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A SAMPLER OF EVENT-RELATED BRAIN POTENTIAL (ERP) ANALYSES OF LANGUAGE PROCESSING

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Abstract: In large part, language comprehension and production occur quickly and unavailable to conscious reflection. Electrophysiological methods – event-related brain potentials (ERPs) and other measures of electrical brain activity – afford a view of the brain in action as it supports these language processes as they unfold in real time. Moreover, ERPs can be utilized even when a comprehender's only task is to understand a word, phrase or sentence or to produce names or more elaborate utterances. Recording electrical brain activity in response to written and spoken words (as well as smaller and larger linguistic units) thus provides a means of tracking the brain's sensitivity to various linguistic inputs, revealing which factors are important to processing and the time course of their influence. As a continuous measure of processing, ERPs allow simultaneous looks at brain activity at the multiple time scales at which language processing transpires, from the first milliseconds of processing a word to the seconds required to comprehend a sentence, or even longer for a discourse. One of the greatest advantages to using ERPs, then, is that this combination of methodological features allows for investigations of aspects of language processing that are otherwise difficult if not impossible to detect via other measures. In this chapter, we will examine such instances, outlining five very different groups of ERP studies which exemplify some of the unique insights made possible by use of the methodology in the study of language-related neural processes. In particular, we will discuss the paradigms and the kinds of information that can be gathered from using ERPs to look at language processing outside the focus of attention, during language learning (before explicit knowing), for individuals in unconscious states, in determining the nature of predictive processing, and for testing how specific contextual cues may activate information in semantic memory. Our examination of these specific experimental examples makes clear the important role that ERPs have to play in studying language processing, both traditionally and as the number of neuroimaging techniques continues to grow.

Key words: Event Related Potentials, N400, MMN, P600, language processing, minimally conscious state, sleep, lexico-semantic processing, attention, spatial selective attention, attentional blink, event location, masking, second language acquisition, speech segmentation, verb aspect, prediction

1. INTRODUCTION

In the 1960's the idea of investigating the psychology of language by recording electrical activity from the human scalp seemed as fantastical as putting a man on the moon. One could perhaps look at differential engagement of the two cerebral hemispheres by measuring the language-specific suppression of alpha activity, but that was a far cry from what psycholinguists wanted to know about language processing. By the 1980's, however, Armstrong's moon walk was part of history, and the idea of using electrophysiology to study linguistic phenomena was becoming a respectable enterprise. Different types of electrical brain responses were being observed at the scalp to words that were incongruent with prior contexts at semantic, syntactic, and phonological levels. Even more interestingly, it had been shown that event-related brain potentials (ERPs) were sensitive to psycholinguistic variables of all sorts in perfectly normal sentences, even when all of the experimental sentences were grammatically well formed and meaningful. Such findings paved the way for the virtual explosion of ERP and magnetoencephalographic (MEG) investigations of language processing over the past quarter century. With a diversity of studies running the gamut from phoneme categorization to discourse processing, with groups ranging from healthy to brain damaged individuals, with measures recorded from populations spanning infancy through old age, virtually no area remained untouched by cognitive ERP researchers.

A major advantage of the ERP technique in the study of cognition is that it affords a continuous but time-stamped look at ongoing neural activity as individuals make sense of the barrage of sensory and internal stimulation they encounter while sensing, perceiving, encoding, recoding, retrieving, and sometimes responding to real or imagined events. ERPs provide a series of snapshots of the synaptic potentials generated primarily by pyramidal cells in the neocortex, which are thought to perform the computations critical for comprehension and cognition. In many cases, ERP effects are highly correlated with overt behaviors and lead to inferences that could just as easily be made from external performance measures such as various speed and accuracy judgments, or the scanning patterns of eye movements across either scenes as people listen to sentences or across printed words as they read text. Such converging measures are important for amassing databases of psycholinguistic phenomena and for constructing comprehensive theories. However, ERP and performance measures are at times dissociable and can occasionally offer different pictures of the same cognitive acts; thus, for thorough understanding of a particular area of interest, the different perspectives afforded by the varying methods must be integrated. Perhaps most importantly though, and in response to those who might advocate the use of only more basic behavioral methods for reasons of time and expense, there are also cases in which ERPs provide a unique view into moment-by-moment cognitive processing, with no parallel in other measures. While the limitations of various performance measures are sometimes clear at the point when the experimental design is conceived, in other instances it is not possible to tell whether more basic methods will provide sufficient power to reveal potential differences between conditions. As experimental design does not come with a crystal ball, it is often only with subsequent testing using more neurally-informed and informative methodologies, such as ERPs, that differences between conditions are revealed where none were originally detected.

In this chapter we will outline five different examples of areas in which ERPs afford insights into language processing that are not readily, if at all, available through other existing methodologies. Specifically, we will review studies in which ERPs are used to: (l) localize the processing source when linguistic content is presented outside of focused attention, (2) monitor lexico-semantic processes during learning, (3) assess cognitive and language competence during alternate states of arousal and awareness (e.g., coma, vegetative state and sleep), (4) capture predictive processes during language comprehension, and (5) test a specific hypothesis about one type of information (event location) that context words (specifically verb aspect) activate in semantic memory. These examples rely on the ERP as an instantaneous detector of current flow across membranes with a temporal resolution on the order of milliseconds. They also take advantage of the fact that ERP measures can be elicited by stimuli regardless of whether they require an immediate overt response. In other words, no additional task is necessary above and beyond the natural behaviors of viewing, reading or listening.

2. LINGUISTIC PROCESSING OUTSIDE THE FOCUS OF ATTENTION

One of the greatest advantages of ERPs is that they allow researchers to investigate aspects of language processing that are inaccessible to conscious reflection, and consequently are difficult, if not impossible, to detect via other measures. They can reveal activity that does not reach overt awareness, cannot be talked about, or might not have immediate behavioral consequences. In this respect, some longstanding and controversial questions about semantic language processing have been examined within the context of selective attention and attentional blink paradigms. Specifically, these paradigms have been used to assess the degree to which language processing is automatic, fast-acting, and largely unconscious versus more slow-acting, strategically controlled, and post-lexical, with the challenge being to tease apart these two classes of processes (assuming of course that these are true distinctions that the human brain honors). So doing would be difficult without a way of observing neural processes as they unfold in real time. Both ERP and MEG recordings afford us just such a view, albeit imperfect. Because ERPs provide continuous measures of neocortical processing between stimuli and responses we can better pinpoint the times at which processing is affected by certain experimental manipulations. The effects of early and later processes (for instance pre-attentive versus post-attentive) are at times not as conflated as they are in final output measures.

In particular, the N400 component has been at the heart of much of this testing. The N400 was first described by Kutas & Hillyard

(1980), who observed that relative to congruous words, semantically anomalous words in a given sentence context (e.g., the word *dog* in '*I take my coffee with cream and dog.*') were characterized by greater negativity between 250-500 ms or so after target word onset, peaking around 400 ms post-stimulus. The component has since been interpreted as the default neural response to any potentially meaningful item, be it a written or spoken word, a picture, or a sign, with an amplitude sensitive to a variety of factors. These factors include, but are not limited to word frequency, repetition, concreteness, number of orthographic neighbors, sentence position, semantic word association, and predictability within a sentence or discourse (see Kutas, Federmeier, Staab, & Kluender, in press, for a review). The N400 is especially large in response to items that do not semantically fit with their preceding context (whether at the word, sentence, or discourse level), but the modulation is also evident in responses to all but the most highly expected of items, even when they fit with the context. It has a peak latency around 400 ms that is relatively stable across experimental paradigms, and a centro-posterior scalp distribution that depends on several factors including whether eliciting stimuli are auditory or visual, pictorial, linguistic or nonlinguistic in nature, etc. In general then, the N400 is thought to reflect the degree of ease or difficulty in retrieving stored knowledge associated with a potentially meaningful item from semantic memory, contingent upon both the characteristics of the stored item itself, as well as the contextual cues available (Kutas & Federmeier, 2000).

