Event-Related Potentials in the Study of Language

Chapter · December 2008

DOI: 10.1016/B978-0-08-045352-1.00009-4

2 authors:

Karsten Steinhauer
McGill University

John F Connolly
McMaster University

CHAPTER

9

Event-Related Potentials in the Study of Language

KARSTEN STEINHAUER[1] and JOHN F. CONNOLLY[2,3]

[1]*Centre for Research on Language, Mind and Brain (CRLMB) and School of Communication Sciences and Disorders (SCSD), Faculty of Medicine, McGill University, Montréal, Québec, Canada*

[2]*Centre de Recherche, Institut Universitaire de Gériatrie de Montréal (CRIUGM), Université de Montréal, Montréal, Québec, Canada*

[3]*Centre de Recherche en Neuropsychologie et Cognition (CERNEC), Département de Psychologie, Université de Montréal, Montréal, Québec, Canada*

ABSTRACT

Why bother recording event-related brain potentials (ERP) in language studies? What is their "added value?" We attempt to answer these questions by providing an overview of recent ERP work investigating word segmentation and phonological analysis during speech processing, semantic integration mechanisms, syntactic processing, and the analysis of prosody in speech. Our view is that the inclusion of ERP has increased our understanding of how the brain accomplishes language. It is equally true that for every question answered there are new questions raised; we address some of these yet unresolved questions as well. The skeptical reader may also ask, "so what?" Are there any practical advantages to such work? The fact is there are practical benefits, such as the newly developed ability to assess cognitive abilities in non-communicative patients including those in so-called vegetative states – a significant advance in health care that is the direct result of basic ERP research in neurolinguistics.

9.1. INTRODUCTION

Investigating how the brain accomplishes language comprehension is a particular challenge compared to other areas of cognitive neuroscience. Animal models are of limited value given that no other species has a comparably complex communication system. On the other hand, areas as distinct as sensory physiology and formal linguistics contribute important details to our understanding of language processes in the brain. Most ERP research discussed here is strongly rooted in psycholinguistic models of word recognition, syntactic parsing, and the online integration of information. This work provides a solid foundation upon which to examine cognitive factors and the brain mechanisms involved in the transformation of a low-level signal into the highly complex symbolic system we know as human language.

Three major goals of using neuroimaging are to understand *where* language is processed in the brain and *when* and *how* the different levels of linguistic processing unfold in time. Thanks to their ability to provide continuous online measures with an excellent temporal resolution, even in the absence of behavioral tasks, ERPs contribute primarily to the second and third goals and can add the valuable perspective of real-time brain dynamics underlying linguistic operations. We will concentrate on these by making reference to a number of established "ERP components," that is, characteristic brain potentials at the scalp assumed to reflect specific neurocognitive processes, and, on occasion, corresponding event-related magnetic field (ERMF) research. We will outline the factors that influence these brain responses, and by inference, the linguistic processes they reflect. As ERP and ERMF measures are not completely without power in addressing *where* in the brain certain language functions may occur, those aspects will briefly be mentioned as well.

ERP research in linguistics has historically had a strong element of component discovery since the first "language" component, the "semantic" N400, was observed (Kutas & Hillyard, 1980). In the intervening years additional ERP components associated with acoustic–phonetic, phonological, orthographic, prosodic, and syntactic processes have been discovered. Those of them concerned with basic operations such as phoneme discrimination or word segmentation tend to be early (100–200 ms), fast, and automatic. Other components reflect integration or revision processes and tend to have larger latencies (up to 1 s). Parallel processes can be distinguished primarily in terms of ERP scalp distributions.

A recent theme that has gained increasing prominence is the degree to which these "linguistic" components are actually domain specific. Most of them have been described initially as being related to language processes only. However, subsequent research has usually weakened the case for domain specificity. For example, the P600 (Osterhout & Holcomb, 1992) had been linked to syntactic processing. More recently, however, it has been proposed that language and music share processing resources and that a functional overlap exists between neural populations that are responsible for structural analyses in both domains (Patel *et al*., 1998). It will become apparent that most "linguistic" ERP components may also be associated with non-linguistic functions. It might even be proposed that some of them might be more accurately thought of as domain-non-specific responses that reflect basic operations critical for, but not limited to, linguistics processes.

9.2. LANGUAGE-RELATED COMPONENTS AND THEIR FUNCTIONAL SIGNIFICANCE

The following subsections will discuss which ERP components have contributed to our understanding of psycholinguistic processes in phonology, lexical/conceptual semantics, syntax, as well as their respective interactions.

9.2.1. The N100: An Exogenous Component with Linguistic Functions?

The complexity of examining language functions with ERP is captured very well by the first component that we will discuss, the N100: a *N*egativity peaking around *100* ms. Long considered an exogenous response sensitive to the physical features (e.g., loudness or brightness) of an auditory, visual, or tactile stimulus, it has more recently been linked to word segmentation processes (Sanders & Neville, 2003). Noting the disagreement in the literature as to whether continuous speech stimuli elicit the early sensory components (including the N100), these studies sought to clarify whether word onsets within a context of continuous speech would elicit the early sensory or "obligatory" components. This work also examined whether the hypothesized word onset responses were related to segmentation and word stress. ERPs to word initial and word medial syllables were obtained within different types of sentence context. It was found that word onset syllables elicited larger anterior N100 responses than word medial syllables across all sentence conditions.

Word onsets in continuous speech can vary in their physical characteristics (e.g., loudness, duration) by virtue of whether the syllable is stressed or unstressed. Thus, word onset effects on the N100 were examined as a function of word stress with the finding that stressed syllables evoked larger N100 responses than unstressed syllables at electrode sites near the midline. Such an effect was expected given the physical differences that exist between stressed and unstressed syllables. However, it was concluded that the N100 was monitoring more than the physical characteristics of the stressed and unstressed syllables because the N100 to these stimuli showed a different scalp distribution compared to that seen for the N100 to word onset and word medial syllables which had been equated for physical characteristics. Further evidence for a language-related role for the N100 was found in an examination of Japanese–English bilinguals who failed to show N100 segmentation effects to English stimuli similar to native English speakers. This observation contrasts with the finding that the Japanese–English bilinguals showed clear N100 responses to sentence onsets thus exhibiting normal acoustic ERPs. The conclusion was made that non-native speakers do not use the acoustic differences as part of a speech comprehension system in the same manner as native speakers. Although these effects require replication as a final confirmation, they nevertheless demonstrate very well the neural flexibility involved in language function as well as the "multipurpose" nature of some ERP components that can reflect simple acoustic processing or complex linguistic segmentation. This work also demonstrates quite well the importance of evaluating all aspects of an ERP component insofar as the primary difference between the N100 as an acoustic or language component was its scalp distribution and thus, by implication, its neural generators.

9.2.2. Prelexical Expectations: The Phonological Mapping Negativity

Terminal words of spoken sentences that violate contextually developed phonological expectations (as in *1b*) elicit this fronto-centrally distributed ERP component that peaks in the late 200 ms range (270–310 ms) and is earlier than and distinct from the N400 reflecting pure semantic anomalies (*1c*) (see also Section 9.2.3). In combined violations of phonological and semantic expectations (*1d*), the Phonological mapping negativity (PMN) precedes the N400 (Figures 9.1 and 9.2(b)).

(1a) Father carved the turkey with a knife (expected word: knife)
(1b) The pigs wallowed in the pen (mud)
(1c) The gambler had a streak of bad luggage (luck)
(1d) The winter was harsh this allowance (year)

This component was labeled the phonological mismatch negativity (PMN) (Connolly & Phillips, 1994, from which

