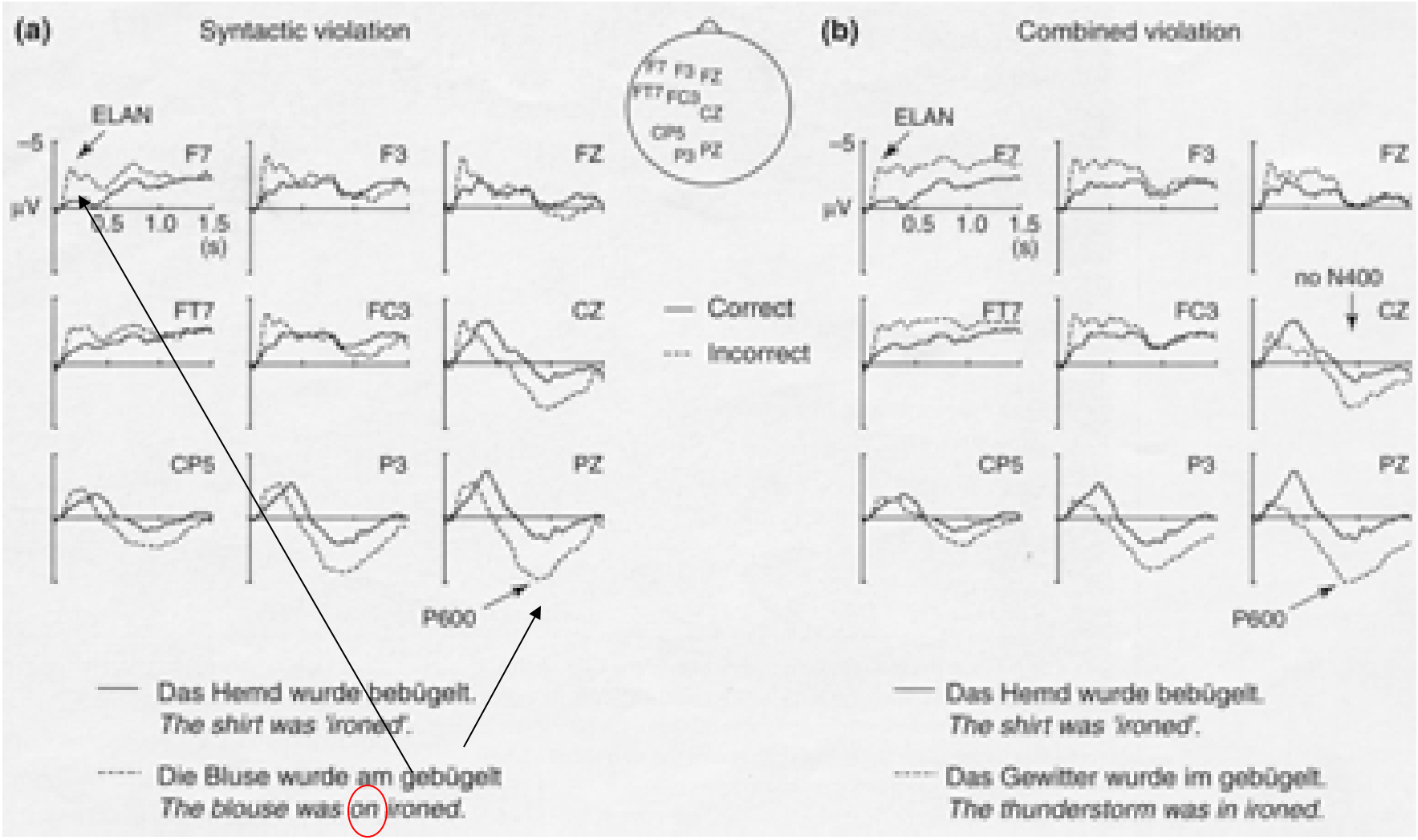
Phrase Structure Violation (word order)



Wh-movement (Specified subject constraint)



The scientist criticized Max's proof of the theorem.
What did the scientist criticize Max's proof of?



ELAN: index of early automatic process of local phrase structure building, during which word category information is used to assign initial syntactic structure.