Modulations in N400 amplitude and latency in controlled tasks are a good way to track semantic processing (as long as other factors to which N400 is sensitive are held constant) and have been used to probe a wide variety of linguistic phenomena. These range from word priming and message level processing to the role of attention and consciousness in language comprehension, to differences in hemispheric activation of semantic memory, to vocabulary building in language learning, just to name a few. The component has been used in a diverse assortment of experimental paradigms, including comparisons between conditions within experiments (e.g., expected sentence completion exemplars vs. less probable continuations or category violations; contextually sensible endings vs. violations of world knowledge), between different subject populations (e.g., young vs. elderly, healthy vs. schizophrenic patients), and less commonly, longitudinally (e.g., novice second language learners before vs. after learning has occurred). In sum, as a tool for investigating issues relating to the time course of language processing and the structure of semantic memory, the N400 has proven remarkably informative, even though it is not unique to language processing.

Although it is clear that N400 amplitude modulation indexes some aspect of semantic processing, it remains a point of contention precisely which process(es) the component reflect(s). One controversy centers around the degree to which the electrical activity during the N400 time window is elicited by more automatic versus more controlled processing. To this end, spatial selective attention and attentional blink ERP studies have been somewhat informative. Respectively, these studies have examined how semantic processing is influenced by manipulating the allocation of spatial attention to primes or probes and by having participants detect multiple target stimuli during rapid serial visual presentation (RSVP) conditions. We will review findings from examples of both of these types of experiments and describe how ERPs have been used with these paradigms to inform us about the temporal locus of the cognitive effects in question.

2.1 Spatial selective attention

McCarthy and Nobre (1993) investigated the role of spatial selective attention on semantic and repetition priming N400 effects. Their main goal was to adjudicate between early versus late selection theories of attention. Early selection theories posit that spatial attention acts to filter out unattended stimuli at an early (pre-semantic) stage of cognitive processing. By contrast, late selection theories propose that all stimuli, even unattended items, are processed automatically and fully, including access to their meaning, with a subsequent filtering stage determining whether or not the items gain access to consciousness. To discriminate between these two possibilities, participants were asked to maintain central eye fixation while ERPs were recorded to words presented lateralized to the left or right visual field. Within each field, the stimulus list consisted of words that were semantically related, semantically unrelated or repetitions. Participants were instructed to focus their attention alternately on one of the visual fields and to detect words that belonged to a specified semantic category (exemplars). If spatially unattended prime words modulated semantic priming and repetition effects as indexed by N400 amplitude modulation, then this would be taken as support for the hypothesis that the N400 reflects some aspect of automatic semantic processing, such as spreading activation; this outcome would correspond more closely to late selection models of attention. If however, there were no N400 amplitude modulations of semantically related or repeated words in the unattended channel, then this would be taken as support for the hypothesis that the N400 reflects more controlled processing; this outcome would correspond more closely to early selection models of attention.

In line with prior results, only exemplars presented to the attended visual field elicited large amplitude P300s compared to those exemplars presented to the unattended visual field. The absence of a reliable P300 effect between 400-800 ms to unattended stimuli suggests that the exemplars were not categorized and consolidated into working memory, and thus argues for selection some time prior to these processes. However, it does not settle the question of whether the unattended words are processed at some semantic level, as the N400 often precedes the P300. In this experiment, however, there were also no N400 effects to either semantically related or literally repeated target items in the unattended channel, in contrast to reliable semantic and repetition related modulation of N400 amplitudes for targets in the attended channel. From this pattern of results, McCarthy and Nobre (1993) concluded that the N400 did not reflect automatic, unconscious processing and that active suppression of processing in a spatial location can indeed influence the extent to which a word is processed at a semantic/conceptual level.

2.2 Attentional blink

As demonstrated by the McCarthy and Nobre (1993) study, an invaluable strength of the ERP technique is that it offers a means of teasing apart different stages and/or subprocesses of analysis. Under the appropriate experimental conditions, different aspects of the ERP waveform can be analyzed to determine whether and when certain neural/mental operations transpire. For example, (1) early sensory potentials such as the occipital P1 and the N1 indicate whether a stimulus is sensed and perceived, (2) potentials between 200 to 550 ms or so post stimulus (the time region of the N400) over posterior scalp sites indicate whether once perceived, a particular event reaches a semantic/conceptual level of analysis, and (3) late positivities between 400 to 600 ms over centro-parietal scalp sites (the P300 or more precisely the P3b) indicate whether the stimulus item was identified, categorized, and consolidated in working memory. ERP researchers have capitalized on this affordance of being able to look at qualitatively different mental processes to isolate the temporal locus of the attentional blink phenomenon. The attentional blink is a short refractory period after the detection of a target item in a stream of rapidly presented stimuli during which subsequent targets are missed (Raymond, Shapiro, & Arnell, 1992). For instance, when individuals are shown rapidly flashing characters (e.g., B T D A 3 N P **Z** F R K M) at a rate 10 per second or less, and are asked to report on two targets (e.g., a number and a letter in a contrasting color – in this example the number 3 and the letter **Z**), they can accurately report whether the first target (T1) is odd or even, but are less accurate at identifying whether the second target (T2, occurring at lag 3) is a vowel or a consonant. This impairment occurs when T2 falls within 300-600 ms after the first target (the attentional blink), but rather surprisingly not when T2 occurs immediately after T1 (at lag 1). Expectedly, T2 targets appearing much later (e.g., at lag 7) also are easily detected. But for a target falling within the period of the attentional blink, it could be that participants are neither sensing nor perceiving the second target, *or* perhaps that participants are detecting the second target, but are unable to identify and categorize it or to consolidate it into working memory.

To establish which of these subprocesses is implicated in the attentional blink (AB), Vogel, Luck, and Shapiro (1998) presented participants with a context word at the beginning of each trial (e.g., *shoe*), followed by a stream of consonant strings presented at a rate of one every 83 ms. Within this rapid stream there were two critical target items: the first (T1) was a string of numbers (e.g., *8888888*) and the second (T2) was a word that was either related to the context word (e.g., *foot*) or unrelated (e.g., *pickle*) to it (Figure 1a). T2 occurred at one of three lags: immediately after T1 (lag 1), at lag 3, or at lag 7. It was always followed by additional consonant strings plus a 1-second delay, after which participants were asked to report on the targets. Participants received both dual and single-target detection trials: in the dual-target condition instructions were to make forced choice responses at the end of each trial on both T1 (odd or even) and T2 (related or unrelated to the context word), and in the single-target condition they only had to perform the T2 task. For the single-target condition, there was no effect of lag in either reporting on T2 or in the ERPs. In the dual-target condition, participants were quite accurate at reporting the even/odd number categorization regardless of the lag. They were also accurate at reporting whether T2 was semantically related to the context word at lags 1 and 7. However, at lag 3 (the attentional blink) participants were not very accurate at making the relatedness judgment (Figure 1b).

A

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
Distractor	83	WDPTBNF	GHJDMVT
Distractor	83	SCDPVBF	HDVCBNM
T2	83	XFOOTXX	XROPEXX
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		

Figure 1a. Example stimuli.

