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Margaret Ugolini

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ELECTROPHYSIOLOGICAL CORRELATES OF NATURAL LANGAUGE PROCESSING IN CHILDREN AND ADULTS

A Dissertation Presented

by

MARGARET HELEN UGOLINI

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Approved as to style and content by:

Lisa D. Sanders, Chair

Kirby Deater-Deckard, Member

Joonkoo Park, Member

Gwyneth C. Rost, Member

Paul S. Katz, Program Director
Neuroscience and Behavior IDGP

DEDICATION

Dedicated to my cohort: Adaeze Egwuatu, Beata Kamińska-Kordowska, Matheus Macedo-Lima and Andrea Silva-Gotay.

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To adequately describe all of the generous individuals I have met during this process and how they have contributed to the completion of this dissertation would surely double the length of this document. In lieu of that, I would like to simply thank: the participants of this study, my advisor – Lisa D. Sanders, my committee – Kirby Deater-Deckard, Joonkoo Park and Gwyneth C. Rost, the research assistants and fellow graduate students in the NeuroCognition and Perception lab, my mother – Norah O'Brien, and the rest of my family, my funding sources – the University of Massachusetts Graduate School, the Department of Psychological and Brain Sciences, and the Developmental Science Initiative, and finally the Neuroscience and Behavior Interdisciplinary Graduate Program and its incredible students.

Thank you.

ABSTRACT

ELECTROPHYSIOLOGICAL CORRELATES OF NATURAL LANGAUGE PROCESSING IN CHILDREN AND ADULTS

MAY 2019

MARGARET HELEN UGOLINI, B.S., UNIVERSITY OF MICHIGAN ANN ARBOR

Ph.D., UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Lisa D. Sanders

To understand the causes of differences in language ability we must measure the specific and separable processes that contribute to natural language comprehension. Specifically, we need measures of the three language subsystems – semantics, syntax, and phonology – as they are used during the comprehension of real speech. Event-Related Potentials (ERPs) are a promising approach to reaching this level of specificity. Previous research has identified distinct ERP effects for each of the subsystems – the N400 to semantic anomalies, the Anterior Negativity and P600 to syntactic anomalies, and the Phonological Mapping Negativity to unexpected speech sounds. However, these studies typically use stimuli and tasks that encourage processing that differs from real-world language comprehension. Further, previous ERP studies indexing language processing in young children not only use unfamiliar tasks, but also typically exclude data from the large proportion of children. We need to measure language-related ERPs in a context as close as possible to real-world processing, and in a manner that includes data from representative rather than highly-selected samples of children. The experiments described in this dissertation achieve that goal.

Adults and five-year-old children listened to a child-directed story while answering comprehension questions. Infrequent violations were included to independently probe the three language subsystems. In children and adults, the canonical

N400 response was evident in response to semantic violations. Morphosyntactic violations elicited a long-duration Anterior Negativity without a later P600. Phonological violations on suffixes elicited a Phonological Mapping Negativity in adults. This is the first report of this phonological effect outside of highly-predictable lexical contexts. Popular normed behavioral assessments were also administered to the children who participated in this study. Results from these assessments confirmed that performance on tasks claiming to measure categorically different abilities are correlated with one another, and that language measures correlate with so-called nonverbal measures. ERPs indexing different language subsystem did not correlate with each other or with measures of nonverbal cognitive ability. Using multiple ERP measures during natural language comprehension, we are able to isolate specific aspects of language processing, increasing the possibility of making meaningful connections between biology, experience, and resulting language ability.

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CHAPTER 1

INTRODUCTION

1.1 Language Comprehension is Necessary for Success

Language comprehension is an essential part of thriving at all ages and in every environment. Children with stronger language skills in early elementary school show better academic achievement in subsequent years (Walker, Greenwood, Hart, & Carta, 1994). Negative outcomes of developmental language disorders or low receptive language ability include less academic success (Young et al., 2002), higher likelihood of emotional, behavioral, and social problems (Beitchman et al., 2001; Chow & Wehby, 2018; Yew & O'Kearney, 2013), and higher high school dropout rates (Scanlon & Mellard, 2002). These effects continue on into adulthood, leading to an overall negative effect on many aspects of life success (Mellard & Woods, 2007) -- individuals with language disorders tend are more likely to be unemployed (Kirsch, Jungelbut, Jenkins, & Kolstad, 1993) and have fewer close personal relationships than the general public (Clegg, Hollis, Mawhood, & Rutter, 2005).

1.2 Current Methods Measuring Language Processing Ability

There are many ways of measuring language ability, but it is not always clear what is truly being indexed by each measure. A common method of assessing individual language ability in children is through the use of standardized language assessments. Scores on these assessments are often used to understand the strengths and weaknesses of an individual child in order to determine if a disorder is present and what treatment is necessary or to assess if progress is being made after a given intervention has begun.

However, the interrelated nature of these tasks, especially across abilities that are theoretically independent from one another such as nonverbal intelligence and language-specific measures like phonological processing, leave room for improvement in how we assess language ability. Specific measures that are relevant to the real world are necessary in order to adequately identify language disorders, decide on the best interventions, and measure if an intervention is having an effect that is generalizable to real-world language processing.

1.3 Isolating Language Subsystems Using Event-Related Potentials

Decades of research have gone into bettering our understanding of how the human brain processes language using electrophysiological techniques – specifically electroencephalography (EEG) and the associated event-related potentials (ERPs) that are elicited when an individual engages in a specific type of processing. ERPs are well suited for the study of language processing because they can capture millisecond-level changes in brain activity that might be highly relevant for the processing of the rapidly-changing, highly-dynamic signal that is spoken language.

ERP methods are particularly promising for pinpointing cognitive processes that are purely related to language processing. ERPs do not require a behavioral response and capture the time course of perceptual and cognitive operations associated with a particular stimulus, even implicit processes that are impossible for the individual to articulate. This technique can provide information that is much more detailed and specific than behavioral or reaction-time measures that only represent the sum of all operations required to process the stimulus, make a decision, and initiate a motor movement to provide a response.

1.4 The Current State of Event-Related Potential Studies of Language Processing

Typically, ERP studies of language processing use methods that are far removed from real-world language processing. For example, subjects may be asked to listen to sentences without any narrative structure and make grammaticality judgments, read individual words as they are presented on a screen, or even listen to the same few syllables hundreds of times while monitoring for deviants. While these tightly controlled experimental contexts are great for testing specific hypotheses about language processing, it is not guaranteed that the results from these experiments will generalize to natural language processing. Just because a participant can correctly identify grammatical violations in a sentence and shows a particular electrophysiological response when doing so does not necessarily mean that this detection ability or the cognitive processing underlying this brain response are relevant when listening to speech for comprehension in a more natural context.

The development of the cognitive processes underlying language processing has also been studied extensively with ERPs. However, like the adult literature, the real-world applicability of these results is unclear. The same kinds of experimental factors that may encourage adults to engage in idiosyncratic language processing are common in child language ERP studies. The unnatural tasks that are commonly used are also associated with a high rate of unusable child subjects due to poor data quality, restricting the sample of children to only the most compliant and attentive. Countermeasures to prevent the restlessness that leads to poor data quality, such as playing an unrelated silent cartoon to hold the child's attention, do not allow for the study of communication as it happens naturally.

The shortcomings of extant ERP language processing experimental methods become even more concerning when we attempt to use this knowledge to understand individual differences in language processing skill. If we expect to use ERP measures to better understand individual variation in language success, the etiology of language disorders, and even general principles of how the brain processes language, we need to ensure that we are measuring something that is truly relevant to real-world, on-line language processing that occurs when an individual listens to spoken language for comprehension.

1.5 Organization of this Dissertation

In this dissertation, Chapters 2.1 – 2.4.3 discuss the three dominant language subsystems – syntax, semantics, and phonology – and the current understanding of their associated ERP correlates, the neuroanatomical basis of these language subsystems, and the still present gap between real-world language processing and the types of experiments that are commonly conducted to understand auditory language comprehension.

Chapters 2.6.2 – 2.6.3 outline the experimental paradigm employed in this dissertation and clarify how the present study is designed to move us closer to understanding real-world language processing. Chapters 2.7.2 – 2.7.2.3 specifically discuss how the results of the present study's first experiment – conducted on adults – relates to results from previous, less natural language-ERP studies and what conclusions can be drawn about how language processing unfolds in a real speech context.

Chapters 3.1– 3.4.1 discuss the present status quo in regard to language development ERP studies, including the shortcomings of this work as it relates to its applicability to real-world language processing and participant data quality and retention, and offer suggestions for the type of study that should be conducted in order to clarify the ERP correlates of natural language processing. Chapters 3.7 – 3.7.3 outline the results of the present study conducted with five-year-old-children and what these outcomes mean for our broader understanding of language development.

Chapter 4.1 discusses why specificity in language measures is so vital if we are to better our understanding of language disorders in an interdisciplinary way, followed by an explanation of why current behavioral measures are inadequate in Chapter 4.2, and why indicators from multiple sources may be beneficial, in Chapter 4.3. Chapter 4.4 summarizes previous work relating the ERP response to language and behavioral scores and Chapter 4.5 outlines why a measure of the variability in the ERP response to auditory onsets may also prove interesting.

Chapters 4.6 – 4.7.5 describe how the experiment conducted to relate behavioral and ERP measures in children. Relationships found within standardized behavioral assessments of language, and across assessments of language and nonverbal intelligence are described in Chapters 4.8.1 and 4.8.2, respectively. Relationships between ERP and behavioral measures are described in Chapter 4.8.3. A discussion of all of these effects follows in Chapters 4.9 – 4.9.3.6. Chapter 5 serves as a final conclusion based on findings of this dissertation as a whole.

CHAPTER 2

ELECTROPHYSIOLOGICAL INDICES OF LANGUAGE PROCESSING IN ADULTS

2.1 The Neurocognitive Subsystems of Natural Language Processing

Despite the fact that event-related potentials have been touted as the ideal measure of on-line language processing, there are few studies that convincingly use ERP measures to index the multiple processes involved in natural language comprehension. While much has been learned from experiments that rely on simplified stimuli and tasks other than comprehension, it is often difficult to determine the extent to which reported effects reflect processes that are typically engaged during normal communication. Common practices, including presenting the words that comprise sentences one-by-one, using isolated words or pairs of words, having an unusually high proportion of a specific sentence structure, and requiring participants to make unfamiliar metalinguistic decisions about stimuli, may engage processes that are rarely used during natural language comprehension and omit other processes that are typical of, or even necessary for, language comprehension. As a result, many of the conclusions reached about on-line language processing, as well as individual and group differences in language processing ability, may not be relevant for daily communication. The goal of the current study is to measure on-line language processing under conditions that are as similar as possible to communication settings outside of the laboratory.

Language processing is not a single, unified process even during natural language comprehension. There are at least three major subsystems of language processing – meaning (semantics), grammatical structure (syntax), and sound patterns (phonology).

Each of these has at least some independence in processing from the others according to results from behavioral studies (Ferreira & Clifton, 1986; Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983; Segui, Dupoux, & Mehler, 1990), lesion studies (Friederici, 1985; Zwitserlood, 1989) and ERP studies (Friederici, Pfeifer, & Hahne, 1993). Strikingly, the effects of simplified or repetitive stimuli and idiosyncratic tasks is unlikely to be the same for each of these subsystems, or even for different ERP indices within a subsystem. For example, the effects of the proportion of a specific type of violation or anomaly within an experiment are different for the semantic and syntactic subsystems. The proportion of semantic anomalies does not influence the amplitude of the N400, an ERP component that has been associated with integration of meaning across words, except in cases where anomalies occur as the first word in the sentence or as part of a list (Van Petten & Kutas, 1990). In contrast, the proportion of grammatical violations within a stimulus set can effect one index of syntactic processing (the P600), but not the other (the left anterior negativity; Hahne & Friederici, 1999).

Since predictability of a word in context has been shown to be the major factor that influences the amplitude of the N400 (Kutas & Hillyard, 1984; Thornhill & Van Petten, 2012), it is important to measure this effect in the rich context of a full narrative. Further, it is known that the manner and rate at which words are presented has an impact on predictability effects in reading (Niefind & Dimigen, 2016). As such, documenting either robustness to, or the effects of, presenting language at the rate of natural speech on N400 amplitude will be important for reaching a greater understanding of which sentence-level processes this component indexes. Other factors that differ between natural language and many of the attempts to experimentally isolate specific syntactic processes are likely to influence the amplitudes, timing, and distributions of the left anterior negativity (LAN) and P600. For example, it has been proposed that factors immediately before syntactic violations and the canonical structures they are compared to could partially or entirely contribute to early portions of the LAN component in experiments where these factors are not properly balanced or controlled for (Steinhauer & Drury, 2012). Further, the proportion of syntactic violations (Hahne & Friederici, 1999), the amount of semantic content (Hahne & Jescheniak, 2001; Yamada & Neville, 2007), and the use of grammaticality judgment tasks (Hasting & Kotz, 2008) all influence the timing and amplitude of the P600. Importantly, although the LAN is typically described as early and anterior and the P600 as late and posterior, the opposite polarity of these effects may mean they cancel each other out at some times and scalp locations; factors that influence the timing, distribution, and amplitude of the P600 may then also influence the later portions of the LAN. Therefore, a second goal of the current study is to separately index semantic and syntactic processing during natural language comprehension to provide additional information concerning which ERP effects are particularly susceptible to stimulus factors and task demands.

Notably, the effects of stimulus factors and task demands on indices of phonological processing during language comprehension are completely unknown. Behavioral measures of phonological awareness and rapid auditory naming, though closely linked to language abilities (Blachman, 1984; Furnes & Samuelsson, 2011; Stappen & Van Reybroeck, 2018), are not intended to measure receptive phonological processing. The most prevalent ERP paradigm related to phonological processing – phonological priming, including rhyming studies – is limited to processing of word pairs (Andersson, Sanders, Coch, Karns, & Neville, 2018; Coch, Grossi, Coffey-Corina, Holcomb, & Neville, 2002; Coch, Grossi, Skendzel, & Neville, 2005; Grossi, Coch, Coffey-Corina, Holcomb, & Neville, 2001; Pakulak & Neville, 2010). The closest measure of phonological processing in a sentence context is the Phonological Mapping Negativity (PMN) (Connolly & Phillips, 1994). To date, the PMN has only been evidenced when a highly constraining context leads listeners to predict a specific lexical item or nonword. This is most commonly achieved using a highly constraining sentence context, for example a sentence such as "The dog chased the cat up a _____" would likely cause listeners to expect to hear the word "tree", and therefore the initial phoneme of /t/. In this case, words that violate both the lexical expectations and the phonological expectations (e.g., cloud) elicit a PMN relative to words that violate the lexical expectations but not the phonological expectations for the initial portions of the word (e.g., treat) (Connolly & Phillips, 1994). The PMN can also be generated by asking participants to remove one sound from a word, and then presenting them with a word that is the incorrect response to this task (either removing the wrong sound or not removing it at all) (Kujala, Alho, Service, Ilmoniemi, & Connolly, 2004; Newman, Connolly, Service, & McIvor, 2003). Since the PMN relies on highly constraining contexts that support the prediction of a specific lexical item or nonword, it is not clear that it is indexing a process that occurs during more typical communications settings. Therefore, the third goal of the current study is to determine the extent to which this or other ERP effects index phonological processing during natural language comprehension.

The above-mentioned factors suggest that a study reporting the ERP effects to natural language for each of these subsystems could allow us to better understand what findings in the literature are truly relevant to everyday speech perception. The goal of the current study is to measure on-line language processing under conditions that are as similar as possible to communication settings outside of the laboratory. A second goal of the current study is to separately index semantic and syntactic processing during natural language comprehension to provide additional information concerning which ERP effects are particularly susceptible to stimulus factors and task demands. The third goal of the current study is to determine the extent to which this or other ERP effects index phonological processing during natural language comprehension.

2.2 Semantic Processing of Language

Semantic processing is the comprehension of the meaning of words. This requires an individual to not only retrieve the meaning of an individual word from memory (termed lexical access), but also to integrate this meaning into the context of what is being communicated.

2.2.1 Electrophysiological Correlates of Semantic Processing

Decades of research employing ERPs to index specific language processes in adults suggest there is an effect that is specific to semantic processing: the N400. The amplitude of the N400 is sensitive to the level of incongruence within a context, whether a sentence or otherwise (for example, a list of words (Bentin, Kutas, & Hillyard, 1995)). Words that are semantically impossible, and therefore more unexpected and difficult to relate to the established sentence context, elicit a larger N400 compared to words that are merely semantically improbable. Further, words that are related to the preferred word in a context (for example, “The pizza was too hot to *drink,”*) elicit an even smaller N400 than more improbable words (Kutas & Hillyard, 1980).

The N400 is not simply a response to anything unexpected; there is no difference in the N400 to written words that are simply printed in a visually unexpected way (for example, “She put on her high heeled *SHOES”*) vs. the expected way (Kutas & Hillyard, 1980). There is also no N400 to language violations unrelated to meaning, like a violation of grammatical structure (Friederici et al., 1993; Osterhout & Nicol, 1999). However, it would also be inaccurate to overstate the specificity of the N400 effect. The N400 effect occurs across modalities – written language, auditory language, singing (Kutas, Neville, & Holcomb, 1987; McCallum, Farmer, & Pocock, 1984), and even in response to a line drawing that is an unexpected completion to a written sentence (Ganis, Kutas, & Sereno, 1996) or an image that is inconsistent with an odor (Castle, Van Toller, & Milligan, 2000).

Both violations of meaning based on world knowledge and based on local discourse context influence N400 amplitude simultaneously (Hagoort, Hald, Bastiaansen, & Petersson, 2004). Cloze probability – the percentage of individuals that would choose a given word as the next word in the sentence based on the previous context (Taylor, 1953) – appears to have the strongest influence on the magnitude of the N400 (Kutas & Hillyard, 1984; Thornhill & Van Petten, 2012). This effect of cloze probability extends beyond local sentence context. Discourse level context also effects the amplitude of the N400: words that are plausible in general but which violate expectations that were generated by the larger context of the discourse elicit a larger N400 than an equally plausible word which does not violate these expectations (van Berkum, Hagoort, & Brown, 1999).

2.2.2 Neuroanatomical Correlates of Semantic Processing

Understanding the neuroanatomical generators of the N400 ERP effect could help to further specify the cognitive process or processes it reflects. However, localization of

ERP effects is problematic even when the scalp distribution is consistent across studies. For example, N400 effects are typically largest at medial or medial-posterior scalp locations and are often right-lateralized (Kutas, Van Petten, & Besson, 1988). However, results from patients who have undergone surgery to sever the corpus callosum, preventing communication across the hemispheres, show that the N400 is only present when the left hemisphere has full access to language input (Kutas, Hillyard, & Gazzaniga, 1988). Therefore, the medial and right lateralized distribution of N400 ERP effects has been attributed to volume conduction – the idea that the orientation of generators and conductance properties of the skull may cause an ERP effect to appear on the scalp at locations other than those closest to the neural generators (Huiskamp, Vroeijenstijn, Van Dijk, Wieneke, & Van Huffelen, 1999).

Since ERPs do not provide direct information about *where* in the brain an effect occurs, other measures including functional Magnetic Resonance Imaging (fMRI), magnetoencephalography (MEG), and intercranial recordings have been used to try to identify the neural generators of N400 ERP effects. Studies employing fMRI measures and stimuli that generate sentence-level N400 ERP effects report a broad constellation of regions that show a larger BOLD response. The left inferior frontal gyrus (lIFG) is the only region that consistently shows greater activity in response to semantic violations than control conditions across studies (Baumgaertner, Weiller, & Büchel, 2002; Ferstl, Rinck, & Von Cramon, 2005; Hagoort et al., 2004; Kiehl, Laurens, & Liddle, 2002; Kuperberg et al., 2003; Kuperberg, Sitnikova, & Lakshmanan, 2008; Rüschemeyer, Fiebach, Kempe, & Friederici, 2005; Stringaris, Medford, Giampietro, Brammer, & David, 2007). This region is thought to be involved in the retrieval of meanings of words, with the anterior and posterior parts serving different functions. The anterior lIFG shows less activation when lexical retrieval is easy, while the posterior lIFG shows increased activity when lexical selection is more difficult (Gold et al., 2006; Rodd, Davis, & Johnsrude, 2005). However, the drastically different time scales of the physiological activity indexed by ERPs and fMRI may mean the measures are indexing fundamentally different processes in response to the same stimuli. The fMRI effect in lIFG may be related to another ERP effect termed the Post-N400 Positivity (Lau, Phillips, & Poeppel, 2008; Thornhill & Van Petten, 2012) or even to differences in brain activity that are not evident in ERPs at all.

The Medial Temporal Gyrus (MTG) has also been implicated in the kinds of processing that can generate an N400 ERP effect. The N400 observed in response to an unrelated or unexpected word in word pairs is insensitive to the length of time between the presentation of the two items (stimulus onset asynchrony, SOA) (Anderson & Holcomb, 1995; Deacon, Uhm, Ritter, Hewitt, & Dynowska, 1999; Franklin, Dien, Neely, Huber, & Waterson, 2007; Hill, Strube, Roesch-Ely, & Weisbrod, 2002; Rossell, Price, & Nobre, 2003). The only region that shows this same robustness to SOA in fMRI experiments is the MTG (Gold et al., 2006). This area of the brain has also been shown to vary its activity as a function of word intelligibility (Davis & Johnsrude, 2003; Giraud et al., 2004) and the number of words being processed (Badre, Poldrack, Paré-Blagoev, Insler, & Wagner, 2005). The MTG seems to be necessary for accessing lexical representations – lesions to this area cause the impairment of comprehension of even extremely simple sentences (Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004). Since the MTG, along with other structures of the posterior temporal cortex, is involved in storing lexical representations (Hickok & Poeppel, 2007), contributions of the MTG to

ERP N400 effects suggests lexical access may be the shared process driving both the BOLD and electrophysiological responses.

MEG, which measures magnetic fields generated by electrical potentials in specific orientations in the brain, can allow for better localization of effects that are more closely related to what is measured using ERPs. This is because the magnetic fields measured by MEG are a result of the same electrical potentials that generate ERPs (although differences do exist because MEG is only sensitive to the activity of neurons organized tangentially to the skull) but these magnetic fields are not as susceptible to the blurring effects of volume conduction. Both studies at the sentence and word-pair levels evidence MEG effects with Equivalent Current Dipole sources in the left MTG, left superior temporal sulcus (STS), and left superior temporal gyrus (STG) (Helenius et al., 2002; Uusvuori, Parviainen, Inkinen, & Salmelin, 2008). Distributed source modeling has been used to localize the early portion of N400-like effects to the left planum temporale, left MTG, and the inferior temporal (IT) cortex and later portions to the left anterior temporal and inferior frontal cortex and the right orbital and anterior temporal cortex (Halgren et al., 2002). Intercranial recordings further implicate the medial temporal lobe in comparisons that typically elicit an N400 in ERPs (Elger et al., 1997; Halgren, Baudena, Heit, Clarke, Marinkovic, et al., 1994; Halgren, Baudena, Heit, Clarke, & Marinkovic, 1994; McCarthy, Nobre, Bentin, & Spencer, 1995; Nobre & McCarthy, 1995; Penke et al., 1997). These studies suggest a link between accessing long-term memories and N400 effects. Across techniques, the many brain regions that show effects of manipulations that produce differences in N400 amplitude suggest this ERP effect reflects multiple processes carried out across multiple brain regions.

