Applied Psycholinguistics **26** (2005), 79–96
Printed in the United States of America
DOI: 10.1017.S0142716405050071

Electrophysiology in the study of developmental language impairments: Prospects and challenges for a top-down approach

COLIN PHILLIPS
University of Maryland

ADDRESS FOR CORRESPONDENCE
Colin Phillips, Department of Linguistics, 1401 Marie Mount Hall, College Park, MD 20742.
E-mail: colin@umd.edu

ABSTRACT
There is a good deal of interest in the application of neurocognitive techniques to investigate the underpinnings of developmental language impairments (DLIs). Electrophysiological techniques such as electroencephalography and magnetoencephalography offer the promise of the ability to track brain activity with precision in time and space. This article describes a number of findings from studies of normal adults and children that are relevant to neurocognitive studies of developmental language impairments and outlines a series of challenges that should be met in order for electrophysiological measures to realize their promise.

As more is learned about the language profiles and about the genetic underpinnings of developmental language impairments (DLIs), a clear puzzle is emerging. On the one hand, the effects of specific genetic disorders on language appear to be surprisingly nonspecific. Similar aspects of language appear to be impacted across a variety of disorders with different genetic causes. On the other hand, the effects of genetic disorders on language are highly specific. DLIs appear to selectively target certain subparts of language while sparing others. To take just one example, morphosyntactic difficulties associated with verb inflection in English are reported across a number of different DLIs, in specific language impairment (Leonard, 1997; Rice, Wexler, & Cleave, 1995), autism (Kjelgaard & Tager–Flusberg, 2001), Williams syndrome (Thomas, Grant, Barham, et al., 2001; but cf. Clahsen & Temple, 2003), fragile X syndrome (Aziz et al., 2003; Schopmeyer & Lowe, 1992), and Down syndrome (Fowler, Gelman, & Gleitman, 1994).

One possible reason for the apparent convergence of language phenotypes across different DLIs is that certain aspects of language are simply more vulnerable than others, with the consequence that a variety of different developmental impairments all lead to similar language profiles. The underlying causes of these impairments need not be specific to language. An alternative possibility is that the appearance of converging language phenotypes is illusory, and merely reflects the narrow range of linguistic phenomena and languages that have been investigated across multiple DLIs. The only way to find out whether either, or both, of these alternatives is correct is to gain a more detailed understanding of the language phenotype of different DLIs, in order to either understand why specific areas of language are especially vulnerable or to understand the more fine-grained features that might differ across DLIs. Standardized testing across populations is unlikely to solve this puzzle. The search for a solution will need to draw on a wider variety of experimental measures that can provide a more detailed understanding of the similarities and differences between normal and disordered language development. I have discussed the relevance of cross-language approaches and detailed linking hypotheses in another article (Phillips, 2004). In this article I discuss ways in which electrophysiological brain recordings might contribute to a more fine-grained understanding of specific language disorders. In addition, I emphasize a number of challenges that must be overcome if neurocognitive studies of DLIs are to realize their substantial promise. The upshot of this is that while it is already possible to conduct electrophysiological studies of children with DLIs, a great deal of basic research on electrophysiological techniques and language processing is needed in order for recordings of disordered children to be fully informative.

THE PROMISE OF ELECTROPHYSIOLOGY

Electroencephalography (EEG) and magnetoencephalography (MEG) provide direct noninvasive measures of neural activity, in the sense that they track the voltages (EEG) or the magnetic fields (MEG) generated at the scalp by cortical neuronal currents. When the electrical activity recorded across many related trials is averaged together, the resulting measure of activity that is time locked to a specific event is known as an *event-related potential* (ERP). The magnetic counterpart is sometimes referred to as an *event-related field* (ERF). Both techniques are fully noninvasive: scalp voltages are nowadays typically recorded from an array of electrodes that are embedded in a flexible electrode cap worn by the subject; scalp magnetic fields are recorded from an array of sensors (typically 140–250 in current systems) housed in a stationary cryogenic dewar that surrounds the head.

Hemodynamic techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) provide excellent spatial resolution, and are hence well suited to address questions about the localization of specific brain functions. These techniques are therefore particularly useful for investigating the possible causes of DLIs from a bottom-up perspective that focuses on the impact on subsequent language development of nonlinguistic precursors to language. To the extent that bottom-up approaches provide detailed localization hypotheses, they can be usefully tested using fMRI or PET, as discussed by Müller (2005). On the other hand, the strength of electrophysiological techniques is their excellent temporal resolution, which is in the order of milliseconds. Distributions of scalp voltages in ERP recordings provide a useful dependent measure, but offer only limited information about brain localization. In contrast, magnetic fields are not attenuated by brain and bone matter in the same way as electrical current, and therefore MEG offers improved localization, with accuracy that is sometimes on the order of a few millimeters. Nevertheless, MEG can only rarely match the spatial precision of fMRI and PET. However, because most current accounts of language functions provide far more detailed hypotheses about the timing of language processes than they do about the localization of language processes, electrophysiological measures are well suited to investigations of DLIs that focus on the details of the language phenotype.

In the ideal case, electrophysiological measures provide an opportunity to pinpoint language processes in the brain with millisecond and (in the case of MEG) millimeter accuracy. In many cases this is possible without the interference of explicit tasks, something that is particularly attractive when working with disordered populations. Furthermore, it is possible to build upon a body of relatively well-established findings from studies of unimpaired language. Therefore, electrophysiological measures offer a great deal of promise for tracking the precise nature of language disorders, for identifying the specific features where they differ, and for understanding why different genetic causes often lead to similar language outcomes. Enthusiasm for these approaches is well motivated. However, it is important to also recognize the challenges that must be addressed if the promise of electrophysiological techniques is to be fully realized. The challenges mostly derive from the fact that although EEG and MEG provide a very rich record of electrical activity in the brain, we are still only at the very early stages of understanding the neural code that they read out. Current techniques for separating signals of interest from irrelevant noise are still relatively rudimentary in most studies. Furthermore, even if it were possible to track cognitive processes with perfect resolution in time and space in the brain, we would face the serious theoretical limitation that current hypotheses are not detailed enough to tell us what to look for in such ideal recordings. In the following, I elaborate on each of these challenges in more detail.