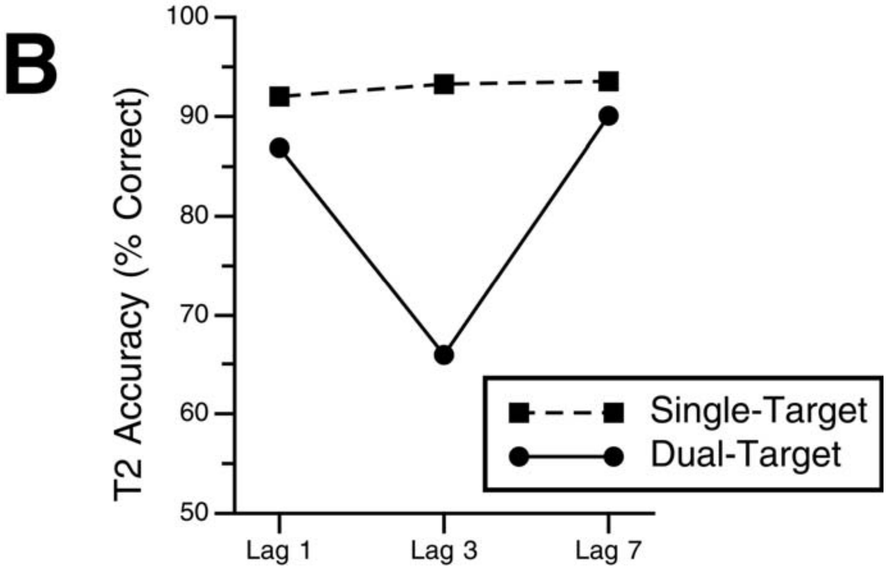

Figure 1b. Mean discrimination accuracy for the second target (T2) word as a function of lag for the single- and dual-target conditions[i].

In contrast, the relatedness effect in the ERP waveforms (the difference between the ERPs to related and unrelated words) at T2 was unaffected by lag: there was a large, similarly sized N400 semantic relatedness effect at all three lags (Figure 2). So although participants could neither identify nor classify words occurring during the attentional blink in terms of their relation to the meaning of the context word, these words nonetheless elicited an N400 semantic priming effect, indicating that they had been analyzed to a semantic/conceptual level. These waveforms were recorded at midline electrode sites and were averaged across participants. Negative is plotted upward. T2 = second target.

In other experiments of this type, Vogel and colleagues demonstrated that the stimuli presented during the attentional blink were perceived and analyzed for sensory characteristics (as evidenced by the normal early sensory components), but were not consolidated into working memory (as indicated by the totally suppressed P3 components). In this manner, ERP analyses were utilized to do what they do best – temporal localization. Specifically, ERPs implicated the synaptic computations involved in stimulus categorization and consolidation into working memory as the ones that were primarily

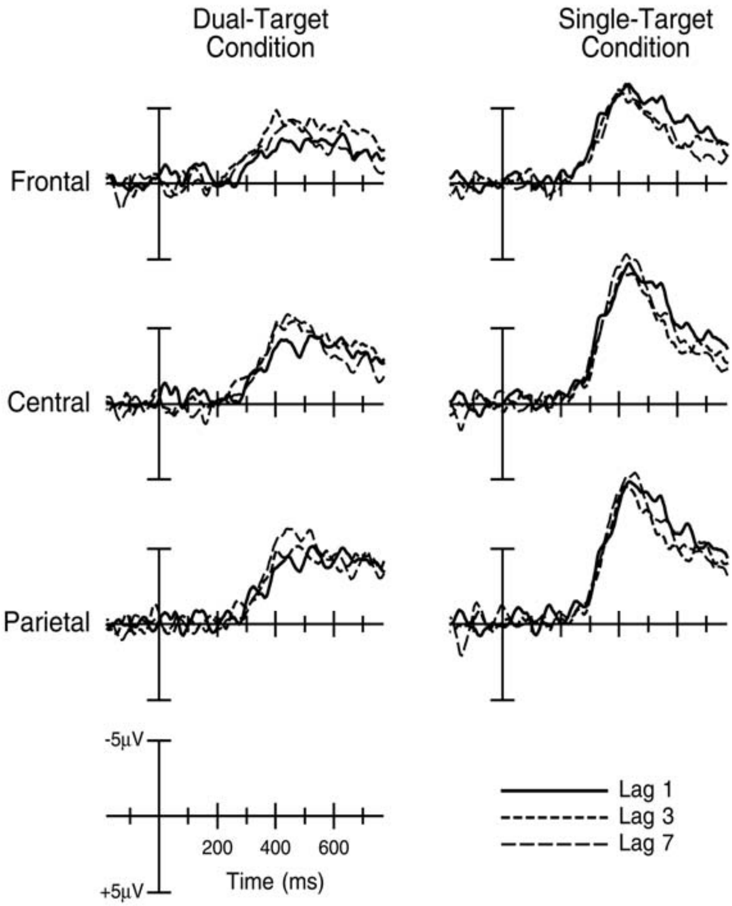

Figure 2. Grand average event-related potential difference waveforms, formed by subtracting related T2 trials from unrelated T2 trials[ii].

responsible for the attentional blink phenomenon. These results can be contrasted to the findings from the McCarthy and Nobre (1993) study, where those experimenters observed neither an N400 nor a P3 effect to spatially unattended stimuli. In that study, active suppression of items in a specific spatial location prevented words from being processed semantically/conceptually (as reflected by the absence of an N400 effect). In contrast, the attentional blink studies showed that if attention is paid to a stream of inputs, then a conceptual level of analysis can be attained, even if individuals report being unaware of the stimulus or certain aspects of the stimulus and are unable to later report on those items. These findings support the idea that perception, and some degree of attention, are needed to facilitate semantic pro-essing, but that semantic processing is not contingent upon consoli-ation in working memory, as evidenced by the absence of a P3 effect.

The spatial selective attention and attentional blink experiments are clever examples of harnessing ERP components, including those sensitive to linguistic stimuli and semantic variables, to capture specific computational processes in action. In doing so, they help to delineate the time course of processing leading to particular behavioral phenomena. In general then, the effectiveness of ERPs rests on the finding that different effects are functionally specific indices of different neural, and hence presumably cognitive, computations. The methodology thus offers a powerful tool for the functional demarcation and dissection of cognitive architectures. More specifically, in the case of the attentional blink studies, there was an immediate effect of semantic relatedness in brain processing – the N400 priming effect – that was not manifest in the subsequent behavioral response, as evidenced by participants not being able to consistently report on the T2 targets. In this sense, the ERP data were essential to analyzing the informational flow leading to the attentional blink. This dissociation of the ERP and overt performance measures is not uncommon in the literature, with frequent examples of the two measures telling different stories about which factors impact processing at which stages. Such results should remind us of the utility of looking at the electroagnetic activity within the brain, especially in situations where behavioral outputs may not be sensitive enough, wholly accurate, or readily, if at all, available.

3. LANGUAGE LEARNING

Language learning is another area where ERPs have been useful in uncovering evidence of certain kinds of linguistic analysis, when more overt behavioral tests revealed no or only slight differences. We know that the dynamics of different language representations in the brain are modulated over the course of development, when individuals acquire first and second languages. In these cases, we also know that there may be delays between comprehenders' declarative knowledge (i.e., what they can talk about) and their implicit knowledge of specific language information. Accordingly, it is the combination of high temporal sensitivity in detecting fast, presumably automatic processing (which imaging techniques like fMRI or PET cannot easily provide) along with the fact that ERPs also allow some insights into the neural underpinnings of how learning affects processing that make it an effective technique for studying language learning. An added advantage of ERPs in studying processing related to language learning is that whereas it is often difficult to use the same behavioral task with different groups of subjects, for instance with infants, monolinguals, and bilingual speakers, with some ERP paradigms it is possible; ERPs thus can at times allow researchers to compare and contrast the time course and mechanisms of language processing across groups.

3.1 Second language acquisition

ERPs have proven particularly useful in studying the early phases of second language acquisition, when explicit testing may underestimate what language learners' brains know about their new language. McLaughlin, Osterhout, and Kim (2004), for example, used the known sensitivity of the N400 to semantic relationships and lexicality (or wordness – the property of a string of letters representing an actual word), to assess the degree to which college students learning French as a second language knew French words at different stages of learning. Specifically, participants were shown semantically related word pairs (e.g., *chien-chat*, Eng. *dog-cat*), semantically unrelated word pairs (e.g., *maison-soif*, Eng. *house-thirst*), and word-pseudoword pairs (e.g., mot-nasier, Eng. *word*-pseudoword), and asked to make a lexical decision. As expected, a control group of non-learners showed no differences in the ERPs to the second member of the word pair, indicating no sensitivity to either word/nonword status or to the semantic relationship between the words (Figure 3). By contrast, the group of French learners showed differences in N400 amplitude (larger for nonwords) after an average of only 14 hours of instruction, indicating an appreciation of wordness within the second language (Figure 4a); conversely, at this same stage of training, lexical decision performance (assessed by *d'* sensitivity measures) was on average at chance (Figure 4b). Moreover, for the French learners, an ERP pattern indicative of semantic processing – smaller N400s to the related than the unrelated words – was observed after an average of only 63 hours of instruction (and also after 138 hours), even though behavioral responses, although improving, were still relatively poor.