2.2.3 Semantic Processing in Natural Language Comprehension

Despite this wealth of information about the ERP correlates of semantic processing and candidate brain regions responsible for generating these ERP effects, it is still unclear which cognitive processes associated with the N400 are relevant for real-world language processing. First, N400 effects have been interpreted as evidence that listeners formulate predictions about upcoming words in sentences. Slow word-by-word presentation of sentences might encourage more or more detailed predictions about upcoming information than does natural speech (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Frisch, Hahne, & Friederici, 2004; Kutas & Hillyard, 1980; Kutas et al., 1987). By including semantic violations in natural speech in the current study it becomes possible to better isolate language processes that occur at the rate of typical language stimuli. Second, the context that modulates the amplitude of the N400 is not limited to the local sentence (van Berkum et al., 1999). In the current study, a story narrative is employed such that the processing of individual words, and the N400s they evoke, can be shaped by the broader context rather than only the most recent few words. Third, even previous studies that have adopted a broader story context have marked the specific words used to elicit an N400 in some way. For example, in van Berkum et al, 1999, the context was established with natural speech, but the sentences with semantic violations and controls were presented visually, word-by-word on a computer monitor. In the current study, sentences that potentially include a semantic violation are presented in the same natural speech as the context. Fourth, in many studies that measure N400 amplitude, participants are asked to make overt judgments about how well-formed the sentences are (Atchley et al., 2006; Barber & Carreiras, 2005; Frisch et al., 2004; Gunter & Friederici, 1999; Hahne & Friederici, 2002; Hahne & Jescheniak, 2001; Kuperberg et al., 2003; Kutas, Hillyard, et al., 1988; Kutas et al., 1987; Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995; Weber-Fox, Davis, & Cuadrado, 2003; Ye, Luo, Friederici, & Zhou, 2006), whether a specific word or sentence had been presented previously (DeLong, Quante, & Kutas, 2014; Friederici et al., 1993; Friederici, Steinhauer, & Frisch, 1999; Hagoort, Wassenaar, & Brown, 2003; Van Petten, Coulson, Rubin, Plante, & Parks, 1999; Van Petten & Kutas, 1990), or the relationship between word or word-picture pairs (Bentin, McCarthy, & Wood, 1985; C. M. Brown & Hagoort, 1993; Deacon et al., 1999; Desroches, Newman, & Joanisse, 2009; Hill et al., 2002; Rossell et al., 2003). These tasks may provide useful behavioral data and serve to ensure that participants are attending to the stimuli, but also cause listeners to engage in processes that are not used during typical language comprehension. Some evidence suggests that these task demands change the characteristics of the N400 response, such that an explicit semantic judgment task is associated with a larger N400 amplitude (Gunter & Friederici, 1999). In the current study, participants will be asked to answer comprehension questions throughout presentation of the stories, but not to make explicit judgments about the sentences or stories. Natural speech, a broad story context, no overt marking of potential semantic violations, and no task other than listening for comprehension mean N400s in response to semantic violations in the current study can be interpreted as an index of the semantic processing that participants engage in during familiar, natural language processing.

2.3 Syntactic Processing of Language

Syntactic processing is the analysis of the structure and hierarchical relationships of language. Word order and word categories (for example, verb, noun, adverb, etc.) are considered in order to understand the relationship of the concepts within a sentence.

2.3.1 Electrophysiological Correlates of Syntactic Processing

ERPs have been used to try to more clearly understand how the cognitive processing associated with syntax unfolds. The most influential model, proposed by Angela Freiderici, asserts that processing of word category information is the very first stage of syntactic processing (Friederici, 2002). This type of syntactic processing is said to happen rapidly and independently of other types of processing, syntactic and otherwise. This level of analysis is claimed to be able to block further processing if word category violations cannot be resolved. Violations of word category (for example, by presenting verb in place of a noun: "The person was in the *climbed*") commonly elicits an early ERP effect (the ELAN) and often a later ERP effect (the P600). In the second stage, morphosyntactic processing occurs. This is the analysis of individual inflectional morphemes (for example, the past tense -ed at the end of a verb) in order to further understand the structure of the sentence. This stage of processing can be probed using, for example, syntactic violations of verb tense given the subject of the sentence (in other words, incorrect morphosyntax – for example "I go*es* to the store"). Experimental paradigms like this commonly elicit both an early ERP effect (the LAN) and often a later ERP effect (the P600). The present study investigates this type of syntactic processing. The third phase of syntactic processing involves the integration of syntactic and semantic processing and the reanalysis of sentences in order to modify a previously incorrect conclusion about meaning or structure or to repair the actual mental representation of the sentence, which is related to the later P600 ERP effect that can be generated after either type of syntactic violation (Friederici, 2002). Questions have been raised about the extent to which the ERP measures are pure indices of distinct stages of syntactic processing, and whether the results found in these ERP studies can generalize to real-world language processing, which may have consequences for this model.

2.3.1.1 Early Effects

Morphosyntax violations – the type of violation included in the present study – usually produce a LAN. Specifically, the LAN presents as a negativity, often left lateralized, with an anterior scalp topography, and occurring 250 - 400ms after presentation of the word that constitutes the grammatical violation (Barber & Carreiras, 2005; Coulson, King, & Kutas, 1998; Friederici et al., 1993; Gunter, Stowe, & Mulder, 1997; Münte, Matzke, & Johannes, 1997; Osterhout & Mobley, 1995). This effect is sometimes called the AN, anterior negativity, if no lateralization is found. This negativity is thought to index difficulty in the initial understanding of the structure of the phrase, caused by incorrect morphosyntax.

This negativity to syntactic violations is thought to reflect an obligatory and bottom-up process, a key tenant of Friederici's model of syntactic processing (Friederici, 2002). However, making conclusions about how a cognitive process unfolds in the real word based on ERP results requires a careful understanding of *all* potential sources of that ERP result within a given experiment. Even subtle patterns within stimuli can dramatically change the processing strategy of participants and therefore change ERP results. The idea that the LAN/AN is bottom-up is confirmed by the component's apparent lack of sensitivity to statistical regularities in stimuli or task demands. In an experiment where an obvious majority of the stimuli includes syntactic violations, it is expected that a top-down process would decrease in sensitivity to these violations (in other words, result in a lower amplitude ERP response) since the erroneous construction would be expected. However, a bottom-up process would not be affected by this expectation and therefore not show expectation-related changes. The early negativity is not modified by expectation, suggesting that it is a bottom-up process (Hahne & Friederici, 1999). Further evidence comes from a study of accented speech processing. While other ERP and behavioral evidence suggest that participants are permissive of morphosyntactic violations when they are produced by talkers with foreign accents (see Chapter 2.3.1.2), the anterior negativity is the same in response to accented and unaccented speech (Hanulíková, Van Alphen, van Goch, & Weber, 2012).

However, consider results of experiments eliciting the early left anterior negativity (ELAN), an earlier version of this LAN ERP component that underlies the first stage of Friederici's model and is elicited by a word category violation. There is evidence that this ERP component *is* sensitive to features of experimental stimuli in a top-down manner. In German, the prefixes *ge-/be-* can be associated with nouns, adjectives, and adverbs and therefore cannot give definitive information about a word's grammatical category (Steinhauer & Drury, 2012). This means that ELANs should not be generated this early in the word because there is not enough information at this time point to conclude whether a syntactic violation has been made or not; the ELAN should occur later when disambiguating information has been encountered. However, in studies where the experimental stimuli is a relatively narrow sampling of actual German language and the *ge-/be-* prefix is only used on nouns, encountering this prefix after a prepositional phrase triggers an ELAN because the prepositional-phrase-followed-by-noun construction is syntactically anomalous (Friederici, Gunter, Hahne, & Mauth, 2004; Friederici, Hahne, & Mecklinger, 1996). Since participants seem to have learned that in this context, encountering a *ge-/be-* prefix always means there is a noun coming next, it seems that the ELAN can be influenced by either top down control or at a minimum, statistical learning. These contradictory effects that suggest that somehow the later LAN/AN component is not sensitive to top-down information, but the earlier ELAN component is – something that is not currently addressed the model of syntactic processing. This also highlights the need for carefully constructed experiments that do not allow participants to pick up on statistical regularities that are not present in real language and then and potentially use these regularities in a way that changes processing.

Stimulus type also seems to change the relative timing of the response to morphosyntactic violations and word category violations, suggesting that they may not be two different processes. In studies where the sentence context is held constant and the target word is manipulated (termed “target manipulation” studies), a very specific pattern of results appears. In all such studies reviewed by Steinhauer & Drury (2012), the ERP effect to syntactic anomaly occurred *after* the 250ms threshold for an ELAN (the expected component given that these syntactic violations are constructed by violating rules of word category) and instead occurred in the time window expected for morphosyntactic violations (the LAN/AN (Hagoort et al., 2003; Martín-Loeches, Muñoz, Casado, Melcón, & Fernández-Frías, 2005; Van Den Brink & Hagoort, 2004; White, Genesee, & Steinhauer, 2012; Zhang, Yu, & Boland, 2010)). This calls into question the assertion that the ELAN and the LAN/AN are indexing two separate types of syntactic analysis and can be disambiguated using relative timing.

These and other discrepancies in the literature remain despite a large number of ERP studies of syntactic processing. Systematic problems with stimuli can lead to spurious results, such as when the stimuli in the study are constructed by manipulating the sentence context in a way that does not balance the word that is presented before the target word across the experimental and control conditions. Context manipulation studies, a type of study which holds the target word constant and presents it both in a sentence context that is syntactically anomalous and a sentence context that is syntactically permissible, have this systematic problem. This design can be problematic because the word directly before the target word is often always of the same word category in the violation condition and never of that word category in the control conditions. Steinhauer and Drury (2012) argue that this difference can have a dramatic influence on the ERP waveform: for example, if the words before the target word in the violation condition always elicited a slightly larger N400 than in the control condition – something that would happen if these words were always slightly more difficult to integrate into the previous context. In this case, the slowly ramping N400 component could survive baseline correction and then manifest as something that looks like an early negativity to a syntactic violation.

Other slightly later and more sustained negativities could also be explained by the effects of previous words. For example, if the violation sentence context always elicits a more positive response compared to the control condition, baseline correction would shift the violation context waveform more negative, and this could manifest as a sustained negativity. Steinhauer and Drury (2012) argue that this is exactly what is happening in many ELAN papers with unbalanced context manipulations. Whether this systematic difference has specific and visible effects on the ERP needs to be carefully considered when drawing conclusions from these types of paradigms. Unfortunately, these studies often use idiosyncratic baseline intervals, often starting *after* the target stimulus is presented, and therefore do not include the ERP activity before the target word in figures (something that is visible in the more common -100 ms to 0 ms baseline window). This makes this re-evaluation of published studies very difficult. It is also necessary to determine if the effect that is being described as an ELAN is also present for control conditions. If it is, this negativity may be explained as a response to the effort involved in processing the prepositional phrase before the syntactic violation and not the syntactic violation itself.

One early ELAN study does show the activity before the target word. A very early baseline window of -250 ms to 0 ms (relative to the target word) was used in a 1993 study by Friederici and colleagues (Friederici et al., 1993). These data show a pre-target-word positivity for sentences that include a syntactic violation, but none of the control sentences. Including this positivity in the baseline would create an artifactual sustained negativity in the violation condition only. Steinhauer and Drury (2012) argue that the ELAN effects in a number of published papers could be explained by an artifact like this and that we are unable to draw strong conclusions until we can see what is happening in the pre-target-word time interval (most notably: Friederici, Steinhauer, & Frisch, 1999; Hinojosa, Martín-Loeches, Casado, Munož, & Rubia, 2003; Neville, Nicol, Barss, Forster, & Garrett, 1991; Rossi, Gugler, Friederici, & Hahne, 2006; Rossi, Gugler, Hahne, & Friederici, 2005).

Fortunately, there is at least one study that directly compared morphosyntactic violations and word category violations, time locked ERPs to the disambiguating information in the target word, had no systematic differences in word type before the violation, and showed an appropriate baseline window (Hasting & Kotz, 2008). This study presented both types of violations in two experimental contexts, one where participants were asked to make grammaticality judgements and one where the participants were asked to ignore the sentences and watch a silent movie. In both experimental contexts, an ELAN-like component was found for both morphosyntactic and word category violations, suggesting that there is *not* a clear distinction between anterior negativities to these two types of stimuli if all variables are properly controlled. It is unclear, however, if these results hold true in a more natural experimental context – listening for comprehension.

The present study represents a significant contribution to understanding the true electrophysiological response to morphosyntactic violations in that it not only is it designed to prevent all potential confounds like Hasting & Kotz, 2008, but also encourages participants to engage in natural language processing. The construction of violations – incorrectly conjugating a first person present tense verb – lacks all systematic confounds mentioned above. Further, participants are asked to listen to a cohesive narrative for comprehension and are therefore not encouraged by task demands to engage in strange metalinguistic processing. Since the proportion of syntactic violations in the present study is quite low, participants are unlikely to be able to predict when these violations are coming or use statistic regularities of the stimuli to aid in processing. All of these factors suggest that the results of the present study will provide the most real-world relevant understanding of syntactic ERP effects to date.

2.3.1.2 Late Effects

In most ERP experiments investigating syntactic processing, the early AN/LAN/ELAN is followed by a later central positivity – the P600 (Barber & Carreiras, 2005; Coulson et al., 1998; Friederici et al., 1993; Gunter et al., 1997; Hahne & Friederici, 1999, 2002; Hahne & Jescheniak, 2001; Münte et al., 1997; Osterhout & Mobley, 1995). The P600 is thought to reflect a reanalysis of a sentence with unexpected syntactic features (Osterhout & Holcomb, 1992). This effect can also be seen in response to target words that, while technically syntactically correct, simply do not make sense with the previous context of the sentence. For example, a P600 was found in response to constructions like, "Jane does not eat any meat at all, instead she eats only *beef* and vegetables" (Shao & Neville, 1998). This suggests that the P600 indexes more general types of reanalysis, not just the reanalysis of anomalous syntax.

This late effect is sensitive to top-down influence and would also be expected to be different when listening to speech for comprehension instead of an unnatural metalinguistic task. In the aforementioned study that investigated differences in syntactic ERP components when syntactic violations were of high and low probability (Hahne & Friederici, 1999), the P600 disappeared when a high proportion of violations was present (in contrast to the earlier LAN effects, which remained in both experimental conditions). This disappearance in experimental settings where there is a high proportion of violations is expected for a top-down process, since participants begin to expect the violation and no longer engage in effortful reanalysis. Other experimental syntactic conditions also result in an absence of the P600. It appears that explicit attention to grammaticality of a sentence is necessary to generate a P600. In the aforementioned Hasting & Kotz, 2008 study, which appropriately controlled for all experimental confounds and compared morphosyntax and word category violations, the P600 was only present when participants were asked to make grammaticality judgments and disappeared when participants instead listened to sentences while watching a silent movie. Additionally, the previously mentioned study of syntactic violations and accented speech showed no P600 when stimuli was produced by a speaker with a foreign accent (Hanulíková et al., 2012). It is likely that syntactic violations are allowable when produced by someone who is still mastering the English language, and therefore these violations are not processed in the same way as violations made by someone proficient at English. This is another example of the P600 being modulated by top down control and explicit attention to violations.

The P600's strong relationship to task demands suggests that it may not be directly relevant to real word, on-line language processing. It is likely that the amplitude of the P600 is relevant to individual language ability. For example, P600 amplitude and scalp topography differ as a function of socioeconomic status when processing syntactic violations in an individual's first language (Pakulak & Neville, 2010). What is unclear is whether the cognitive processes underlying this specific ERP component are engaged in real-world language processing or if the P600 reflects processes that are more metalinguistic and only engaged in idiosyncratic contexts. By avoiding explicit grammaticality judgments and encouraging language processing that is as natural as possible, the present study is well positioned to shed light on how the P600 relates to real communication.

2.3.2 Neuroanatomical Correlates of Syntactic Processing

Much work has been done to determine the brain structures underlying different aspects of syntactic processing. Unfortunately, these studies suffer from the same issues as ERP studies of syntax – they use tasks that are far from natural language processing and it is unclear which results are relevant for the real world. Further, given the poor temporal resolution of fMRI, it is difficult to accurately disentangle syntactic processing as a whole vs. early phrase structure building and later syntactic analysis or reanalysis.

In general, syntactic processing is believed to occur in brain areas connected by white matter tracts such as the arcuate and uncinate fasciculi in the left planum temporale and parts of the inferior frontal and temporal cortices (Caplan, Alpert, & Waters, 1998; Caplan & Waters, 1999; Goucha & Friederici, 2015; Musso et al., 2003; Opitz & Friederici, 2003, 2007; Stromswold, Caplan, Alpert, & Rauch, 1996; Tettamanti et al., 2002).

Violations of phrase structure, the same violations that would produce an ELAN ERP response, are associated with activity in the Frontal Operculum (FOP—part of the lIFG, located adjacent to Broca's area) (Friederici, Rüschemeyer, Hahne, & Fiebach, 2003; Ni et al., 2000; Opitz & Friederici, 2003) and the anterior left STG (Friederici et al., 2003; M. Meyer, Friederici, & Von Cramon, 2000). These structures are connected via a white matter tract called the uncinate fasciculus (Friederici, Bahlmann, Heim, Schubotz, & Anwander, 2006). This entire pathway has been implicated in the early and automatic syntactic processing that is similar to the kinds of processing thought to be indexed by the ELAN/LAN/AN.

Integrating complex syntax, a process that is thought to be associated with the P600, is related to increased activity in the left posterior STG. This effect is visible in response to a complex hierarchical relationships (for example, "Maria who loved Hans who was good looking kissed Johann,") (Makuuchi, Bahlmann, Anwander, & Friederici, 2009), specifically to sentences with that both have a high memory demand and include complex syntax (Cooke et al., 2002). Perhaps the most compelling evidence that the left posterior STG is related to the P600 comes from a lesion study demonstrating an absence of the P600 in participants with damage to this brain region (Friederici & Kotz, 2003).

Processing associated with the P600 may also occur in the left IFG, in addition to this brain region's role in ELAN/LAN/AN relevant processing. Sentences with scrambled order of subject and object noun phrases elicit a P600 and also activate the lIFG. Further, the strength of activation correlates with how badly scrambled the sentence is (Friederici, Fiebach, Schlesewsky, Bornkessel, & Von Cramon, 2006; Grewe et al., 2005; L. Meyer, Obleser, Anwander, & Friederici, 2012; Röder, Stock, Neville, Bien, & Rösler, 2002).

It is know that the P600 can be generated not just by incorrect syntax, but also nonpreferred or more difficult to integrate syntax (Kaan, Harris, Gibson, & Holcomb, 2000). Sentences that include relative clauses that are nested or object-relative (for example, "The boy who the tall girl is chasing is Derek,") are difficult to process. These sentences also activate the lIFG, but the activity localizes more specifically to Brodmann Area 44 and 45, not including the FOP (Santi & Grodzinsky, 2010). These effects are thought to be syntax-specific and unrelated to working memory demand which, for syntactic processing at least, seems to be supported by the inferior frontal sulcus (Makuuchi et al., 2009). These results suggest that while the ELAN/LAN/AN and P600 are clearly separate ERP effects, at least some common brain regions, such as the lIFG, may be recruited in the generation of both ERP components.

2.3.3 Syntactic Processing in Natural Language Comprehension

In order to understand syntactic processing as it unfolds in real language processing, an experiment that includes stimuli that is as similar as possible across the control and experimental condition except for the syntactic violation itself and encourages language processing that is as natural as possible is needed. An ideal syntactic manipulation would be to add an incorrect morpheme to first person singular verbs ("I go*es*"). This manipulation keeps everything before the syntactic violation consistent across conditions because the sentence context itself does not need to change in order to create this violation. Further, all sentences will be naturally produced which prevents any unintended effects of splicing in a sound that is inconsistent with the previous pronunciation (coarticulatory cues) that may be present in the production of just the verb stem. Finally, using the /s/ morpheme as a violation allows for precise timelocking to the point at which listeners encounter the violation without the need for splicing because the onset of this sound is easily visibly identifiable in the sound waveform. These syntactic violations will be embedded in a larger story context that participants will be asked to listen to for comprehension and answer frequent simple questions about the plot. This experimental design encourages participants to engage in natural language processing instead of making metalinguisitic judgments that could differ wildly from real-world processes. Further, the infrequency of these violations and their unpredictability prevents listeners from using experiment-specific statistical regularities of the stimuli to support processing, a problem that may explain or obscure the results of some previous studies.

The present study uses this experimental design, allowing us to investigate the electrophysiological signature of syntactic processing as it is relevant to real speech. This will allow us to make more specific claims about which ERP effects currently in the literature are truly indexing real-world language processing and if the characteristics of these effects differ based on ecological validity of the language paradigm. Of particular interest is the timing of the LAN/AN. This manipulation includes morphosyntactic violations, so a later LAN effect is expected (at 250 - 400ms) while the other type of syntactic violation, word category violations, are thought to elicit the earlier ELAN effect (before 250ms). If the effect generated by incorrect morphosyntax is earlier in real speech this could suggest either that the LAN and the ELAN are not separable in real language processing. It is also possible that processing in general happens earlier in real speech and the ELAN under these conditions would be shifted even earlier in time, making an early LAN consistent with previous accounts of at least the relative timing of these effects. Either way, this would suggest that simple timing cutoffs cannot accurately disambiguate these two types of syntactic processing. The presence of the P600 is also of interest. The P600 is thought to represent reanalysis of incorrect or difficult to understand syntax, but it is unclear if this reanalysis happens when a listener encounters an infrequent violation in real communication or if this effect is an artifact of experimental designs that encourage explicit metalinguistic judgments. The presence or absence of the P600 in this study – an experiment that only encourages comprehension – could shed light on the P600's relevance to real language processing.

2.4 Phonological Processing of Language

Phonological processing is the perception and analysis of language sounds. Perhaps not surprisingly, skill with the sounds of a language has been linked to many other language skills. Specifically, phonological awareness, the understanding that language is made of discrete sounds that are combined to form words, and the ability to manipulate these sounds, is predictive of both speech comprehension (Gillon, 2000, 2002; Larrivee & Catts, 1999) and written-language comprehension (Bradley & Bryant, 1983; Vellutino et al., 1996; Ziegler & Goswami, 2005). The particularly strong link between phonological awareness and early reading during development has been explained in terms of fluency in mapping orthography to phonology (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Ehri, 2008; Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003). A measure of on-line phonological processing during natural speech comprehension has the potential to provide critical information about both typical and atypical language processing. However, unlike for semantic and syntactic processing, there are no firmly established ERP indices that are specific to the kinds of phonological processing that are necessary for natural language comprehension.

2.4.1 Electrophysiological Correlates of Phonological Processing

Since the previous literature does not provide an established paradigm for eliciting phonological ERP effects, the two most closely related procedures will be described instead.

2.4.1.1 The ERP Correlates of Phonological Processing in Continuous Speech

Phonological processing has been investigated by setting up lexical predictions and then violating both expectations concerning the initial sounds of a word and semantic expectations or only semantic expectations to elicit a PMN. Specifically, the PMN is a larger negativity to an unexpected phoneme 150 - 300 ms after onset (Connolly & Phillips, 1994; Connolly, Phillips, Stewart, & Brake, 1992; Connolly, Stewart, & Phillips, 1990). The PMN can be dissociated from the N400 both in timing and topography – has a shorter latency and more anterior distribution than the N400 – and experimentally – the PMN can be elicited without the N400 and vice versa (Connolly & Phillips, 1994). Further, similar effects have been observed when lexical expectations were set up by images rather than sentence context (D'Arcy, Connolly, & Crocker, 2000; Duta, Styles, & Plunkett, 2012) and when creating phonological expectations for nonwords (e.g., "replace the /b/ in bouse with /t/") (Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Kujala et al., 2004; Newman & Connolly, 2009; Newman et al., 2003). In the current study, a PMN response may be present if the story and sentence context is sufficient to set up specific phonological expectations and then those expectations are violated.

2.4.1.2 ERP Correlates of Phonological Priming

Phonological processing has also been studied by comparing responses to words or nonwords that are preceded by phonologically similar or dissimilar items. In many of these studies, phonological similarity was defined in terms of rhyming (e.g., DAZE – PAYS vs. DARE – PATS from Rugg, 1984a). The second item in rhyming pairs compared to nonrhyming pairs elicits a smaller N400 for printed words (Grossi et al., 2001; Rugg, 1984b), printed pseudowords (Rugg, 1984a), spoken pseudowords (Coch et al., 2002, 2005), and picture-word pairs (Desroches et al., 2009). The effect is considered phonological because it is observed when orthographic similarity is equated for rhyming and nonrhyming pairs, when different talkers produce the first and second items in pairs (Praamstra & Stegeman, 1993), and when the first word in a pair is invoked by an image rather than speech sounds. Further, the reduction in N400 amplitude is larger when there is more phonological overlap between words or pseudowords (Dumay et al., 2001). This reduction in N400 amplitude is typically interpreted as a reduced response to recently activated phonological and phonologically similar lexical representations. In the present study, if the stems of words are sufficient to prime what the suffix should sound like, a smaller N400 may be generated in response to canonical as compared to violation suffixes.