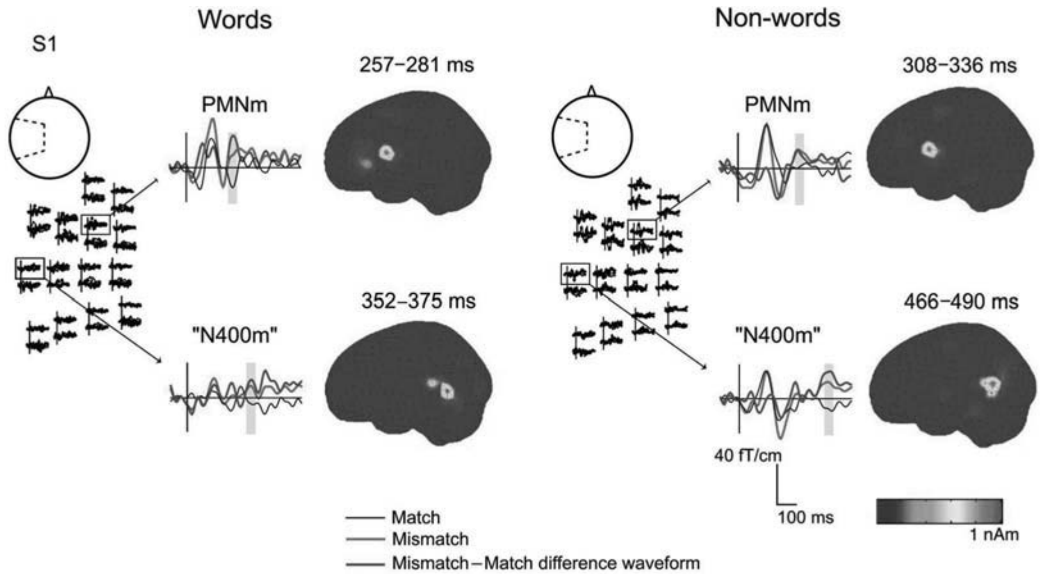


FIGURE 9.1 Phonological mapping negativity (PMN) and semantic N400. MEG responses to words (left) and non-words (right) for one participant for those left-hemisphere channels showing maximum amplitude for the magnetic PMN (PMNm) and the N400-like response. The corresponding estimates of the PMN- and N400m-like response sources (over a 25 ms time window centered at the peak of the response) are depicted in the brain images. The gray vertical bars indicate the 50 ms time periods within which significant PMNm- and N400m-like responses occurred. *Source*: Modified after Kujala *et al*., 2004 (see Plate 9).

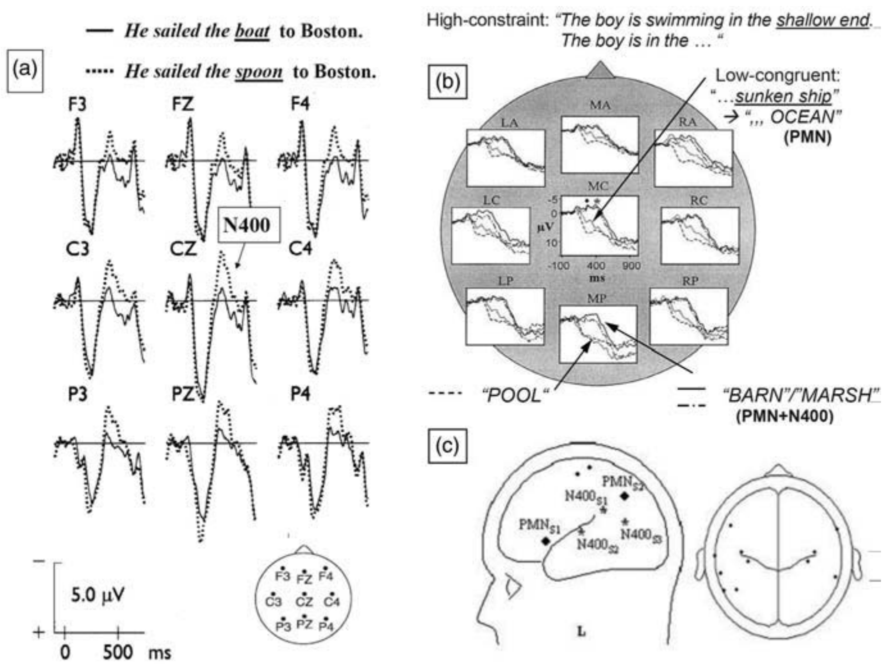
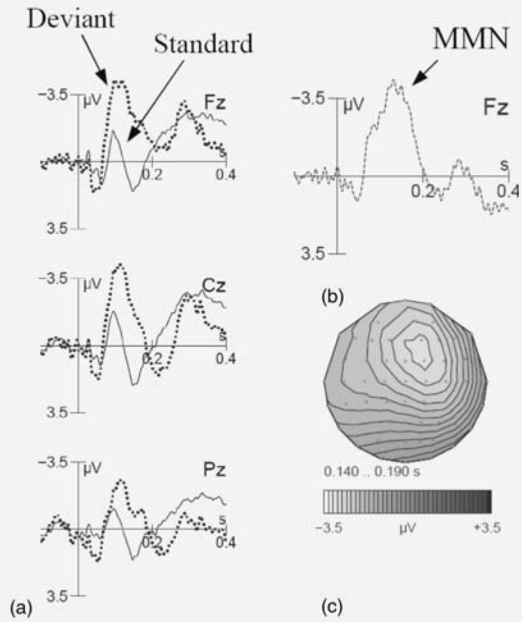


FIGURE 9.2 ERPs to target words illustrating N400 effects. Negative polarity is plotted upwards. (a) Semantic anomaly in sentences. Semantically implausible content words in sentence contexts elicit larger centro-parietal N400s (dotted lines) than plausible words (solid lines) between 300 and 600 ms. *Source*: Modified after Steinhauer *et al*. (2001). (b) PMN and N400 effects in a cross-modal priming study in which written sentences that ended in subordinate words primed superordinate words that ended spoken sentences. Exemplar-subordinate probabilities for congruent endings determined high-constraint primes (shallow end) or a low-constraint primes (sunken ship) which primed auditory target words in the paired sentences (in capitals) that were either congruent (Pool/Ocean) or not (Barn/Marsh). While incongruent targets (e.g., Barn/Marsh) always elicited PMNs and N400s, congruent targets following low-constraint contexts (Ocean) yielded PMNs only (L = left, R = right, M = middle, A = anterior, C = central, P = parietal). *Source*: Modified after D'Arcy, 2004. (c) Source localization revealed distinct neural generators for PMN and N400 components, primarily in the left hemisphere.

Box 9.1 The mismatch negativity

The mismatch negativity (MMN) is a pre-attentive response to discriminable auditory differences between a frequently occurring "standard" stimulus and a rare "deviant" stimulus – the so-called oddball paradigm (Näätänen *et al*., 2001). Panel a in the figure shows ERPs at midline electrodes for standard stimuli (85%, solid line) and deviant stimuli (15%, dotted line) in an auditory oddball. In panel b the difference wave (deviant minus standard) at frontal electrode FZ displays a large MMN and in panel c the voltage map between 140 and 190 ms post stimulus onset illustrates the frontal distribution of the MMN (Steinhauer, unpublished data). Within language research the MMN has been used to study categorical phoneme perception, most recently also probing the audio–visual McGurk–MacDonald effect (Massaro, 1998). This effect is achieved by having a subject watch a speaker articulate a syllable that differs from what is recorded on the audio channel the subject hears. The effect occurs when the subject sees the speaker articulate/ka/ but hears /pa/ – this combination results in the perception of /ta/. Examination of the McGurk–MacDonald effect has led one group to suggest the existence of an "audio–visual" MMN that has generators different to or overlapping with those that produce the purely acoustic MMN (Colin *et al*., 2002). They argue that, since their audio–visual stimuli had no acoustic deviants and the visual stimuli *per se* were incapable of eliciting MMNs, the visual stimuli required an appropriate auditory context within which a MMN was generated to an illusory deviant auditory percept. Also, they suggest that the MMN must result from an automatic, precognitive comparison between phonetic traces held in short-term memory.



Colin, C., Radeaua, M., Soquetc, A., Demolinc, D., Colind, F., & Deltenre, P. (2002). Mismatch negativity evoked by the McGurk–MacDonald effect: a phonetic representation within short-term memory. *Clinical Neurophysiology*, *113*, 495–506.

Massaro, D.W. (1998). *Perceiving talking faces: From speech perception to a behavioural principle*. Cambridge, MA: MIT Press.

Näätänen, R., Tervaniemi, M., Sussman, E., Paavilainen, P., & Winkler, I. (2001). "Primitive intelligence" in the auditory cortex. *Trends in Neurosciences*, *24*, 283–288.

the above examples are taken) although this was a misleading description of its behavior inasmuch as it is found to occur in response to all sentence-ending words but is larger to those that violate phonological expectations and is *not* related to the mismatch negativity (MMN; Box 9.1). Thus, the PMN now refers to the phonological *mapping* negativity as this phrase better describes its behavior. The PMN appears to be modality specific (auditory) and prelexical as it is equally responsive to words and non-words. It also appears to be related to phonological awareness, responds to single phoneme violations of localized expectations, and is insensitive to phonologically correct pattern masking (e.g., Connolly *et al*., 1992). Preliminary data indicate it is absent in many poor and dyslexic readers. Using both magnetoencephalography (MEG) and high-resolution (hr)ERP, the PMN has been localized predominantly to left perisylvian regions (Kujala *et al*., 2004; Figure 9.1) and the left inferior frontal area (Broca's area) as well as left inferior parietal region (D'Arcy *et al*., 2004; Figure 9.2(c)). The MEG findings also indicate that the PMN is anterior to both the N1 and N400 in MEG responses (Kujala *et al*., 2004). Other work (Newman *et al*., 2003) has used a phoneme deletion paradigm to isolate the PMN from frequently occurring larger negativities (e.g., the semantic N400 discussed in the next section). These findings have confirmed the PMN as a prelexical response reflecting a compulsory stage of word processing that is sensitive to top-down phonological expectations established by the experimental circumstances. Current thinking is that the PMN reflects phoneme awareness and the consequent phonological processing activity. Although influenced by top-down phonological expectations, once a violation of expectations is perceived the PMN does not appear to be sensitive to gradations of phonological relatedness but rather shows an "all-or-none" response that is equally large for all violations. The PMN may reflect a phonological stage of word processing that operates at the level of transforming acoustic input into phonological code assisting in the establishment of a lexical cohort. It is also compatible with the data to suggest that the PMN may reflect the earliest point at which top-down contextual information influences bottom-up processes at or just prior to the Isolation Point within, for example, a version of the Cohort Model (Connolly & Phillips, 1994).