LAN: reflect difficulties in the use of grammatical (as opposed to semantic) information like inflectional morphology (person, number, gender, and case features) used in thematic role assignment

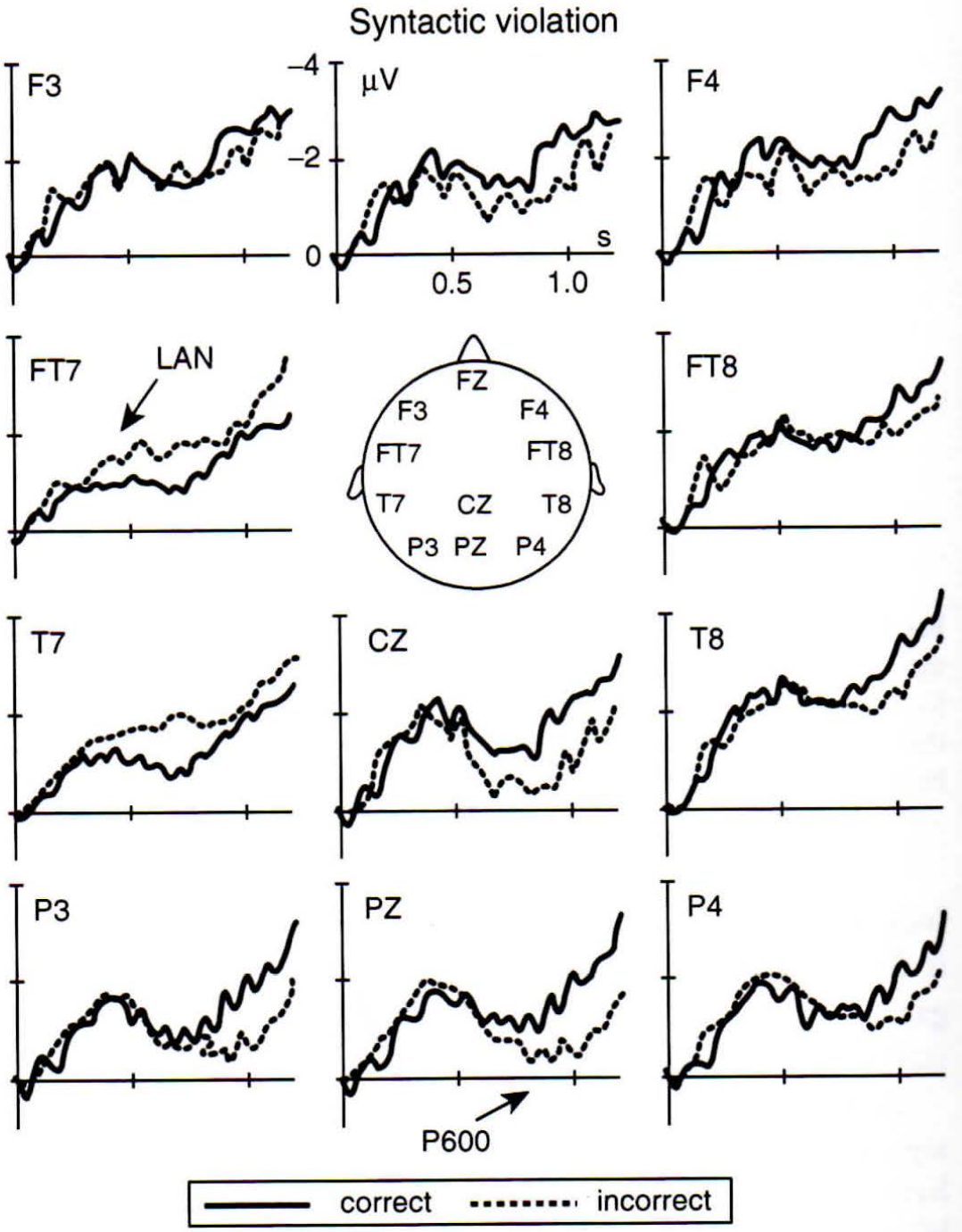


Fig. 15.22 The LAN and the P600 response to syntactic violations (dotted line). Reprinted with permission from Friederici et al. (2004).

Is LAN specific to syntactic violations?