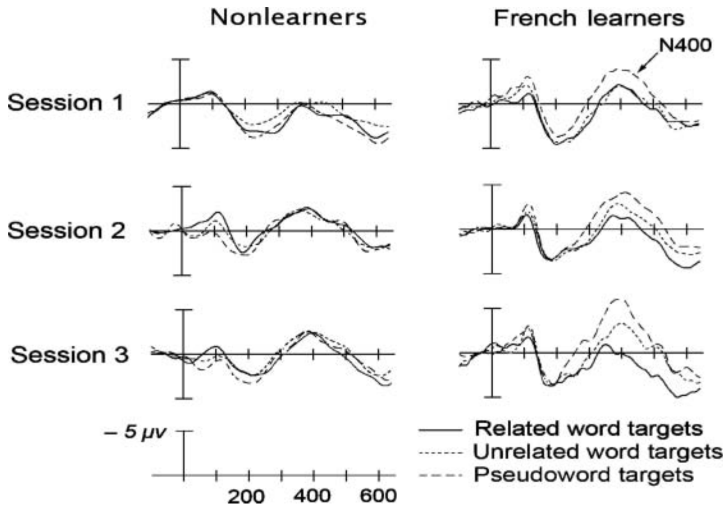

Figure 3. ERPs to word and pseudoword targets during the three testing sessions, for the nonlearners and French learners. Data acquired over the central midline site (Cz) are shown[iii].

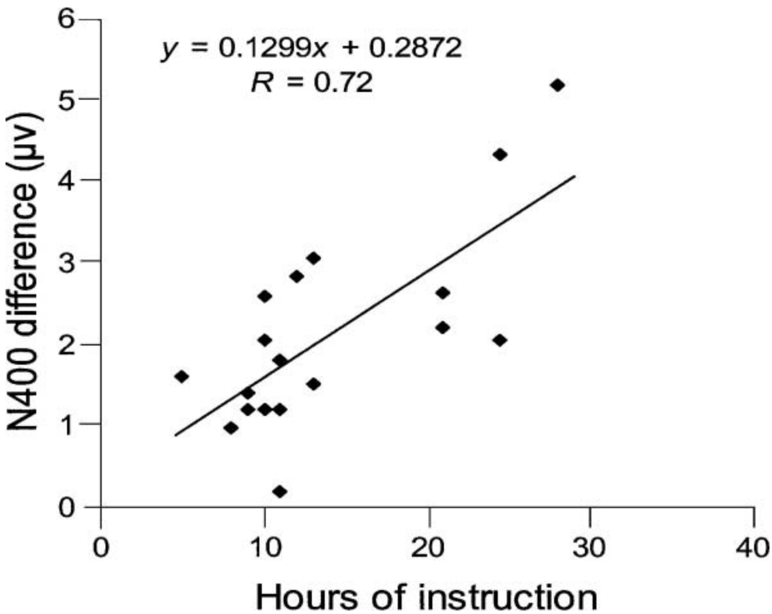

Figure 4a. Session 1 N400 amplitude difference between words and pseudowords. N400 differences were correlated with hours of instruction[iv].

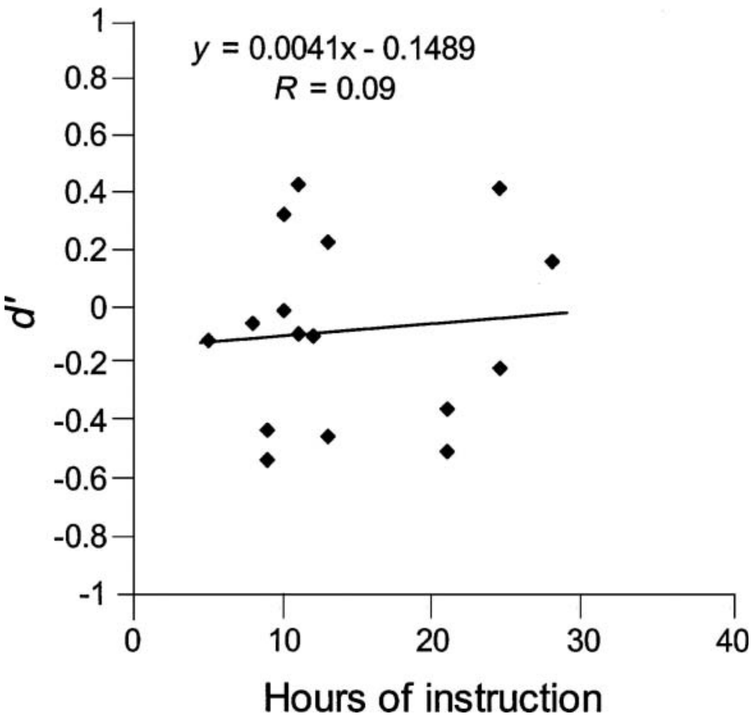

Figure 4b. d' scores regressed onto hours of instruction before session 1. d' scores were not correlated with hours of instruction.

3.2 Speech segmentation

The method of comparing ERPs before and after linguistic training also has been used to monitor speech segmentation processes (Sanders, Newport, & Neville, 2002). After establishing that the initial syllables of (actual) English words elicited larger sensory N100 components than medial syllables presented in continuous speech (Sanders & Neville, 2003), these researchers wanted to test whether the N1 indexed perceived word onsets. To that end, participants were trained to identify 3-syllable nonsense words like *babupu* or *bupada.* Learning was assessed behaviorally and monitored, with ERPs recorded to these "words" as they occurred in continuous speech streams both before and after training. Individuals' accuracy following training varied significantly, and was highly correlated with the change in N1 amplitudes before and after training: participants who learned more "words" showed larger N100 word-onset effects. These results suggest that N100 amplitude can serve as a marker for speech segmentation.

Moreover, as word onset effects occurred quite early, these data would seem to implicate predictive or very fast, automatic processes in speech segmentation. In this experiment, then, unlike the McLaughlin et al. (2004) second language learning study, the behavioral results and the ERPs went hand-in-hand, although in the latter, perhaps a different behavioral measure might have been more sensitive and/or correlated with the ERP data. Still, this ERP marker of speech segmentation has real utility in that it can be used to track speech continuously and not just at a few target test points. Critically, it can also be used in situations where even the most limited behavioral testing is not an option, as with infants or with various patient populations.

These language learning studies show us that ERPs are a good measure of synaptic plasticity. The changes in ERP indices of neural processing as a function of experience can be used to investigate, for instance, the effects of various instructional methods (e.g., temporally massed versus spaced, or immersion versus pictorial), similarities between first and second languages at multiple levels, or age of acquisition, to mention a few. For each of these contrasts, ERPs provide a tool for tapping into potential distinctions between language competence and performance.