THE DOUBLE-EDGED NATURE OF TEMPORAL PRECISION

The extreme temporal precision of electrophysiological recordings is both a blessing and a curse. It is a blessing because it makes it possible to distinguish a neural response that reliably occurs 100 ms after a particular event from a neural response that reliably occurs 120 ms after the same event (e.g., Obleser, Lahiri, & Eulitz, 2003; Poeppel et al., 1997). This is the kind of time resolution that must be reckoned with if we are to understand linguistic computation in detail. Temporal precision is also a curse, because it can be difficult to isolate neural responses that are not precisely time locked to an eliciting event. The most widespread approach in electrophysiological studies of language averages the responses elicited by hundreds or thousands of presentations of a similar event type, in order to generate a record of the activity that is time locked to the eliciting event. A response that is not time locked to the eliciting event will not survive the averaging process.

The need for responses to be time locked to the eliciting event explains why linguistic anomalies have played a central role in electrophysiological studies of language. Brain activity is most likely to be time locked to an eliciting event when the event is not predictable. Linguistic anomalies and violations are primary examples of unpredictable events. The most famous and extensively studied ERP response component is the N400, a negative voltage shift with a broad central scalp distribution that typically appears 300–500 ms after presentation of a word that is syntactically congruous but semantically anomalous (Example 1a) or unexpected (Example 1b; Kutas & Hillyard, 1980, 1984; for a recent review see Kutas & Federmeier, 2000). A small number of MEG studies have elicited the magnetic counterpart of the N400 and have determined the source to be primarily in the posterior temporal lobe (Halgren et al., 2002; Helenius, Salmelin, Service, & Connolly, 1998).

1. a. He spread the warm bread with {butter, socks}.
   b. The girl put the candy in her {mouth, pocket}.

Studies of morphological and syntactic anomalies have yielded a family of different ERP responses. A wide variety of different syntactic anomalies, including ungrammaticalities of various kinds (Example 2) and garden path sentences (Example 3), have been shown to elicit a positive voltage deflection with a broad posterior scalp distribution and an onset latency of 300–600 ms after the critical **AQ1** word. This response is known as the P600 or the *syntactic positive shift* (Hagoort, Brown, & Groothusen, 1992; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Holcomb, 1992). In a narrower set of studies of syntactic anomaly an anterior negativity has been observed in the 300–500 ms latency range. This response is most commonly known as the *left-anterior negativity* (LAN), because **AQ2** of the fact that it shows a left hemisphere focus in some studies (Coulson, King, & Kutas, 1998; Friederici, Pfeifer, & Hahne, 1993; Münte, Heinze, & Mangun, 1993; Osterhout & Mobley, 1995). The LAN has mostly been elicited by ungrammatical sequences, but there is at least one recent report of a LAN elicited by well-formed garden path sentences like (Example 4; Kaan & Swaab, 2003).

2. a. The plane took we to paradise.
   b. Every Monday he mow the lawn.
3. The broker persuaded to sell the stock was sent to jail.
4. The man is painting the house and the garage is already finished.

In an even narrower range of studies, a very early response known as the *early left anterior negativity* (ELAN) has been observed, with peak latencies in the 150–250 ms range. Although this response has sometimes been taken to indicate a general stage of syntactic structure building that occurs extremely rapidly, it should be borne in mind that most current evidence for the ELAN derives from just two constructions, one each in English (Example 5; Neville et al., 1991) and German (Example 6; Friederici et al., 1993; Hahne & Friederici, 1999). In the only existing study of MEG responses to syntactic anomalies, Friederici, Wang, Herrmann, Maess, and Oertel (2000) report that the magnetic counterpart of the ELAN response is primarily accounted for by activity in the anterior temporal lobe. For recent reviews of ERP responses to syntactic anomalies, see Hagoort, Brown, and Osterhout (1999) and Friederici (2002).

5. The scientist criticized Max's of proof the theorem.
6. Die Gans wurde im gefüttert.
   the goose was in-the fed

In studies of speech sound processing, the electrophysiological literature is similarly dominated by studies of unpredictable events. Many studies of the *mismatch negativity* (MMN) elicited by oddball sounds in sequences of similar sounds have shown sensitivity to phonetic and phonological properties (e.g., Dehaene–Lambertz, Dupoux, & Gout, 2000; Näätänen et al., 1997; Phillips et al., 2000; for a recent review, see Phillips, 2001). Even the N100 and its magnetic counterpart M100, which is an early response elicited in auditory cortex by any sharp change in an auditory stimulus, have been found to be affected by predictability (e.g., Sanders, Newport, & Neville, 2002; for a recent review, see Näätänen & Winkler, 1999).

Although much has been learned from the fact that different types of linguistic anomaly elicit different types of electrophysiological response, it remains unclear what the link is between the mechanisms involved in the detection of anomalies and the mechanisms involved in successful processing of well-formed language input. Therefore, in order to realize the promise of the temporal precision of electrophysiological approaches, while also avoiding its pitfalls, it will be important to address two challenges. The first challenge involves the need to understand successful processing of nonanomalous material.

> *Challenge 1: Understanding Normal Processes.* In order to use electrophysiology to understand why normal language processing is impaired in DLIs, it is important to have a greater understanding of the electrophysiological profile associated with processing normal, congruous linguistic stimuli.

A growing body of research addresses Challenge 1. Although electrophysiological research on language has been dominated by studies of anomalous or unexpected events, there is also a growing set of findings about ERP and MEG responses associated with the processing of congruous stimuli. The N400 response was first observed as a response to semantically anomalous words, but it is now well understood that the N400 is a more general response that is elicited by all content words, and that it varies in amplitude as a function of frequency, priming, and cloze probability (Federmeier & Kutas, 1999; Fischler, Bloom, Childers, Roucos, & Perry, 1983; van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). The responses elicited by semantically odd sentences are merely a special case of this more general phenomenon. A similar conclusion is beginning to emerge from ERP research on syntactic processing. A small number of recent studies have shown that the P600 response, which is normally associated with the detection and repair of syntactic anomalies, is also elicited in the construction of fully congruous long-distance dependencies in English (Kaan, Harris, Gibson, & Holcomb, 2000; Phillips, Kazanina, & Abada, 2004) and German (Fiebach, Schlesewsky, & Friederici, 2002), leading to the suggestion that the P600 reflects a more general measure of the costs associated with syntactic structure building. However, the morphosyntactic processes that underlie evoked responses such as the LAN and the P600 remain poorly understood. There are also findings that suggest that the working memory demands of holding an incomplete syntactic dependency in memory elicit a sustained anterior negativity (SAN), which may span many words of a sentence (Fiebach et al., 2002; King & Kutas, 1995). However, work in this area is in its infancy, and there is still a great deal to be learned.

The second challenge involves the need for less dependence on time-locked responses.