9.2.3. Lexico-Semantic Integration: The N400 Component

This typically centro-parietal and slightly right-lateralized component peaks around 400 ms and was first observed to sentence-ending words that were incongruous to the semantic context of the sentences in which they occurred (e.g., in examples *1c* and *1d* above) (Kutas & Hillyard, 1980; Steinhauer & Friederici, 2001; D'Arcy *et al.*, 2004; Figure 9.2(a) and (b)). More generally, the N400 amplitude seems to reflect costs of lexical activation and/or semantic integration, such as in words terminating low versus high contextually constrained sentences (Connolly *et al.*, 1992). Other work has proposed that the N400 is larger to open- than closed-class words and in a developing sentence context becomes progressively smaller to such words as sentence context develops and provides contextual constraints (Van Petten & Luka, 2006). A particularly important report has demonstrated similarities between open- and closed-class words on the N280/Lexical Processing Negativity (LPN) and the N400 (Münte *et al.*, 2001). It was found that the N280/LPN responded to both word classes. The N400 was also seen with both classes (albeit smaller to closed-class words, as mentioned above, due to their reduced semantic complexity), reinforcing the view that neither component offers support for different neural systems being involved in the processing of word class. In word-pair semantic priming paradigms (e.g., *bread–butter* versus *bread–house*) the N400 amplitude to the second word was reduced when it was related to the prime (Van Petten & Luka, 2006). N400s have also been shown to be larger to concrete than abstract words and to words with higher density orthographic neighborhoods (Holcomb *et al.*, 2002). Word frequency appears to affect N400 amplitude, being larger for low than high frequency words. However, this effect disappears when the words are placed in a sentence context; a finding that has been interpreted as suggesting the N400 word frequency effect is probably semantically based (Van Petten & Luka, 2006).

The issue of domain specificity refers to a recurring theme about whether N400 activation reflects activity in an amodal conceptual-semantic system. Two studies exemplify work in the area. Also, both studies directly address the issue of "other" negativities (such as the PMN in the work already described) associated with the N400 and of conceptualizing the N400 as a response composed of distinct subprocesses rather than a monolithic process.

Based on earlier work that used line drawings of objects within an associate priming paradigm that required participants to indicate whether they recognized the second item in each pair, McPherson and Holcomb (1999) used color photos of identifiable and unidentifiable objects in three conditions in which an identifiable object preceded a related identifiable object, an unrelated identifiable object, and an unidentifiable object. Replicating earlier work, they found both a negativity at 300 ms as well as an N400 to the unrelated and unidentifiable objects. The N400 exhibited an atypical frontal distribution that was attributed to the frontal distribution of the adjoining negativity at 300 ms. An argument was made that as no equivalent of the N300 had been seen to linguistic stimuli it might be a response specific to objects/pictures. We now know that a similar response is seen to linguistic stimuli but that fact does not invalidate the proposal that the "N300" may be object/picture specific. Again, the possibility is raised that both the PMN and N300 may reflect the action of similar neural populations that reflect pre-semantic processes (phonological and object based, respectively) that facilitate subsequent semantic evaluation of a stimulus.

In a similar vein, simple multiplication problems in which the answer is incorrect exhibit an N400 that is smaller if the incorrect solution is conceptually related to one of the operands in a manner similar to contextual modulation of the language-related N400 (Niedeggen *et al.*, 1999). The explanation of this N400 effect is a combination of activation spread and controlled processing mechanisms. A particularly interesting aspect of this study is that the authors take the position that treating the N400 as a unitary monolithic phenomenon is likely to be incorrect. They divided the N400 component into three sections: the ascending limb, the peak, and the descending tail of the waveform. Having done this, they demonstrate that the ascending limb appears related to automatic aspects of activation spread while the descending limb is associated with the more controlled processing functions. This study represents another instantiation of a recurring theme: the N400 is not a unitary phenomenon and/or there are other independent but related components (PMN, N300, N280/LPN) that play an important role in how the process(es) reflected by the N400 fulfills its functional duties within a broadly defined conceptual-semantic system. A final note regarding these earlier components is that they are often difficult to observe in grand averages due, as Münte and colleagues suggest, to their overlap with the larger N400. Connolly and colleagues have made a similar argument regarding the PMN and added that these responses may show individual differences in processing speeds, for example, leading to their "loss" in grand averages despite being clear in individual's waveforms.

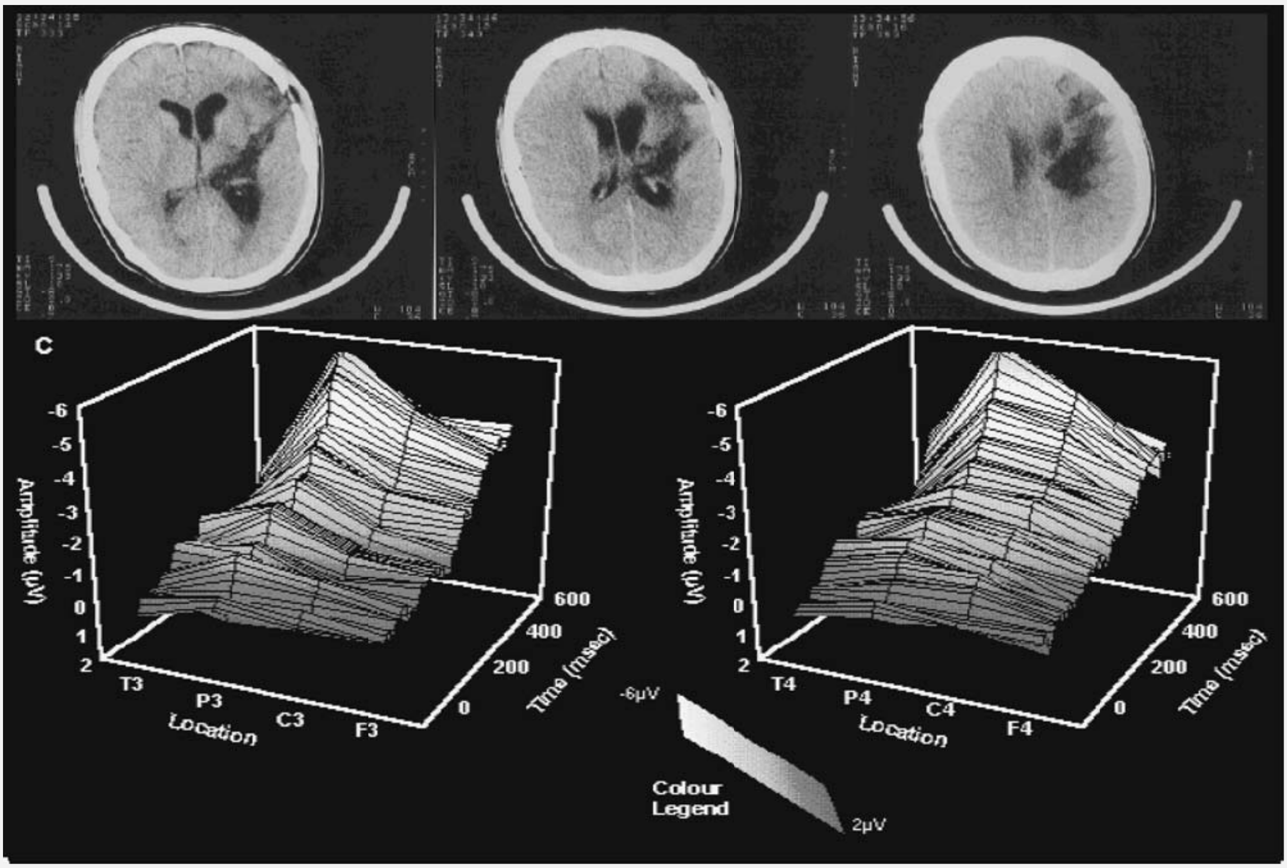
Finally, the importance of the conceptual system(s) reflected by the N400 is emphasized by the fact that it has become one of the principal components utilized in recent research using ERPs as clinical assessment tools in brain-injured populations (Box 9.2).