2.4.2 Neuroanatomical Correlates of Phonological Processing

The current understanding of the brain structures underlying phonological processing is far more advanced than our understanding of any of the electrophysiological effects. A precursor to processing and identifying individual phonemes is the accurate perception and representation of the speech signal – a signal that contains more rapid fluctuations than other types of sound. A patient population termed "pure word deaf" not only have difficulty processing speech but also non-speech sounds that share the extremely rapid intensity and pitch fluctuations found in natural speech. This suggests that there is a more domain-general a pre-step that underlies phonological processing, thought to take place in the bilateral posterior superior temporal cortex (Poeppel, 2001). Since this structure is relied upon so early in processing, it is likely that the bilateral superior temporal cortex is generally involved in the types of processing that generates both the ERP effects related to phonological priming and the PMN, although it is unclear if this structure generates the ERP effect per se.

The asymmetric sampling in time framework proposed by David Poeppel suggests differential lateralization in processing depending on the timescale at which sounds are being processed (Poeppel, 2003). After this bilaterally similar and early processing in the posterior superior temporal cortex, each hemisphere processes its preferred timescale separately. Since auditory processing regions in the left hemisphere have neuronal populations that oscillate preferentially at roughly 40Hz (Giraud et al., 2007), this hemisphere is thought to process auditory features that fluctuate rapidly, such as phonological features. The right hemisphere has neural populations that oscillate preferentially at roughly 5Hz (Giraud et al., 2004), so this hemisphere is thought to process sounds with slower dynamics, such as syllables. Experimental support for this theory of differing lateralization for the processing of phonemes versus syllables can be found in tasks where participants were asked to attend to different aspects of an identical speech signal. When participants were asked to attend to phonological features (such as place of articulation), PET indicated activity in the left hemisphere; when participants were asked to judge pitch (a judgment that requires analysis at or above the timescale of a syllable), PET indicated activity in the right hemisphere (Zatorre, Evans, Meyer, & Gjedde, 1992). The present study includes phonological violations that are related to a phonological feature. Suffixes on plural nouns were replaces with an allomorph that differed in voicing status (/z/, a voiced sound, was replaced with /s/, a voiceless sound). Therefore, oscillatory activity in the left hemisphere likely underlies the detection of voicing status and allows for the detection of the phonological violations in the present study.

The auditory signal is then processed into individual phonemes in the mid STG (Obleser, Zimmermann, Van Meter, & Rauschecker, 2007), adjacent to the primary auditory cortex. A meta analysis of fMRI studies combined with diffusion tensor imagining (DTI) of white matter tracts suggested that the dorsal pathway which consists of the posterior STG and Brodmann Areas 44 and 45 (Broca’s area) connected by the arcuate fasciculus is involved in phonological processing (Glasser & Rilling, 2008). While processing in the mid STG and by this larger phonological pathway is undoubtedly relevant to the kinds of computations necessary to generate a differential response to expected vs. unexpected phonemes (the PMN) or to phonemes that were heard recently vs. newly heard phonemes, the current state of the literature makes it difficult to disentangle which regions are relevant for which process.

A meta-analysis of brain imaging studies published between 1992 and 2004 that investigated phonological processing implicates left frontal regions and left temporal and inferior parietal areas (Vigneau et al., 2006). The frontal activations were clustered relatively posteriorly in the brain region, near the precentral gyrus. Temporal activations were clustered along the superior temporal gyrus and the supramarginal gyrus. The authors of this meta-analysis suggest that these areas actually comprise two networks – one for generating speech sounds and one for perceiving speech sounds. They suggest that the fronto-parietal network is involved in speech production while the fronto-temporal network is related to rehearsal of the auditory signal in order to hold phonemes in working memory (Vigneau et al., 2006). The overlap of phonological processing and motor areas along with studies that show that language listening and language production use overlapping areas in individual subjects (Wilson, Saygin, Sereno, & Iacoboni, 2004) and that tongue muscle excitability is modulated by language listening (Fadiga, Craighero, Buccino, & Rizzolatti, 2002) suggest that phonological processing involves the reactivation of motor processes that would be required to generate those phonemes. Again, these processes likely relate both to the cognition underlying the PMN and the N400 phonological priming effect.

2.4.3 Phonological Processing in Natural Language Comprehension

Studies investigating both the electrophysiological and neuroanatomical correlates of phonological processing suffer from designs that are very different from natural listening conditions, including presenting isolated word pairs, nonwords, or sentence contexts that are far more constraining than those used in typical communication settings. Further, they often require that participants engage in metalinguistic, phonological-awareness type tasks that are unfamiliar and would not be expected to contribute to listening to speech for comprehension. As such, a new type of phonological violation that can be included in natural speech stimuli is needed.

English speakers implicitly know whether to pluralize a noun with an /s/ sound or a /z/ sound, depending on the previous phonological context. A demonstration of this implicit ability can be found in the classic “wug” study (Berko, 1958). Children were shown an image of one novel character and given its name. They were then shown a picture of two of these characters and asked to complete the frame “two ______”. As early as age five, children were able to correctly pluralize novel nouns based on their phonological characteristics (Berko, 1958). Due to the fact that these rules are stored implicitly, defining them in a more declarative way is relatively complicated. In general, the default way to pluralize a noun is using the /z/ allomorph. This /z/ is substituted for an /s/ when the noun ends in a voiceless obstruent (such as /k/, /t/, or /p/; for example, “back/s/”). The other special case is when nouns end in a coronal sibilant (such as /sh/ or /s/) which are pluralized using the /iz/ allomorph (for example, “hous/iz/”). Pronouncing a plural noun that ends in a voiceless obstruent with the voiced /z/ allomorph is phonotactically illegal in English, and therefore not possible to pronounce (for example, “back/z/”). However, it is possible to produce some nouns with the wrong allomorph. These productions are cases of a violation of the phonological rule that governs pluralization, but not a violation of the phonotactics of the English language. This is the case for nouns that end in sonorants (such as /l/, /r/, /n/, /w/, /j/). These nouns are pluralized with a /z/ (for example, ton/z/) but it is also physically possible to produce a sonorant with a /s/ directly after (for example, “once”).

These specific regularities of pluralization in English can be exploited to study phonological processing in continuous speech. Using the wrong allomorph for a plural noun (an /s/ when a /z/ is expected) results in a phonological violation while still maintaining a degree of acoustic similarity across phonological violations and correct pluralizations since /s/ and /z/ only differ on one phonological feature – voicing. This makes it less likely that any ERP effects would be driven by simple low-level acoustic differences in the violation vs. canonical condition. It is also possible to record a real production of the phonological violation word as opposed to relying on recording the word with the correct allomorph and then splicing in the incorrect one. In fact, the most salient cue of whether a phoneme is voiced or not comes from the length of the syllable root before the phoneme in question, not actually in the duration of voicing of the fricative itself. This suggests that phonological violations may be detectable by the participant before the erroneous phoneme itself is heard, making it vital that the phonological violations are produced naturally. This ensures that any cues about the voicing status of the final consonant are congruent with the consonant that participants end up hearing. Whether a participant is capable of using the information prior to hearing a phoneme in order to predict whether that phoneme is voiced or not may be visible in ERP results and may be related to individual differences in language comprehension ability.

Although it is not entirely clear what the ERP effects in response to this type of violation might be or if ERP effects will even be detectable, it is possible to present these violations under natural listening conditions with no task other than comprehension.

There are at least five distinct possible ERP effects related to encountering a plural nouns with the wrong allomorph. First, an incorrect allomorph could be processed as a violation of phonological expectations and trigger an effect that looks similar to a PMN. Previous work with the PMN has focused on word-initial phonemes, however there is no reason to assume that this effect is restricted to this type of stimulus. A result like this would indicate that specific phonological expectations are made for word-final phonemes, in contexts that are not any more predictable than in typical communication, and including inflectional morphemes – the smallest units of sound that can be used to mark number and tense. Effects may also resemble the AN, a classically syntactic effect, because this effect is generated by absent or erroneous inflectional morphemes and the phonological violation in this study is also on an inflectional morpheme. Third, we may see an N400 effect if using the incorrect allomorph causes the word to be processed as a nonword as a whole instead of an acceptable word with the incorrect inflectional morpheme, or similar to effects found in phonological priming studies, we may get a smaller N400 response to canonical as opposed to anomalous suffixes. Fourth, it is also possible that the effect will be something that does not resemble any previously reported ERP effect because this particular phonological violation has not yet been explored. Finally, it is also possible that no discernible ERP effect will come out of the presentation of this relatively subtle phonological violation. Listeners encounter huge variability in pronunciation while listening to real speech, and can even accommodate systematically incorrect pronunciations in the case of listening to talkers with a foreign accent (Sidaras, Alexander, & Nygaard, 2009). Additionally, the present study encouraged comprehension of the speech in general and did not explicitly ask about phonological violations or warn participants of their presence. This may make the violations more likely to be tolerated by listeners as normal speech.

2.5 The Present Study

In the present study, adults listened to a story with the singular goal of comprehension. During this story, adults answered simple questions about the plot. This story included semantic violations –nouns that are unexpected based either general world knowledge or knowledge of the story context, syntactic violations – adding a /s/ morpheme to present tense singular verbs ("I goes"), and phonological violations – using the incorrect allomorph to form a plural noun ("horn/s/"). By including these three types of violations in natural speech that listeners attend to for comprehension, we can determine which subsystems and which indices of which subsystems are most influenced by experimental factors including rate of presentation, modality, and experimental task and therefore which are relevant for natural speech comprehension.

2.6 Methods

2.6.1 Participants

Twenty-four adults (ages 18 – 29 years, mean age 21 years, 8 males) participated in this study. An additional five participants were recruited but were excluded due to excessive high frequency noise in EEG data. All participants were right handed, native English speakers, with self-reported normal hearing, normal or corrected to normal vision, with no neurological disorders and taking no psychoactive medications.

2.6.2 Materials

Stories originally written for a study to be conducted with five-year-old children served as auditory stimuli. These three stories were written to include semantic violations, syntactic violations, and phonological violations (see Appendix A). Semantic violations were created by replacing a noun with one from another sentence to make the sentence semantically implausible at the switched word (for example, “I am reading a *cupboard*” instead of “I am reading a *book*”). These sentences were always implausible given the context of the story and occasionally also implausible even for the isolated sentence, based on world knowledge. Syntactic violations were created by using the wrong tense of a first-person singular verb (for example “I run*s*” instead of “I run”). Phonological violations were created by pronouncing plural nouns with an /s/ sound as the inflectional morpheme instead of the correct /z/ sound (for example “shoe/s/” instead of “shoe/z/”). A native English-speaking female from Western Massachusetts produced all sentences in a sound attenuated room. Extraneous pauses and noises (breathing, coughing, etc.) were removed, but recordings were otherwise left as natural as possible. Canonical and violation sentences were similar in key acoustic features and the duration of key elements of the sentence (see Table 2.1).

Table 2.1: *Key acoustic features of stimuli*

	Canonical		Violation	
	Mean Duration (ms)	Mean Intensity (dB)	Mean Duration (ms)	Mean Intensity (dB)
Semantic Sentences				
Target Word	438	61.93	461	62.01
Preceding Context	1978	66.02	2022	66.02
Syntactic Sentences				
Preceding Context	335	68.81	333	68.36
Post-Target Word Context	1799	63.66	1816	64.78
Phonological Sentences				
Preceding Context	1399	65.90	1422	66.13

Additionally, cues to final consonant voicing are length of the syllable nucleus or syllable root, which should be longer for /z/ than /s/, the length of the fricative itself, which should be shorter for /z/ than for /s/, and the amount of voicing in the fricative, which should be more for /z/ than for /s/. Table 2.2 shows measurements for all of these key features for the critical /s/ and /z/ in the phonological condition. The canonical /z/ and violation /s/ differed on all of these dimensions in the expected direction. Additionally, the phonemes were similar in mean intensity.

Table 2.2: *Key acoustic features of phonological stimuli*

	Duration (ms)	Syllable Root Duration (ms)	Percent Voiced	Mean Intensity (dB)
Canonical /z/	146	170	15.34%	56.87
Violation /s/	190	151	0.89%	57.95

This suggests that natural pronunciation of these phonological violations, as opposed to constructing them by splicing in the anomalous phoneme, gives auditory stimuli with acoustic cues to voicing that are consistent with what is found in normal speech.

The stories consisted of 250 experimental sentences intermixed with 270 filler sentences that served to advance the plot of the story. Participants were randomly assigned to one of two experimental groups such that participants heard only the canonical or violation version of each sentence, necessary for the story context. Each sentence that was a violation for one group was presented as the canonical control for the other such that across participants, any effects of when the sentence occurs in the story, what was happening in the story, or the specific sequences of words are accounted for. Due to equipment error, number of canonical vs. violation sentences were not perfectly counterbalanced across groups. Group 1 heard 126 violation sentences, 124 canonical sentences, and 250 filler sentences. Group 2 heard 124 violation sentences, 126 canonical sentences, and 250 filler sentences. See Appendix A for the full experimental stimuli, which indicates which group heard each sentence as a violation.

Key events in this experiment are the onsets of violation and canonical words for semantic processing effects, and the offset of verb and noun stems for syntactic and phonological processing effects. Time locking to the ends of stems rather than the beginning of words is necessary for the syntactic and phonological conditions because the time between word onsets and the information that distinguishes between canonical and violation forms varies widely across items. The onset of these words/phonemes in continuous speech was determined independently by three research assistants. If the three estimates differed by more than 10 milliseconds, that onset was recalculated by Margaret Ugolini and Dr. Lisa D. Sanders.

Participants answered 84 comprehension questions, presented at semi-regular intervals during the stories (every 2-4 sentences; see Appendix B for the full text of the stories with questions embedded). Comprehension questions were identical for both groups. Four answer choices were offered for every question, one of each of the following categories: the correct answer, a plausible answer that was clearly incorrect based on the information provided in the story, a word that has been said before in the story, and a word that is unfamiliar and not a plausible answer to the question.

2.6.3 Procedure

Participants were seated in front of a computer screen in a chair while wearing an EEG cap. While the story was playing, the computer screen displayed a centrally presented white fixation cross on a black background. Approximately every 2-4 sentences, the story paused, and the central fixation cross changed to a "?". At this time, a research assistant read a question aloud. The written question was not visible to the participant. The participant was then presented with an Apple iPad running custom software (GameSalad) that displaying four line-drawings. Participants were instructed to tap the drawing that corresponded to the answer to the question.

2.6.4 EEG Data Acquisition and Processing

EEG data was recorded throughout the presentation of the story. Continuous data from 128 electrodes was collected using a HydroCel Geodesic Sensor Net (EGI, Eugene OR) at a 250 Hz sampling rate, using CZ as an on-line reference with a 0.01-100 Hz on-line bandpass filter. Scalp impedances at all electrode sites were kept below 50 kΩ.

Data was processed using ERPlab and EEGlab, EEG data analysis software packages written for MATLAB. A 60-Hz notch filter was applied to remove external electrical noise from the data. Independent Component Analysis (ICA) was used to correct blink artifacts in an effort to keep as much data as possible. Data was then filtered with a highpass filter of 0.1 Hz to remove excessive low frequency noise that could not be attributed to brain activity and was then rereferenced to the average of the mastoids.

EEG data was segmented into epochs of different lengths depending on the effect of interest. For the semantic condition, violation and canonical word onsets served as the event of interest and EEG data was segmented starting 100 ms before each event and 500 ms after that event, baseline corrected to 100 ms before the event. This epoch length is ideally suited for detecting the N400. For the syntactic condition, violation and canonical morphemes (the presence or absence of a word-final s) served as the event of interest. Epochs were constructed by segmenting EEG data starting 100 ms before each event and 1000 ms after that event, baseline corrected to 100ms before the event. This epoch length is ideally suited for detecting both early syntactic effects such as the ELAN/LAN/AN and the later P600. For the phonological condition, violation and canonical sound onsets (transition between the noun stem and the suffix /s/ or /z/) served as the event of interest. It is possible that, due to coarticulatory cues that allow listeners to predict the voicing status of an upcoming phoneme, participants were able to predict whether a word would end with a canonical or a violation phoneme before the onset of that specific phoneme. In order to investigate this possibility, EEG data was segmented starting 200 ms before each event and 500 ms after that event, baseline corrected -200 - -100 ms before the event. This epoch is ideally suited for detecting a PMN to an unexpected phoneme, but would also make it possible to detect LAN, N400, or previously unreported effects.

Epochs were submitted to an automatic artifact rejection routine which flagged any epoch with activity below -50uV or above 50uV. Margaret Ugolini then inspected each epoch by hand to ensure that the algorithm properly detected trials with lingering blink effects that were not successfully removed by ICA, trials with excessive muscle tension, or trials with excessive drift, while rescuing as many usable trials as possible. On average, for each of the 3 conditions (semantics, syntax, and phonology), 28 trials were kept for the canonical condition (ST DEV 5.45) and 27 for the violation condition (ST DEV 4.94).

2.6.5 Analysis

ERPs were computed for each participant at each electrode and for each condition. ERPs were then averaged into clusters for each participant in a 3x3 configuration (Left, Medial, Right x Anterior, Central, Posterior). Figure 2.1 shows a graphical representation of these clusters.

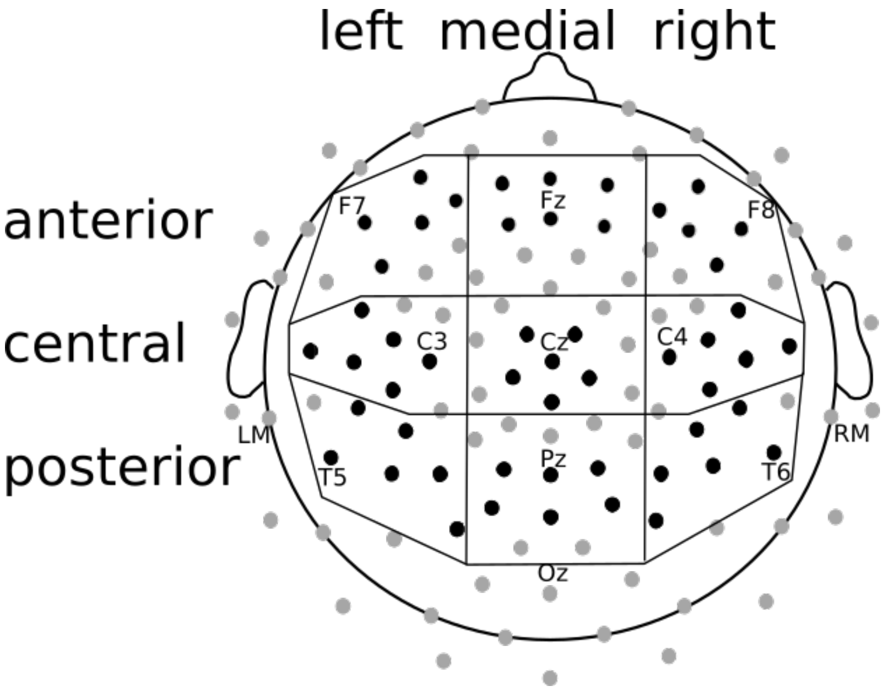

Figure 2.1: Nine regions of interest, 6 electrodes each. Grey dots indicate electrodes not included in the analysis.

Mean voltage during relevant time windows of interest was calculated for each condition at each cluster. These time windows were selected based on the literature and on visual inspection of the grand averaged waveforms. In order to detect the N400, mean voltage 300-500 ms post critical-word onset was measured for semantic violation sentences and semantic canonical sentences. In order to detect early syntactic effects (ELAN/LAN/AN), mean voltage 150-300 ms post grammatical morpheme onset (or absence thereof) was measured for syntactic violation sentences and syntactic canonical sentences. In order to detect late syntactic effects (P600) and investigate the full duration of our early syntactic effect, mean voltage 200-1000 ms post grammatical morpheme onset (or absence thereof) was also measured for syntactic violation sentences and syntactic canonical sentences. In order to detect the PMN, mean voltage -100-0 ms before the critical phoneme was measured for phonological violation sentences and phonological canonical sentences. In order to detect phonological effects after the presentation of the phonological violation itself, mean voltage 200-300 ms after the critical phoneme was measured for phonological violation sentences and phonological canonical sentences.

Data were submitted to a 2 x 3 x 3 repeated measures ANOVA with the following factors: Condition (Violation, Canonical), Anteriority (Anterior, Central, Posterior), and Lateralization (Left, Medial, Right) (approximate location of electrodes included in electrode-position factors is shown in Figure 1). All reported p-values have been Greenhouse-Geisser corrected to account for potential violations of the assumption of sphericity in order to be as conservative as possible.

2.7 Results

2.7.1 Comprehension Questions

On average, accuracy was 98.9% (ST DEV 1.5%), indicating that participants were paying attention to the story and that comprehension was successful.

2.7.2 ERP Data

2.7.2.1 Semantic ERP Effects

Figure 2.2 shows grand average ERPs time locked the onsets of words that were semantically congruent and anomalous. Mean amplitude from 300-500 ms across electrode position was more negative for semantic anomalies, $F(1, 23) = 7.98$, $p = 0.010$, generalized $\eta 2 = 0.104$. Further, semantic anomaly interacted with left to right electrode position, $F(2, 46) = 5.103$, $p = 0.011$, generalized $\eta 2 = 0.010$, reflecting that the effect was largest over medial regions.

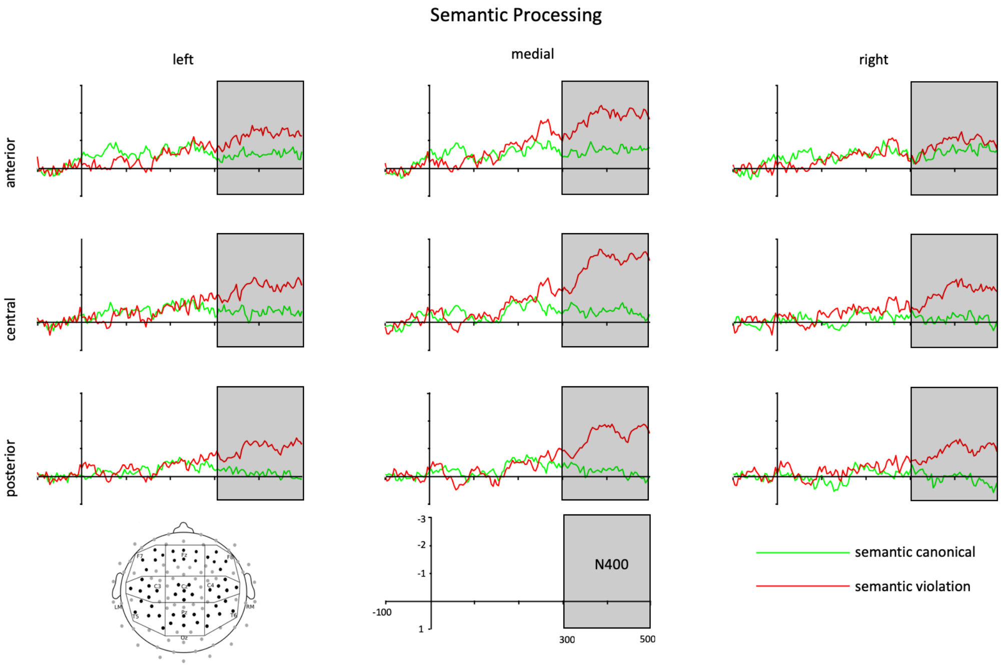

Figure 2.2: Grand average ERPs to semantic violations (red) and canonicals (green), from -100 to 500 ms after onset of critical word.

2.7.2.2 Syntactic ERP Effects

Figure 2.3 shows grand average ERPs time locked to the end of verb stems that are syntactically well formed compared to verb stems that are followed by a morpheme creating a verb agreement violation. There was a marginally significant interaction of syntactic anomaly and both electrode position factors on mean amplitude 150-300ms, $F(4, 92) = 2.910$, $p = 0.057$, generalized $\eta 2 = 0.003$. To directly measure the lateralization of the anterior negativity, a further comparison of the effect at left anterior and right anterior electrode sites was conducted. The anterior negativity was left lateralized, $F(1,23) = 4.80$, $p = 0.039$, generalized $\eta 2 = 0.009$. A t-test at the left anterior locations indicated that syntactic violations elicited a larger negativity than the canonical form, $t(23) = 2.766$, $p = 0.011$, $M = 0.826$ mV, 95% CI [0.208, 1.443].