4. UNCONSCIOUS STATES

4.1 ERPs to assess brain trauma patients

Arguably, the benefit ERPs afford in being able to observe cognitive and conceptual processing independent of behavioral or verbal output could be considered most advantageous in situations where individuals exhibit limited consciousness or behavioral responsivity. The methodology's value is particularly evident when assessing the integrity of the cognitive and language comprehension systems in patients who have survived severe brain trauma. These may include comatose individuals who show no indication of arousal or awareness, individuals in vegetative state who are awake but unaware of themselves or their environment, individuals in minimally conscious state (MCS) who are not in a vegetative state but are unable to communicate consistently (i.e., they can follow simple commands, make yes/no responses somehow, have intelligible speech, or exhibit purposeful behavior), and individuals with locked-in syndrome who show an awareness of their environment but are unable to move (for instance, quadriplegics). It is very difficult to assess the integrity of language comprehension in such individuals, and thus it is well worth an attempt to do so via electrical and hemodynamic neuroimaging methodologies, especially using auditory inputs. In these patient groups, there have been promising attempts to look for normal or delayed early sensory potentials (e.g., P1s and N1s), mismatch negativities (MMN), P3, N400, and P600 components, among others. The MMN, a frontal negativity recorded in response to infrequent, deviant stimuli embedded in a stream of auditory events has proven to be an especially good predictor of awakening in coma patients. For instance, Naccache, Puybasset, Gaillard, Serve, & Willer (2005) found that in 30 comatose patients, 10 showed a MMN, and 9 of these eventually awakened, whereas from the remaining 20 MMN-negative group, 13 died and 7 awakened. Although these findings are based on MMNs to tones, we can envision a MMN battery to different types of deviants – not just of frequency, intensity, duration, timbre, and phonetic content, but also of higher, more abstract linguistic and non-linguistic features which are known to elicit reliable MMNs (e.g., Paavilainen, 2001; Pulvermüller, Shtyrov, Kujala, & Näätänen, 2004; Saarinen, Paavilainen, Schöger, & Tervaniemi, 1992;). Testing of this sort would be relevant, because the MMN data imply the existence of a memory trace in which features of the frequent standard stimuli are represented.

A few researchers have examined semantic processing in such patients. Schoenle and Witkze (2004), for example, maintain that 38% of patients diagnosed as being in a vegetative state showed some evidence of N400 activity (although they specify that only 12% showed clear N400s), indicating some level of sensitivity to semantic or lexical processing. However, the data are rather poor quality and lacking in methodological controls. (N400s were assessed visually, not statistically, by three independent investigators. It is not specified whether these raters were blind to the patients' diagnoses or to the experimental conditions. It is also not clear from the description of the materials exactly what kind of sentence stimuli were used and which factors were or were not controlled for. The authors stated that they used 5-word sentences with either semantically correct or incorrect final words, yet the example they provide, "*The coffee is too hot to drink/fly*" is clearly longer than 5 words. Even assuming this was a misstatement, they do not indicate whether the stimuli were normed for semantic fit, nor whether the target words in the two conditions were matched on factors such as word frequency, length, or concreteness, to mention but a critical few. We believe these omissions are particularly relevant and potentially detrimental because if such studies are to be taken seriously as a means for diagnosing conditions as grave as vegetative state, then it is critical for these early investigations to be methodologically sound. Additionally, it was difficult for readers of this article to assess for themselves the ERP findings, as only a limited subset of single subject waveforms for selected vegetative state patients were shown, and even these were presented in a way not conducive to comparisons between conditions.) Kotchoubey (2005), using chord and vowel-sound P3 oddball paradigms as well as sentence and word pair N400 paradigms, have cleaner recordings and likewise claim that both the P3 and N400 occur in vegetative state patients with above chance frequency, suggesting that current methods for diagnosis may underestimate their remaining information processing abilities. Given the grave consequences to misdiagnosis in these cases, an ERP approach may be cost effective even for the occasional patient.

4.2 ERPs during sleep

ERPs also have been used to demonstrate the extent to which the human brain can process auditory information during sleep, when individuals cannot actively attend to or easily control their behavioral output. ERP studies have shown that sleeping brains are not completely isolated from the sensory environment and that at least some auditory information can be processed during sleep, sometimes in ways remarkably similar to wakefulness. For example, sleeping brains seem able to discriminate between different types of auditory stimuli by detecting deviant tone stimuli in oddball paradigms, exhibiting P300-like responses during rapid eye movement (REM) sleep, and various other ERP effects during other stages of sleep (see Bastuji, Perrin, & Garcia-Larrea, 2002, for a review). This indicates that at least some stimulus categorization is possible during this sleep stage, and that the responsible mechanism(s) overlap with those in the waking state.

But questions remain about whether these signs of auditory discrimination are related to higher-level semantic recognition, or whether they simply reflect the acoustic salience of the oddball. To test the sleeping brain's sensitivity to semantically relevant input, researchers have primarily used one of two different ERP experimental paradigms. The first examines the participant's own name, which during wakefulness elicits a large P300 compared to other names or words in a list, even without explicit instructions to attend or respond to one's own name. Participants' own names are used because their emotional content and high natural frequency in the individuals' everyday lives make them especially relevant stimuli that seem to be difficult to ignore consciously or unconsciously. Perrin, García-Larrea, Mauguière, and Bastuji (1999), for instance, recorded ERPs to the subject's own name presented equiprobably with 7 other names during waking and during REM (also known as paradoxical sleep or PS). In both cases participants' own names exhibited late positive waves between 400-600 ms, maximal over posterior scalp sites – in other words, a P300. Given that all the names were equiprobable, these results demonstrated that the sleeping ERP effect could not simply be due to the acoustic difference or physical rarity of the individual's own name. The authors concluded that the ERPs thus showed that some top-down processing remains functional during PS, since some sort of comparison of a deviant to a standard is necessary for detection. However, it is not clear whether these findings are due to the fact that as a pattern, one's own name is a more frequent stimulus relative to other environmental inputs, or whether the ERP response is more directly related to the name's inherent meaning. One potential way of addressing this question (which to our knowledge has not been done) might be to overtrain individuals over a period of days with some other name, not their own, and then determine whether the training influences the P3 during sleep to that particular name (relative to others that have not been so trained).

Because using the participant's own name might leave in question how "semantic" this processing is, due to the emotional content and higher natural occurrence baseline rate of individuals' own names, other ERP studies have instead employed word/word priming paradigms to argue for some degree of semantic analysis during sleep. In two separate studies, ERPs showed that related and unrelated words continued to elicit differential responses during sleep, and also indicated that differential responses to pseudowords were possible, depending on the stage of sleep. Perrin, Bastuji, and García-Larrea (2002) presented word primes followed by either congruous or incongruous target words, with pseudowords inserted between word pairs during waking, Stage 2 (S2) sleep, and PS. For both S2 and PS sleep, incongruous words showed larger N400-like waves than congruous words, with latencies and topographies similar to the waking N400. (Brualla, Romero, Serrano, & Valdizán, 1998 reported a similar finding, although with delayed N400 latencies during sleep.) Pseudowords, by contrast, elicited different ERPs depending on the vigilance state: during wakefulness they exhibited larger N400s than incongruous words, whereas during S2 sleep pseudowords and incongruous words elicited similarly greater amplitude N400s relative to congruous words. Less apparent is why during PS the ERPs to pseudowords, but not incongruous words, resembled those to congruous words. The authors suggest that these results are consistent with the finding by Stickgold, Scott, rittenhouse, & Hobson (1999) that linguistic absurdity is accepted in a different manner in dream-sleep than during waking, as reflected by an abnormal pattern of semantic behavioral priming (upon being awoken from PS) where weak primes show greater effects than strong primes. However, it is unclear why this pattern, for which the equivalent in the Perrin study would be reduced N400s to more weakly associated words, would not also hold for the incongruous words as well as for the pseudowords. Although the patterns observed for the pseudowords undoubtedly require deeper investigation, the finding of incongruous words continuing to elicit larger N400s relative to congruous words throughout S2 and PS sleep (as supported by two separate studies) is an intriguing one, and hints at a sleeping brain that is capable of processing language in a more semantically active way than perhaps previously would have been thought.