> *Challenge 2: Identifying Time-Varying Electrophysiological Responses.* The focus on responses to linguistic anomalies derives from the sensitivity of standard ERP methodologies to neural activity that is both time locked and phase locked to the eliciting event. Development of novel analysis techniques that reduce the need for time locking and phase locking will lead to improved understanding of successful processing of normal language input.

Research on analysis techniques that do not require time locking and/or phase locking of responses is a substantial growth area at present, although specific applications to language are only just beginning to emerge. For example, a number of studies have examined activity that is time locked but not necessarily phase locked to an eliciting event by decomposing continuous EEG waveforms into activity in different frequency bands. The Fourier transform of a wave preserves most timing information, but it destroys information about the phase of waves and thus makes it possible to identify activity that is consistent in timing but not in phase (*induced* responses, contrasting with standard *evoked* responses, which require phase locking). Variants of this approach have been used to identify activity in the *gamma band* (30–50 Hz), which is associated with perception of coherent visual objects (Tallon–Baudry & Bertrand, 1997), and to identify changes in the *theta band* (4–6 Hz), which is associated with the processing of clausal structure (Bastiaansen & Hagoort, 2003). Techniques are also being developed that allow identification of activity that shows a consistent spatial distribution but inconsistent timing, such as *independent components analysis* (ICA; Bell & Sejnowski, 1995). To date, ICA has been successfully used in a number of studies of sensory processing (e.g., Makeig et al., 1999, in press) and is also commonly used as a method for removal of irrelevant artifacts in ERP and MEG studies of language, but it has not been extensively applied to identification of language-related brain activity.

ELECTROPHYSIOLOGICAL PROFILES OF NORMALLY DEVELOPING CHILDREN

In electrophysiological studies involving adults there is a relatively large body of findings about the processing of linguistic anomalies, and rather less is known about electrophysiological markers of successful linguistic processing. The situation is more acute in the case of studies of children. There are only a limited number of existing electrophysiological studies of language processing in children, and most of these have focused on the responses elicited by different kinds of anomalies.

A number of studies with children have investigated N400-like responses elicited by words in lists (Coch & Holcomb, 2003; Coch, Maron, Wolf, & Holcomb, 2002), primed words (Dykman, Ackerman, Loizou, & Casey, 2000) or anomalous words in sentence contexts (Atchley et al., in press; Holcomb, Coffey, & Neville, 1992; Mills & Schweisguth, 2001). These studies have demonstrated an N400-like response in children aged between 4 and 12 years that is modulated by expectancy in a similar manner to the adult N400. In some studies it is reported to occur later than its adult counterpart, suggesting slower processing.

Published findings about responses to morphosyntactic anomalies in normally developing children are even more scarce, but a couple of findings suggest an interesting developmental delay. Although two studies report that syntactic anomalies elicit P600-like responses in children, either at the same latency as adults (Atchley et al., in press) or at some delay (Friederici & Hahne, 2001), some other studies report nonadultlike response profiles. One study of anomalous German plural nouns in sentence context found that the morphological anomaly elicited a LAN/P600 response pattern in adults, but that a broadly distributed N400-like response was present in children aged 6–8 years, and that the P600 response first appeared in children aged 11–13 years (Lück, Hahne, & Clahsen, 2001). Similarly, an N400-like response was elicited by word-order violations in a group of English-speaking 4-year-olds (Mills & Schweisguth, 2001). Interestingly, a similar pattern of results was found in a study of syntactic anomalies involving adult agrammatic aphasic patients (Hagoort, Wassenaar, & Brown, 2003). In another study, the N400 response was been found to be present by age 5 but the ELAN was not present until substantially later (Hahne & Friederici, 1999, as cited in Koelsch et al., 2003). Note that in each of these cases the children who fail to show an adultlike ERP profile in response to syntactic anomalies nevertheless show adultlike ability to detect the anomalies in a behavioral task. Therefore, an important goal for future studies will be to investigate the reason for the protracted development of responses to syntactic anomalies.

A larger number of studies have investigated the MMN response elicited in infants and children by acoustic or phonetic contrasts. The main finding in this area has been that MMN response profiles reflect the major developmental changes in speech perception abilities as infants change from “universal listeners” around 6 months of age to “native language listeners” by around 12 months of age, and then largely track native language discrimination abilities thereafter (Cheour et al., 1998; for a review, see Cheour, Leppänen, & Kraus, 2000). Nevertheless, there are important developmental changes in the amplitude and timing of the MMN response that occur between infancy and school age (Kurtzberg, Vaughan, Kreuzer, & Fliegler, 1995).

Therefore, in light of the limited current understanding of the ERP profile of normally developing children, particularly with regard to word recognition and sentence processing, it will be important to develop reliable normative benchmarks in order to make effective use of electrophysiological approaches in studying DLIs.

> *Challenge 3: Electrophysiological Profiles of Unimpaired Children.* In order to reliably identify abnormal electrophysiological profiles in children with language impairments, there is a need for a more detailed understanding of the electrophysiology of language processing in normally developing children.

The need for detailed models of the development of normal ERP response profiles is particularly acute in light of claims that at least some language impairments reflect a pattern that is normal but delayed (e.g., Rice, 2002). We have seen that ERP response profiles continue to develop in normally developing children after the time when they have reached ceiling performance on some language tasks. This implies that behavioral performance is a weak predictor of electrophysiological responses in children. This suggests that the normal practice of comparing language impaired children with younger controls that are chosen based on their performance on behavioral tasks may be inadequate in electrophysiological studies.

GRANULARITY OF THEORETICAL MODELS

The fine-grained temporal resolution of electrophysiological measures is most valuable if we have theoretical models of normal and disordered language processes that share a similar granularity. It is only useful to know that ERP response component X reliably precedes ERP response component Y by 50 m if we can link this finding to a model that accounts for the cognitive processes underlying components X and Y and that makes timing predictions on the order of tens of milliseconds. In other words, detailed measurements require equally detailed linking hypotheses.

Unfortunately, however, most currently available models lack the temporal granularity of electrophysiological recordings. Most models in theoretical linguistics explicitly disavow predictions about the timing of real-time processes, and even those that do make claims about real-time processes tend to have a temporal granularity at the level of individual words (e.g., Kempson, Meyer–Viol, & Gabbay, 2001; Phillips, 2003; Steedman, 2000). At the sentence level, most psycholinguistic models also have a granularity that is close to the level of individual words. There is a small number of computational models whose temporal dynamics make more fine-grained predictions about the time course of sentence processing (e.g., Spivey–Knowlton & Tanenhaus, 1998). However, these models primarily focus on the dynamics of selecting among competing alternative parses in ambiguity resolution, and provide less information on the question of how errors might be diagnosed or how possible structural analyses are generated (but cf. Vosse & Kempen, 2000). The relative scarcity of explicit models of structure generation and anomaly detection has meant that the electrophysiological literature on anomaly detection has been forced to rely on models that were designed to account for quite different types of phenomena.