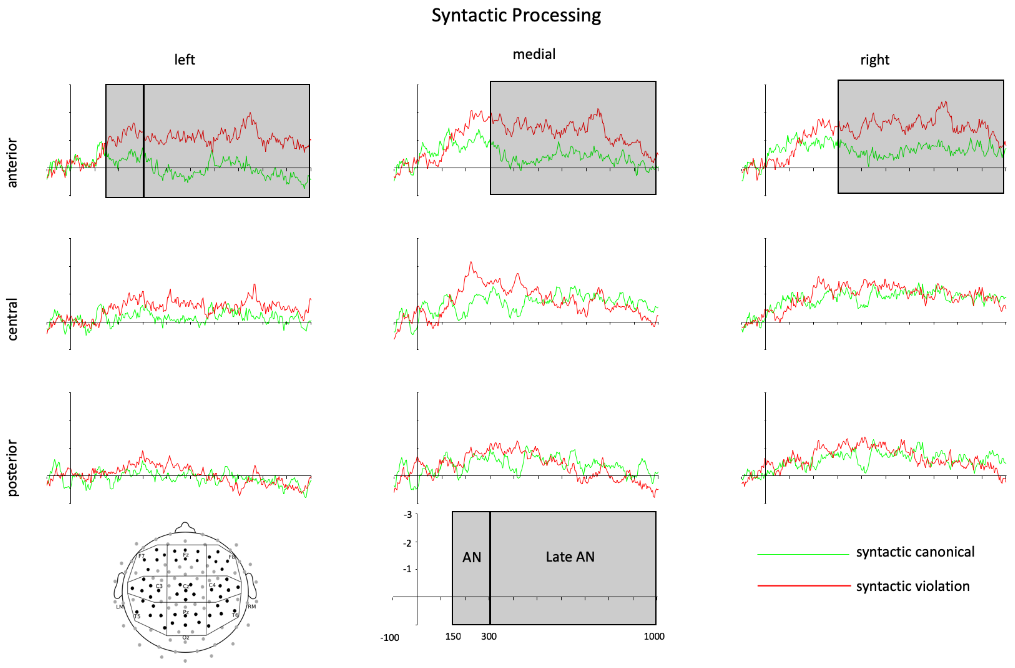

Figure 2.3: Grand average ERPs to syntactic violations (red) and canonicals (green), from -100 to 1000 ms after critical morpheme in the violation condition and end of verb stem in the canonical condition.

To investigate the duration of the anterior negativity as well as check for the presence of a P600, a later 300 - 1000 ms time window was investigated. Even at this extended time window, the only effect was syntactic violations eliciting a larger *negativity* when compared to the canonical form. There was a significant interaction of syntactic anomaly and anterior to posterior electrode position on mean amplitude, 300-1000 ms, such that the differences in response to the canonical and violation forms was largest at anterior sites, F(2, 46) = 7.369, p = 0.007, generalized η2 = 0.0248. Over anterior and central regions, syntactic violations elicited a larger negativity, F(1, 23) = 5.14, p = 0.033, generalized η2 = 0.040. Unlike the effect observed in the earlier time window, there was no evidence that this longer duration effect was lateralized ($p = 0.465$).

2.7.2.3 Phonological ERP Effects

Figure 2.5 shows grand average ERPs time locked to the onset of canonical and phonological violation suffixes. The baseline used for other conditions (-100 - 0 ms) appeared to show a difference between phonological conditions, potentially driven by voicing cues that precede the suffix. Therefore, a baseline of -200 - -100 ms was used instead. Phonological violations elicited a broadly distributed negativity -100 - 0 ms, $F(1, 23) = 9.431$, $p = 0.005$, generalized $\eta2 = 0.061$. No interaction with electrode position factors was evident, however the effect was numerically largest at medial and anterior sites $t(23) = 2.739$, $p = 0.012$, $M = 0.562$ mV, 95% CI [0.138, 0.987]. The analysis on mean amplitude 200 - 300 ms did not reveal any effects of phonological violations (p’s > 0.154).

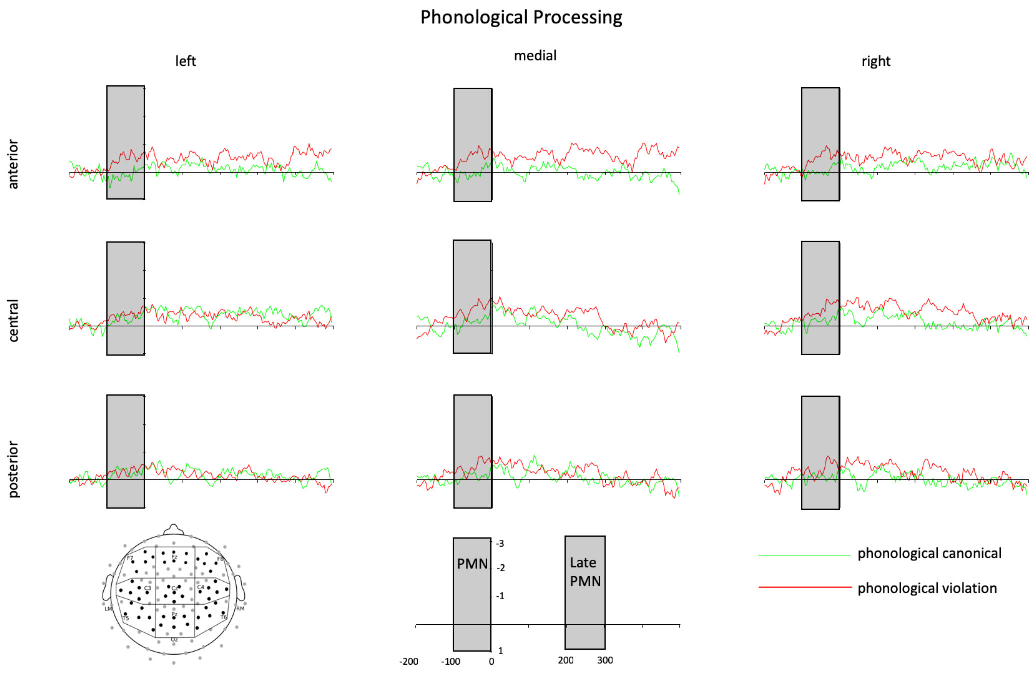

Figure 2.4: Grand average ERPs to phonological violations (red) and canonicals (green), from -200 - 500 ms after critical phoneme.

2.8 Discussion

2.8.1 Semantic Effect

Semantic violations elicited the classic N400 effect – a negativity from 300 - 500 ms that was largest over medial regions. These results are consistent with decades of research employing semantic violations in sentence contexts and cement the idea that it is entirely possible to study the N400 in a natural language context with sentences of varying levels of predictability. Further, it is possible to use sentences that are semantically implausible sometimes in a general way and sometimes only due to the broader context created by the stimulus itself, that are naturally produced, and without specific tasks encouraging judgment of semantic acceptability.

Interestingly, the N400 does appear to be qualitatively similar across disparate stimulus categories – simple priming studies, disconnected sentences with an extremely high cloze probability, sentences that are only made implausible by more local discourse context as opposed to global world knowledge, and a combination of these two types of sentences as was used in the present study. This may indicate that the N400 indexes a very high-level process that is divorced from effects of the original format of the information being processed. It is also possible that the N400 is indexing processing from so many different brain regions or cognitive operations that subtle differences in stimulus characteristics do not visibly influence this effect. For example, predictability in sentence context, priming from semantically related words, easing of lexical access, and retrieval of information from long-term memory are all potentially reflected by the N400.

Using an approach that is as close to real communication is possible is particularly important if we want to accurately measure how electrophysiological effects relate to the ability of individuals with and without language disorders or to developmental stage. This approach will ensure that we are capturing an N400 that represents the processing that actually happens during speech perception, and not just the processing that *could happen* and then generate an N400. Specifically, since contextual effects drive the N400 whenever they are available, as opposed to simple lexical neighborhood effects that are relied upon in priming studies without a broader context (Camblin, Gordon, & Swaab, 2007; Coulson, Van Petten, Federmeier, & Kutas, 2005), a strong focus should be put on using natural language experiments with rich contexts and a natural rate of language presentation – both in the domains of fMRI and ERP – if we are to truly understand semantic processing as it unfolds in real life. This is because the more natural approach used here is tapping in to the cognitive processing that people likely do during real language processing, and not other processes that may be captured by paradigms that ask participants to engage in tasks that are more tangentially related to real-world language processing.

2.8.2 Syntactic Effect

Syntactic violations elicited an early onset, long-lasting negativity (up to 1000 ms) across the anterior scalp that was left lateralized early on. This effect was in response to morphosyntactic violations, which are thought to elicit a LAN that onsets after 250 ms. However, the present study reports an effect that occurs at 150ms, within the ELAN time window that is typically associated with word category syntactic violations. These results taken together with the fact that word category violations occasionally also elicit effects much later than expected for an ELAN (Hagoort et al., 2003; Martín-Loeches et al., 2005; Van Den Brink & Hagoort, 2004; White et al., 2012; Zhang et al., 2010) suggest at a minimum that timing is not an adequate way to distinguish between these effects. A stronger form of this argument would be that morphosyntactic and word category syntactic violations do not elicit reliably different ERP effect, but since the present study lacks a word category manipulation, this must remain speculative.

Early syntactic negativities such as the ELAN/LAN/AN are thought to index fast and unconscious processes, these results suggest that in some cases – especially natural speech without an added grammaticality task – this effect can last far past 400 ms, into a time window that includes conscious, controlled processing such as top down processing. These findings resemble previous auditory ELAN studies – studies with word category violations – that found a long extended anterior negativity that is largest centrally and is evident over more posterior regions (Friederici et al., 1993; Rossi et al., 2006, 2005).

It is unclear if this sustained negativity reflects two separate processes – one early automatic process and one later controlled one – or if it is truly all one process. For word category violations, an interaction effect between an early and a late time window and electrode location suggests that these long-lasting effects are reflecting two separate processes that coincidentally have the similar scalp distributions (Friederici et al., 1993). The authors also argued that the presence of a small local peak around 150 ms suggests two separate processes. Curiously, the local peak at 150 ms was also present in the syntactic control sentences, suggesting that this peak is *not* a function of syntactic violations. These conclusions are also at odds with fMRI results suggesting that the generator of later portions of anterior negativities is very near to the generator of the early portion (Pakulak, 2008). Nevertheless, this same study's findings for morphosyntactic violations (the type of violations used in the present study) show a sustained negativity across the anterior scalp with no evidence of two separate negativities (Friederici et al., 1993).

The results of the present study do suggest that there are topographical differences in early vs. later processing of morphosyntactic violations. It does appear possible that an early, left lateralized effect that represents a fast and automatic response to incorrect syntax is followed by a separate later effect, possibly representing increased working memory demands while individuals hold words in memory while listening to the rest of the sentence before integrating these words into a syntactic context (Steinhauer, Drury, Portner, Walenski, & Ullman, 2010). This explanation does leave one question unanswered – how is it that some studies can report a long duration anterior negativity like the present study, and others report a transient effect? Is working memory somehow not engaged in all scenarios? The more likely scenario is that both the early and late anterior negativities are near-always present but can be prematurely silenced by a later positivity – the P600 – that occurs when participants begin to try to correct the erroneous syntax they heard and integrate the words held in their working memory into a syntactic structure.

For example, Hahne & Friederici 1999 found quick local LAN and long sustained AN in two different experimental conditions in the *same* participants (Hahne & Friederici, 1999). As mentioned previously (Chapter 2.3.1.1), both conditions elicited an ELAN. In the condition where syntactic violations were high probability, the P600 was not expected to occur. It did not, and the ELAN continued on to ~1500 ms after onset of the critical word. In the condition where syntactic violations were low probability, the later more controlled P600 was expected to appear after an ELAN. This P600 appeared around 300 ms after onset of critical word, the same time that the ELAN appears to end.

A study of the effects of socioeconomic status (SES) and first language ability allows for an interesting look at how the strength and scalp distribution of the P600 can have varying effects on the later portions of anterior syntactic effects (Pakulak & Neville, 2010). Individuals in the high SES group had a transient LAN effect, ending at 300 ms followed by a large, and long duration P600 that was broad enough to extend to medial sites. Individuals in the low SES group had a smaller, more posterior P600 which seemingly allowed their AN to remain visible all the way out to 1200 ms at frontal electrode sites and silenced the AN at more central electrode sites at P600 onset. Additionally, in an ELAN study that found no P600, likely due to overlapping N400 effects – a negative ERP component that the authors claim silenced the P600 – an extended ELAN was reported (Ye et al., 2006). An extended anterior negativity without a corresponding P600 was also reported in the previously mentioned in the Hasting & Kotz, 2008 study. This constellation of results has led Steinhauer, Drury, and colleagues to conclude that these long duration negativities may be indexing working memory effort, reflecting the process by which individuals rehearse words in order to maintain them in memory and later integrate them into the syntactic context of the sentence (Steinhauer et al., 2010).

A fundamental question, however, is why the P600 is occasionally absent from studies of syntactic anomaly processing, and what it means that there was no P600 in the present study. The P600 is generally associated with more effortful reanalysis of erroneous syntax, so experimental contexts that do not encourage this reanalysis would likely not elicit a P600. For example, no P600 is generated in cases when participants are asked to watch a silent movie while listening to syntactic violations instead of making explicit judgments about the grammaticality of the sentences (Hasting & Kotz, 2008). In addition, stimulus properties that render the syntactic violations very predictable can lead to an absence of the P600, such as when participants listen to heavily accented speech (Hanulíková et al., 2012) or stimuli with an extremely large proportion of violations (Hahne & Friederici, 1999).

The results of the present study suggest that the P600 is less relevant for natural speech contexts when the goal is comprehension of the overall message and not specific metalinguistic judgments. This effect may interact with the difficulty of processing, however. The present study consisted of stories originally written for children and the syntactic violations themselves were a very simple construction. It is possible that no prolonged reanalysis step was necessary (or visible in averaged ERP) because of the ease of the particular grammatical correction that was required. For example, previous work with adults using adult directed passages of natural speech and an experimental paradigm that encourages overall comprehension did find a P600 with an onset corresponding to the offset of the anterior negativity (Shen, Staub, & Sanders, 2013).

Taken together, the results of the present study suggest that the results of tightly controlled and unnatural language experiments may not be fully applicable to our understanding of real speech processing. These results affirm that it is possible to develop experiments that approximate natural language, still elicit ERP effects relevant to syntactic processing, and that these experiments may differ from work with more constrained stimuli or metalinguistic tasks. It follows that fMRI paradigms then also need to be conducted on natural speech if we are to be sure that they are reflecting the real processing that matters. The effort to ensure that experiments are as relevant to the real world as possible will likely pay off in the form of providing results that are more relevant to real-world language skill, making it possible to understand individual differences in language processing as it relates to disorders and development.

2.8.3 Phonological Effect

Phonological violations elicited a transient negativity (-100 - 0 ms before onset of critical phoneme) across the scalp. The scalp topography and polarity of the effect are not similar to any syntactic effects such as the AN or semantic effects like the N400. General features of the syntactic AN suggest that it is often left lateralized, can be transient, is negative, and is anterior. While the phonological effect is anterior and negative and transient, the syntactic effect generated by this group of participants in this paradigm was later than this effect and continued to 1000 ms, well past the -100 - 0 ms time window that was significant for this phonological effect. The semantic N400 is usually present at central or posterior electrode sites and is a negative going deflection, often beginning around 200 ms for continuous speech. Scalp distribution and timing of this phonological effect is not consistent with the N400's general characteristics or the characteristics of the N400 effect generated by this group of participants in this paradigm. The present phonological effect most closely resembles the PMN – a negative going effect that appears over the anterior scalp, is not associated with syntactic violations, and is relatively transient.

These results suggest that the PMN reflects a violation of phonological expectations in general, not just an unexpected word-initial phoneme in a highly constrained context. Most previous PMN studies rely on using sentences with very high cloze probability and manipulating whether a participant hears the expected word, a semantically acceptable word with a different initial phoneme as the expected word, a semantically unacceptable word with a different initial phoneme as the expected word. These highly controlled and artificial circumstances revealed a negativity to the unexpected phoneme, with the presence of a semantic N400 varying as a function of semantic acceptability (Connolly & Phillips, 1994; Connolly et al., 1992, 1990). The PMN could also be generated by encouraging participants to engage in a phonological swap or deletion task to generate very specific predictions about upcoming stimuli (Connolly et al., 2001; Kujala et al., 2004; Newman & Connolly, 2009; Newman et al., 2003). The presence of the PMN in the present study suggests that these highly artificial contexts and designs are unnecessary, and that phonological processing can be studied in natural speech.

Attention to the PMN has dwindled in recent decades, likely because the idiosyncratic stimuli needed to elicit the effect suggests the effect may not be relevant to language processing generally. The results of the present study suggest that this may be untrue. The PMN appears to be indexing processing that is relevant for natural speech and may reflect phonological predictions that are being made rapidly and often and are relied upon by listeners in order to comprehend speech. While it is accepted that implicit phonological rules are acquired during language development and then used in order to produce correct utterances (Rumelhart & McClelland, 1986), it is less clear whether these rules are also being applied to aid in comprehension. Studies of accented speech suggest that the rapid generation of specific phonological expectations is necessary for the perceptual adaptation of phonological categories. When encountering accented speech, listeners quickly and implicitly adjust the sound features that they associate with a particular phoneme (Bradlow & Bent, 2008; Norris, McQueen, & Cutler, 2003). This requires that listeners can determine which phoneme the speaker was intending to produce and then use the accented phoneme they hear to adjust their perceptual boundaries. It is unclear if specific phonological predictions are made before the word is fully complete (especially in cases of relatively unpredictable sentence contexts) or if phonological categories are adjusted after encountering the full word and retroactively deciding which phoneme was intended.

The very early effect in the present study – an effect that begins before the specific phoneme is encountered –suggests that participants were able to ascertain that a phoneme was not voiced (and therefore not the correct phoneme for pluralizing the noun) before even hearing the phoneme in question, likely based on the length of the word's final syllable root. This further argues that phonological rules are indeed used to generate specific *predictions* about upcoming speech sounds as early as possible during auditory language comprehension. In order to get the effects observed in the present study, participants needed to first predict that the upcoming noun will be plural. This was likely easy to do from context given the simple, child-directed nature of the stimuli. Listeners then need to use their implicit knowledge of phonological rules to predict a specific allomorph – either /s/ or /z/.

One lingering question is the importance of phonological violations that are made of an incorrect allomorph vs. a more distantly related incorrect phoneme. In the present study, the incorrect /s/ ending is a unique case because it is a sound that is perfectly acceptable as a pluralization marker in other phonological contexts, and therefore an allomorph of the correct /z/ ending (for example, words ending in /k/, /p/, and /t/ are correctly pluralized with an /s/ sound). Future work is needed to investigate whether words that do not rely on allomorphs to make a violation will show this same effect (for example, comparing shoe/s/ vs. shoe/z/ vs. shoe/v/) or if allomorphs are a special case.

Additionally, the level of predictability may be important. Since the present study used a child directed story, it is likely that it was highly predictable from context that the noun would be plural (at least for most items) and therefore participants generated a specific expectation to hear a /z/. Future work could also investigate whether this negativity reflects the prediction of a specific phoneme, violation of expectations generated by the application of a phonological rule, or both. For example, determining whether this ERP effect interacts with whether the nouns plural status is predictable (hearing an article that specifies number like “two” in “two shoes” vs. one that does not, like “the” in “the shoes”) can tell us what sort of cognitive operations are necessary to generate the effect.

Regardless, the results of the present study suggest that it is possible to study phonological expectations on-line and with natural speech in a way that does not call on metalinguistic processing. This opens the door for future research into how natural phonological processing relates to language ability, which may have very different results from the measures of phonological processing that are more far removed from the actual goal of language processing – extracting meaning for the auditory signal. It is entirely possible that the ability to generate specific phonological predictions supports successful speech comprehension, especially in noisy environments where clear acoustic information never reaches the listener. This effect opens up a new avenue for understanding the specific factors that underlie successful language comprehension in terms of not only the ability to process speech in noise, but also during development, and across disordered and typical language processing.

2.9 Conclusion

In a real speech context with the explicit goal of comprehension, adults demonstrated an N400 to semantic violations, a long duration and early onset AN without a later P600 to syntactic violations, and a PMN to phonological violations. The N400 effect was quite similar to that found in previous research, including studies that used tasks far removed from typical language processing such as phonological priming. The N400 appears to not be affected by factors like whether the violation is in a sentence context or is in a word pair, if the violation is evident based on broad world knowledge or understanding of the more local story context, or whether the task is comprehension or explicit judgment of sentence correctness. This may be because the N400 represents numerous cognitive processes and the activity of many brain regions, all of which are necessary natural language processing as well as all other tasks that would elicit an N400. Clearly, syntactic effects are much more influenced by task. The onset of the AN to syntactic violations looks like it does in other studies, but everything else is different. This suggests that syntactic processing as a means to comprehension is really different than syntactic processing for other purposes and under other conditions. Results from phonological processing are novel, which does not allow for a direct comparison to prior literature. These results represent the first ERP evidence that phonological predictions are happening in natural real speech and that this influences processing.

CHAPTER 3

ELECTROPHYSIOLOGICAL INDICES OF LANGUAGE PROCESSING IN FIVE-YEAR-OLD CHILDREN

3.1 The Current Understanding of Language Processing in Children

At the age of five, children are in a unique stage of language development. While typically developing five-year-old children have a basic command of their native language, they still have much progress to make before reaching adult-like levels. Identification of a language disorder would ideally take place at this age or younger in order to maximize potential benefits from therapeutic interventions. Children who are categorized as "normal" or "typically developing" show a large amount of variability in language skill – both across individuals and within an individual across language subsystems. This variability makes this age group particularly well suited for the investigation of relationships between ability general cognitive abilities and domain-specific experience and processing. A better understanding of language-related skills as they develop normally is necessary if we hope to understand what has happened and how to help when language acquisition does not proceed normally.

Language disorders, such as dyslexia and specific language impairment, affect 4.4 million school-aged children in the United States (U.S. Department of Education, 2014). The effects of these disorders are far reaching. Children diagnosed with a language disorder are twice as likely to have poor literacy and mental health in adulthood than their peers (Law, Rush, Schoon, & Parsons, 2009). Additionally, developmental language disorders are associated with lower levels of academic success (Young et al., 2002), a higher likelihood of emotional, behavioral, and social problems (Beitchman et al., 2001;

Yew & O'Kearney, 2013), higher high-school dropout rates (Scanlon & Mellard, 2002) and fewer strong interpersonal and love relationships in adulthood (Clegg et al., 2005).

Importantly, language disorders and their outcomes are not monolithic. For example, individuals with receptive language disorders are more likely to have negative outcomes than those with productive language disorders (Clegg et al., 2005; Johnson et al., 2010). This is likely because receptive language disorders prevent the child from processing and understanding language – a necessary skill for nearly every aspect of life.

A promising approach to studying receptive language abilities is to use ERPs to investigate the cognitive processes that occur during language comprehension. ERPs are particularly suited for studying language processing in children because they are non-invasive, require no overt response from the child, and are capable of measuring changes on the order of milliseconds – a timescale that is particularly relevant for the fast and complex changes that define speech signals. A massive body of research has relied on ERPs to identify distinct neural subsystems of language processing, including semantics (meaning), syntax (structure), and phonology (sound). However, a large portion of this work uses tasks that are far removed from real-world language processing. Since children at age 5 have recently mastered their native language and likely have less automatic processing, experimental tasks that are very dissimilar to real-world language processing may encourage children to adopt very unnatural task strategies, even more so than when these studies are conducted with adults. Also, studies with this population have been unable to retain a large enough proportion of usable subjects to accurately capture the variability that is likely present in the population, which makes these studies inapplicable to children and language development as a whole.

Our understanding of three key language subsystems – semantics, syntax, and phonology – could be greatly improved if studied using Event-Related potentials in children with an appropriately designed paradigm. Results of ERP language studies of children would not only impact theories of language development but also could be extended to understanding why individual children differ in language skill as measured behaviorally or why certain children remain resistant to language interventions while others benefit greatly.

3.2 Semantic Processing and Language Development

Semantic processing – the processing of the meanings of words in context – is fundamental to understanding the message being conveyed in language. While it is necessary to have a robust vocabulary to allow for the understanding of meaning, simply measuring vocabulary size does not fully capture all of the abilities underlying semantic processing. The ability to understand how each new lexical item fits in context with the rest of the sentence is perhaps the most important factor in achieving adult-like semantic ability. This process can be relatively easily studied using event-related potentials.