The sleeping brain reportedly is also sensitive to sentence level contextual priming. Ibáñez, López, and Cornejo (2006) examined both waking and sleeping participants using spoken Spanish sentence stems completed with endings of varying degrees of congruency, such as (translated from original Spanish) "*Something that flies and has a motor is a…*" followed by either a congruous ending (*airplane*), or one of three types of incongruous endings: 1) *bird* (incongruous with the second part of the sentence), 2) *car* (incongruous with the first part of the sentence), or 3) *television* (incongruous with both parts of the sentence). Waking individuals showed a significant differentiation in the N400 time window to the target types, with the largest negativities in response to the totally incongruous endings, the smallest negativities to congruous endings, and intermediate negativities to both Incongruous 1 and 2 endings which themselves were not discriminable. Sleeping participants were presented with the same stimuli during both Stage II and REM sleep, with ERP results showing no significant differences in relation to sleep stage, and overall a similar ERP congruency pattern to that of waking participants. The maximum negativity in both waking and sleep was in the left frontal regions, and was functionally similar regardless of sleep-wake status. Cognitive processing reflected by N400-like negativities it seems thus can be generated outside of conscious awareness.

The combination of superior temporal resolution, access to the neural activity generated by cortical networks, lack of necessity for an external response, and the added benefit of being able to collect data in bedside settings make ERPs an optimal methodology for monitoring the cognitive processes of brains in various states of consciousness. Using ERPs to examine unconscious states provides an important tool not just for gaining a better understanding of functions such as language comprehension (i.e., research in a more fundamental scientific sense), but also may turn out to have more practical applications as a critical component in establishing diagnostic criteria for patients who have suffered various degrees of brain trauma. The relatively untapped possibilities and potential knowledge to be gained in both areas represent an exciting new direction for ERP research, but one that calls for very careful experimental design.

5. PREDICTIVE LANGUAGE PROCESSING

Because so much of language processing occurs quickly and is unavailable to conscious reflection, ERPs have arguably made their greatest contributions in probing natural language processing in healthy, intact brains. One especially contentious issue in the language comprehension literature has been whether or not individuals might predict upcoming items at various linguistic levels (syntactic, semantic, phonological, etc.) Traditionally, a majority of psycholinguists have believed that language is too unpredictable and too ambiguous to allow for prediction except in very rare cases where contextual constraint is unusually high (e.g., Stanovich & West, 1979). More recently though, a few researchers have begun to propose that prediction (or perhaps better said, preactivation) may occur routinely (DeLong, Urbach, & Kutas, 2005; Federmeier & Kutas, 1999; Kamide, Altmann, & Haywood, 2003; van Berkum, Brown, Zwitserlood, Kooijman, &

Hogoort, 2005; Wicha, Moreno, & Kutas, 2004). Preactivation, however, is not so easy to capture, the difficulty being in how to observe the consequences of an event that has not yet occurred. ERPs are well suited for prediction research, though, because they can provide a continuous monitor of brain responses throughout the course of a sentence or discourse, i.e., prior to target events that might be subject to prediction. They also can provide a measure of the quantitative and qualitative changes that may distinguish two conditions, including sensitivity to semantic and syntactic variables and processing. In these ways, ERPs can be used to explore research questions that behavioral or in some cases even eye-tracking studies cannot as easily resolve.

In a precursor to electrophysiological studies designed specifically to track prediction, Van Petten, Coulson, Rubin, Plante, and Parks (1999) used ERPs to investigate whether or not semantic integration could begin to operate prior to the complete identification of a spoken word. Participants listened to sentences (e.g., "*It was a pleasant surprise to find that the car repair bill was only seventeen…*") that were completed by a word that was either a high cloze probability semantically congruous word (*dollars*) or one of 3 types of incongruous words: (a) incongruous words that either shared the same initial auditory fragment as the congruous word (*dolphins*), (b) rhymed with the congruous target (*scholars*), or (c) had initial phonemes differing from those of the highest-cloze probability word (*bureaus*). As long as the auditory input from the target word was consistent with the sentence context (i.e., for the *dol-* portion of *dollars* and *dolphins*), the ERPs for the two conditions were similar. However, as soon as the auditory signal for the congruous and incongruous sentence completions diverged, so did their ERPs. For the incongruous conditions (b) and (c), where the initial phonemes differed from those of the expected completion, the ERPs began to diverge much earlier than for the *dolphins* condition, condition (a). From these results, Van Petten et al. concluded that semantic processing of a word begins even before it is uniquely identified and that there is a continuous mapping from linguistic input onto semantic representations.

These ERP results suggested that verbal processing may begin prior to receiving all the relevant input. Subsequent studies have more directly explored the various levels at which anticipatory processing could occur. For instance, prediction need not be at the level of specific word forms, but could instead or also be at the level of meaning. So even if individuals were not anticipating a specific lexical form, they could be anticipating semantic features of the word most likely to appear in a given context. Federmeier & Kutas (1999) demonstrated just this in an ERP study in which expected sentence completion targets were compared to those for within and between category violations in high and low constraint sentences. For example, a high constraint context such as "*He caught the pass and scored another touchdown. There was nothing he enjoyed more than a good game of...*" was followed by one of three possible continuations: the expected item ("*football*"), an unexpected item from within the same category ("*baseball*"), or an unexpected item ("*monopoly*"), from a different category. The researchers showed that although both types of unexpected items showed a larger N400 than to the expected item ("*football*"), the N400 to the within category violation ("*baseball*") was smaller than that to the between category violation ("*monopoly*"). This pattern of results, where within category violations were easier to process semantically, was observed for high constraint sentences such as the example sentence provided here, but not for the low constraint sentences. Although within and between category violations were judged implausible for both high and low constraint sentences, the within category violation N400 was reliably reduced only when the target noun was highly constrained. The researchers suggested that this pattern of results could only be explained by the greater overlap in perceptual and semantic features of the expected exemplar with the within category violation exemplar compared to the between category violation exemplar. They proposed that in high constraint sentences, contextual information had already acted via semantic memory to preactivate some of the features of the expected exemplar.

Studies by Wicha, Moreno and Kutas (2003, 2004) and by van Berkum et al. (2005), have also demonstrated syntactic anticipation by capitalizing on grammatical gender manipulations in Dutch and Spanish, respectively. These ERP experiments used pre-nominal gender marking that either agreed or disagreed with an expected noun or depiction of a noun in a particular sentence context. In the Wicha et al. studies, native Spanish speakers received constraining sentences that contained a gender-marked article followed by either a noun or an embedded line drawing. The noun or line drawing target could be either an expected continuation or a semantically incongruent continuation of the same gender class as the expected continuation. In half of the sentences, the gender of the pre-nominal article was manipulated to be incongruent with the gender of the following noun or picture. Similarly, van Berkum et al. conducted an auditory ERP study using gender marking on pre-nominal adjectives in Dutch (for words only), but without gender mismatches between pre-nominal adjectives and nouns. In both studies, an ERP difference (albeit somewhat different in timing and distributional detail across studies) at the pre-nominal word between the prediction consistent and inconsistent conditions indicated that individuals had already formed an expectation for representations specifying words' semantic and syntactic properties (lemmas).

ERPs have also been instrumental in finding evidence for preactivation at the level of specific phonological word forms. DeLong et al. (2005) took advantage of a phonological regularity in English whereby the singular indefinite article is phonologically realized as *an* before words beginning with vowel sounds (e.g., *an airplane*, *an eagle*) and as *a* before words beginning with consonant sounds (*a kite*, *a carrot*). Participants read sentences such as "*The day was breezy so the boy went outside to fly…*", where *kite* is the expected noun and by extension *a* is the expected article. Participants also saw sentences such as "*Because it frequently rains in London, Nigel always carries …*", where *umbrella* is the expected noun and *an* the expected article. The experimental design assumes that if readers are predicting a specific upcoming noun, then these expectations should be violated when they get a contextually less likely (but still plausible) article (and noun) such as *an airplane* in the case of the first example or *a newspaper* in the case of the second. Given comprehenders' background knowledge about entities like boys, breezy days, outdoor activities, and flying objects, it is not difficult to see why *kite* and *airplane* might differ in how well they fit with the schemas or event knowledge that the sentential context "brings to mind" via semantic memory processes. It is exactly this line of reasoning that led to the original hypothesis of the N400 indexing the ease or difficulty of contextual integration processes in the first place. However, whereas the nouns *kite* and *airplane* differ in their semantics, the indefinite articles immediately preceding each do not, possessing identical semantics ("some one thing or other"). Since the indefinite articles' semantics are identical and the two forms differ only in phonological form, frequency of usage and length, there is no reason for one to be differentially difficult to integrate into the mental representation of any particular sentence context, unless people are forming predictions for specific word forms.