It is commonly assumed in ERP studies of sentence processing that the timing of a response to a violation at a given linguistic level (e.g., syntax, semantics) reflects the timing of the processes that ensure successful processing at the same level of analysis. For example if violations that can be characterized as “phrase structure violations” elicit an ELAN component, with a characteristic latency of 150–250 ms, then it is assumed that successful syntactic phrase structure building may occur in the same time-window (Friederici, 1995, 2002). In Friederici’s model the fact that certain syntactic violations trigger earlier responses than semantic anomalies (i.e., [E]LAN vs. N400) is taken to indicate that *successful* syntactic processing precedes successful compositional semantic interpretation. Furthermore, these claims about the priority of syntactic over semantic information are also linked to claims about the priority of syntactic over semantic information in models of structural ambiguity resolution, such as Frazier's *garden path* model (Frazier, 1987; Frazier & Rayner, 1982).

However, notions like "syntax first" entail rather different commitments in each of these three areas. In models of structural ambiguity resolution syntax first amounts to the claim that syntactic simplicity outranks other measures of fitness based on frequency and plausibility in decisions about competing structural analyses of a sentence. Such models typically place less emphasis on how the competing analyses are identified in the first place. This first type of syntax first claim has been highly controversial in psycholinguistic research (Clifton et al., 2003; Frazier, 1987; MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell, Tanenhaus, & Garnsey, 1994). By contrast, in models of the successful generation of unambiguous structures, syntax first amounts to the claim that compositional semantic interpretation is only possible for word combinations that are sanctioned by the syntax. This is a relatively standard assumption, although it coming under increasingly close scrutiny (Jackendoff, 2002; Kim, Chen, Rippey, & Osterhout, 2003; Tabor, Galantucci, & Richardson, in press). Lastly, in models of error detection, syntax first entails the claim that syntactic errors are detected more quickly than semantic errors (Friederici, 1995; McElree & Griffith, 1995), but this does not necessarily entail a commitment about the time course of successful structure generation. For this reason, there is a need for caution when linking findings from violation-based ERP studies to models of the time course of sentence processing.

Although it has often been assumed that the timing of ERP responses to violations at a given level of analysis reflects the timing of successful processing at the same level, this assumption has not been directly tested. Some interesting recent studies suggest that timing estimates derived from ERP studies conform well to timing estimates derived from behavioral speed—accuracy trade-off studies (Bornkessel, McElree, Schlesewsky, & Friederici, 2004), but these comparisons involve violation detection paradigms in both cases. In fact, some of the most interesting timing arguments in the ERP literature involve cases where violations at one level of analysis provide evidence for the timing of successful processing at a different level of analysis. For example, Garnsey, Tanenhaus, and Chapman (1989) used the timing of the N400 response elicited by semantic anomaly to draw inferences about the timing of syntactic processing. They reasoned that in filler-gap constructions like (Example 7), the fact that the fronted phrase is a semantically anomalous direct object of the verb could only be detected if syntactic processes have first identified it as the object of the verb. Thus, the timing of the onset of the N400 response (which typically occurs less than 400 ms after word onset) provides a good estimate of the time by which syntactic processing of the filler-gap dependency must have occurred.

7. The businessman knew which {customer, article} the secretary called _______ at home.

A related logic has been successfully applied in electrophysiological studies of lexical access, where more explicit models of successful processing are available. For example, Levelt and colleagues (Levelt, Praamstra, Meyer, Helenius, & Salmelin, 1998) use an independently motivated model of picture naming to interpret timing information from an MEG study. According to their model, phonological encoding of a word is the first level of analysis that is sensitive to word frequency. Therefore, the timing of the first MEG response component that shows sensitivity to word frequency in a picture naming task places an upper bound on the timing of word form retrieval. A similar approach has been successfully applied in MEG studies of word recognition (see Pylkkänen & Marantz, 2003, for a review).

Electrophysiological studies have been used with some success in studies of aphasic patients, due to the availability of theoretical claims that link aphasic deficits with disruptions in the timing of syntactic processing operations. For example, in the context of hypotheses that comprehension difficulty in Broca's aphasia reflects delayed lexical access (Milberg, Blumstein, Katz, Gerschberg, & Brown, 1995) or delayed lexical integration processes (Hagoort, 1993; Tyler, Ostrin, Cooke, & Moss, 1995), it is particularly informative to find that N400 responses elicited by semantically anomalous words are delayed by around 100 ms in low-comprehending aphasic patients, relative to high-comprehending aphasics and normal controls (Swaab, Brown, & Hagoort, 1997). Similarly, in the context of the proposal that syntactic processes are slowed in Broca's aphasia (Friederici & Kilborn, 1989; Haarmann & Kolk, 1991), it is interesting to find that syntactic violations like Example 6 elicit the normal pattern of an early ELAN component followed by a P600 in patients with subcortical lesions, but elicit only the P600 in a group of patients with left anterior cortical lesions (Friederici, von Cramon, & Kotz, 1999). It is interesting to find differences between the ERP response profiles of aphasics and normal controls, but the comparison is far more informative when guided by specific time-based hypotheses. For recent reviews see Kotz and Friederici (2003) and Friederici and Kotz (2003).

In the area of DLIs, however, we find mostly static characterizations of the language impairments in terms of knowledge that is present or absent, or skills that are stronger or weaker. We find few accounts that make predictions about the time course of language processing in DLIs. The upshot of this is that extant models of DLIs provide little guidance regarding how to exploit the temporal precision of electrophysiological measures. This provides the fourth challenge for neurocognitive studies of DLIs.

> *Challenge 4: Temporal Granularity of DLI Models.* In order to fully exploit the temporal precision of electrophysiological measures, models of DLIs must be fine-grained enough to make predictions about the detailed time course of linguistic processes in language impairments.