3.2.1 Electrophysiological Correlates of Semantic Processing in Children

As with adults, of all the language subsystems, the ERP correlates of semantic processing are the most well-understood in children. Like adults, children also show an N400 in response to a word that is semantically anomalous in sentence contexts (Hahne, Eckstein, & Friederici, 2004; Holcomb, Coffey, & Neville, 1992; Silva-Pereyra, Rivera-Gaxiola, & Kuhl, 2005; Weber-Fox, Wray, & Arnold, 2013), and they also show an N400 priming effect to incongruent as compared to congruent picture-word pairs (Byrne et al., 1999). In general, the topography, latency, and polarity of the N400 is similar to that of an adult, although slightly later in timing, less lateralized, and more posterior in topography. Studies that compare the N400 across different ages find a smaller effect for the youngest children, including five-year-olds. This is due to the fact that younger children show a negativity even to *correct* sentences (Hahne et al., 2004; Holcomb et al., 1992).

While a consistent story about the development of the N400 seems to exist within the literature, major issues with sample size and data quality plague these studies. Most of the effects discussed above are from less than 20 subjects (Byrne et al., 1999; Hahne et al., 2004; Holcomb et al., 1992; Silva-Pereyra et al., 2005; Usler & Weber-Fox, 2015), though 27 were included in Weber-Fox et al., 2013. Perhaps more importantly, among the studies that report how many children were excluded due to poor EEG data quality, 11 – 47% of children were excluded (Byrne et al., 1999; Hahne et al., 2004; Silva-Pereyra et al., 2005) . Other studies did not provide this critical information (Holcomb et al., 1992; Usler & Weber-Fox, 2015; Weber-Fox et al., 2013). Collecting clean data from young children is without a doubt a difficult endeavor, and while excluding some data may always be necessary, the amount that is regularly excluded in developmental ERP studies likely biases the sample. If a task is so unnatural or difficult that it will only elicit clean data from 53% of the population, that 53% is likely not representative of all five-year-olds. These children are likely exceptional – just those who are have the strongest inhibitory control which allows them to follow task instructions and stay still. Further improvement is needed to ensure we are conducting studies that are relevant to all children.

Current studies of the development of the N400 also lack appropriate task designs for understanding real-world language processing. While measuring the N400 to word-picture pairs may be an interesting way to measure receptive vocabulary in populations that cannot provide a behavioral response, this task is not relevant to real language processing (Byrne et al., 1999). While this is perhaps an extreme example, tasks associated with sentence listening paradigms are also inadequate. Children likely engage in different cognitive processes when they are listening to a cogent narrative in order to extract meaning vs. when they are listening to the unrelated sentences that often serve as stimuli in N400 experiments (Hahne et al., 2004; Holcomb et al., 1992; Silva-Pereyra et al., 2005). The likelihood of abnormal processing is compounded when these sentences are combined with unnatural tasks such as pressing a button to indicate if a sentence does not make sense (Hahne et al., 2004; Holcomb et al., 1992) or watching an unrelated, and likely attention-grabbing puppet show (Silva-Pereyra et al., 2005). Perhaps the most ecologically valid study design also included visual information that does not allow us to disentangle pure auditory language processing from other factors. In this design, children were asked to watch a cartoon about Pingu the penguin while listening to a narrative that described what was happening in the cartoon (Usler & Weber-Fox, 2015; Weber-Fox et al., 2013). While the study design was highly ecologically valid and likely a very natural experience for the participants, it is unclear what effect was had by the visual information provided by the cartoon. It is likely that this task was not just measuring a child's ability to comprehend spoken language, but also their ability to integrate information from the visual modality (i.e. the cartoon) and use this information to support semantic processing.

An obvious avenue into solving this problem of poor data retention and ecological validity would be to design a task that children not only *can* complete, but enjoy and are familiar with, so that data can be collected from children representative of the entire population. Asking a child to listen to a story for comprehension while they answer questions about the plot of the story may be just the task to solve this problem. A story-listening task is highly developmentally appropriate – nearly all children regularly sit quietly and listen to a story with an adult while occasionally talking with that adult about the plot of the story. This task is not only something that a five-year-old child is used to – and likely enjoys – doing, it is also similar enough to the real world to allow us to study ERPs in response to a real-world communication context. Using sentences that are part of a narrative, instead of sentences that seem disconnected and random to the child, will also tap into discourse level processes – something that may be key to real-world language processing but is absent from experiments without this level of context. Doing away with artificial behavioral measures like rating sentences on correctness, or worse ignoring the sentences altogether, in favor of simple questions about the plot not only will encourage natural comprehension of the story but would also provide a measure of the actual goal of language processing – comprehension.

3.3 Syntactic Processing and Language Development

Syntactic processing allows for the understanding of relationships between words – specifically grammar. Fast and automatic syntactic processing is key to a child's ability to determine how the semantic information in a sentence is related in order to extract accurate meaning. Morphosyntactic development specifically requires that a child attend to, and appreciate the significance of, small speech sound units that mark tense on verbs (for example, the /s/ on "She goes" as opposed to the absence of this /s/ on "I go"). Adequate syntactic development requires that children not only learn the morphosyntactic system of their native language but apply it quickly and effortlessly to their own utterances and the utterances of others. While a basic abstract concept of tense agreement exists as early as age three (Rispoli & Hadley, 2011), learning the rules of morphosyntax and applying them to production proves difficult for children across many languages (Legate & Yang, 2007). The relationship between accurate use of morphosyntax and the cognitive processes that occur while listening to morphosyntax could be clarified using ERP methods.

3.3.1 Electrophysiological Correlates of Syntactic Processing in Children

Modest progress has been made in understanding the ERP correlates of syntactic processing in five-year-olds. There is some evidence that an anterior negativity is present in five-year-old children in response to correct but complex syntax as compared to correct but more simple syntax (Schipke, Knoll, Friederici, & Oberecker, 2012) and to incorrect phrase structure (Weber-Fox et al., 2013). However, a follow-up study of phrase structure processing with these exact stimuli in six to seven-year-old children did not find this effect, although this may be driven by a lack of statistical power due to sample size (n = 9) (Usler & Weber-Fox, 2015). A separate study on five to six-year-old children also used phrase structure violations but instead found a negativity to *correct* syntactic structure. Further, the only study of morphosyntax in this age group found a *positivity* to incorrect morphemes (Silva-Pereyra et al., 2005). These issues of replicability cement the idea that the developmental story of the anterior negativity is far from settled.

Understanding of the development of the P600 is more complete. Children ages five to seven show a P600 to incorrect phrase structure (Hahne et al., 2004; Usler & Weber-Fox, 2015; Weber-Fox et al., 2013). A P600 is also present for complex syntactic structures as compared to simpler ones (Schipke et al., 2012). The results from this study provide the most compelling account for how the AN and P600 may develop, both in terms of age and as the effect relates to syntactic ability measured behaviorally. A separate behavioral experiment was conducted to independently measure comprehension of the two types of syntax. ERP effects seem to coincide with success on this behavioral task and with age. Six- and four-and-a-half-year-olds both had chance level performance in interpretation of the sentences. Both groups showed a P600-like effect while only the older group also showed an early negativity. This is in contrast to adults who showed near perfect behavioral performance combined with only an early negativity and three-year-olds who showed below-chance behavioral performance and only a P600. This pattern of results suggest a sequence of development where even children who struggle with behavioral measures of syntactic processing show a P600, which remains through at least age six while behavioral abilities are developing, and is abolished by adulthood when behavioral performance reaches its peak. These changes occur in tandem with the development of the AN that only appears once children reach at least chance level behavioral performance and continues through adulthood.

Unfortunately, studies of syntax related ERP effects suffer from the same problems as studies of semantic related ERP effects. All but one of the studies mentioned here were first introduced in section 3.2.2. This study included 21 four-and-a-half-year-olds and 29 six-year-olds, excluding 26% of the younger children and 38% of the older children due to poor data quality (Schipke et al., 2012). The need for a larger sample size is even more apparent in studies of syntactic processing since conflicting results across studies with low subject numbers have prevented any sort of clear developmental picture for the AN.

Careful selection of stimuli is also particularly important for syntactic processing since there is evidence that correct but difficult to integrate syntactic constructions elicit an AN and therefore cannot serve as control conditions. This very confound likely exists in one study of phrase structure processing in children. Hahne et al., 2004 found a relatively adult-like response to phrase structure violations in children ages seven to thirteen years but saw an early negativity to *correct* syntax at anterior sites. This was followed by the more expected P600 effect which was late, right lateralized, and smaller than all other age groups.

The authors argue that the negativity to correct syntax may be due to the difficulty of the particular type of syntax used. This study, conducted in German, included passive syntax. For example, a correct sentence would be translated to "*The baby was fed"* and an incorrect sentence would be "*The goose was in the fed"*. Passive syntax has been shown to be quite difficult for children under four and a half years (Fox & Grodzinsky, 1998). However, the authors admit that by six years of age, the processing of this syntactic form should be possible, and their own behavioral evidence indicates that the children understood these sentences (83% accuracy in the correctness judgment for this sentence type). However, effortful processing of this type of syntax seems to likely still be occurring in these children given the AN to these sentences. This effect could be interpreted as an increase in difficulty of processing syntax in the control sentences, specifically encountering a locative prepositional phrase when children did not expect to hear one, despite the fact that this syntax is technically correct.

Future work needs to move away from syntactic constructions that obscure potential ERP results. ERP effects related to even correct syntax have been found in response to intentionally more difficult syntactic constructions (Schipke et al., 2012) or, more controversially, in the supposed control condition (Hahne et al., 2004). If progress is to be made in understanding syntactic processing in this age group, stimuli need to be carefully selected so that control syntax is as unlikely to generate an ERP effect as possible (i.e., is as easy to process and as correct seeming as possible, from the perspective of a five-year-old).

The present study's more natural story-listening and comprehension question approach will be combined with syntactic violations that are carefully selected to avoid effects in the control condition. Syntactic violations created by using incorrect morphosyntax in order to produce the incorrect verb tense in first-person sentences will be used (for example, "I go*es* to the store" vs. "I go to the store"). The correct form of this syntax is extremely simple and the violation form is a clear violation. Not only is the canonical syntax well suited for use with five-year-olds, the violation condition is as well. Specifically, this particular construction would be considered a violation even by children in the "optional infinitive" stage of development. The concept of the optional infinitive states that children consider certain morphemes – in particular the past tense -ed and the -s or -es to mark third person singular verbs ("She goes") as optional, so they are often dropped (Wexler, 1994). This model has very specific predictions about the types of production errors that children make, and erroneously adding an -s to present tense first person verbs is not expected, indicating it is unlikely that children in this stage would consider that construction to be correct. This type of carefully considered syntax condition is well positioned to answer important questions about syntactic development in children, even those with language disorders.

3.4 Phonological Processing and Language Development

While it is all but assured that that children use phonological processing skills on-line while processing real speech, measuring this skill in action is difficult to do, especially with behavioral tasks that rely on output that is generated long after the initial phonological processing occurs. The closest thing that we can measure is phonological awareness.

Phonological awareness is the ability to separate and manipulate the smallest language sounds. The development of this ability is often thought of as a three stage process, beginning with syllable awareness, followed by onset-rime awareness (noticing the difference between the first sound of a word and everything that follows), and finally phonemic awareness (noticing individual language sounds) (Cisero & Royer, 1995). Despite the fact that phonological awareness is likely a crude proxy for real on-line phonological processing, across many cultures, languages, and orthographies, phonological awareness has been implicated as one of the best predictors of later reading ability, and has the power to explain the majority of variability seen between individuals (McBride-Chang & Kail, 2002; Sénéchal & LeFevre, 2002; Wagner, Torgesen, & Rashotte, 1994).

3.4.1 Electrophysiological Correlates of Phonological Processing in Children

While ERPs are likely our best hope for measuring on-line phonological processing, very little is known about the ERP indices of phonological processing during speech comprehension, especially in young children. In adults, the Phonological Mapping Negativity is present when specific expectations about an upcoming phoneme are violated. Based on results from Chapter 2, adults do appear to make specific phonological predictions and notice quite early in processing if they are violated. The generation of phonological expectations may be a key process necessary for adult-like receptive language processing. Understanding the developmental trajectory of when these predictions are made while listening to real speech and what happens when these expectations are violated is necessary for full understanding of the development of language processing.

Unfortunately, no studies investigating the PMN have been conducted on five-year-old children. At least one study has found a PMN in older children, but not in continuous speech (Archibald & Joanisse, 2012). This study relied on phonological priming, a more distal measure of phonological processing, to investigate what happens when children make specific phonological predictions that are later violated. A phonological mapping negativity was found in 8-10-year-old children. A general lack of studies of the PMN across development leaves unanswered questions about when in development the PMN first emerges, and whether the PMN to simple priming, the PMN in sentence contexts with a high level of predictability for specific lexical items, and the PMN to more subtle phonological violations (like the effect found in Chapter 2.7.2.3) develop concurrently or consecutively.

A more common way of studying phonological processing, especially in younger children, is to use phonological priming in the form of rhyme. In rhyming studies, participants are presented with a prime word followed by a rhyming or nonrhyming target word and are asked to indicate via button press whether the two words rhyme or not. The nonrhyming target elicits a larger negativity roughly 450 ms after stimulus onset across the parietal/occipital scalp, often with a reversal of this effect at anterior and lateral sites such that rhyme is more negative than nonrhyme not only for real words, but also pseudowords in both adults and children as young as six (Coch et al., 2002, 2005; Rugg, 1984a; Wagensveld, Van Alphen, Segers, & Verhoeven, 2012). This effect is indistinguishable from the reduced N400 to phonologically congruent targets, as described in Chapter 2.2.1., but can be independent of semantic processing and relies on low level phonological comparisons across ages.

This paradigm serves as an important example for why brain measures are often necessary, in addition to behavioral ones, in order to understand the full picture of language development. While seven-year-old children were significantly slower than adults in judging whether a word pair rhymed, their ERP response to rhymes vs. nonrhymes were very similar (Coch et al., 2002). Both groups showed a larger N450 to non-rhyming than rhyming targets over posterior and parietal regions of the scalp, with a reversal of this affect at anterior and lateral sites. This suggests that the demands of generating a response or making an explicit rhyme judgment were obscuring the fact that low level phonological comparative processes are in fact present and remarkably adult-like in children.

These results suggest that a study with even younger children is needed to grasp the full developmental story. A nonword rhyming ERP study was conducted with three to five-year-olds to answer this very question (Andersson et al., 2018). This study included 62 three to five-year-old children. An additional 15 children participated but had to be excluded due to poor EEG data quality. This study did not include a rhyme judgment after every trial, just infrequent questions about whether the previous words "sounded the same" or a request to remember what words were included in the previous trial. The young children in this study showed a posterior rhyming effect similar to that of older children and adults – namely a larger negativity to nonrhymes than rhymes that began at

100 ms and continued out to 1000 ms. This effect was significant across the scalp from 500 - 700 ms but at occipital sites only for the rest of the trial. An anterior and lateral reversal of this rhyming effect was also present, and its amplitude was correlated with the amplitude of the posterior rhyming effect.

The results of this study suggest that even preschool aged children have near adult-like ability to compare sounds for phonological similarity, and that words that do and do not rhyme are processed differently even without an explicit rhyming task. This is in contrast with the fact that behavioral measures of rhyming indicate that children at this age are still struggling and behavioral measures of other phonological abilities show that children continue to improve well past the age of five. While it is true that rhyming skill has strong links to language comprehension, relating to speech decoding ability at age four (Janssen, Segers, McQueen, & Verhoeven, 2017; van Goch, McQueen, & Verhoeven, 2014), this indirect avenue into receptive phonological processing could be improved upon. More automatic phonological processes that are related to on-line language processing, such as a potential PMN in children, may be easiest to detect with ERPs, a method that does not require response generation. The stimuli in the present study – phonological rule violations on the suffixes of plural nouns in a child-friendly story listening paradigm with comprehension questions – are well suited to detect any on-line phonological processing ERP effects that may be present in five-year-old children.

3.5 Methods

3.5.1 Participants

Forty-two children between the ages of 5 years, 0 months and 5 years, 11 months, 30 days (mean age 5 years, 5 months, 9 days) participated in this study (23 males). An additional two children were recruited, but the experiment was terminated before data collection could begin due to discomfort with the EEG net. All children were right handed, native English speakers, with parent-reported normal hearing, normal or corrected to normal vision, with no neurological disorders and taking no psychoactive medications. All children passed the Test for Early Grammatical Impairment (TEGI) screening test (Rice & Wexler, 2001). Average scores on the following language and cognitive assessments are listed in Table 3.1: Test of Auditory Processing Skills 3 (TAPS) (Martin & Brownell, 2005), Test for Auditory Comprehension of Language 4 (TACL) (Carrow-Woolfolk, 2014), and the Primary Test of Nonverbal Intelligence (PTONI) (Ehrler & McGhee, 2008). Further details about these behavioral assessments, their relationships to one another and to the electrophysiological data presented in this chapter can be found in Chapter 4.

Table 3.1: *Standardized cognitive and language assessments.*

Assessment	Mean	Standard Deviation
PTONI Nonverbal Intelligence Index	116.64	20.99
TAPS Phonological Index	103.10	13.49
TAPS Word Discrimination	12.14	2.99
TAPS Phonological Segmentation	11.67	3.01
TAPS Phonological Blending	7.71	3.96
TAPS Memory Index	105.93	14.05
TAPS Number Memory Forward	11	3.32
TAPS Number Memory Reversed	10.38	2.95
TAPS Word Memory	11.33	3.78
TAPS Sentence Memory	11.91	3.97
TACL Receptive Language Index	115	12.71
TACL Vocabulary	12.60	2.55
TACL Grammatical Morphemes	13.12	3.10
TACL Elaborated Phrases	11.83	3.02

Standard scores reported (norm for population = 10) unless otherwise noted as an Index (norm for population = 100)

3.5.2 Materials

Materials are identical to those described in Chapter 2.6.2.

3.5.3 Procedure

Procedure is identical that which was described in Chapter 2.6.3. In addition to the EEG session, a second session was conducted with each child to collect the behavioral data necessary to fully describe the sample. Further details about this procedure can be found in Chapter 4.7.3.

3.5.4 EEG Data Acquisition and Processing

Data acquisition and processing is identical to what was described in Chapter 2.6.4, except for two notable exceptions. First, EEG data for all conditions was segmented into epochs starting 100 ms before each event and 500 ms after that event, baseline corrected to 100 ms before the event. Second, the automatic artifact rejection routine used a threshold of -100 uV to 100 uV (as opposed to the -50 uV to 50 uV threshold that was used for adults). After by-hand verification of the automatic artifact rejection routine, on average, for each of the 3 conditions (semantics, syntax, and phonology), 23 trials were kept for the canonical condition (ST DEV = 4.08) and 23 trials were kept for the violation condition (ST DEV = 4.11).

3.5.5 Analysis

As in Chapter 2.6.5, ERPs were computed for each participant at each electrode and for each condition. ERPs were then averaged into clusters for each participant in a

3x3 configuration (Left, Medial, Right x Anterior, Central, Posterior). Figure 2.1 shows a graphical representation of these clusters.

Mean voltage during relevant time windows of interest was calculated for each condition at each cluster. These time windows were selected based on the literature and on visual inspection of the grand averaged waveforms. In order to detect the N400, mean voltage 300 - 500 ms post critical word onset was measured for semantic violation sentences and semantic canonical sentences. In order to detect early syntactic effects (ELAN/LAN/AN), mean voltage 100 - 200 ms and 200 - 500 ms post grammatical morpheme onset (or absence thereof) was measured for syntactic violation sentences and syntactic canonical sentences on the shorter (-100 - 500 ms) epoch. In order to investigate later syntactic effects like the P600, the time window for the trials included in this shorter epoch was extended out to 2000ms. Visual inspection indicated that there was no effect and therefore no time window was selected for statistical analysis. In order to detect the PMN, mean voltage 0 - 100 ms after the critical phoneme was measured for phonological violation sentences and phonological canonical sentence. In order to detect potential later phonological effects, mean voltage 100 - 300 ms after the critical phoneme was measured as well.

Data were submitted to a 2 x 3 x 3 repeated measures ANOVA with the following factors: Condition (Violation, Canonical), Anteriority (Anterior, Central, Posterior), and Lateralization (Left, Medial, Right). All reported p-values have been Greenhouse-Geisser corrected for violation of the assumption of sphericity in order to be as conservative as possible. Follow up analyses were conducted where appropriate.

Despite the fact that all participants in the present study were age five, it is likely that ERP differences will exist between younger five-year-olds and older five-year-olds.

This is due to the fact that this age is a period of rapid language development, both in terms of productive and receptive vocabulary and syntactic ability, and in terms of pre-reading or early reading skills. Younger five-year-olds are also less likely to have had lengthy experience with intensive daily or near-daily schooling as compared to children nearing six years of age. All of these factors could lead to age-related differences and motivated a comparison of the ERP response between children under five years, six months and children over five years, six months.

The mean amplitude during the above-defined time windows for each experimental condition (semantic, syntactic, and phonological) were measured separately for each age group and submitted to a 2 x 2 x 3 x 3 mixed effects ANOVA with Age Group (Young vs. Old) as a between subjects factor, and the following as within subjects factors: Condition (Violation, Canonical), Anteriority (Anterior, Central, Posterior), and Lateralization (Left, Medial, Right). All reported p-values have been Greenhouse-Geisser corrected for violation of the assumption of sphericity in order to be as conservative as possible. Follow up analyses were conducted where appropriate.

3.6 Results

3.6.1 Comprehension Questions

On average, accuracy was 91% (ST DEV = 12%), indicating that children were paying attention to the story and that comprehension was successful.

3.6.2 ERP Data

Figures 3.1-3.4 show grand average ERPs from each of the above-defined clusters for each language subsystem (semantics, syntax, and phonology) and the two conditions (canonical, violation).

3.6.2.1 Semantic ERP Effects

Figure 3.1 shows grand average ERPs time locked the onsets of words that were semantically congruent and anomalous. There was an interaction of semantic anomaly and anteriority of electrode on mean amplitude from 300 - 500 ms, $F(2, 82) = 15.707$, $p = 0.0002$, generalized $\eta 2 = 0.029$. A follow up ANOVA at only posterior and central electrode sites revealed a main effect of condition, indicating that semantic violations elicited a larger negativity than the canonical form, $F(1,41) = 9.55$, $p = 0.004$, generalized $\eta 2 = 0.052$.

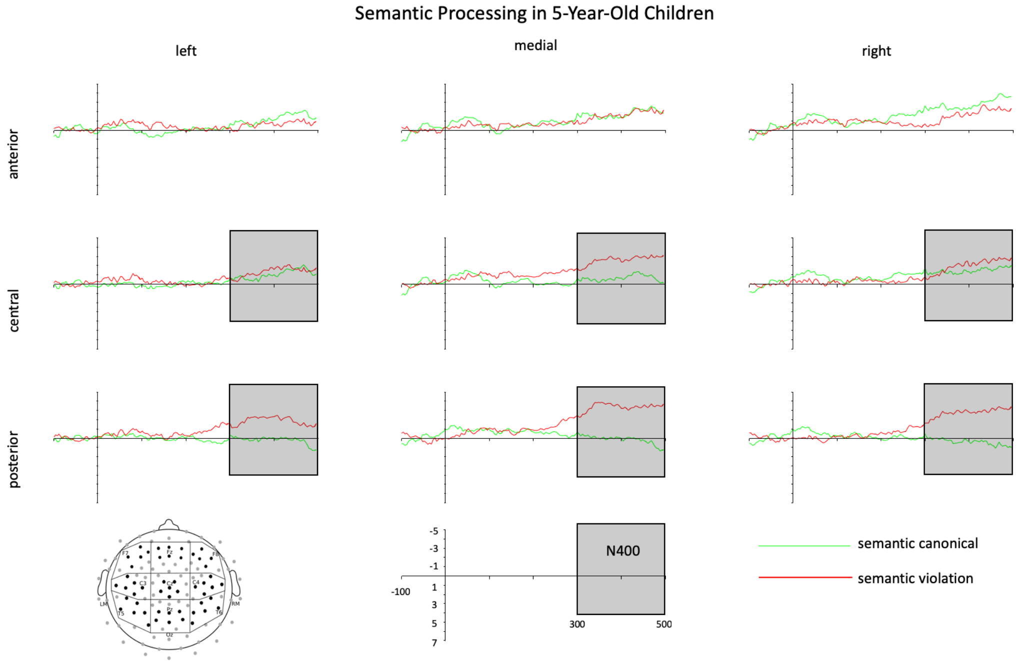

Figure 3.1: Grand average ERPs to semantic violations (red) and canonicals (green), from -100 to 500 ms after onset of critical word.