We tested this possibility with sentences of varying constraint leading to expectations for particular consonant-initial or vowel-initial nouns with offline expectancy (cloze probability) ratings ranging from highly probable to highly unlikely, based on the percentage of individuals who continued the truncated sentences with that particular word in an offline norming questionnaire. Using broad ranges of cloze probabilities (article cloze probabilities ranged from 0-96%, nouns ranged from 0-100%) allowed us to conduct correlational analyses to determine whether there was a systematic relationship between ERPs at the article and their offline cloze probabilities.

In line with previous research (Kutas & Hillyard, 1984), unexpected nouns were associated with a greater posterior negativity between 200 and 500 ms relative to expected nouns, the amplitude of which was inversely correlated with noun cloze probability. These data thus demonstrate that the different degrees of constraint in these materials are reflected in offline expectancies and in modulations of N400 amplitude in the usual way, but do not speak to the issue of prediction per se. To address that question we turned to the indefinite articles. Just as for the nouns, high cloze articles were associated with less negativity between 200-500 ms post-article onset than lower cloze articles. A comparison of ERP waveforms after a median split on their offline cloze probabilities revealed a very similar pattern for articles as for nouns, although much smaller for articles (Figure 5a). Moreover, the amplitude of this negativity was highly correlated with the article's offline cloze probability, although again slightly lower than for nouns (Figure 5b). Also similar to the nouns, the maximum article correlations were not randomly distributed, but rather clustered over the posterior sites where N400 effects are typically seen (Figure 5c). So at least over certain scalp areas, a large percentage of the variance (up to 52%) in N400 amplitude for the indefinite articles was accounted for by the average probability that individuals would continue the sentence context with that article.

In short, these results offered evidence of lexical prediction, indicating that people do use sentence context to form graded predications for specific upcoming words. These findings also refute the idea that, as some have suggested, prediction is limited to highly constraining contexts, with only a single lexical item activated when its representation exceeds some threshold given a very constraining context. Even in moderately constraining sentence contexts at least one and perhaps multiple items seem to be pre-activated but to varying degrees.

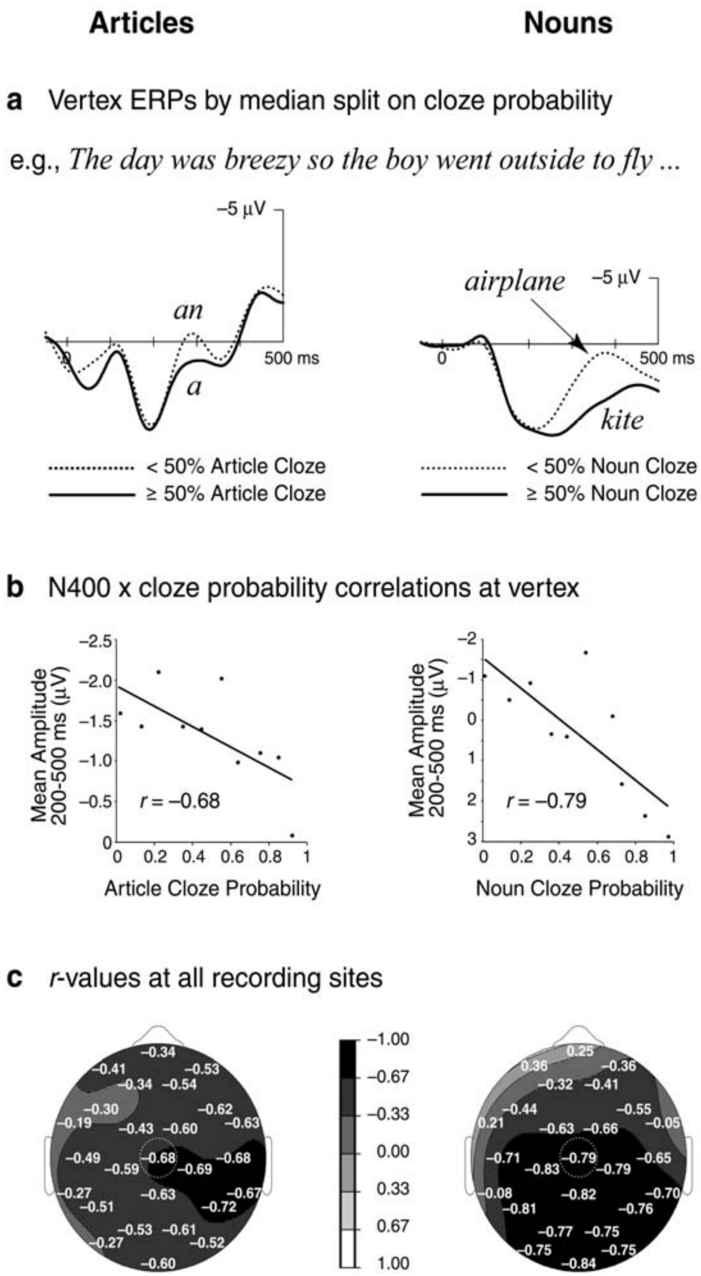

Figure 5. ERP waveforms and correlations between N400 amplitude and cloze probability for articles (left) and nouns (right) showing that specific words are predicted during language comprehension. (a) ERPs at the vertex recording site according to a median split on cloze probabilities. Both articles and nouns with cloze probability less than 50% elicit a greater negativity between 200-500 ms post-stimulus

onset (N400) than those with cloze probability greater than or equal to 50%. (b) There are strong inverse relations between the items' cloze probabilities and mean N400 amplitudes at MiCe for both the articles and the nouns. The solid lines in the scatter diagrams indicate the best fitting regression line. (c) The r-values calculated as in (b) for each electrode site. Analyses indicated that both articles and nouns show a focus of maximal correlations over centro-parietal sites[v].

The studies described here relating to predictive language processing indicate that in the course of sentence comprehension, semantic memory for a particular item is likely not just triggered at the time point when the phonological word form or linguistic item is received. Rather, information of all sorts, both linguistic and extra-linguistic, is actively accessed and integrated to continually update representations of contexts which dynamically constrain linguistic expectations at a variety of different levels (e.g., semantic/conceptual, syntactic, phonological) and aid in meaning construction. While preactivation of linguistic information could be inherently difficult to observe – because we must capture evidence of processing for an event that has not yet occurred – ERPs offer one method of tracking online updating and provide a means of distinguishing between qualitative and quantitative differences. In combination with clever experimental designs, then, the ERP methodology will continue to play an important role in delineating the time course of language processing.