Even in the absence of more detailed time course predictions, electrophysiological approaches can still be useful for the study of DLIs. First, because ERP and MEG methods track automatic brain responses and do not require explicit tasks from the speaker, they may provide an opportunity to demonstrate linguistic sensitivity that is not apparent in standard behavioral measures that require explicit tasks such as button pressing or metalinguistic judgments. Second, electrophysiological studies may reveal differences in the time course of language processing between normal and language impaired individuals, by showing that similar responses are elicited in normal and affected subjects, but with different timing. In this way, electrophysiology could be used to provide an impetus for more fine-grained hypotheses about the time-course of language processing in impaired individuals.

One example of how both of these properties of ERPs might effectively be exploited in research on DLIs can be found in the area of filler-gap dependencies. It is commonly reported that children with DLIs have particular difficulty with sentences that involve filler-gap dependencies, such as object relative clauses (Example 8a and *wh*- questions Example 8b). In a number of instances this is manifested in the form of difficulty with object relative clauses in comprehension tasks (Karmiloff–Smith et al., 1997; Stavrakaki, 2001; Zukowski, 2004). In at least one case, it has been argued that in a special subclass of children with SLI this difficulty extends to grammaticality judgment and production (van der Lely & Battell, 2003), such that children produce sentences that contain fronted *wh*-phrases but no gap (e.g., 9), and judge similar sentences to be well formed.

8. a. The cat [$_{\text{relative clause}}$ that the dog is chasing ______] is brown.
   b. Which cat is the dog chasing ______?
9. a. Which one did he wear the coat.
   b. What did Mrs. Peacock like jewelry.

It would be instructive to follow up on these behavioral findings in DLIs using a version of the ERP study by Garnsey et al. (1989) described previant. If children show an N400 response to sentences with implausible filler-gap dependencies, then this would indicate that they are able to construct filler-gap dependencies, even if this is not apparent in behavioral tasks. Furthermore, the results might provide useful information about the time course of constructing such dependencies. In an ERP study conducted with normal adults, Phillips and colleagues (2004) found that the completion of a semantically congruous filler-gap dependency elicited a P600 response, as had been found previously by Kaan et al. (2000), and also found that the P600 response had a significantly later onset for longer filler-gap dependencies that spanned two clauses. In light of the finding that longer filler-gap dependencies are computed more slowly than shorter dependencies, it is possible that a comparison of normal and disordered populations would show a delayed N400 response to semantically anomalous filler-gap dependencies in children with DLIs.

IMPROVING SIGNAL/NOISE RATIOS (SNRs)

An additional challenge for realizing the promise of electrophysiology in research on DLIs derives from technical issues affecting the practical use of these measures with children and affecting their use in individual diagnoses. Solutions to these problems will require investment in the development of infrastructure and improved analytical tools.

Scalp voltages or magnetic fields reflect the combined effect of many different neural sources that are simultaneously active. In ERP studies, the standard approach to improving the SNR is to compute averages over many different presentations (typically 30–100 trials) of the same or equivalent stimuli, and to then create grand averages of recordings from 15 to 30 participants. The effect of this is that ERP studies tend to be rather long. A typical sentence comprehension study with 4 conditions (two target conditions, two control conditions) and a bare minimum of 30 trials per condition requires 120 experimental sentences per subject. When combined with at least twice as many filler items, in order to minimize the development of experiment-specific strategies, this yields at least 360 sentences, requiring over an hour of recording time. Time for electrode application and clean-up can add another hour to the study. The duration of the studies creates obvious challenges for working with normal or disordered children. To make matters worse, ERP recordings are particularly susceptible to motion artifacts and eye movements, and thus studies with children may require even more trials in order to achieve the same SNR attained in adult studies.

MEG recordings add the promise of localization in addition to precise temporal resolution. However, this also introduces additional technical challenges. Since the sensors in whole-head MEG arrays have a fixed position inside the liquid-helium filled dewar, individual sensors are not consistently aligned with specific scalp locations or brain regions. Individual sensors have different positions in a head-defined coordinate space, depending on the size and position of the head. The practical consequence of this is that it is not normally possible with MEG to use the grand-averaging procedures that are standard in ERP studies. Instead, it is necessary to convert recordings from individual participants into a sensor-independent format before data are combined across participants. Localization information must be computed on an individual basis. This means that higher individual SNRs are needed, and thus more trials are needed per participant. For example, whereas ERP studies of syntactic processing typically present each participant with 30–50 tokens of each sentence type, MEG studies of similar phenomena have presented each participant with much larger numbers of tokens per condition, ranging from 100 tokens per condition per participant in studies that have computed more approximate localization information (e.g., Helenius et al., 1998) to as many as 390 tokens per condition per participant in a study that combined localization information from MEG and fMRI recordings (Friederici et al., 2000). In the latter case, this required each subject to undergo multiple recording sessions. Clearly, it would be difficult to undertake studies of this length with normal or disordered children. Furthermore, whereas the use of head-mounted electrode caps in ERP studies allows participants to move their head during the study, the head must remain motionless during an MEG study, due to the fact that the sensors are in a fixed position. Also, the fact that children have smaller heads than adults has implications for the quality of MEG recordings. For the gradiometer sensors that are used in most current MEG systems, the strength of the MEG signal is inversely proportional to the cube of the distance from the source to the sensor. For example, for a child who is lying in a whole-head MEG device, strong signals will be recorded from occipital regions at the rear of the head, where the scalp is touching the MEG dewar, but weaker signals will be recorded from other areas where a few centimeters separate the scalp from the MEG sensors. This latter issue may be addressed by MEG devices that are specially designed for use with smaller heads, or by using older MEG devices that have smaller arrays of sensors that only cover part of the head, and hence can be moved to fit any head size.

Therefore, the fifth challenge facing electrophysiological investigations of DLIs is how to maximize SNRs, such that recording sessions can be kept to a length that is manageable for children. It is probably no accident that the most successful line of electrophysiological language research on children to date has involved MMN studies of phonetic perception. Since the individual experimental trials are shorter in these studies, typically involving just one syllable, it is possible to record many hundreds of trials in a relatively short period of time.

> *Challenge 5: Improving SNRs.* Analytical techniques that make it possible to attain better SNRs with smaller numbers of experimental trials will contribute greatly to the feasibility of electrophysiological studies of normal and disordered language in children.

An additional consequence of the signal/noise problem is that electrophysiological studies of language processing have tended to rely on group data in order to achieve reliable results. This has implications for studies of DLIs, where there would be interest in using electrophysiological measures as diagnostic tools for assessing individuals. This is only feasible to the extent that it is possible to achieve a good SNR from the number of trials that can be reasonably recorded from a single person. Until that is possible, electrophysiological measures will continue to be most effective for group studies. One study of syntax-related ERP effects in aphasia used a single case study approach with analyses of individual data (Friederici, Hahne, & von Cramon, 1998), and was able to find significant effects of anomaly detection. However, this study also showed that only very large ERP effects are likely to be statistically reliable in case studies.