3.6.2.2 Syntactic ERP Effects

Figure 3.2 shows grand average ERPs time locked to the end of verb stems that are syntactically well formed compared to verb stems that are followed by a morpheme creating a verb agreement anomaly. Mean amplitude from 100 - 200 ms across electrode position was more negative for syntactic anomalies, F(1, 41) = 4.10, p = 0.049, generalized η2 = 0.030. A t-test at the left anterior electrode indicated that syntactic violations elicited a larger negativity than the canonical form, t(41) = 2.125, p = 0.040, M = 2.081 mV, 95% CI [0.104, 4.058]. No significant effects were found for the 200 - 500 ms time window (p's greater than 0.19). In order to investigate later syntactic effects like the P600, the longer epoch is also provided (Figure 3.3). Visual inspection shows no evidence of a positive syntactic effect.

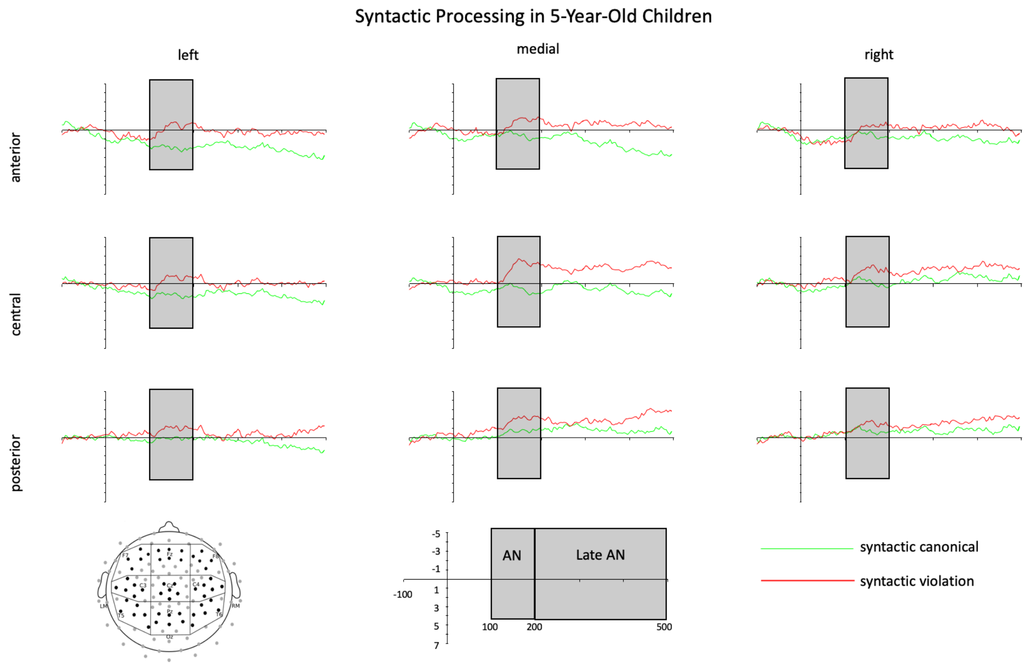

Figure 3.2: Grand average ERPs to syntactic violations (red) and canonicals (green), from -100 to 500 ms after critical morpheme in the violation condition and end of verb stem in the canonical condition.

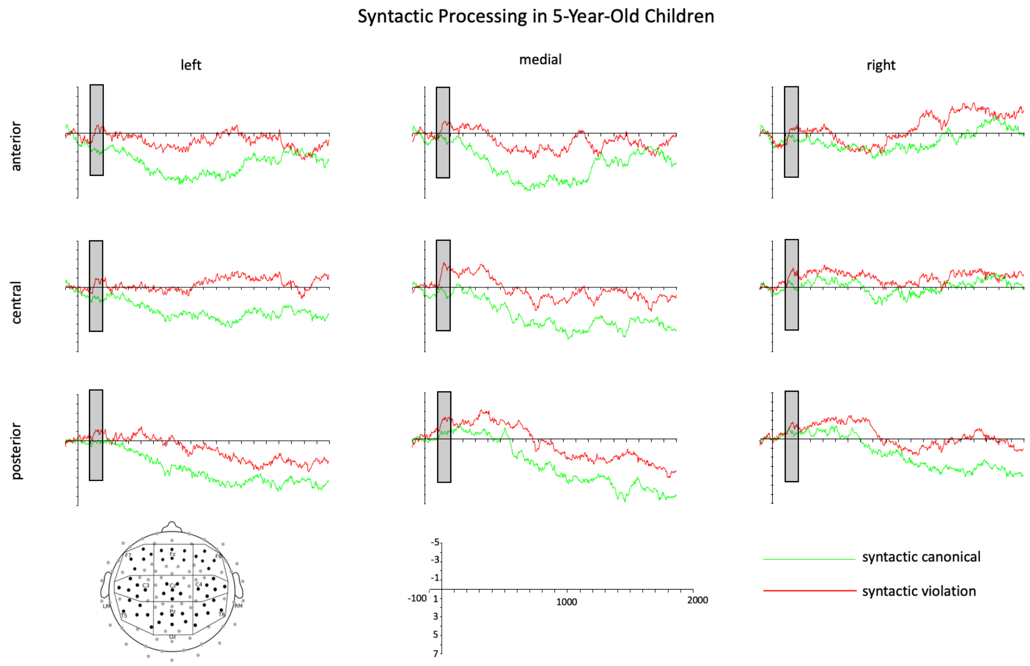

Figure 3.3: Grand average ERPs to syntactic violations (red) and canonicals (green), from -100 to 2000 ms after critical morpheme in the violation condition and end of verb stem in the canonical condition. Grey boxes show significant effect of syntactic violation condition, as shown in Figure 3.2.

3.6.2.3 Phonological ERP Effects

Figure 3.4 shows grand average ERPs time locked to the onset of canonical and phonological violation suffixes. There were no significant effects of phonological anomaly in the earlier 0 - 100 ms time window (p’s > 0.11) or the later 100 - 300 ms time window (p’s > 0.25).

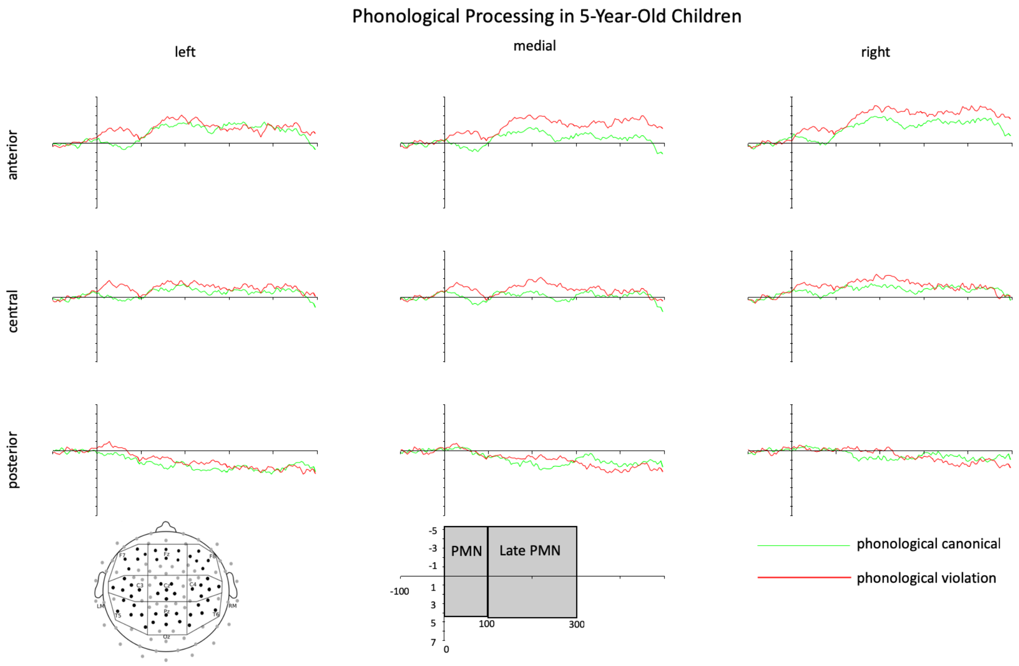

Figure 3.4: Grand average ERPs to phonological violations (red) and canonicals (green), from -100 to 500 ms after critical phoneme.

3.6.3 Results by Age Group

Comparisons based on age group (younger than five years six months or older than five years six months) were also conducted to see if differences in processing exist during this developmentally important year of life. Unlike semantic and syntactic comparisons, the comparison between ERPs in response to syntax for younger and older children differed. The waveforms for the syntactic condition are shown separately for these age groups in Figures 3.5 and 3.6.

3.6.3.1 Age-related Behavioral Results

Performance on comprehension questions did not differ between children younger than five years six months and older than five years six months, $t(40) = 0.727$, $p = 0.471$, Mean difference = 2.98%, 95% CI [-5.30%, 11.35%].

3.6.3.2 Age-related ERP Effects

Grand average ERPs time locked the onsets of words that were semantically congruent and anomalous for young children and older children were compared. There were no significant interactions with mean amplitude from 300 - 500 ms for the two conditions and age groups (p's > 0.20). A Pearson's correlation of age and difference in mean amplitude between correct and incorrect semantics in this time window at the electrode site with the numerically largest effect – the central posterior location – was also not significant ($p = 0.067$).

Figures 3.5 and 3.6 show grand average ERPs time locked the onsets of words that were syntactically congruent and anomalous, for young children and older children, respectively. There were no significant interactions of condition and age group on mean amplitude from 100 -200 ms for the two conditions and age groups (p's > 0.09). However, a Pearson's correlation of age and difference in mean amplitude between response to syntactic anomaly and correct syntax in this time window at the electrode site with the numerically largest effect – the left anterior location – revealed a significant effect of age, $r = -0.358$, $p = 0.022$, such that older children had the greatest difference in response to correct and incorrect syntax, showing a more negative response to syntactic violations. Separate ANOVAs were conducted for each age group at this time window. No significant effects were present in the younger children (p's < 0.34). In the older children, there was evidence of an effect of syntactic violation at some electrode positions (condition by left to right electrode position interaction for an analysis including all electrode positions, F(2, 30) = 4.63, p = 0.035, generalized η2 = 0.012, and an interaction between condition and anterior to posterior electrode position when analysis was restricted to left lateralized electrode sites only, F(2,30) = 5.34, p = 0.021, generalized η2 = 0.028). At left anterior electrodes, syntactic violations gave a significant effect, t(15) = 3.665, p = 0.002, Mean difference = 4.761 mV, 95% CI [1.992 7.530].

For the later 200 - 500 ms time window, a significant interaction of age group by left to right electrode position by condition was present, indicating that the difference in response to violations and canonical forms was more left lateralized in older children, F(2,80) = 4.66, p = 0.013, generalized η2 = 0.004. When analysis was restricted to only left lateralized electrode sites, a significant interaction of age group and condition remained such that older children had a larger effect of syntactic violation than younger children over the left portion of the scalp, F(1,40) = 4.853, p = 0.033, generalized η2 = 0.050 with no interactions with anterior to posterior location (p’s > 0.378). Separate ANOVAs were conducted for each age group at this time window. No significant effects were present in the younger children (p’s < 0.20). In the older children, there was evidence of an effect of syntactic violation at some electrode positions (condition by left to right electrode position interaction for an analysis including all electrode positions, F(2, 30) = 4.80, p = 0.016, generalized η2 = 0.007). Across all left lateralized electrodes, violations elicited a larger negativity, F(1,15) = 4.74, p = 0.046, generalized η2 = 0.143). A Pearson’s correlation of age and difference in mean amplitude between response to syntactic anomaly and correct syntax in this time window at the electrode site with the numerically largest effect – the left anterior location – revealed a significant effect of age, r = -0.349, p = 0.025, such that older children had the greatest difference in response to correct and incorrect syntax, showing a more negative response to syntactic violations.

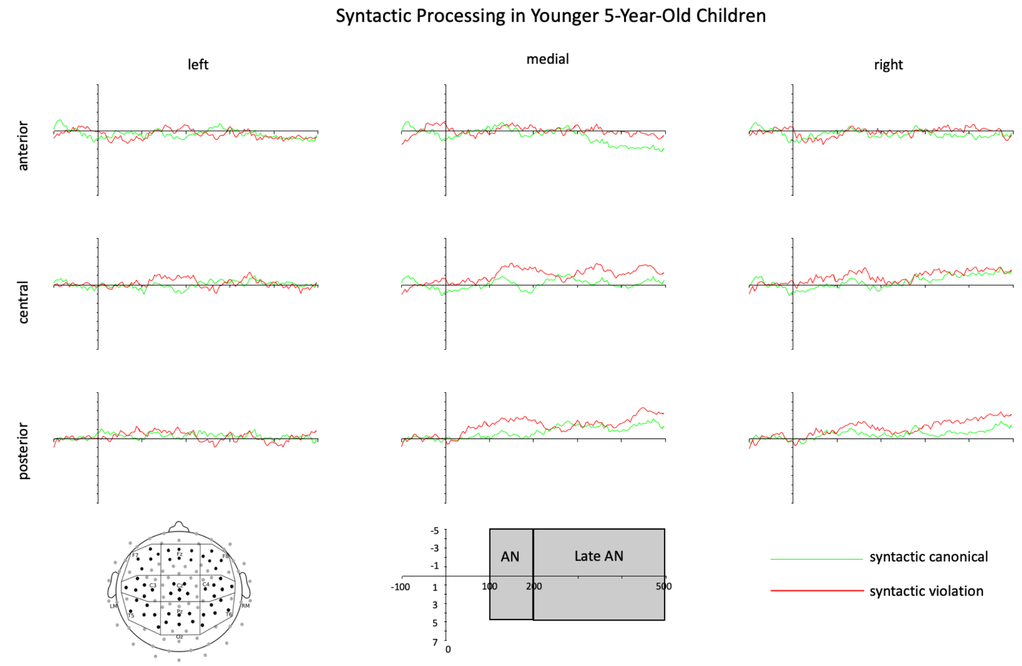

Figure 3.5: Grand average ERPs to syntactic violations (red) and canonicals (green), from -100 to 500 ms after critical morpheme in the violation condition and end of verb stem in the canonical condition in children under five years six months (n = 26).

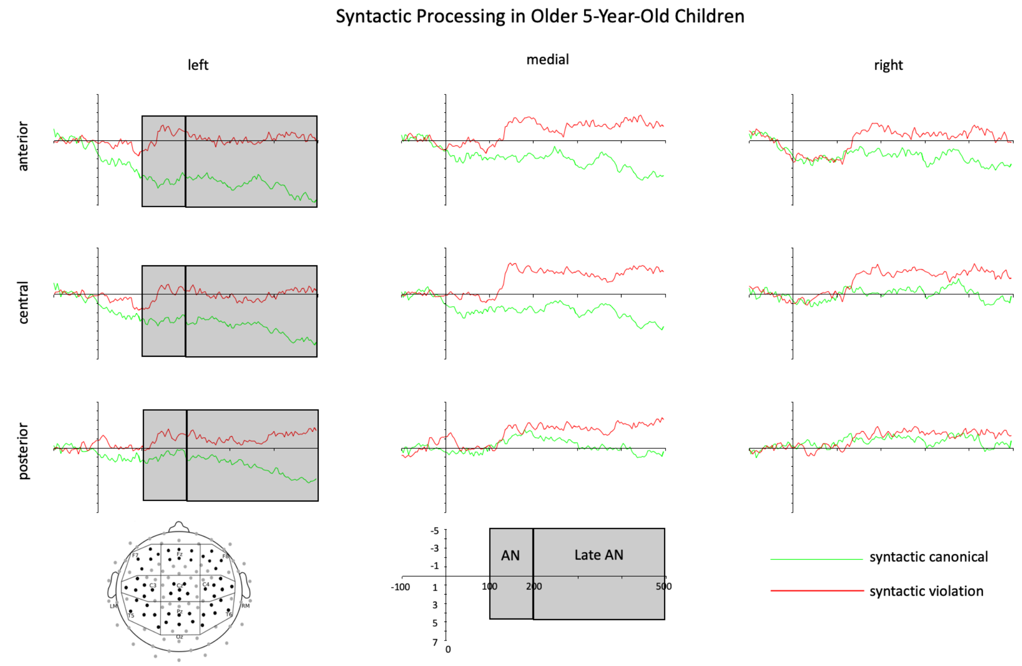

Figure 3.6: Grand average ERPs to syntactic violations (red) and canonicals (green), from -100 to 500 ms after critical morpheme in the violation condition and end of verb stem in the canonical condition in children over five years six months (n = 16).

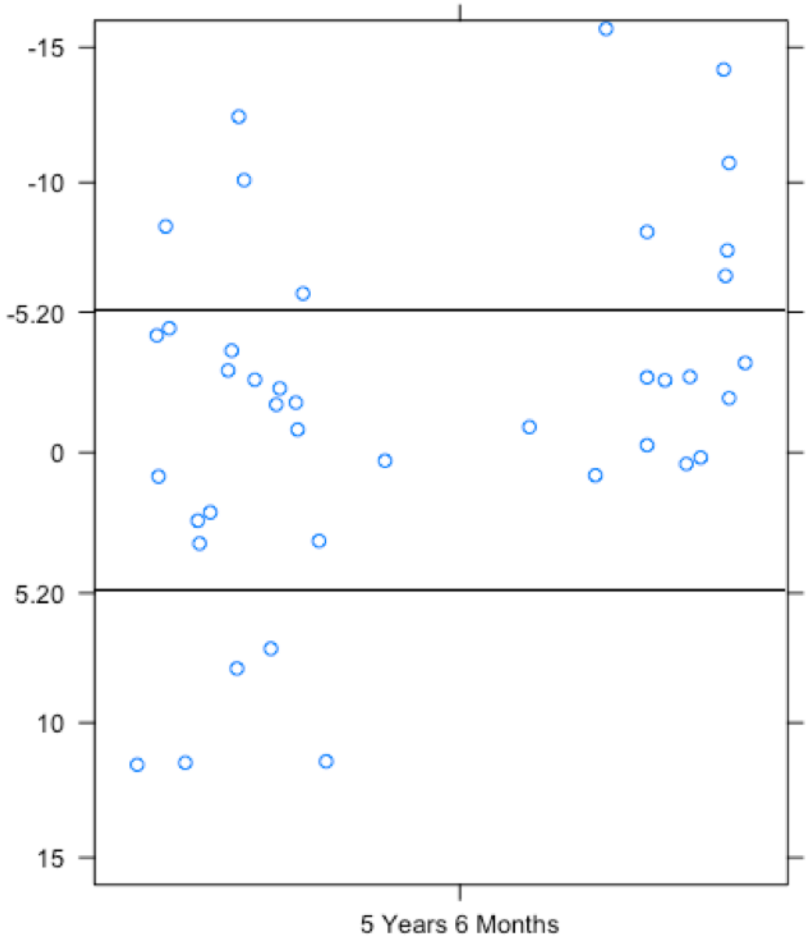

Figure 3.7: Scatter plot showing mean difference in response to syntactic violations and correct syntax plotted with age. Horizontal lines plotted at +/- 1 standard deviation of mean difference in response to syntactic violations and correct syntax in older children away from zero.

Grand average ERPs time locked the onset of canonical and phonological violation suffixes that were semantically congruent and anomalous were compared across age groups. There were no significant interactions with mean amplitude for the two conditions and age groups from 0 - 100 ms (p's > 0.18) or from 200 - 300 ms (p's > 0.19). However, a Pearson's correlation of age and difference in mean amplitude between response to phonological anomaly and the correct phoneme in the early 0 - 100 ms time window at the electrode site with the numerically largest effect – the medial anterior location. Younger children showed a larger difference in response to an incorrect phoneme as compared to a correct one, r = 0.348, p = 0.026. For the later 200 - 300 ms time window, the effect was largest at medial central electrode sites. The Pearson's correlation with age at this location and time window was not significant (p = 0.737).

3.7 Discussion

3.7.1 Semantic Effect

As expected, semantic violations presented to five-year-old children elicited an N400 effect from 300 - 500 ms that was largest over posterior regions. It is thought that as children develop, the N400 moves more anterior, becomes more right lateralized, and appears earlier in latency, at least in studies of that use sentence contexts while asking children to make judgments about semantic congruency (Hahne et al., 2004; Holcomb et al., 1992). These studies do not find adult-like latency of the N400 until children reach age 10 and topography is not similar to adults until age 13. This is in contrast with the present study, which found an N400 at the same time window for both adults and children: 300 - 500 ms after word onset, and a similar topography, particularly the lack of lateralization (although adults did show a main effect of semantic anomaly across the scalp while children showed this effect at central and posterior sites only).

This highlights the importance of using the most naturalistic task when comparing language processing in adults and children. While differences in latency and lateralization exist across age groups in more artificial and contrived language tasks, these differences disappear in response to natural language stimuli using a task that encourages comprehension and does not require metalinguistic judgment. The absence of these differences in this more natural context suggests that they are not relevant to our understanding of how semantic processing unfolds in the real world. Alternatively, it is possible that adult and child responses were so similar because this child-directed story context did not adequately challenge the semantic processing of five-year-old children. Putting children and adults through a story context that was still easy for adults, but more difficult for children may reveal differences in latency and lateralization that were not present in response to this easier story.

Varying story difficulty may also help us identify weaknesses in semantic processing that are associated with developmental language disorders. Semantic processing in children ages nine to twelve who were typically developing and diagnosed with developmental dyslexia was compared using sentence stimuli with no overarching narrative context paired with judgments about the correctness of the sentences (Sabisch, Hahne, Glass, Von Suchodoletz, & Friederici, 2006). Across all three groups of children, the N400 was present from 400 - 800 ms across the entire head with a similar amplitude. Importantly, these children did not differ in their ability to detect semantic violations. One previous study did find a difference between N400 amplitude in children with or without dyslexia (Neville, Coffey, Holcomb, & Tallal, 1993), but this effect is likely explainable by the different subjective difficulty of the tasks for the two populations. This study, which involved visual presentation of words and therefore relied on reading, found a larger amplitude N400 for children with developmental dyslexia, likely explainable by the fact that this disorder is characterized by difficulties with reading, necessarily leading to a larger N400 when trying to integrate semantic information.

These results suggest that it is possible to probe *what* exactly makes semantic integration difficult for younger children and for children with language disorders by comparing the N400 response to sentences with differing levels of semantic processing difficulty that tax the system in different ways. For example, differences in semantic processing may not be present in sentences that are rendered semantically anomalous based on general world knowledge (Hahne et al., 2004; Holcomb et al., 1992; Sabisch et al., 2006), but differences may appear when children must use the context of the story itself, not just general global plausibility, to determine that a word is anomalous. Future work specifically separating these variables – age, language proficiency, and type of semantic violation– embedded into an experimental design that is as natural as possible is necessary to fully understand how the N400 effect relates to semantic processing in the real world.

3.7.2 Syntactic Effect

Syntactic violations elicited a left anterior negativity without a later P600. Despite the fact that previous studies suggest that the P600 may develop before early anterior syntactic effects, the present study found an AN without the presence of a P600 in young children. This again raises important questions about how experimental task demands may yield ERP results that differ dramatically from what is happening in real language processing. Even in experimental paradigms that do not include an explicit syntactic judgment task, the P600 can be found in young children (Usler & Weber-Fox, 2015; Weber-Fox et al., 2013). However, both of these studies included cartoons acting out the sentences that the children were listening to. It is possible that the clash between the syntactically incorrect auditory stimuli and the visual information that depicted the correctly formed sentence encouraged a reanalysis process just like asking explicit questions about syntactic correctness would. It appears that in the most natural of contexts, the P600 is not present. Due to the fact that the P600 may interfere with later effects related to the AN (see Chapter 2.7.2.2), it is likely that any attempts to connect real-world factors to the AN when contaminated by the P600 component will yield misleading or null results.