9.2.4. Left Anterior Negativities (LANs) and P600s in Morpho-Syntactic Processing

In order to understand the difference between *John is hitting the ball* and *John was hit by the ball* our brain is not

Box 9.2 Clinical assessment of language using cognitive ERP

Unlike the history of evoked potentials in assessing sensory function (EP; Chiappa, 1997) cognitive ERP have only recently been employed to examine patients' language abilities and the functional integrity of systems upon which language depends. The failure to employ ERP in clinical settings was partially due to the outdated belief that these components were insufficiently reliable in their occurrence, physical characteristics (such as latency), and functional specificity. Today, however, a high level of specificity and replicability have been established, in some cases by adapting psychometrically valid neuropsychological tests for computer presentation and simultaneous ERP recording. These tests provide a method for neuropsychological assessment of patients who are otherwise impossible to assess due to the severity of their brain injuries, for example, after stroke (D'Arcy *et al*., 2003). The link between basic research and clinical application is exemplified by an auditory ERP study that tested semantic and phonological sentence processing in a traumatic brain injury patient in a persistent vegetative state (Connolly *et al*., 1999). The top part of the figure shows axial computerized tomography (CT) scans of patient's head. Left brain is on the right side of scan, the entry wound is left frontal. Three-dimensional figures in the bottom part depict N400 responses in the left (T3–F3) and right (T4–F4) hemisphere to sentences such as *The gambler had a streak of bad luggage* (see Sections 9.2.2 and 9.2.3). Amplitude is on left vertical axis, scalp location on bottom axis, and time (ms) on right axis. Despite his apparent vegetative state, the patient exhibited classic N400 responses to the semantically incongruous sentence endings. Having demonstrated the patient's comprehension abilities were intact, the inference was drawn that he was mentally intact and possessing sufficient mental resources to merit rehabilitation (ultimately highly successful) instead of the scheduled discharge to a long-stay facility and the associated poor prognosis for patients in such conditions.



Chiappa, K.H. (1997). *Evoked potentials in clinical medicine* (3rd edn). New York: Lippincott-Raven.

Connolly, J.F., Mate-Kole, C.C., & Joyce, B.M. (1999). Global aphasia: An innovative assessment approach. *Archives of Physical Medicine and Rehabilitation*, *80*, 1309–1315.

D'Arcy, R.C.N., Marchand, Y., Eskes, G.A., Harrison, E.R., Phillips, S.J., Major, A., & Connolly, J.F. (2003). Electrophysiological assessment of language function following stroke. *Clinical Neurophysiology*, *114*, 662–672.

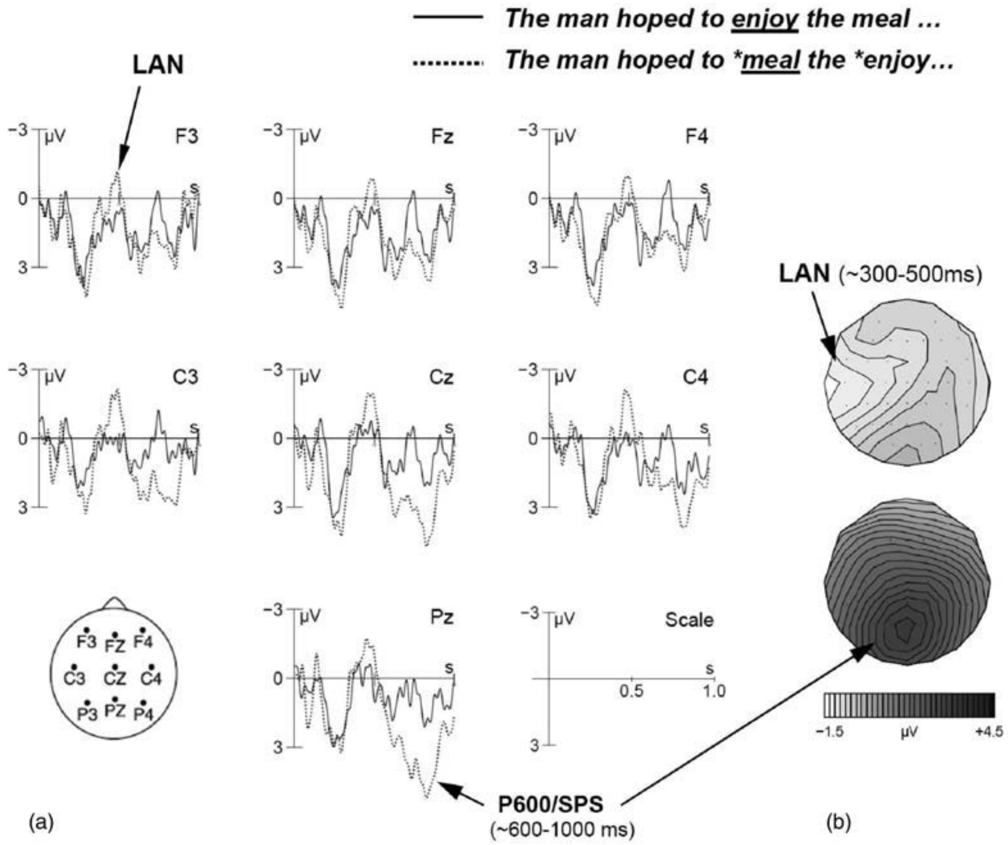


FIGURE 9.3 Biphasic LAN and P600 pattern elicited by syntactic word category violations in an English reading study. Negative polarity is plotted upwards. (a) ERP plots of the ungrammatical target words (dotted lines) show a LAN effect between 300 and 500 ms, that is in a similar time interval as the N400 (see Figure 2(a)), which was followed by a late posterior P600/SPS between 600 and 1000 ms. (b) Voltage maps of the difference waves (violation minus correct control) illustrate the scalp distribution of both ERP components (Steinhauer, unpublished data).

only required to identify the conceptual meaning of content words (*John*, *hit*, *ball*) but it also needs to analyze the grammatical relations between them. This syntactic parsing of the hierarchical structure of utterances will reveal whether *John* is the agent of the action, and whether this action is continuing or has been completed. Parsing takes place incrementally in real time at rates of approximately three words per second and involves (1) the analysis of word order and word category information including function words (*is*, *the*, *was*, *by*) and (2) the checking of certain features that need to be congruent between linked sentence constituents (e.g., subject–verb agreement in English).

The most common way of studying ERP correlates of morpho-syntactic processing has utilized violation paradigms. The rationale is that violations should disrupt or increase the workload of the brain systems underlying the type of processing that is of interest. These changes are intended to elicit a specific differential ERP. Two such ERP components have indeed been identified as markers of two stages of syntactic processing: an early, often left-lateralized anterior negativity (LAN) typically occurring between 100 and 500 ms that has been linked to automatic first pass parsing, and a late centro-parietal positive component between 500 and 1000 ms (P600), that may reflect rather controlled attempts to reanalyze and fix the anomaly at a later stage (Figure 9.3). The qualitative differences between these two components and the semantic N400 have been taken as evidence that syntactic and semantic information are processed differently in the brain (Osterhout & Holcomb, 1992).

9.2.5. Early and Other Left Anterior Negativities

LANs have primarily been reported for outright syntactic violations and not, for example, for structure ambiguities. Typical conditions eliciting LANs are word category violations (in *2a*,*b*; Neville *et al.*, 1991; Friederici, 2002) and violations of number agreement between the subject and verb (*2c*). (*Note*: an asterisk "*" marks the ungrammatical word.)

*(2a) He criticized Max's * of proof the theorem*
*(2b) Die Bluse wurde am *ge-bügelt* (The blouse was at the *ironed)
*(2c) The children *plays in the garden*

Among these, only word category violations (*2a*,*b*) have been found to yield a particularly early LAN (ELAN) between 100 and 300 ms, which appeared more reliable in auditory than visual studies, and has been linked to neural generators in Broca's area and the anterior temporal lobe. Some models suggest that this ELAN is distinct from other later LAN effects and reflects interruptions of highly automatic processes during the very first phase of building up a phrase structural representation that is required in subsequent processing stages. Within this framework, other morpho-syntactic operations (and respective violations) affecting agreement features or verb arguments which already depend on a phrase marker, are processed in parallel to semantic information, and elicit the later LANs between 300 and 500 ms (concurrently with the semantic N400; Rossi *et al.*, 2005). Unlike P600s (see Section 9.2.6), ELANs were not influenced by the relative proportion of violations in an experiment, suggesting their "autonomous" status independent of processing strategies (Hahne & Friederici, 1999).