CONCLUSIONS

There is considerable excitement about the possibility of using neurocognitive measures to gain a deeper understanding of DLIs, and it is clear that electrophysiological techniques like EEG and MEG hold considerable promise, due to their precise temporal resolution and their ability to track brain processes involved in language processing without an extrinsic task. Once the possibility of precise localization using MEG is included, it becomes possible to imagine a time in the future when researchers will be able to track the brain activity of language impaired children with great precision in space and time. This is certainly an attractive prospect. However, I have tried to emphasize here that a great deal of important basic research must be undertaken in order for this ideal to be properly realized. Theoretical and neurocomputational modeling research is needed in order to provide a better idea of what to look for, and technical research on analysis techniques is needed to show how to look for it. Electrophysiological measures will be particularly useful if it is possible to formulate specific hypotheses about the time course of language processes in DLIs.

There are some questions about DLIs that can already be usefully addressed using electrophysiological measures, and a number of studies have already done so, particularly in the domain of auditory and phonetic processing (for a review, see Cheour et al., 2000). At the sentence level it should be possible, for example, to investigate whether children who show a morphosyntactic impairment in behavioral studies also show insensitivity to morphosyntactic anomaly in standard electrophysiological error-detection paradigms. This might appear as a failure to exhibit a P600 response. Studies of this kind would be particularly informative if they did not merely corroborate existing behavioral findings of insensitivity to morphosyntactic detail, but instead revealed latent sensitivity, or a differential time course relative to normal controls. However, even in straightforward studies such as this, there is still a need for substantial basic research on language processing in normal children, in order to provide reliable benchmarks.

ACKNOWLEDGMENTS

Thanks to Alison Austin and Andrea Zukowski for valuable discussion of the material presented here. Preparation of the paper was supported in part by grants from the NSF (BCS-0196004) and the Human Frontiers Science Program (RGY-0134).

REFERENCES

Atchley, R. A., Rice, M. L., Betz, S. K., Kwasney, K. M., Sereno, J. A., & Jongman, A. (in press). A comparison of semantic and syntactic event related potentials generated by children and adults. *Brain and Language*.

Aziz, M., Stathopulu, E., Callias, M., Taylor, C., Turk, J., Oostra, B., Willemsen, R., & Patton, M. (2003). Clinical features of boys with fragile X permutations and intermediate alleles. *American Journal of Medical Genetics Part B, 121B*, 119–127.

Bastiaansen, M., & Hagoort, P. (2003). Event-induced theta responses as a window on the dynamics of memory. *Cortex, 39*, 967–992.

Bell, A. J., & Sejnowski, T. J. (1995). An information-maximization approach to blind separation and blind deconvolution. *Neural Computation, 7*, 1129–1159.

Bornkessel, I., McElree, B., Schlesewsky, M., & Friederici, A. D. (2004). *Multi-dimensional contributions to garden-path strength: Dissociating phrase structure from relational structure*. Manuscript submitted for publication.

Cheour, M., Ceponiene, R., Lehtokoski, A., Luuk, A., Allik, J., Alho, K., & Näätänen, R. (1998). Development of language-specific phoneme representations in the infant brain. *Nature Neuroscience, 1*, 351–353.

Cheour, M., Leppänen, P. H. T., & Kraus, N. (2000). Mismatch negativity (MMN) as a tool for investigating discrimination and sensory memory in infants and children. *Clinical Neurophysiology, 111*, 4–16.

Clahsen, H., & Temple, C. (2003). Words and rules in Williams syndrome. In Y. Levy & J. Schaeffer (Eds.), *Language competence across populations: Toward a definition of specific language impairment* (pp. 323–352). Mahwah, NJ: Erlbaum.

Clifton, C., Traxler, M. J., Mohamed, M. T., Williams, R. S., Morris, R. K., & Rayner, K. (2003). The use of thematic role information in parsing: Syntactic processing autonomy revisited. *Journal of Memory and Language, 49*, 317–334.

Coch, D., & Holcomb, P. J. (2003). The N400 in beginning readers. *Developmental Psychobiology, 43*, 146–166.

Coch, D., Maron, L., Wolf, M., & Holcomb, P. (2002). Word and picture processing in children: An event-related potential study. *Developmental Neuropsychology, 22*, 373–406.

Dehaene–Lambertz, G., Dupoux, E., & Gout, A. (2000). Electrophysiological correlates of phonological processing: A cross-linguistic study. *Journal of Cognitive Neuroscience, 12*, 635–647.

Dykman, R. A., Ackerman, P. T., Loizou, P. C., & Casey, P. H. (2000). An event-related potential study of older children with an early history of failure to thrive. *Developmental Neuropsychology, 18*, 187–212.

Federmeier, K. D., & Kutas, M. (1999). A rose by any other name: Long-term memory structure and sentence processing. *Journal of Memory and Language, 41*, 469–495.

Fiebach, C., Schlesewsky, M., & Friederici, A. (2002). Separating syntactic memory costs and syntactic integration costs during parsing: The processing of German WH-questions. *Journal of Memory and Language, 47*, 250–272.

Fischler, I., Bloom, P. A., Childers, D. G., Roucos, S. E., & Perry, N. W. (1983). Brain potentials related to stages of sentence verification. *Psychophysiology, 20*, 400–409.

Fowler, A., Gelman, S., & Gleitman, L. (1994). The course of language learning in children with Down syndrome. In H. Tager–Flusberg (Ed.), *Constraints on language acquisition* (pp. 91–140). Hillsdale, NJ: Erlbaum.

Frazier, L. (1987). Sentence processing: A tutorial review. In M. Coltheart (Ed.), *Attention and performance XII*. Hillsdale, NJ: Erlbaum.

Frazier, L., & Rayner, K. (1982). Making and correcting errors in sentence comprehension: Eye-movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology, 14*, 178–210.

Friederici, A. D. (1995). The time-course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language, 50*, 259–281.

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

Friederici, A. D., & Hahne, A. (2001). Development patterns of brain activity reflecting semantic and syntactic processes. In J. Weissenborn & B. Höhle (Eds.), *Approaches to bootstrapping: Phonological, lexical, syntactic, and neurophysiological aspects of early Language Acquisition* (pp. 231–246). Amsterdam: John Benjamins.