Perhaps the most compelling results come when splitting participants into age groups. In general, children under five years six months of age tend to show either a positivity to incorrect syntax or an effect that is near zero at left anterior electrode sites. After five years six months, children begin to show either the adult-like negative response at these electrode sites while some continue to show an effect near zero (Figure 3.7). This relationship is further confirmed by significant correlations with age and anterior negativity amplitude for both the early and late time windows. Older children also show a larger negativity over the left hemisphere in the later time window than younger children. This response is similar to what was found in adults with this same paradigm (see Chapter 2.7.2.2). These results clearly demonstrate that rapid syntactic development is occurring across age five.

These age-related results may reveal important information about the relationship between the development of semantic and syntactic processing. While older children show both an extended duration AN and an N400 effect, younger children show an immature, transient AN with an N400 that is similar to older children. Age related correlations between the early AN window and age also indicate that this early portion of the AN effect is more robust in older children. These clear age-related differences in the AN are at odds with the fact that the N400 appears not to differ between older and younger five-year-olds.

Theoretical models of syntactic processing based on ERP findings assert that syntactic processing happens before semantic processing – semantic processing only occurs after word category information about each word has been extracted (Friederici, 1995; Friederici et al., 2004). It is possible that this earlier portion of the AN represents the detection of anomalous morphosyntax that is followed by the later sustained negativity which represents working memory demand. Older children and adults who are more experienced and confident in their use of morphosyntax may take an incorrect grammatical morpheme as sort of a red flag that something strange may be happening in the sentence. This cue may cause participants to maintain unintegrated words in memory just in case they encounter later evidence that their original parse of the sentence is incorrect and needs to be reanalyzed. The youngest children did not engage in this strategy, possibly because they lack the ability to hold these unintegrated individual words in memory while also processing the rest of the sentence. It is also possible that these children are slightly more permissive of incorrect morphosyntax and, despite showing an early AN that suggests their syntactic system has registered this violation, and did not find this erroneous morphosyntax to be a strong enough cue to prepare for the need for reanalysis. Since the morphosyntactic violations in the present study were very easy to correct and were always of the same type, the correction to the proper morphosyntax may have occurred early and with minimal effort. This would explain the lack of P600 in both age groups – correct syntax was already determined earlier in processing so there is no need for an effortful and late reanalysis step.

The results of this study also open an avenue into studying the development of not just syntactic processing in general, but how receptive and productive morphosyntax relate. Children in the present study are typically developing and have morphosyntactic skills in the normal range (see Table 3.1) and typically developing children do not have issues with the optional infinitive at five years of age (Rice, Wexler, & Cleave, 1995).

However, future work with children who are still in the optional infinitive stage of syntactic development may show differences in the processing of morphosyntax. This paradigm may serve as an interesting way to investigate if younger children or children with specific language impairment (SLI) perceive this morpheme and consider it erroneous even if they themselves are still in the optional infinitive stage. This could answer questions about whether older children with language disorders are simply processing morphosyntax similar to younger children much later in development than they should, or if fundamental differences exist between the type of processing that younger typically developing children and children with language disorders engage in.

Syntactic processing in children when measured using a naturalistic paradigm that encourages comprehension and not metalinguistic cognitive operations looks very different than syntactic processing of more artificial stimuli. Task differences appear to modulate whether a P600 is present (Hahne et al., 2004; Usler & Weber-Fox, 2015; Weber-Fox et al., 2013) and can even generate AN effects that look backwards in polarity – showing a larger negativity to correct conditions (Hahne et al., 2004; Silva-Pereyra et al., 2005). This highlights the importance of conducting experiments that are as natural as possible to ensure we are measuring the kind of processing that is relevant to real life. Only processing that is used in real-world contexts has any hope of relating to genetic, experiential, or neurobiological factors in a meaningful way.

3.7.3 Phonological Effect

The absence of a phonological effect in five-year-old children raises important questions about the timing of the development of phonological skills in general vs. the development of phonological skills that are used in on-line language processing in order to support language comprehension through the generation of predictions. Children as young as three years show electrophysiological evidence of the ability to differentiate between rhyming and nonrhyming word pairs (Andersson et al., 2018). While the ability to compare phonological forms undoubtedly contributes to on-line phonological processing, this ability is not the full picture. The results from the present study taken together with the results from Chapter 2 regarding the PMN in real speech (see Chapter 2.7.2.3) suggest that at age five children do not engage in fully adult-like generation of phonological predictions despite the fact that adult-like rhyme processing develops as much as two years earlier.

It is entirely possible that five-year-old children are generating phonological predictions in a similar manner to adults, but due to a number of possible reasons, this prediction process does not result in a detectable PMN. The first possibility is variability in timing of the prediction prevents a PMN that is synchronized across time both within and across participants, and therefore visible on an individual subject basis and in the grand average. A general principle of ERP signal averaging is that an effect that is not precisely timelocked across trials and individuals tends to average itself out. It is possible that the PMN effect is present in children, but this effect is less well timelocked than in adults. The PMN, at least in this context, is particularly vulnerable to this temporal smearing effect because many cues exist to the presence of the phonological violation, and these cues vary as a function of time and also ease of use.

The best cue of whether a phoneme is voiced or not (and therefore a violation or not in this paradigm) is the length of the syllable root, which is present before the start of the phoneme itself. The timing of this effect in adults suggests that this cue is being used, because ERP effects appear much earlier than they would if they were related to the onset of the phoneme itself (Chapter 2.7.2.3). Children may have varying ability to make use of this earlier cue and may find it necessary to hear the later information contained by the phoneme itself before determining whether a violation is present. This temporal variability may be present both across children and within an individual child. Some children may be more likely to use the earlier cues while others may need to rely on later cues, in general. Additionally, cue use may also be variable within individual children, dependent on factors such as the strength of the child's representation of a given word in their vocabulary combined with support that may or may not be available from lexical predictions. This would lead some children to switch which cue they use on a case-by-case basis.

Correlational analyses revealed a relationship between age and difference in response to correct vs. incorrect phonemes in the first 100 ms of processing such that younger children had a larger effect. At first glance, this correlation appears spurious since it is unlikely that younger children would show processing differences between correct and incorrect phonemes that is lost as children age and then reemerges in adulthood. However, it is important to note that the effect was a full 100 ms later than the effect found in adults, which suggests that, if real, this effect could be supported by cues that are present later than the cues that adults are using. This may suggest a differential use of cues depending on age. Adults may exclusively use syllable root information and therefore show an early PMN that is strongly coordinated in time across individuals and trails, while older children can switch between the use of syllable root information and later cues which generates a PMN that is smeared across time, and younger children generate a precisely timelocked but later PMN since they are forced to use only late cues. Further work on this PMN effect in children older and younger than 5 years of age is clearly necessary to test this assertion.

Another reason why the PMN may not be present in children in this paradigm is if children are in fact generating phonological predictions, but these predictions are not specific enough to differentiate between allomorphs that only differ by one phonological feature, something adults are capable of (see Chapter 2.7.3.2). It is known that phonological categories in infants are quite underspecified, particularly for phonemes that differ only in place of articulation (Fikkert, 2006). However, evidence from PMN a study suggests that, by age eight to ten, even subtle subphonemic cues on word initial phonemes can be detected by typically developing children and produce a response similar to the response generated when the entire phoneme is unexpected (Archibald & Joanisse, 2012). When in development do children transition from being permissive of slight variation in pronunciation of individual phonemes, to reaching more adult like levels of phonological specification?

The key to this question may lie in differences in how children treat phonemes in general (especially word-initial ones in a highly predictable semantic context) vs. how they treat word-final allomorphs. At age five, children can most certainly differentiate between voiced and voiceless phonemes outside of a suffix context. For example, voicing status changes meaning of words, like “fairy” vs. “very”, and children at age 5 clearly can distinguish between these two words. The way children treat allomorphs, in this case sounds that differ in voicing but not in meaning, may be very different from how they treat voiced vs. voiceless consonants in other contexts. Their concept of which phonological contexts require which allomorph is likely fully specified for production, given that incorrect voicing in plural suffixes is not a common productive language error in children. However, the specificity of this representation may not be strong enough to allow for the generation of specific predictions about an upcoming allomorph when processing language input, and children may simply be predicting that one of these two allomorphs will be present.

Age-related differences in the PMN found in this study could also be explained by this account. It is possible that the youngest children show a reliable PMN effect because they are making predictions based entirely on the lexical item. If these children generate a prediction about the entire word as a chunk, for example predicting “horns” as a whole instead of just predicting the suffix will be a “/z/”, their effect would be more consistently timelocked and therefore easier to see in a grand average. Slightly older children may be moving towards more adult-like predictions about specific upcoming phonemes but may be more permissive about which phoneme they hear. For example, children may expect to hear that a noun is plural and generate a prediction that either a /s/ or a /z/ should be coming next, with no differentiation regarding which of these allomorphs is more expected. Some time after reaching age 6 but before adulthood, individuals begin predicting specific allomorphs based on durational cues found in the syllable root, generating a mature, early PMN (Chapter 2.7.3.2).

3.8 Conclusion

The present study represents a critical methodological departure from previous work on the electrophysiological correlates of language processing in children. The results described here confirm that it is possible to detect ERP responses associated with language processing using a paradigm that closely approximates a typical communication setting commonly encountered by children – listening to a story while engaging in questions about the plot of that story. These results not only show that metalinguistic tasks, highly controlled stimuli, and the use of distractions such as puppet shows to encourage participation are unnecessary to generate significant results, but that these techniques are eliciting different effects than what is found in a more naturalistic experimental context. Importantly, the present study reports results from every child that participated in the task. Of 44 recruited children, only two were unable to complete the study due to fear of the EEG net itself, and not an inability to tolerate the task. With the right experimental design, it is possible to collect usable data from all participants, allowing us to study language processing in all kids, not just the ones who are most able to sit still and follow unnatural or challenging task instructions.

Results from this natural and inclusive design demonstrate the following. First, the N400 effect is present, with adult-like timing and near adult-like distribution, at age five in response to continuous speech without explicit tasks that encourage children to assess semantic congruence. Further, this effect was generated by sentences with a variety of semantic contexts. Stimuli in the present study was not specifically designed to include only sentences with an extremely high cloze probability, but also included sentences that could correctly be completed many different ways but happened to be completed in a semantically anomalous way. Further, semantic incongruence could be established for some sentences based on simple world knowledge, while others were only rendered incongruent based on the broader context of what was happening in the story. The fact that this N400 effect is a response to the types of semantic contexts that would actually exist in real speech also speaks to the strengths of this paradigm in terms of real-world relevance.

Results from syntax related results reveal a few important findings regarding both the importance of task when studying syntactic processing and the developmental time course of syntactic processing. First, although a P600 effect was found previously in younger children, this effect is not present in five-year-old children in a natural language processing experiment without explicit encouragement to engage explicit syntactic reanalysis. This suggests that the P600 may not be relevant to language processing as it occurs during real communication. Important developmental differences, even within this narrow one year long age bracket, were present in the later portions of the AN – an effect that likely would have been masked if task demands had led to the generation of a P600, something that has happened in previous studies with adults (Hasting & Kotz, 2008). Younger children may not engage in the same maintenance of individual words in working memory that older children and adults seem to do after encountering evidence of syntactic anomaly. This is in contrast with general accounts of syntactic processing that suggest that children at age five are fully capable of processing syntactic constructions as simple as the one in the present study. In fact, the construction used in the present study, first person present tense morphosyntactic agreement, is acquired first, likely since the correct form is actually a bare unmarked verb and therefore the simplest possible case (R. Brown, 1973). These ERP effects appear to reveal subtle strategic differences that emerge across childhood despite a seemingly plateaued behavioral performance for this type of syntax.

The ERP response to phonological violations seems to develop the latest, as this effect was not visible in children in the present study. This highlights an important theoretical distinction between the simple ability to make phonological comparisons and the application of phonological rules while listening to real speech. The fact that children show electrophysiological evidence that words with a similar phonological form, such as a pair of rhyming words, are processed differently than words that differ as early as age three (Andersson et al., 2018) but do not show an adult-like response to phonological violations in real speech at age five suggests that adult-like processing requires more than the ability to make simple comparisons. Questions remain about when the specific phonological abilities relied on by adults, likely the ability to use phonological rules to make predictions, develops, and whether variability in the timing of the generation or confirmation/denial of these predictions or the specificity of these predictions is obscuring effects that are actually present in individual children.

The strong link between these results and real-world communication combined with the ability to collect usable data from 100% of children represents two unique opportunities. First, it is now possible to connect these ERP results with other established measures of language and cognitive ability in the most meaningful way yet. Relationships between skills measured behaviorally and ERP indices of real-world language processing could more precisely reveal the skills that are associated with mature and efficient language processing and what kinds of behavioral profiles are associated with less mature processing. Additionally, the ERP indices of real language processing may reveal differences between typically developing children and those with language disorders that could be narrowed down to specific cognitive operations that support language processing (for example, ability to detect semantic anomaly based only on contextual factors, ability to hold individual words in working memory for later integration, ability to make specific phonological predictions, ability to use early cues to voicing status of a phoneme, etc.). Interventions could then be developed to target skills that support these abilities. ERP changes in children over the course of the intervention could shed light on what interventions are working, and further what types of behaviorally measured skill gains relate to changes in brain function that are relevant for the processing of real speech.

CHAPTER 4

RELATIONSHIPS BETWEEN ELECTROPHYSIOLOGICAL AND BEHAVIORAL INDICES OF LANGUAGE PROCESSING IN FIVE-YEAR-OLD CHILDREN

4.1 Specificity in Measurement is Necessary to Connect Disparate Fields of Scientific Inquiry

The fields of neuroanatomy, genetics, speech language pathology, and developmental psychology each have made progress in explaining how language processing develops. Our ability to relate the finding from these fields hinges on our ability to measure aspects of language processing that are separable, specific, and relevant to real-world language processing. Cognitive neuroscience methods, specifically ERPs, offer a unique opportunity to measure the cognitive operations underlying language processing as they unfold in real time and independently of the demands of response generation that are embedded in behavioral tasks. While ERPs allow us to better separate language-relevant processing into operations that support semantic processing, syntactic processing, and phonological processing, the experimental designs commonly used with ERPs are too dissimilar to real-world communication contexts to have any hope of relating to the findings of other fields studying language processing.

The experiment described in Chapter 3 represents a departure from this status quo, providing results from an ERP experiment that is close enough to the real world to provide meaningful information about how children process language in their everyday lives. This provides the best opportunity to make meaningful connections between these cognitive neuroscience findings and commonly used measures of language ability relied upon by speech language pathologists and developmental psychologists.

4.2 Using Behavioral Assessments to Understand Language Development

The most common way to assess a wide range of cognitive abilities of a child is to use standardized behavioral assessments. The popularity of these assessments is not unjustified. They are designed to be as easy and fast to administer as possible. During the development of these assessments, they are administered to extremely large and diverse samples of children from across the country, and occasionally the world, to ensure that an accurate standard score can be computed for age groups as precise as two months in length. The popularity of these assessments also allows for specific and widely understood scoring that allows for multiple different clinicians to easily understand the capabilities of a child or multiple different readers to understand the results in a paper.

These assessments often promise to measure a very specific ability, such as receptive vocabulary or verbal working memory. Unfortunately, it is unlikely that these assessments are truly measuring separate abilities. This interrelatedness between assessments is commonly acknowledged, with many commercially available assessment tools including sections that detail how scores on their tasks relate to other tasks. It is true that some level of relationship between tasks is expected. For example, it would be unsurprising to find relationships between a child's scores on a measure of vocabulary and a measure or receptive language because having a sizeable vocabulary is necessary for understanding complex spoken language. In fact, not finding a relationship here may cause one to question the validity of their assessment. Even seemingly distantly related abilities are also expected to be associated with one another, such as verbal short-term memory and vocabulary. These two abilities are often strongly correlated, even when the items on the vocabulary task and the short term memory task do not overlap (Gathercole

& Baddeley, 1989, 1990; Reynell & Gruber, 1997). The discovery of these relationships can lead to interesting theoretical arguments, for example that verbal short term memory specifically supports vocabulary development by allowing children to maintain specific sequence information in memory, and also allows for rehearsal of words that promotes long term consolidation (Ellis & Sinclair, 1996).

The discovery of associations like these often inspire language interventions that specifically target a supposedly lower level skill in order to improve higher level language outcomes. The most famous example of this is the FastForWord Language computer program. This intervention was developed based on the premise that children with developmental aphasia also seem to have a "temporal processing deficit" which presents as a difficulty in identifying individual phonemes if they are presented in rapid succession or if the phonemes themselves include rapidly changing acoustic features (Tallal & Piercy, 1973). These children were better at discriminating two phonemes with rapidly changing acoustic properties if some of the shortest acoustic features of the sounds were artificially lengthened. This theory was later extended to children with reading impairments (Reed, 1989; Tallal, 1980), and children with the more general label of "language learning impaired" (Tallal et al., 1996).

The intervention that came out of these findings focused on training children on a range of artificially modified language stimuli designed to slowly improve their ability to process rapid auditory changes. The sellers of this intervention program promised dramatic changes, such as an increase in ability equivalent to one-and-a-half to two years after only one to two months using the program ("National field trial results: Results of Fast ForWord training for children with language and reading problems," 1999). Unfortunately, these results were not consistent across children (Gillam et al., 2008;

Gillam, Loeb, & Friel-Patti, 2001; Pokorni, Worthington, & Jamison, 2004). A metanalysis conducted in 2011 concluded that the use of FastForWord led to no significant effect on any outcome measure (Strong, Torgerson, Torgerson, & Hulme, 2011). The failure of this program brings up important questions about why seemingly theoretically-sound interventions do not lead to improvements in all children. This speaks to the need for further specificity in how we can measure component skills related to language success.

4.3 The Need for Multiple Indicators

A long-accepted principle of the measurement of psychological phenomenon is that using multiple indicators of a construct is the best way to get a true measurement of that construct. Specifically, aggregation of different sources of information increases the likelihood that random error or noise will be averaged out, leaving a more accurate measure. This effect was summarized in 1983 by Rushton et al., in a paper outlining that, across many literatures, scores on individual tasks claiming to measure an ability correlate weakly with other outcome measures that are theoretically expected to vary as a function of that ability (for example, subjective report of peers, academic success, etc.). However, creating a composite score of multiple ways of capturing the same ability often results in the expected correlation with outcome measures (Rushton, Brainerd, & Pressley, 1983). These authors assert, "Whenever there is the possibility of unreliability of measures, then aggregation becomes a desideratum," (Rushton et al., 1983, pg. 34).

This conceptual framework can be applied to how we measure language skill. It is true that many language-ability measures are already composite scores. For example, a common way to measure receptive language ability involves an amalgamation of scores on three tasks – receptive vocabulary, understanding complex syntax (termed "elaborated phrases”), and understanding grammatical morphemes (Carrow-Woolfolk, 2014). However, all of the component scores of this receptive language measure share important vulnerabilities to error, so averaging them together cannot remove this error. All of these measures rely on a child’s ability to point at one of three pictures, indicating that that picture matches best with the sentence that was read to them by an experimenter. While this is no doubt a valid way to measure a child’s understanding of spoken language, it also relies on other skills that the task is not intending to measure. Skills that are far beyond language comprehension are necessary for success in this task. Children also need to accurately interpret the images that are presented to them as possible answer choices and then accurately point to the picture that is associated with the sentence they heard. Even if other tasks related to receptive language that do not involve picture selection are used, children still need to be able to remain attentive for a long period of time, frequently on the order of hours if this task is administered as part of a longer cognitive battery. While these abilities are likely associated with language skill, they prevent us from generating a pure measure of receptive language.

4.4 Using Electrophysiological Measures of Language Processing to Understand Language Development

It is possible that methods that do not rely on the presence of explicit knowledge and the production of a response – motor (pointing), verbal, or otherwise – may allow us to more specifically measure underlying cognitive processes that support language ability. Event-related potentials may be one of these methods. The timing and distribution of ERPs in response to language stimuli has already proven to relate very specifically to language processing. The clearest relationship is between the N400 and vocabulary knowledge. In children as young as five, the magnitude of the N400 can be used to determine whether a child knows that a visually presented image and auditorily presented word do or do not match (Byrne et al., 1999). This method is so reliable that it can be used with children who have moderate to severe cerebral palsy and are unable to give verbal or motor responses (Byrne, Dywan, & Connolly, 1995). In a study of syntactic processing, the presence or absence of syntax-related ERP components tracked closely with age and differentiated groups more specifically than behavioral measures alone (Schipke et al., 2012). Children ages four years six months and six years achieved chance-level accuracy in a task that asked them to choose which picture correctly represented syntactically complex sentences. While a P600-like effect was present in both groups of children, an effect similar to the adult anterior negativity was only present in the older group of children despite no difference in behavioral performance, indicating that ERP methods were more sensitive in detecting differences between groups than behavioral methods. ERP measures of phonological processing can also shed more light on language ability than behavioral measures alone. In a study of nonword rhyming, three to five-year-old children showed remarkably adult-like ERP effects in response to nonrhyming stimuli despite the fact that their behavioral responses showed no evidence that they could distinguish rhyming from nonrhyming pairs (Andersson et al., 2018).

These results show that event-related potentials can be used at the very least, in the case of semantic-related ERPs, to confirm what is already know from behavioral measures, and in the case of syntax- and phonology- related ERPs, can provide more information than behavioral measures. More work is needed to determine what is exactly is being captured by these ERP measures as compared to behavioral ones, and if these ERP effects are truly more specific and separable.

Only one previous study has attempted answer this question, and in slightly older children than the present study. Wray and Weber-Fox (2013) investigated how language and cognitive ability as measured behaviorally, specifically measures of nonverbal IQ, verbal working memory, and grammar, relate to ERPs in seven to nine-year-old children. Response to semantic violations, as indexed by the N400, was related to verbal working memory and performance on grammar-related tasks, such that better performance on both predicted a smaller amplitude, and therefore more adult-like, N400 effect. An anterior negativity similar to that reported in Chapter 3.7.2 was observed in response to syntactic anomalies but was not associated with any of the three abilities that were measured behaviorally. In contrast, the P600, which was not observed in the current study (Chapter 3.7.3), was more adult like in children who earned better scores on all behavioral tasks. The P600 had an earlier latency in children with better nonverbal IQ and grammatical ability, and a was larger in amplitude in children with better verbal working memory.

These results suggest that the present study may find relationships between N400 maturity and measures of working memory and grammar, especially since the younger children who participated in the present study may have an even greater range of N400 response and behavioral ability. Although relationships between behavioral measures and the AN were not found by Wray and Weber-Fox, these relationships may be present in this sample again due to likely greater variability in AN response and behavioral abilities due to the massive amount of development that is occurring in this younger age group. These results do not provide any clues to the relationships that may exist between behavioral measures and ERPs related to phonological processing. However, the stimuli used in this study does not approximate real-world language processing. Children listened to a stream of unrelated sentences, some of which included semantic or syntactic violations, combined with an image of the agent in the sentence. Children were asked to press a button when they heard any error. Additionally, while the sample size for this study was adequate (n = 30), no information was provided about how many children were excluded due to poor EEG data quality so it is unclear if these results represent only the subsample of children who were best at tolerating the experimental task. These factors add further uncertainty to how behavioral abilities will relate to ERP effects in this younger, inclusive sample using an ERP paradigm that closely approximates real communication.

4.5 Using Electrophysiological Measures of Auditory Processing to Understand Language Development

The ERP measures described in Chapter 3 – the N400, AN, and PMN –indexed specific aspects of language processing while children listened to natural speech for comprehension. However, EEG was recorded continuously and can be time-locked to other events in the narratives other than violations and their canonical controls. Specifically, continuous speech includes acoustic onsets that would be expected to elicit typical auditory evoked potentials. The N1, a negative going wave that is present over central medial scalp after auditory onsets, varies in magnitude as a function of attention and in latency as a function of sound or task complexity (though usually peaking between 80 ms and 200 ms) (Berman & Friedman, 1995; Hansen, Dickstein, Berka, & Hillyard, 1983; Hillyard, Hink, Schwent, & Picton, 1973; Hink, Hillyard, & Benson, 1978). The timing, amplitude, and distribution of these basic responses to sound onset, specifically simple stimuli constructed from a stream of beeps, might be expected to be mature in five-year-old children (Ponton, Eggermont, Khosla, Kwong, & Don, 2002). However, it is not clear that their sensitivity to specific acoustic features, including the length of preceding silence, abruptness of the acoustic onset, and changes in acoustic features in addition to amplitude, is fully mature – a question that is very relevant to speech processing given the fact that real speech varies on all of these dimensions.