In psycholinguistics, the short latency of the "syntactic" ELAN component has been of theoretical importance as it lent strong empirical support to so-called syntax first models that claim an initial autonomy phase for the syntactic parsing device, as opposed to more interactive models. However, the short ELAN latency has convincingly been shown to depend on the rapid availability of word category information in the respective experimental paradigms (e.g., the prefix *ge* in the prevailing German paradigm in (*2b*)), rather than the proposed early stage of processing *per se*. In absence of such early phonological markers, word category violations elicit LANs in the typical 300–500 ms time window of other morpho-syntactic violations (Hagoort *et al.*, 2003), even though primacy of syntactic over semantic processes may still hold. The critical impact of phonological markers on the ELAN latency raises yet another issue; since the German prefix *ge* is not restricted to verb forms (and, therefore, is not a reliable word category marker), the ELAN likely reflects violations of phonological expectations related to word category violations rather than an automatic response to syntactic violations as such. This in itself, however, is remarkable as it suggests an extremely early phonological mismatch/detection mechanism based on experimental processing regularities and resulting expectations, modulating the ERP in less than 200 ms. Such an account may also explain the modality differences, that is, the greater robustness of ELANs in auditory experiments. Compatible with this notion are studies that reported a similar early anterior negativity over the right hemisphere (ERAN (early right-anterior negativity)) for certain musical violations (Patel *et al.*, 1998). Hagoort *et al.* (2003) set out to replicate ELAN effects in a Dutch reading study that avoided word initial markings of the word category. As expected, they observed an anterior negativity only between 300 and 500 ms which, moreover, was bilaterally distributed rather than left lateralized. Lau *et al.* (2006) found that clear LAN-like effects occurred only if local phrase structure imposed high constraints on the target word, whereas less predictable structures resulted in attenuated LAN effects. Predictability and expectations may be crucial to our understanding of LAN-like effects in morpho-syntactic processing more generally. Previous reviews have argued that failure to replicate [E]LANs was due to the failure to create outright syntax violations. However, even the standard paradigm used to successfully elicit ELAN effects in German in (*2b*) does actually not meet this particular criterion (see (*3*)). That is, at the position of the supposed "outright violation" sentences can still be completed such that a syntactically correct (although semantically somewhat odd) sentence results:

(3) Die Bluse wurde am gebügelt noch festlicher wirkenden Jackett mit Nadeln befestigt
The blouse was to the ironed even more festive seeming jacket with pins fixed (Literal translation)
The blouse was pinned to the jacket which, after being ironed, appeared even more festive (Paraphrase)

The adverbial and adjectival use of participles in German illustrated in (*3*) poses a major problem to the traditional interpretation of ELAN components. Based on word category information alone, the brain has simply no reason to assume an outright syntax violation, unless (a) it either knows in advance that such sentences are not included in the experiment (i.e., a pragmatic constraint) or (b) it uses prosodic cues (or punctuation) to determine that the sentence will not be continued beyond the past participle. In this latter case, however, the word category is entirely irrelevant as *any* single-word completion following *am* would cause a syntax violation.

To summarize, whereas the ELAN appears to be related to violations of expected speech sounds or orthographic patterns in particularly constrained structural environments, the somewhat later anterior negativities between 300 and 500 ms may be more directly linked to structural/syntactic processes proper. Several current models have associated these later LAN components with (the interruption of) proceduralized cognitive operations such as rule-based sequencing or structural unifications, either within the linguistic domain or across cognitive domains (see Chapter 18, this volume; Hoen & Dominey, 2000). In fact, there exist a few reports of LAN-like effects for non-linguistic sequencing (Hoen & Dominey, 2000). A rule-based interpretation of LANs beyond syntax would also be compatible with LAN effects found for over-regularizations in morpho-phonology (e.g., *childs* instead of *children*).

9.2.5.1. Working Memory

In the previous section we discussed rule-based accounts of LAN-like components. Another account explains these components in terms of working memory (WM) load increases.

This appears appropriate for syntactic structures involving long-distance dependencies (such as *wh* questions) and may, in fact, refer to a distinct set of left anterior negativities. LAN effects reflecting WM load usually tend to display broader distributions and longer durations than the focal, transient morpho-syntactic LAN components (Martin-Loeches *et al.*, 2005). Whether a unified WM-based LAN interpretation could appropriately account for LANs elicited by word category or agreement violations remains a controversial issue.

9.2.5.2. Scalp Distribution of LAN Components

Despite their name, the scalp distribution of LAN-like components is not always left lateralized, nor is it always frontal. Factors underlying this variability are not well understood, nor are the reasons explaining why the same paradigm employed for eliciting LANs in some studies fail to do so in others (Lau *et al.*, 2006). The consistency of phonological or orthographic markings along with predictable sentence structures may be important for the elicitation of ELAN components. Recent data indicate that left lateralization of LANs may be modulated by linguistic proficiency levels even in native speakers (Pakulak & Neville, 2004).

9.2.6. P600/Syntactic Positive Shift

The second syntax-related ERP component is a late positivity between 500 and 1000 ms, dubbed the P600 (Osterhout & Holcomb, 1992) or *syntactic positive shift* (SPS), which may be preceded by [E]LAN components (Figure 9.3). The P600/SPS has been linked to more controlled processes during second pass parsing and, unlike LANs, is often found to be modulated by non-syntactic factors including semantic information, processing strategies, and experimental tasks. P600 components have been found across languages for a large variety of linguistic anomalies, such as (a) non-preferred "garden path" sentences that require structural reanalyses due to local ambiguities (Osterhout & Holcomb, 1992; Mecklinger *et al.*, 1995; Steinhauer *et al.*, 1999) and (b) most types of morpho-syntactic violations (such as those in *1a*,*b*,*c*). Kaan *et al.* (2000) demonstrated that structurally more complex sentences may evoke a P600 even in the absence of any violation or ambiguity. Taken together, these findings would suggest that the P600/SPS is a rather general marker for structural processing.

The considerable range of (linguistic) phenomena eliciting P600 effects raised the question of whether this response was language-specific at all. A direct comparison of linguistic and musical violations found P600-like waveforms in *both* domains; moreover, their amplitudes displayed parametric modulation as a function of violation strength (Patel *et al.*, 1998) – a finding that clearly questions the P600 as a language-specific response. It was suggested the P600/SPS may rather be viewed as a member of the *P300 family* of WM-related components, providing a parsimonious domain-general P600 account (Coulson *et al.*, 1998; but see Friederici *et al.*, 2001). Studies examined if the P600 behaved like a P300 and shared its topographical profile, but the overall results were inconclusive. For example, increasing the probability of violations did reduce the P600 amplitude in some studies (pro P300 interpretation) but not in others (contra P300) (Friederici *et al.*, 2001). Patient data showed that basal ganglia lesions affect only the P600 but not the parietal P300 (Kotz *et al.*, 2003), suggesting a dissociation of the components. Current thinking is that the P600 should not be viewed as a monolithic component, but may occasionally comprise P3b-like subcomponents. This hypothesis was strongly supported by a study using temporal–spatial principle component analysis (PCA) to tease apart P600 subcomponents (Friederici *et al.*, 2001). In fact, the authors suggested that P600 subcomponents may reflect the diagnosis of syntactic problems, attempts to fix them, secondary checking processes, and phonological revisions.

9.2.7. Verb Argument Structure Violations and Thematic Roles

Verb argument structure violations seem to elicit more complex patterns than other violations, arguably because they affect thematic role assignments (i.e., "who did what to whom?") in addition to syntactic aspects. These effects also vary across languages. A German study found that, whereas violating the case of an object noun phrase (NP) by swapping dative and accusative case markings elicited a LAN/P600, violating the *number* of arguments by adding a direct object NP to an intransitive verb, as in (*4*), evoked an N400/P600 instead (Friederici & Frisch, 2000).

*(4) Sie weiß, dass der Kommissar (NOM) den Banker (ACC) *abreiste (V)*
She knows that the inspector (NOM) the banker (ACC) departed (V, intransitive)

Revisions of case assignment elicited N400 effects (sometimes without P600s), while thematic role revisions yielded P600-like positivities (sometimes without preceding negativities) (Bornkessel & Schlesewsky, 2006; Kuperberg *et al.*, 2006). The most striking findings in this respect have been unexpected P600s instead of N400s for sentences in which the thematic roles violated animacy constraints as in (*5*).

(5) For breakfast the eggs would only #eat toast and jam.