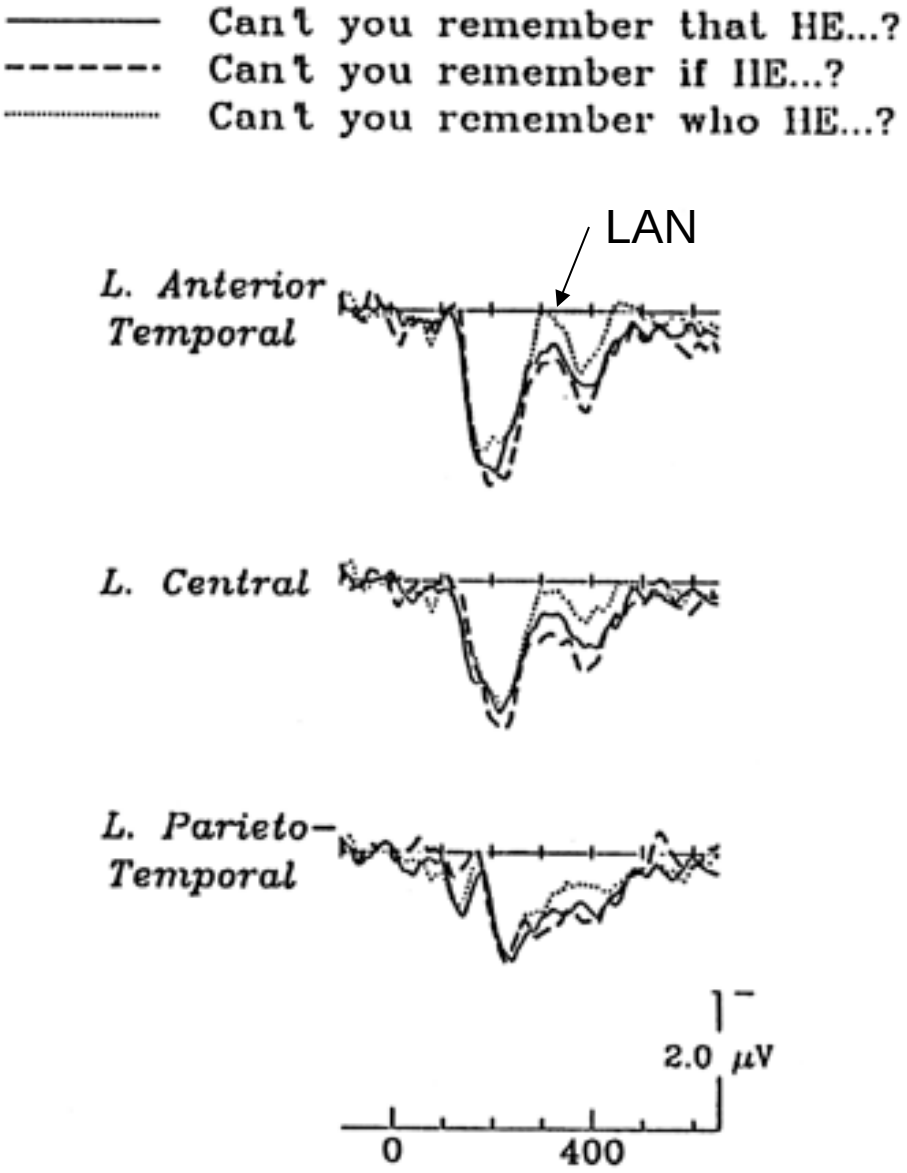
Can’t you remember that he advised them against it on previous occasions?
Can’t you remember if he advised them against it on previous occasions?
Can’t you remember who he advised ___ against it on previous occasions?

Filler gap

Can’t you remember that he advised them against it on previous occasions?
Can’t you remember if he advised them against it on previous occasions?
Can’t you remember who he advised ___ against it on previous occasions?

Filler gap

Note all of these are perfectly grammatical sentences!



Any condition containing a filler-gap relation elicits a larger negativity over left anterior sites when compared to conditions in which this filler gap relation is absent.

——— (7d) What did you remember that HE advised them AGAINST ___ ON...?

– – – – (7e) What can't you remember if HE advised them AGAINST ___ ON...?

..... (7f) What can't you remember who HE advised ___ AGAINST ___ ON...?