Friederici, A. D., Hahne, A., & von Cramon, D. Y. (1998). First-pass versus second-pass processes in a Wernicke's and a Broca's aphasic: Electro-physiological evidence for a double dissociation. *Brain and Language, 62*, 311–341.

Friederici, A. D., & Kilborn, K. (1989). Temporal constraints on language processing: Syntactic priming in Broca's aphasia. *Journal of Cognitive Neuroscience, 1*, 262–272.

Friederici, A. D., & Kotz, S. A. (2003). The brain basis of syntactic processes: Functional imaging and lesion studies. *NeuroImage, 20*, S8–S17.

Friederici, A. D., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing: Effects of semantic, morphological, and syntactic violations. *Cognitive Brain Research, 1*, 183–192.

Friederici, A. D., von Cramon, D. Y., & Kotz, S. A. (1999). Language-related brain potentials in patients cortical and subcortical left hemisphere lesions. *Brain, 122*, 1033–1047.

Friederici, A. D., Wang, Y., Herrmann, C. S., Maess, B., & Oertel, U. (2000). Localization of early syntactic processes in frontal and temporal cortical areas: A magnetoencephalographic study. *Human Brain Mapping, 11*, 1–11.

Garnsey, S. M., Tanenhaus, M. K., & Chapman, R. M. (1989). Evoked potentials and the study of sentence comprehension. *Journal of Psycholinguistic Research, 18*, 51–60.

Haarmann, H. J., & Kolk, H. H. J. (1991). Syntactic priming in Broca's aphasia: Evidence for slow activation. *Aphasiology, 5*, 247–263.

Hagoort, P. (1993). Impairments of lexical–semantic processing in aphasia: Evidence from the processing of lexical ambiguities. *Brain and Language, 45*, 189–232.

Hagoort, P., Brown, C. M., & Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes, 8*, 439–484.

Hagoort, P., Brown, C. M., & Osterhout, L. (1999). The neurocognition of syntactic processing. In C. M. Brown & P. Hagoort (Eds.), *The neurocognition of language* (pp. 273–316). Oxford: Oxford University Press.

Hagoort, P., Wassenaar, M., & Brown, C. (2003). Real-time semantic compensation in patients with agrammatic comprehension: Evidence for dual-route plasticity. *Proceedings of the National Academy of Sciences, USA, 100*, 4340–4345.

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*, 193–204.

Halgren, E., Dhond, R. P., Christiansen, N., van Petten, C., Marinkovic, K., Lewine, J. D., & Dale, A. M. (2002). N400-like magnetoencephalography responses modulated by semantic context, word frequency, and lexical class in sentences. *Neuroimage, 17*, 1101–1116.

Helenius, P., Salmelin, R., Service, E., & Connolly, J. F. (1998). Distinct time courses of word and context comprehension in left temporal cortex. *Brain, 121*, 1133–1142.

Holcomb, P. J., Coffey, S., & Neville, H. (1992). The effects of context on visual and auditory sentence processing: A developmental analysis using event-related brain potentials. *Developmental Neuropsychology, 8*, 203–241.

Jackendoff, R. S. (2002). *Foundations of language*. Oxford: Oxford University Press.

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

Kaan, E., & Swaab, T. Y. (2003). Electrophysiological evidence for serial sentence processing: A comparison between non-preferred and ungrammatical continuations. *Cognitive Brain Research, 17*, 621–635.

Karmiloff–Smith, A., Grant, J., Berthoud, I., Davies, M., Howlin, P., & Udwin, O. (1997). Language and Williams syndrome: How intact is "intact"? *Child Development, 68*, 246–262.

Kempson, R., Meyer–Viol, W., & Gabbay, D. (2001). *Dynamic syntax*. Oxford: Blackwell.

Kim, A., Chen, J., Rippey, C., & Osterhout, L. (2003). Combinatory semantic processing can occur independently of syntactic support. Talk presented at the conference on Architectures and Mechanisms for Language Processing (AMLaP 2003), Glasgow, UK.

King, J., & Kutas, M. (1995). Who did what and when? Using word- and clause-level ERPs to monitor working memory usage in reading. *Journal of Cognitive Neuroscience, 7*, 376–395.

Kjelgaard, M. M., & Tager–Flusberg, H. (2001). An investigation of language impairment in autism: Implications for genetic subgroups. *Language and Cognitive Processes, 16*, 287–308.

Koelsch, S., Grossman, T., Gunter, T. C., Hahne, A., Schröger, E., & Friederici, A. D. (2003). Children processing music: Electric brain responses reveal music competence and gender differences. *Journal of Cognitive Neuroscience, 15*, 683–693.

Kotz, S. A., & Friederici, A. D. (2003). Electrophysiology of normal and pathological language processing. *Journal of Neurolinguistics, 16*, 43–58.

Kurtzberg, D., Vaughan, H. G., Kreuzer, J. A., & Fliegler, K. Z. (1995). Developmental studies and clinical application of mismatch negativity: Problems and prospects. *Ear and Hearing, 16*, 117–129.

Kutas, M., & Federmeier, K. (2000). Electrophysiology reflects semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*, 463–470.

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

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature, 307*, 161–163.

Leonard, L. (1997). *Children with specific language impairment*. Cambridge, MA: MIT Press.

Levelt, W. J. M., Praamstra, P., Meyer, A. S., Helenius, P., & Salmelin, R. (1998). An MEG study of picture naming. *Journal of Cognitive Neuroscience, 10*, 553–567.

Lück, M., Hahne, A., & Clahsen, A. (2001). How brain potentials develop: An ERP study about the processing of German noun plurals in adults and children. In A. D. Friederici & D. Y. von Cramon (Eds.), *Max Planck Institute of Cognitive Neuroscience Annual Report 2001* (pp. 55–56). Available on-line at http://cns.mpg.de

MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review, 101*, 676–703.

Makeig, S., Debener, S., Onton, J., & Delorme, A. (in press). Mining event-related brain dynamics. *Trends in Cognitive Sciences*.

Makeig, S., Westerfield, M., Jung, T.-P., Covington, J., Townsend, J., Sejnowski, T. J., & Courchesne, E. (1999). Functionally independent components of the late positive event-related potential during visual spatial attention. *Journal of Neuroscience, 19*, 2665–2680.

McElree, B., & Griffith, T. (1995). Syntactic and thematic processing in sentence comprehension: Evidence for a temporal dissociation. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21*, 134–157.