Several research groups have suggested that these findings may require a reinterpretation of P600 (sub)components, for example in terms of a re-checking mechanism in cases of conflicts between the syntactic parser and a parallel thematic evaluation heuristics (e.g., van Herten *et al.*, 2005).

9.2.8. Interactions Between Syntax, Semantics, Discourse, and Prosody

Some of the most interesting questions in psycholinguistics concern the integration and interplay of different kinds of information, such as syntax and semantics. Can the syntactic parser be viewed as an autonomous, encapsulated module, as suggested by some "syntax first" models? Or rather is there a continuous multidirectional exchange of all varieties of information as proposed by interactive models? How do N400, LANs, and P600s interact in the case of double violations?

As far as the incoming target word itself is concerned, most available data suggest an early stage of largely parallel semantic/thematic and morpho-syntactic processing followed by a later integration stage (P600 interval) that allows for interaction between different types of information. Thus double violations typically tend to elicit additive effects of a syntactic LAN/P600 pattern and a semantic N400 with possible non-additive modulations of the P600 (Osterhout & Nicol, 1999; Gunter *et al*., 1997).

One exception, however, is that unlike other syntax violations, word category violations seem to require immediate phrase structural revision and thus temporarily block further semantic processing during this period (thereby preventing or delaying N400 effects of the semantic incongruency). Thus, in a standard grammaticality judgment task, these double violations did not elicit a late N400-like response until a P600 reflecting a structure revision had already occurred (Friederici *et al*., 1999). This suggests that semantic integration in sentences is at least partly guided by syntactic structure. Typical N400s were observed only if semantic task instructions explicitly required instant semantic integration. Conversely, in order for semantic information to be able to influence syntactic parsing decisions, it must be available much earlier in the sentence, or may not show an effect at all. A study on German "garden path" sentences by Mecklinger *et al*. (1995) demonstrated that even reliable semantic plausibility information failed to facilitate syntactic reanalysis suggesting that initial syntactic analyses are relatively independent from local semantic information.

However, there are at least two types of contextual information that have been shown to radically change initial parsing preferences: referential support and prosodic cues. First, van Berkum *et al*. (1999) demonstrated that a discourse providing either one or two potential referents

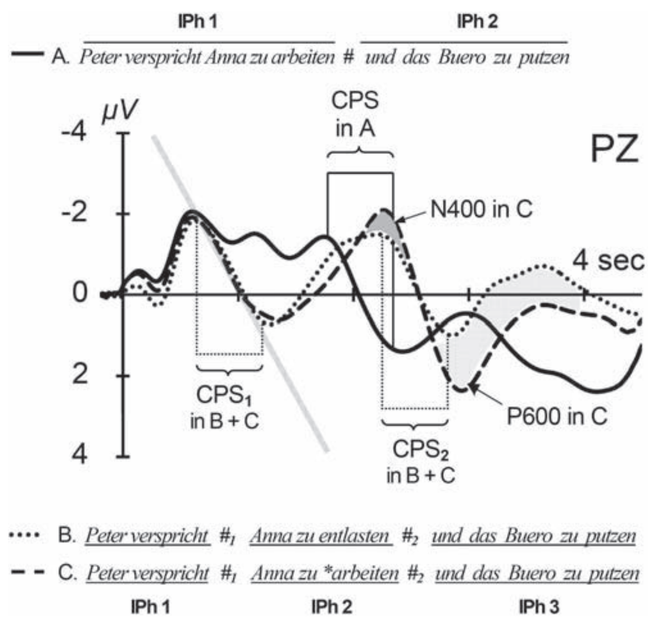
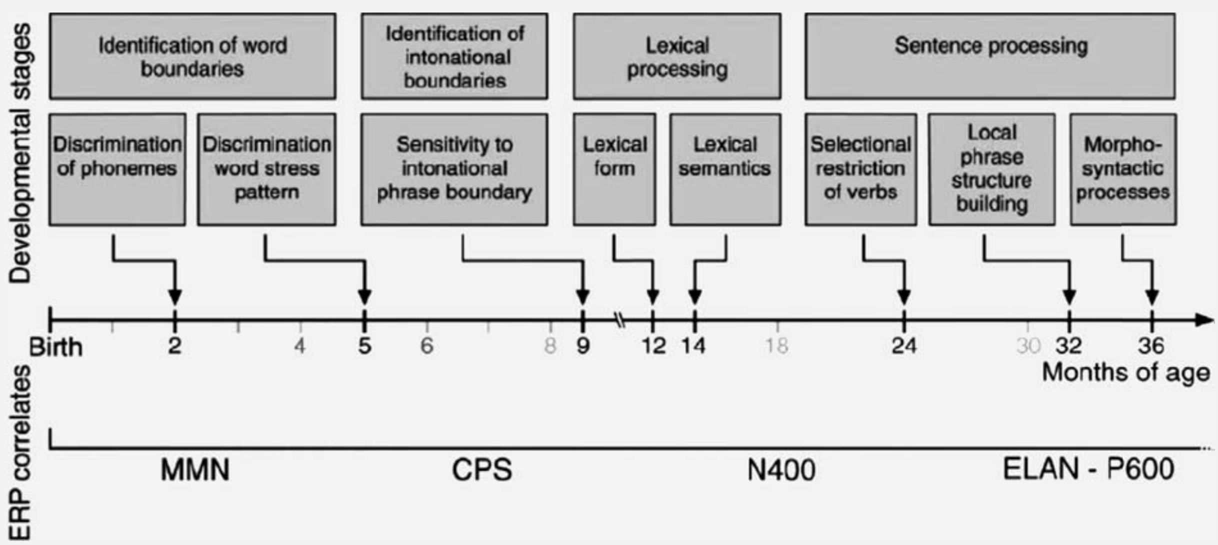


FIGURE 9.4 Illustration of the closure positive shift (CPS) at prosodic boundaries of spoken German sentences, and a prosody-induced syntax violation negative polarity is plotted upwards. Boundary positions and intonational phrases (IPh) are aligned to the time axis. Sentence A (solid line) has only one prosodic boundary (#) after the verb "arbeiten," while B (dotted line) and violation condition C (dashed line) have two such boundaries. At each boundary position a large CPS component was elicited in each condition. Magnitude and slope of the CPS (illustrated by the thick gray line at CPS1) are very similar at all boundary positions. In C, the syntax-prosody mismatch on the verb "arbeiten" additionally elicited an N400/P600 pattern which superimposes the second CPS. Waveforms represent a grand average ERP at PZ across 40 subjects and approximately 5000 trials per condition. Prosodic boundary information is not only important during language learning but also guides the listener's syntactic analysis and sentence comprehension. *Source*: Modified after Steinhauer (2003) and Steinhauer *et al*. (1999). Translation of sentences: A. Peter promises Anna to work # and to clean the office. B. Peter promises # to support Anna # and to clean the office. C. Peter promises # *[to work Anna] # and to clean the office. (Conditions A and C are lexically identical and differ only prosodically.)

for a NP determined whether readers were biased toward a complement clause or relative clause reading. If a context sentence had introduced "*two* girls" in the discourse, a singular NP "*the* girl" required further specification, thus favoring the (usually non-preferred) relative clause reading (as indicated by an enhanced P600/SPS component). Second, Steinhauer *et al*. (1999) demonstrated that prosodic information in speech can dramatically alter parsing preferences typical for reading. This study showed that the presence or absence of an intonational phrase boundary determined whether the following NP was parsed as the object of either a preceding verb or a subsequent verb. Introducing prosodic boundaries between verbs and their object NPs caused a prosody-induced verb argument structure violation which elicited an N400/P600 pattern to the incompatible verb (*cf.* condition C in Figure 9.4). These two studies demonstrate that at least some kinds of context information can immediately influence the syntactic parsing mechanism.

Box 9.3 Order of emerging ERP components in language development

Language-related ERP components emerge during childhood in a temporal order that nicely corresponds to the development of respective linguistic and cognitive subdomains. As a general pattern, ERP components in childhood are initially larger and more broadly distributed both spatially and temporally and develop the more focused and specialized ERP profiles of adults usually until puberty (Holcomb *et al*., 1992; Mills *et al*., 1997; Hahne *et al*., 2004). The diagram illustrates the timeline of cognitive development and the emergence of corresponding ERP components during the first 3 years of life (adapted from Friederici, 2006). The MMN reflecting one's ability to discriminate sounds is the earliest ERP response and is already present in newborns. During the first months, babies are able to discriminate phonemes of all natural languages. However, at about 10 months a particular specialization for sound distinctions important in their mother tongue is reflected by larger and more robust MMN effects whereas speech sounds that do not belong to the phonemic inventory of their first language lose the ability to elicit MMNs (categorical perception). The next ERP response found in infants is the CPS reflecting prosodic phrasing. The CPS is present no later than at 8 months, that is, when infants are able to distinguish between adequate and inadequate pausing in speech. As large prosodic boundaries typically coincide with syntactic boundaries and the presence of function words, the presence of the CPS component may indicate the onset of "phonological bootstrapping" in language acquisition. The lexico-semantic N400 component emerges at 12–14 months, just after infants have started to babble. The N400 was observed when infants saw a picture of an animal or simple object (e.g., a dog) and heard a word that did not match (e.g., pencil). Last, LAN and P600 responses to simple syntactic violations develop only 1 year later, at an age of 24 months (P600) and 32 months (LAN).