6. CONTEXTUAL ACTIVATION OF INFORMATION IN SEMANTIC MEMORY

In DeLong et al. (2005) we suggested that probabilistic pre-activations are supported by semantic memory, which includes experiential knowledge about people, places, things and events accessed by linguistic input (see also, Kutas & Federmeier, 2000). Although our knowledge of the precise cognitive and neural mechanism involved in activating information in semantic memory remains relatively under-specified, we believe that words and various structures in sentences act as cues that activate different types of information in semantic memory and are thus involved in constructing word and sentence meanings. Some researchers have attempted to use the ERP technique to test specific hypotheses about the types of information that words may activate. Ferretti, Kutas, and McRae (2007), for example, used

ERPs to investigate the hypothesis that information in verbs, such as verb aspect, activates knowledge about events in semantic memory, including which individuals usually take part in the event, the typical locations where those events occur, and the instruments involved. In turn, the availability of this information at different time points across the course of a sentence is presumed to influence how sentence representations are built in real time. The grammatical category of aspect captures some ways in which languages use morphology to refer to the temporal structure of events, in this case as ongoing versus completed. Imperfective aspect, which in English is marked with a verbal form of *be* + a main verb ending with *-ing* (e.g., *was skating*), makes specific reference to the internal structure of events by focusing on their ongoing development. The imperfective makes no reference to an event's completion, highlighting the internal phases of dynamic events instead. Perfect aspect, in contrast, is used to refer to some time period that follows an event and emphasizes the resultant phase or states. In English, this aspectual category is marked by *to have* + a past participle (e.g., *have skated*). Perfect aspect functions to indicate the continuing relevance of a past situation for the present or for some other reference time. One can consider the causal (and temporal) structure of events to include the initiating conditions (beginning), the actual event (middle), and the resultant states (end). Related to each are the various entities, objects, and locations that typically characterize these events. Importantly, the entities and objects relating to particular events will be more or less salient during their different causal components. For instance, location and instrument information are often salient during ongoing events, but not after they are completed. The authors proposed that if this is indeed the case, then there should be differences in the processing of location information when events are linguistically signaled as ongoing compared to when they are signaled as having been completed, and that among other measures, this should be reflected in the accompanying electrical brain activity.

Ferretti et al. collected ERP evidence consistent with this view. Using sentences such as "*The girl was skating/had skated in the rink/ring*" that varied in both aspect (imperfective or perfect) and typicality (high or low) of the location of the verb-related activity, they observed that the N400s were smallest to nouns representing typical locations of particular activities (e.g., *rink*) in imperfective sentences and largest to atypical locations (e.g., *ring*) in imperfective sentences (Figure 6). By contrast, N400s to location nouns completing perfect aspect sentences were less sensitive to location information. These results suggest that the imperfective form of the verb leads to specific expectations about where the events denoted by the verb will occur, whereas location expectancies are less well formed (and/or more difficult to integrate into the sentence representation once the location is known) for sentences in the perfect aspectual form, presumably because locations are generally less expected. In addition to the N400 findings at the location nouns, ERPs throughout the sentence varied as a function of verb aspect. This effect manifested as a sustained frontal negativity spanning the prepositional phrases that was larger following perfect than imperfective aspect verbs. These over-sentence averages indicate that processing differences began with the verbs, if not before.

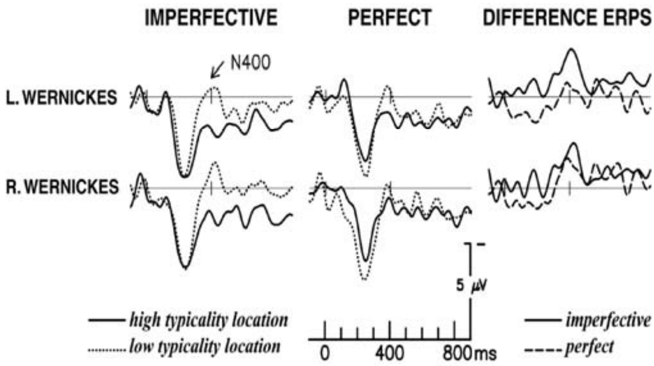

Figure 6. Grand averages for the four experimental conditions at Wernickes (LDPa, RDPa) electrode sites. Column 1 shows the averages for high and low typicality locations for imperfective aspect, and Column 2 shows the averages for high and low typicality locations for perfect aspect. Column 3 shows the difference waves (high – low typicality) for each of the two aspects[vi].

Verb aspect is just one instance of the type of linguistic information that is likely to activate comprehenders' background knowledge of the world and influence sentence processing in real time. ERP recordings show us that this is the case by offering a neural view into how linguistic stimuli cue information in semantic memory to help in constructing word and sentence meaning. The cognitive electrophysiology literature abounds with examples of this sort, where ERPs have been used to examine factors believed to influence language comprehension processes or to test alternative accounts of various psycholinguistic phenomena, in normal and abnormal individuals of all ages.

7. CONCLUSIONS AND FUTURE DIRECTIONS

In this chapter we have presented five varied groups of experimental examples demonstrating how ERPs can provide and have provided insights into different types of language processing. Each subset of studies benefited in a unique way from either the type of information that the electrophysiological measures afforded or from an inherent feature of the methodology itself. In some cases, the sensitivity of the ERP revealed differences that were not readily, if at all, manifest in corresponding behavioral measures. In others, the factor that made the ERP technique the most appropriate solution was that no external responses were required. In yet other studies, the continuous nature of the ERP measurements allowed critical monitoring at different time points of more temporally extended cognitive events. In all cases, the ERP's millisecond-level resolution and the amassed knowledge of the functional correlates of different ERP components were vital in designing the experiments and analyzing and interpreting the data collected. Although we have discussed many of these components throughout the chapter, focusing on the N400, but also mentioning the P1, N1, P3b, P300, P600 and MMN, there are others, both sensory/perceptual and more cognitive, that did not make the cut due to limited space and scope. In ways similar to the studies included here, these unmentioned components have served as useful tools in delineating the cognitive architectures associated with particular perceptual, behavioral, and linguistic phenomena.

Although this chapter has featured studies that capitalize on the strengths of (scalp-recorded) ERPs, the methodology is certainly not the only game in town when it comes to studying language processing. However, with exception to their most obvious deficiencies – a lack of spatial resolution and more superficial depth of recording than neuroimaging techniques such as PET or fMRI – ERPs rank respectably high on a number of characteristics when directly compared to other methodologies. Even with respect to spatial resolution and neural source localization, ERPs have improved in recent years with the use of more densely arrayed electrode caps and more sophisticated inverse modeling software tools. As is often noted, ERPs have an unbeatable temporal resolution and temporal span. In addition, the technique is relatively noninvasive, with the primary inconvenience in some of the older systems being the requisite mild scalp abrasion and administration of electrolyte gel. ERPs are also inexpensive when contrasted with either hemodynamic methods or MEG (although clearly a behavioral study, when appropriate and sufficient, would offer a more economical solution). A final practical advantage of ERPs is that they are relatively convenient to use across a wide variety of population groups, from infants to elderly, and for different patient populations in clinical, laboratory, and in some cases, even residential settings. And unlike MEG or fMRI, ERPs do not require head restraint, although none of these measures tolerates much head movement without additional computations. Even after enumerating these benefits of ERPs, it is worth keeping in mind that recent advances in combining methodologies make these either/or distinctions less relevant than they might have been even five years ago. As cognitive neuroscientists, we would all like to have our methodological cake and eat it, too – temporal *plus* spatial resolution, not one or the other. It is unlikely that ERP measures for studying language processing will be rendered obsolete anytime soon; rather, it is more probable that in the future there will be an even greater emphasis on converging methods, with ERPs (and various electroencephalographic measures more generally) continuing to play an irreplaceable role.

Certainly with respect to language processing, we have demonstrated that even on their own, electrophysiological recordings have come a long way from those early days of monitoring differences in language-related suppression of alpha activity between the cerebral hemispheres. For the most part, the experiments described in this chapter are meant to be representative examples of clever and sophisticated ways in which ERPs can be utilized to reveal how the brain extracts meaning from visually and auditorily presented linguistic stimuli. At least a few of these studies will likely, over time, establish themselves as landmark experiments, perhaps by merit of their designs, but more likely through the novelty of their findings. Although their subject matter is diverse, each serves to fit a small piece of the huge puzzle of figuring out not only how language is neurally instantiated in the brain, but how it works, for instance, in combination with the brain's attentional system, during various states of consciousness, and under the pressures of natural language time constraints. And similar to the aforementioned inter-methodology cross-talk that we assume will play an ever larger role in future neurolinguistic research, equally important is the idea that language researchers working within the ERP methodology stay apprised of other electrophysiological findings outside their specific areas of study. In this way, we can begin, in tandem with our individual endeavors, to gain a more "big picture" understanding of how the brain negotiates the linguistic world.

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