Milberg, W., Blumstein, S. E., Katz, D., Gerschberg, F., & Brown, T. (1995). Semantic facilitation in aphasia—Effects of time and expectancy. *Journal of Cognitive Neuroscience, 7*, 33–50.

Mills, D., & Schweisguth, M. (2001, February). Developmental changes in sentence processing: Electrophysiological responses to semantic and syntactic anomalies in 3 to 4 year old children and adults. Talk presented at the University of California at San Diego, Center for Research on Language. Available on-line at http://crl.ucsd.edu/pdpnlp/abstract/20010227.html

Müller, R.-A. (2005). Neurocognitive studies of language impairments. *Applied Psycholinguistics, 26*, 65–78. **EQ1**

Münte, T. E., Heinze, H. J., & Mangun, G. R. (1993). Dissociation of brain activity related to syntactic and semantic aspects of language. *Journal of Cognitive Neuroscience, 5*, 335–344.

Näätänen, R., Lehtokoski, A., Lennes, M., Cheour, M., Huotilainen, M., Ilvonen, A., Vainio, M., Alku, P., Ilmoniemi, R., Luuk, A., Allik, J., Sinkkonen, J., & Alho, K. (1997). Language-specific phoneme representations revealed by electric and magnetic brain responses. *Nature, 385*, 432–434.

Näätänen, R., & Winkler, I. (1999). The concept of auditory stimulus representation in cognitive neuroscience. *Psychological Bulletin, 125*, 826–859.

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

Obleser, J., Lahiri, A., & Eulitz, C. (2003). Auditory-evoked magnetic field codes place of articulation in timing and topography around 100 milliseconds post syllable onset. *NeuroImage, 20*, 1839–1847.

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

Osterhout, L., & Mobley, L. A. (1995). Event-related brain potentials elicited by failure to agree. *Journal of Memory and Language, 34*, 739–773.

Phillips, C. (2001). Levels of representation in the electrophysiology of speech perception. *Cognitive Science, 25*, 711–731.

Phillips, C. (2003). Linear order and constituency. *Linguistic Inquiry, 34*, 37–90.

Phillips, C. (2004). Linguistics and linking problems. In M. Rice & S. Warren (Eds.), *Developmental language disorders: From phenotypes to etiologies* (pp. 241–287). Mahwah, NJ: Erlbaum.

Phillips, C., Kazanina, N., & Abada, S. (2004). *ERP effects of the processing of syntactic long-distance dependencies*. Manuscript submitted for publication.

Phillips, C., Pellathy, T., Marantz, A., Yellin, E, Wexler, K, Poeppel, D., McGinnis, M., & Roberts, T. (2000). Auditory cortex accesses phonological categories: An MEG mismatch study. *Journal of Cognitive Neuroscience, 12*. **AQ3**

Poeppel, D., Phillips, C., Yellin, E., Rowley, H., Roberts, T., & Marantz, A. (1997). Processing of vowels in supratemporal auditory cortex. *Neuroscience Letters, 221*, 145–148.

Pylkkänen, L., & Marantz, A. (2003). Tracking the time course of word recognition with MEG. *Trends in Cognitive Sciences, 7*, 187–189.

Rice, M. L. (2002). A unified model of specific and general language delay: Grammatical tense as a clinical marker of unexpected variation. In Y. Levy & J. Schaeffer (Eds.), *Language competence across populations: Toward a definition of specific language impairment* (pp. 63–95). Mahwah, NJ: Erlbaum.

Rice, M. L., Wexler, K., & Cleave, P. L. (1995). Specific language impairment as a period of extended optional infinitive. *Journal of Speech, Language and Hearing Research, 38*, 850–863.

Sanders, L. D., Newport, E. L., & Neville, H. J. (2002). Segmenting nonsense: An event-related potential index of perceived onsets in continuous speech. *Nature Neuroscience, 5*, 700–703.

Schopmeyer, B. B., & Lowe, F. (1992). Speech and language characteristics in fragile X syndrome. In B. B. Schopmeyer & F. Lowe (Eds.), *The fragile X child* (pp. 71–89). San Diego, CA: Singular Publishing.

Spivey–Knowlton, M. J., & Tanenhaus, M. K. (1998). Syntactic ambiguity resolution in discourse: Modeling the effects of referential context and lexical frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 1521–1543. **AQ4**

Stavrakaki, S. (2001). Comprehension of reversible relative clauses in specifically language impaired and normally developing Greek children. *Brain and Language, 77*, 419–431.

Steedman, M. (2000). *The syntactic process*. Cambridge, MA: MIT Press.

Swaab, T. A., Brown, C., & Hagoort, P. (1997). Spoken sentence comprehension in aphasia: Event-related potentials evidence for a lexical integration deficit. *Journal of Cognitive Neuroscience, 9*, 39–66.

Tabor, W., Galantucci, B., & Richardson, D. (in press). Effects of merely local syntactic coherence on sentence processing. *Journal of Memory and Language*.

Tallon–Baudry, C., & Bertrand, O. (1997). Oscillatory gamma activity in humans and its role in object perception. *Trends in Cognitive Sciences, 3*, 151–162.

Thomas, M. S. C., Grant, J., Barham, Z., Gsödl, M., Laing, E., Lakusta, L., Tyler, L. K., Grice, S., Paterson, S., & Karmiloff–Smith, A. (2001). Past tense formation in Williams syndrome. *Language and Cognitive Processes, 16*, 143–176.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: Use of thematic role information in syntactic disambiguation. *Journal of Memory and Language, 33*, 285–318.

Tyler, L. K., Ostrin, R. K., Cooke, M., & Moss, H. E. (1995). Automatic access of information in Broca's aphasics: Against the automaticity hypothesis. *Brain and Language, 48*, 131–162.

van der Lely, H. K. J., & Battell, J. (2003). Wh- movement in children with grammatical SLI: A test of the RDDR hypothesis. *Language, 79*, 153–181.

van Petten, C., Kutas, M., Kluender, R., Mitchiner, M., & McIsaac, H. (1991). Fractionating the word-repetition effect with event-related potentials. *Journal of Cognitive Neuroscience, 3*, 131–150.

Vosse, T., & Kempen, G. (2000). Syntactic structure assembly in human parsing: A computational model based on competitive inhibition and a lexicalist grammar. *Cognition, 75*, 105–143.

Zukowski, A. (2004). Investigating knowledge of complex syntax: Insights from experimental studies of Williams syndrome. In M. Rice & S. Warren (Eds.), *Developmental language disorders: From phenotypes to etiologies* (pp. 99–119). Mahwah, NJ: Erlbaum.