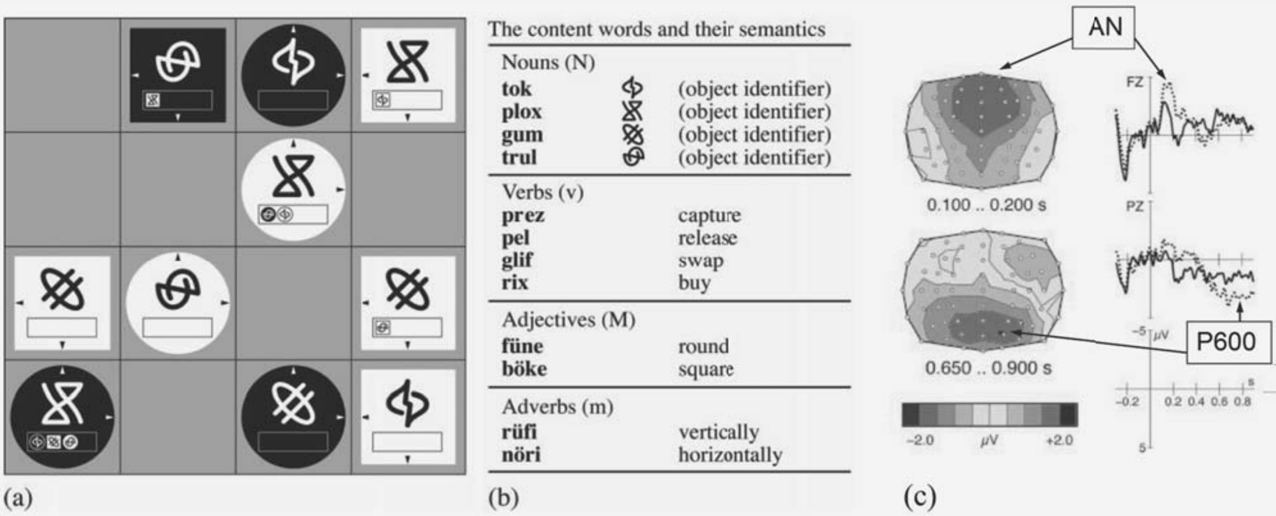
Friederici, A.D. (2006). Neurophysiological markers of early language acquisition: From syllables to sentences. *Trends in Cognitive Science*, *9*(10), 481–488.

Hahne, A., Eckstein, K., & Friederici, A.D. (2004). Brain signatures of syntactic and semantic processes during children's language development. *Journal of Cognitive Neuroscience*, *16*(7), 1302–1318.

Holcomb, P.J., Coffey, S.A., & Neville, H.J. (1992). Visual and auditory sentence processing: A developmental analysis using event-related brain potentials. *Developmental Neuropsychology*, *8*(2/3), 203–241.

Mills, D.L., *et al*. (1997). Language comprehension and cerebral specialization from 13 to 20 months. *Developmental Neuropsychology*, *13*, 397–445.

Box 9.4 ERP components in second language: evidence for "critical periods?"



Native-like mastery of a language seems almost impossible if this language was not acquired early in childhood. This observation is often explained with an early "critical period" (CP) during which the brain is particularly well prepared to learn the sounds, words, and grammatical rules. An ERP study by Weber-Fox and Neville (1996) tested Chinese subjects who had learned English at different ages, and found support for a CP in syntactic but not semantic processing. Semantic anomalies elicited native-like N400s in all groups, but even short delays in age of exposure to English prevented LANs in syntax conditions. More posterior and right-lateralized negativities, delayed P600/SPS components, or no ERP effects were found instead. Data seemed to indicate that late L2 learners are unable to do early automatic parsing and rely on compensatory brain mechanisms that are distinct from those of native speakers. Alternatively, ERPs might primarily reflect the level of proficiency which was at least partially confounded with age of exposure. To tease these factors apart, Friederici *et al.* (2002) trained adult subjects in the artificial miniature language "Brocanto" to native-like proficiency. A computer-implemented chess-like board game (panel a) was employed to engage subjects in speaking Brocanto: sentences referred to the moves of the game (panel b). After training, high proficient subjects displayed the typical "native-like" ERP patterns of syntactic processing (panel c): an early anterior negativity (AN) followed by a P600, here shown for a syntactic subcondition that was controlled for transfer effects between first language (German) and second language (Brocanto). Subsequent studies investigating adult L2 learners of *natural* languages found similar but mixed evidence (Clahsen & Felser, 2006; Steinhauer *et al.*, 2006). Overall, while ERP support for a CP in L2 grammar learning appeared unambiguous by 2001, more detailed research and new paradigms have raised new controversies.

Clahsen, H., & Felser, C. (2006). Grammatical processing in language learners. *Applied Psycholinguistics*, *27*(1), 3–42.

Friederici, A.D., Steinhauer, K., & Pfeifer, E. (2002). Brain signatures of artificial language processing: Evidence challenging the critical period hypothesis. *Proceedings of the National Academy of Sciences*, *99*(1), 529–534.

Steinhauer, K., White, E., King, E., Cornell, S., Genesee, F., & White, L. (2006). The neural dynamics of second language acquisition: Evidence from event-related potentials. *Journal of Cognitive Neuroscience*, Supplement 1, 99.

Weber-Fox, C.M., & Neville, H.J. (1996). Maturational constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers. *Journal of Cognitive Neuroscience*, *8*(3), 231–256.

Source: Modified after Friederici *et al.* (2002); Figures 2 and 4.

9.2.9. Prosodic Phrasing: The Closure Positive Shift

The Steinhauer *et al.* (1999) study discussed above also identified a novel ERP correlate of prosodic processing, which was labeled the *closure positive shift* (CPS; Figure 9.4). This component is reliably elicited at prosodic boundaries and is assumed to reflect prosodic phrasing (closure of intonational phrases) in listeners cross-linguistically. Unlike most other language-related components, it is independent of linguistic violations. In both first and second language acquisition the CPS is among the first brain responses observed (see Boxes 9.3 and 9.4) and may help learners identify syntactic phrase boundaries and even word boundaries. The CPS is also elicited (1) by boundaries in delexicalized and hummed sentence melodies and (2) during silent reading, both at comma positions and when subjects were instructed to reproduce prosodic boundaries at specific positions (Steinhauer & Friederici, 2001). The former finding suggests that the CPS is independent of lexical/syntactic information and may be domain general; the latter one establishes a link between covert prosody and punctuation (in reading and writing). By revealing that, and how, prosody guides language processing, ERPs have addressed longstanding issues in psycholinguistics.

9.3. CHALLENGES AND FUTURE DIRECTIONS

During the last 25 years, electrophysiological investigations have contributed to our understanding of the various processes involved in speech and text comprehension, their roles in language development and clinical applications. In all of these areas there remain many new and interesting challenges to be met.

What different kinds of cognitive subprocesses contribute to the classical ERP components discussed above? Do language-specific ERP (sub)components exist?

What more can ERPs tell us about shared domain space amongst language, music, and other cognitive domains?

How can we move beyond "violation paradigms" in isolated words and sentences towards more ecologically valid paradigms of language processing?

What are the differential effects of explicit (e.g., classroom) versus implicit (e.g., immersion-like) training environments on L2 acquisition? How do they affect which brain systems are involved in language?

References

Bornkessel, I., & Schlesewsky, M. (2006). The extended argument dependency model: A neurocognitive approach to sentence comprehension across languages. *Psychological Review*, *113*(4), 787–821.

Connolly, J., Phillips, N., Stewart, S., & Brake, W. (1992). Event-related potential sensitivity to acoustic and semantic properties of terminal words in sentences. *Brain and Language*, *43*(1), 1–18.

Connolly, J.F., & Phillips, N.A. (1994). Event-related potential components reflect phonological and semantic processing of the terminal word of spoken sentences. *Journal of Cognitive Neuroscience*, *6*(3), 256–266.

Coulson, S., King, J.W., & Kutas, M. (1998). ERPs and domain specificity: Beating a straw horse. *Language and Cognitive Processes*, *13*(6), 653–672.

D'Arcy, R.C.N., Connolly, J.F., Service, E., Hawco, C.S., & Houlihan, M.E. (2004). Separating phonological and semantic processing in auditory sentence processing: A high-resolution event-related brain potential study. *Human Brain Mapping*, *22*(1), 40–51.

Friederici, A.D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences*, *6*(2), 78–84.

Friederici, A.D., & Frisch, S. (2000). Verb-argument structure processing: The role of verb-specific and argument-specific information. *Journal of Memory and Language*, *43*, 476–507.

Friederici, A.D., Steinhauer, K., & Frisch, S. (1999). Lexical integration: Sequential effects of syntactic and semantic information. *Memory and Cognition*, *27*(3), 438–453.

Friederici, A.D., Mecklinger, A., Spencer, K.M., Steinhauer, K., & Donchin, E. (2001). Syntactic parsing preferences and their on-line revisions: A spatio-temporal analysis of event-related brain potentials. *Cognitive Brain Research*, *11*(2), 305–323.

Gunter, T.C., Stowe, L.A., & Mulder, G. (1997). When syntax meets semantics. *Psychophysiology*, *34*(6), 660–676.

Hagoort, P., Wassenaar, M., & Brown, C. (2003). Syntax-related ERP-effects in Dutch. *Cognitive Brain Research*, *16*(1), 38–50.

Hahne, A., & Friederici, A.D. (1999). Electrophysiological evidence for two steps in syntactic analysis: Early automatic and late controlled processes. *Journal of Cognitive Neuroscience*, *11*(2), 194–205.

Hoen, M., & Dominey, P.F. (2000). ERP analysis of cognitive sequencing: A left anterior negativity related to structural transformation processing. *Neuroreport*, *11*(14), 3187–3191.

Holcomb, P., Grainger, J., & O'Rourke, T. (2002). An electrophysiological study of the effects of orthographic neighborhood size on printed word perception. *Journal of Cognitive Neuroscience*, *14*(6), 938–950.

Kaan, E., Harris, A., Gibson, E., & Holcomb, P. (2000). The P600 as an index of syntactic integration difficulty. *Language and Cognitive Processes*, *15*(2), 159–201.

Kotz, S.A., Frisch, S., von Cramon, D.Y., & Friederici, A.D. (2003). Syntactic language processing: ERP lesion data on the role of the basal ganglia. *Journal of the International Neuropsychological Society*, *9*(7), 1053–1060.

Kujala, A., Alho, K., Service, E., Ilmoniemi, R.J., & Connolly, J.F. (2004). Activation in the anterior left auditory cortex associated with phonological analysis of speech input: Localization of the phonological mismatch negativity response with MEG. *Cognitive Brain Research*, *21*(1), 106–113.

Kuperberg, G.R., Caplan, D., Sitnikova, T., Eddy, M., & Holcomb, P.J. (2006). Neural correlates of processing syntactic, semantic, and thematic relationships in sentences. *Language and Cognitive Processes*, *21*(5), 489–530.

Kutas, M., & Hillyard, S.A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*(1), 203–205.

Lau, E., Stroud, C., Plesch, S., & Phillips, C. (2006). The role of structural prediction in rapid syntactic analysis. *Brain and Language*, *98*(1), 74–88.

Martin-Loeches, M., Muñoz, F., Casado, P., Melcon, A., & Fernandez-Frias, C. (2005). Are the anterior negativities to grammatical violations indexing working memory? *Psychophysiology*, *42*(5), 508–519.

McPherson, W.B., & Holcomb, P.J. (1999). An electrophysiological investigation of semantic priming with pictures of real objects. *Psychophysiology*, *36*(1), 53–65.

Mecklinger, A., Schriefers, H., Steinhauer, K., & Friederici, A.D. (1995). Processing relative clauses varying on syntactic and semantic dimensions: An analysis with event-related potentials. *Memory and Cognition*, *23*(4), 477–494.

Münte, T.F., Wieringa, B.M., Weyerts, H., Szentkuti, A., Matzke, M., & Johannes, S. (2001). Differences in brain potentials to open and closed class words: Class and frequency effects. *Neuropsychologia*, *39*(1), 91–102.

Neville, H., Nicol, J.L., Barss, A., Forster, K.I., & Garrett, M.F. (1991). Syntactically based sentence processing classes: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience*, *3*(2), 151–165.

Newman, R.L., Connolly, J.F., Service, E., & McIvor, K. (2003). Influence of phonological expectations during a phoneme deletion task: Evidence from event-related brain potentials. *Psychophysiology*, *40*(4), 640–647.

Niedeggen, M., Rosler, F., & Jost, K. (1999). Processing of incongruous mental calculation problems: Evidence for an arithmetic N400 effect. *Psychophysiology*, *36*(3), 307–324.

Osterhout, L., & Holcomb, P.J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language*, *31*, 785–806.

Osterhout, L., & Nicol, J. (1999). On the distinctiveness, independence, and time course of the brain responses to syntactic and pragmatic anomalies. *Language and Cognitive Processes*, *14*(3), 283–317.

Pakulak, E., & Neville, H. (2004). Individual differences in online syntactic processing in monolingual adults as reflected by ERPs. *17th Annual CUNY Conference on Human Sentence Processing*, College Park (Maryland, USA), 149.

Patel, A.D., Gibson, E., Ratner, J., Besson, M., & Holcomb, P.J. (1998). Processing syntactic relations in language and music: An event-related potential study. *Journal of Cognitive Neuroscience*, *10*(6), 717–733.

Rossi, S., Gugler, M.F., Hahne, A., & Friederici, A.D. (2005). When word category information encounters morphosyntax: An ERP study. *Neuroscience Letters*, *384*(3), 228–233.

Sanders, L.D., & Neville, H.J. (2003). An ERP study of continuous speech processing. II. Segmentation, semantics, and syntax in non-native speakers. *Cognitive Brain Research*, *15*(3), 214–227.

Steinhauer, K. (2003). Electrophysiological correlates of prosody and punctuation. *Brain and Language*, *86*, 142–164.

Steinhauer, K., & Friederici, A. (2001). Prosodic boundaries, comma rules, and brain responses: The closure positive shift in ERPs as a universal marker for prosodic phrasing in listeners and readers. *Journal of Psycholinguistic Research*, *30*(3), 267–295.

Steinhauer, K., Alter, K., & Friederici, A.D. (1999). Brain potentials indicate immediate use of prosodic cues in natural speech processing. *Nature Neuroscience*, *2*(2), 191–196.

Steinhauer, K., Pancheva, R., Newman, A.J., Gennari, S., & Ullman, M.T. (2001). How the mass counts: An electrophysiological approach to the processing of lexical features. *Neuroreport*, *12*(5), 999–1005.

van Berkum, J.J., Hagoort, P., & Brown, C. (1999). Semantic integration in sentences and discourse: Evidence from the N400. *Journal of Cognitive Neuroscience*, *11*(6), 657–671.

van Herten, M., Kolk, H.H.J., & Chwilla, D.J. (2005). An ERP study of P600 effects elicited by semantic anomalies. *Cognitive Brain Research*, *22*(2), 241–255.

Van Petten, C., & Luka, B.J. (2006). Neural localization of semantic context effects in electromagnetic and hemodynamic studies. *Brain and Language*, *97*(3), 279–293.

Further Readings

Brown, C.M., & Hagoort, P. (Eds.) (2000). *The neurocognition of language*. Oxford, UK: Oxford University Press.
This work provides a critical overview of how neurocognitive methods have been used to address psycholinguistic research questions in listeners, readers, and speakers, focusing in particular on electrophysiological techniques (EEG, ERPs, MEG). The book first introduces the reader to linguistic theory, psycholinguistics, and cognitive neuroscience, and then explains how current theories and models have been tested using brain imaging and ERPs.

Handy, T.C. (Ed.) (2005). *Event-related potentials: A methods handbook*. Cambridge, MA: The MIT Press.
Provides a good introduction to the world of ERP recording, analysis, and evaluation.

Nunez, P.L. & Srinivasan, R. (2006). *Electric fields of the brain: The neurophysics of EEG*. Oxford, UK: Oxford University Press.
The definitive and comprehensive text on the EEG signal from the relevant principles of physics to the analysis of the response with extensive discussion of issues related to recording the EEG (e.g., choosing the best reference).

Rugg, M.D. & Coles, M.G.H. (1996). *Electrophysiology of mind*. Oxford, UK: Oxford University Press.
Despite its age, this classic book is one of the best introductions to ERPs in cognitive neuroscience.

Zani, A., & Proverbio, A. (Eds.) (2003). *The cognitive electrophysiology of mind and brain*. Amsterdam: Academic Press.
An introduction to EEG/ERP and MEG measures in perception, language, and memory.