The N1 also varies as a function of attentional state – sounds that are attended generate a larger N1 response as compared to sounds that are not attended if stimulus properties are properly balanced (Fitzroy et al., 2018). This selective attention effect is less well understood in children. When presented with attention probes embedded two simultaneous stories, one of which was attended and one ignored, children's auditory evoked responses to acoustic onsets and the associated attention effect are different from that of adults (Sanders, Stevens, Coch, & Neville, 2006; Stevens, Sanders, & Neville, 2006). Typically developing children show a broad positivity to these attention probes, which is largest to probes embedded in the attended story (Sanders et al., 2006). This is not identical to the typical adult N1 attention effect, likely due to difference in the ERP response caused by sound saturation of two simultaneous speech streams. The N1 response is highly refractory, meaning that after responding to an initial auditory onset, it is reduced in amplitude to subsequent sound that are not preceded by silence, and the length of this refractory period decreases with age. In the context of two simultaneous speech streams, the immature N1 was likely reduced in amplitude due to the sheer volume of sound, leaver later positive components of the obligatory auditory response, such as the P2, as the strongest response and only locus of attentional modulation. Questions remain as to whether this immature positive response to auditory onsets is present to the onsets in real continuous speech (as opposed to superimposed beeps or other probe sounds) and when only one story is playing.

In addition to attentional state, the amplitude of the N1 response is also driven strongly by stimulus features. It is known that the N1 closely tracks stimulus characteristics such as loudness, pitch, and duration of silence between onsets. It is unclear if more accurate tracking of stimulus characteristics also facilitates auditory processing in a way that has downstream influences on higher level language processing. Since there is a large amount of variability naturally present in the speech signal, larger N1 fluctuations over time may represent more accurate tracking of this variability. A relationship between greater N1 variability and more advanced language skill as measured behaviorally would suggest that a more responsive N1 component supports better language processing.

4.6 The Present Study

Results from studies investigating language ability as measured behaviorally and as measured with ERPs provide evidence that both of these avenues can provide information about language development, even more so when they are combined. Questions remain as to whether event-related potential response to language stimuli offers more specific and less contaminated measurement of language ability as it is related to three separable language subsystems – semantics, syntax, and phonology. The ERP measures reported in the previous chapter (N400, AN, and PMN) were compared to an additional ERP measures (variability in the N1) as well as performance on standardized behavioral tests: assessments of receptive language (Carrow-Woolfolk, 2014), phonological processing and memory (Martin & Brownell, 2005), and nonverbal intelligence (Ehrler & McGhee, 2008) and a behavioral measure of language comprehension that was completed during EEG data acquisition. Doing so makes it possible to investigate potential relationships between and with these methods of analysis to further understand not only how electrophysiological measures relate to the abilities as measured behaviorally but also if there is evidence that ERP measures each capture processing specific to one language subsystem, something that has proven difficult to do with behavioral measures alone.

4.7 Methods

4.7.1 Participants

Participants are identical to those in Chapter 3.5.1 with exception. One child was unable to complete the behavioral assessments and is therefore excluded from analysis. This leaves 41 children (22 males) in the present experiment. Mean scores on the standardized cognitive and language assessments administered to these children can be found in Table 3.1.

4.7.2 Materials

The present study reports the relationship between results of the EEG experiment in Chapter 3 and a battery of behavioral measures. Information about the stimuli used in the EEG experiment can be found in Chapter 2.6.2. The battery of behavioral measures included the following tasks: the Test of Early Grammatical Impairment (TEGI) (Rice & Wexler, 2001) was used to confirm that all children had grammatical abilities in the normal range. This task screened for deficits in production of the following: phonemes that serve as grammatical morphemes (and are therefore necessary to mark grammatical relationships), past tense -ed, and third person singular. The Primary Test of Nonverbal Intelligence (PTONI) (Ehrler & McGhee, 2008) measured nonverbal reasoning. The Test of Auditory Processing Skills 3 (TAPS) (Martin & Brownell, 2005) was used to measure auditory processing ability, specifically auditory short term memory and phonological processing skills. Finally, the Test for Auditory Comprehension of Language 4 (TACL) (Carrow-Woolfolk, 2014) was used to measure receptive language ability, specifically receptive vocabulary, understanding of grammatical morphemes, and understanding of complex syntax.

4.7.3 Procedure

Procedure for the EEG experiment is identical that which was described in Chapter 2.6.3. An additional session was also conducted within three weeks of EEG data collection to collect behavioral data. All except six children completed the EEG session before this behavioral session. These six individuals completed the sessions in the opposite order due to scheduling constraints. Assessments were administered to children in a quiet, distraction free room. All tasks were administered according to their respective administration manuals, discontinuing administration after the appropriate basal and ceiling criteria were reached.

The Test of Early Grammatical Impairment (TEGI) was administered first to ensure that children did not show evidence of a grammatical impairment before continuing with the rest of the session. In this task, children demonstrated the ability to produce phonemes that serve as grammatical morphemes (/z/, /s/, /d/, /t/), produce verbs that are appropriately marked for first person present tense (“A teacher teaches”) and the past tense (“She skated”).

All children passed this screener and then moved on to the Test of Auditory Processing Skills (TAPS). This assessment was always administered second due to the high attentional load associated with it. All of the tasks in this assessment are auditory in nature and the experimenter is not permitted to repeat any items, so moments of off-task behavior would artificially lower the score on these tasks more severely than tasks that include support from images. These factors motivated a fixed order for this task as opposed to counterbalancing order across participants. The TAPS included assessments that measured phonological ability and auditory memory. Phonological tasks included word discrimination (the ability to determine if a pair of words was composed of two different words or the same word twice), phonological segmentation (the ability to remove specific syllables or phonemes from words) and phonological blending (the ability to listen to individual phonemes and put them together to form a word). Memory tasks included number memory forward (ability to repeat digit spans of increasing length), number memory reversed (ability to repeat a digit spans of increasing length in backwards order), word memory (ability to repeat word lists of increasing length), and sentence memory (ability to repeat sentences of increasing length and complexity).

The order of the next two tasks, Primary Test of Nonverbal Intelligence (PTONI) and Test of Auditory Comprehension of Language (TACL), were counterbalanced across children. The TACL was comprised of a series of three tasks during which children listened to words, phrases, or sentences and pointed to one of three pictures that appropriately depicted the sentences. The tasks measured vocabulary, grammatical morphemes (ability to understand sentences that rely on grammatical morphemes to fully convey their message), and elaborated phrases (ability to understand sentences with complex syntactic structures). A composite score – the receptive language index – was also calculated from scores on these three tasks. The PTONI presented children with a series of matrices – between three and six images each – and required children to select the image that did not go with any of the others. This single assessment served as a measure of nonverbal ability. Each child completed all four assessments during this session, lasting approximately 90 minutes.

4.7.4 EEG Data Acquisition and Processing

The EEG data acquisition for the data in this experiment is described in Chapter 3.5.4. The present study includes two types of ERP data – ERPs to language violations and ERPs to auditory onsets. ERPs to language violations are identical to those described in Chapter 3. In order to calculate one value for each participant for each language subsystem, mean difference in voltage between the violation and the canonical condition was computed at the electrode cluster where the effect was numerically largest during the time windows specified in Chapter 3.5.5. Table 4.1 details the electrode location, time window, mean difference in voltage, and standard deviation for difference in voltage for each relevant comparison.

Table 4.1. *Mean difference in voltage between canonical and violation conditions for each relevant electrode cluster and time window*

Language Subsystem	Electrode Location	Time Window	Mean (St Dev)
Semantics (N400)	Medial Posterior	300 – 500 ms	-3.38 (6.02) mV
Syntax (AN)	Left Anterior	100 – 200 ms	-1.95 (6.36) mV
Syntax (AN)	Left Anterior	200 – 500 ms	-1.74 (8.26) mV
Phonology (PMN)	Medial Anterior	0 – 100 ms	-1.27 (4.48) mV
Phonology (PMN)	Medial Central	100 – 300 ms	-0.97 (5.60) mV
Auditory attention (N1)	Central Medial	150 – 170 ms	-0.62 (0.77) mV

ERPs to auditory onsets were calculated using a different data processing pipeline. Only data collected in response to filler sentences from the story used in Chapter 2 and 3 – sentences that advanced the plot of the story but did not include violations – were submitted to this pipeline. First, auditory onsets in these filler sentences were identified using an automatic auditory onset detector. Specific details regarding this custom Matlab code can be found in Fitzroy et al., 2018. In general, time points when the auditory signal included large fluctuations from low intensity to high intensity (as measured by root-mean-square amplitude) were first identified and then checked against a set of criteria to see if each time point constituted an auditory onset. In order for a period of high intensity to be accepted as an auditory onset, it had to be preceded by relative quiet and its initial few milliseconds (attack) and later portion (sustain) had to meet a minimum threshold of increased intensity relative to previous time points. A total of 2,054 onsets were detected.

Data was then segmented into epochs beginning 100 ms before each onset and ending 300 ms after each onset, baseline corrected to 100 ms before the onset, and submitted to the automatic artifact rejection routine described in Chapter 2.6.4 with a threshold of -100uV to 100uV. These onsets were separated into 15 sequential bins, each bin including onsets from roughly 2 minutes 38 seconds of story presentation. Of the 42 participants, four had less than 20 artifact free onsets in at least one of these time bins and were therefore excluded from N1 analyses. Mean N1 amplitude from 150 ms -170 ms was extracted for each participant at the central medial electrode cluster for each of these time chunks. The standard deviation of these 15 values was computed and used as a measure of the variability of the strength of the N1 response.

4.7.5 Analysis

Behavioral scores, mean difference in ERP response to violations and the canonical form, and variability of the N1 response were submitted to Pearson's correlations to look for relationships within and across measurement modalities.

4.8 Results

4.8.1 Relationships Within Behavioral Measures

Table 4.2 lists correlations (r values) within the behavioral measures. A remarkable number of significant correlations existed within the dataset – 48 out of a possible 91. Some of these correlations included in these 48 were between a composite score and its component subscales. Such correlations are crossed out in Table 4.2. Removing these correlations leaves 38 significant correlations out of a possible 81. Of these 38 correlations, some were between tasks that contributed to the same composite score. Given the fact that these tasks are theoretically strongly related, correlations between them are expected. Such correlations are italicized in Table 4.2. Removing these correlations leaves 29 significant correlations out of 69 possible. Note that all significant correlations were in the positive (and expected) direction.

Table 4.2: *Correlations between language measures and nonverbal intelligence (r values).*

Variables	1	1a	1b	1c	2	2a	2b	2c	2d	3	3a	3b	3c
1. TAPS Phono Index	–												
1a. TAPS Word Discrimination	~~0.78***~~	–											
1b. TAPS Phonological Segmentation	~~0.84***~~	_0.59***_	–										
1c. TAPS Phonological Blending	~~0.80***~~	_0.36*_	_0.50***_	–									
2. TAPS Memory Index	0.56***	0.57***	0.38*	0.42**	–								
2a. TAPS Number Memory Forward	0.42**	0.41**	0.29	0.30	~~0.86***~~	–							
2b. TAPS Number Memory Reversed	0.39*	0.37*	0.18	0.38*	~~0.62***~~	_0.32*_	–						
2c. TAPS Word Memory	0.47**	0.51***	0.30	0.36*	~~0.83***~~	_0.75***_	_0.23_	–					
2d. TAPS Sentence Memory	0.54***	0.53***	0.43**	0.34*	~~0.90***~~	_0.70***_	_0.56***_	_0.63***_	–				
3. TACL Receptive Language Index	0.39*	0.55***	0.38*	0.09	0.15	0.07	0.07	0.15	0.19	–			
3a. TACL Vocabulary	0.21	0.26	0.14	0.13	0.10	-0.01	0.11	0.08	0.14	~~0.57***~~	–		
3b. TACL Grammatical Morphemes	0.41**	0.50***	0.39*	0.16	0.23	0.14	0.18	0.19	0.23	~~0.80***~~	_0.24_	–	
3c. TACL Elaborated Phrases	0.24	0.42**	0.32*	-0.08	0.03	0.02	-0.10	0.08	0.07	~~0.74***~~	_0.08_	_0.41**_	–
4. PTONI Nonverbal Intelligence Index	0.63***	0.51***	0.52***	0.49**	0.27	0.19	0.10	0.38*	0.19	0.45**	0.28	0.47**	0.21

*$p < .05$. **$p < .01$. ***$p < .001$.

Crossed out values indicate obligatory correlations due to a relationship between a composite score and its contributing subscales. Values in italics indicate expected correlations between measures contributing to the same composite scores.

4.8.1.2 Relationships Between Language Measures and Nonverbal Intelligence

Despite the fact that the PTONI is designed to measure nonverbal intelligence, numerous significant correlations exist between scores on this task and scores on language ability tasks. In particular, strength of nonverbal intelligence is correlated with phonological processing in general, $r = 0.63$, $p < 0.001$, (including word discrimination ability, $r = 0.51$, $p < 0.001$, phonological segmentation, $r = 0.52$, $p < 0.001$, and phonological blending, $r = 0.49$, $p < 0.01$), word memory, $r = 0.38$, $p < 0.05$, and receptive language in general, $r = 0.45$, $p < 0.01$, (including understanding of grammatical morphemes, $r = 0.47$, $p < 0.01$).

4.8.2 Relationships Within ERP Measures

Table 4.3 lists correlations (r values) within the ERP measures and the comprehension questions that were asked while this data was collected. Of a possible 21 correlations, two were significant, both within the same language subsystem. Mean difference in amplitude 100 - 200 ms after correct morphosyntax vs. incorrect morphosyntax correlated with the mean difference 200 - 500 ms after correct morphosyntax vs. incorrect morphosyntax, $r = 0.82$, $p < 0.001$. Mean difference in amplitude 0 - 100 ms after the correct phoneme vs. an incorrect phoneme correlated with the mean difference 100 - 300 ms after the correct phoneme vs. an incorrect phoneme, $r = 0.39$, $p < 0.05$.

Table 4.3: *Correlations between ERP measures and comprehension questions (r values).*

Variables	N400	Early AN	Late AN	Early PMN	Late PMN	N1 Variability†
1. N400	–					
2a. Early AN	-0.04	–				
2b. Late AN	0.01	*0.82****	–			
3a. Early PMN	0.18	-0.14	-0.08	–		
3b. Late PMN	0.10	0.02	0.01	*0.39**	–	
4. N1 Variability†	-0.13	0.11	0.08	-0.17	0.10	–
5. Comprehension Question Accuracy	0.13	-0.20	-0.27	-0.02	0.32	0.09

**p < .05. **p < .01. ***p < .001.*
N = 41 except where indicated with †, n = 37.
Values in italics indicate expected correlations between ERPs in response to the same language condition.

4.8.3 Relationships Between ERP Measures and Behavioral Measures

Table 4.4 lists correlations (r values) between the ERP measures, the comprehension questions that were asked while this data was collected, and scores from the standardized behavioral tests.

Table 4.4: *Correlations across ERP and behavioral measures (r values).*

Variables	N400	Early AN	Late AN	Early PMN	Late PMN	N1 Variability†	Comprehension Questions
1. TAPS Phono Index	0.26	-0.28	-0.12	0.13	0.14	0.11	0.36*
1a. TAPS Word Discrimination	0.27	-0.27	-0.09	0.04	0.09	0.26	0.36*
1b. TAPS Phonological Segmentation	0.34*	0.01	0.11	0.01	0.12	-0.09	0.30
1c. TAPS Phonological Blending	0.04	-0.37*	-0.24	0.23	0.13	-0.01	0.24
2. TAPS Memory Index	0.40*	-0.30	-0.22	0.09	-0.04	-0.06	0.28
2a. TAPS Number Memory Forward	0.32*	-0.30	-0.32*	0.06	-0.01	-0.07	0.17
2b. TAPS Number Memory Reversed	0.23	-0.17	-0.10	0.16	0.07	0.02	0.19
2c. TAPS Word Memory	0.23	-0.34*	-0.28	0.02	-0.12	-0.02	0.29
2d. TAPS Sentence Memory	0.49**	-0.15	-0.03	0.07	-0.05	-0.10	0.23
3. TACL Receptive Language Index	0.12	-0.06	0.01	-0.13	0.17	0.41*	0.25
3a. TACL Vocabulary	-0.01	-0.03	0.04	-0.14	0.01	-0.07	0.10
3b. TACL Grammatical Morphemes	0.26	-0.03	-0.04	-0.06	0.20	0.28	0.40*
3c. TACL Elaborated Phrases	0.04	-0.07	0.06	-0.12	0.14	0.50**	0.05
4. PTONI Nonverbal Intelligence	0.13	-0.20	-0.16	<0.01	-0.08	0.01	0.25

**p < .05. **p < .01. ***p < .001.*
N = 41 except where indicated with †, n = 37.
ERP measures were calculated as violation - canonical, so larger ERP effects are more negative values. Better performance on standardized measures and comprehension questions are higher positive numbers. As a result, positive correlation coefficients reflect that smaller ERP effects were associated with better performance; negative correlation coefficients reflect that larger ERP effects were associated with better performance. Since N1 variability, rather than N1 amplitude, was measured, positive correlations indicate greater variability in N1 amplitude is associated with better performance.

ERP activity in the time window and at electrode sites that showed the strongest N400 effect correlated with performance on phonological segmentation, $r = 0.34$, $p < 0.05$, and auditory memory in general, $r = 0.40$, $p < 0.05$ (including number memory forward, $r = 0.32$, $p < 0.05$, and sentence memory, $r = 0.49$, $p < 0.01$) such that a smaller negative difference in ERP amplitude 300 - 500 ms after semantic violations compared to canonical controls was associated with better performance on these tasks. It should be noted that, in some extreme cases, not just a smaller negative difference but a more positive response to semantic violations as compared to correct semantics was associated with better performance.

ERP activity in the time window and at electrode sites that showed the strongest LAN effects also correlated with behavioral measures. For the earlier time window, ERP activity after correct morphosyntax vs. incorrect morphosyntax correlated with phonological blending, $r = -0.37$, $p < 0.05$, and word memory, $r = -0.34$, $p < 0.05$ such that a larger difference in ERP amplitude 100 - 200 ms after syntactic violations compared to canonical controls was associated with better performance on these tasks. In the later time window, ERP activity correlated with number memory forward, $r = -0.32$, $p < 0.05$ such that a larger difference in ERP amplitude 200 - 500 ms after syntactic violations compared to canonical controls was associated with better performance on this task.

Just as no significant effect of phonological violation vs. canonicals was found in Chapter 3, no significant correlations were present between ERP measures of phonological processing in this time window and location this effect appeared numerically largest and any behavioral measures.

While a direct measure of mean amplitude of the N1 response is driven primarily by stimulus properties and therefore not expected to correlate with language skill, the grand average N1 response from the 37 children included in the N1 variability analysis is shown in Figure 4.1.

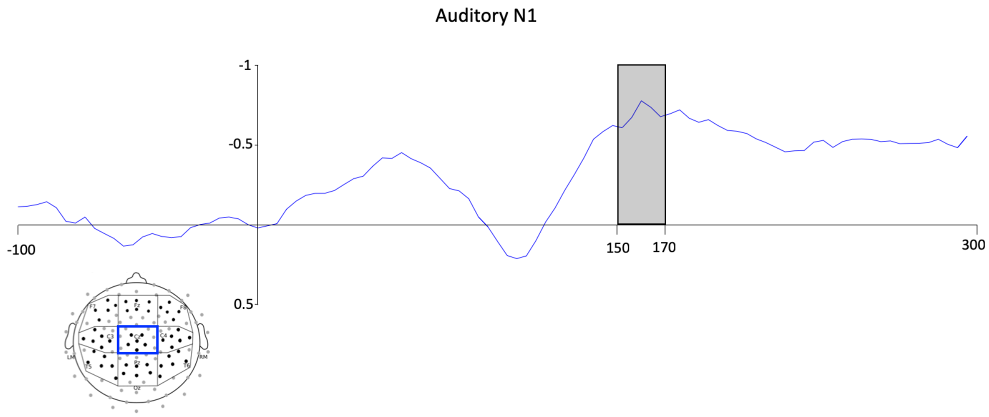

Figure 4.1: Grand average ERPs to auditory onsets, from -100 to 300 ms.

Visual inspection of this figure and individual subject averages indicates that the typical N1 response to auditory onsets was present. Variability in mean N1 amplitude 150 - 170 ms after auditory onsets correlated with receptive language in general, $r = 0.41$, $p < 0.05$, including elaborated phrases, $r = 0.50$, $p < 0.01$, such that more variability in the N1 response was related to better performance.

Performance on the comprehensions questions that were asked during EEG data collection correlated with standardized measures of phonological processing in general, $r = 0.36$, $p < 0.05$, including word discrimination, $r = 0.36$, $p < 0.05$, and grammatical morpheme ability, $r = 0.40$, $p < 0.05$ such that children who scored well on these comprehension questions also scored well on these standardized tasks.

4.9 Discussion

4.9.1 The Intercorrelated Nature of Behavioral Measures

The presence of numerous correlations, even across behavioral measures that claim to measure separate abilities, suggests that a task impurity problem exists within the assessments that are commonly used in order to measure language ability (see Table

4.2). The existence of the task impurity problem in behavioral assessments of ability is not a new concept. For example, starting in the 90's, working memory ability was connected with nonverbal intelligence (Jensen, 1998), and since then a metanalysis including over 50 studies found a correlation of roughly 0.48 between the two constructs (Ackerman, Beier, & Boyle, 2005).

It is likely unrealistic and unreasonable to expect behavioral measures to be fully uncorrelated with one another. However, language disorders are often defined as difficulties with specific aspects of language processing despite otherwise normal levels of intelligence, including developmental dyslexia (Lyon, 1995) and specific language impairment (Bishop, 2003). In order for these diagnostic criteria to be theoretically sound, there needs to be a way to measure language ability separately from nonverbal intelligence.

Additionally, it is known that abilities in the three language subdomains – semantics, syntax, and phonology – develop on different timescales and likely rely on the support of at least somewhat nonoverlapping cognitive abilities and neural systems. Correlations were found across behavioral assessments that were supposedly measuring skills belonging to separate language subsystems, for example composite scores of phonological processing, auditory memory, and receptive language all correlated (r's > 0.39, p's < 0.05). Again, while it may be expected that some overlap exists such that abilities in one of these language domains supports ability in another, these strong correlations clearly show that simple scores on behavioral assessments are inadequate if our goal is to parse out abilities related specifically to each subsystem in order to identify individual profiles of language skill or link language skill to neural systems, genetics and experience.

4.9.2 The Independent Nature of ERP Measures

ERPs to language violations in continuous, real speech while children listened with the goal of comprehension, and the variability in the ERP response to auditory onsets within these stimuli do correlate across language subsystems. These measures seem to be tapping in to separate underlying processes related to the processing of semantic and syntactic violations. It should be noted that ERP effects related to phonological processing did not reach significance in this group of children (Chapter 3.6.2.3), and therefore it would be questionable to draw conclusions about relationships between phonological processing and the other ERP measures, but no correlations existed here either. This independence makes ERPs uniquely suited for the investigation of differences in processing across language subsystems. Having separable measures of the cognitive processes that underlie different core types of language processing without contamination from the need to generate behavioral responses using explicit knowledge represents our best hope in relating meaningful language ability measures to factors like genetics, experience, and neuroanatomy.

4.9.3 ERP Measures and Behavioral Measures

Significant relationships between ERP measures and some behavioral measures were present. These relationships demonstrate that ERP effects are reflecting cognitive operations that are relevant to measurable differences in language processing ability as measured behaviorally. The specific relationships that are present suggest that ERPs are uniquely pure and separable from skills most relevant to other language subsystems and to nonverbal intelligence.

It is important to note that these correlations represent a measure of the difference between response to the violation condition and the canonical condition. This includes effects from individuals who do not show the expected more negative response to semantic, syntactic, and phonological violations as compared to canonical forms. For a number of children in every comparison, this effect is near zero or even goes in the opposite direction such that the response to a violation is more positive than the response to a canonical form. This poses important questions about how these correlational effects should be interpreted. It is possible that these correlations reflect differences in performance for children who have the ERP effect vs ones that don't, and that all effects near 0 and in the opposite direction are simply noise. Alternatively, correlations between behavioral scores and ERP effects that go in the unexpected direction, especially in cases where an ERP effect in this direction is related to *better* behavioral performance, may represent some other relationship with difference in mean amplitude for the violation and canonical conditions that is not captured by the ERP effects themselves as visible in a grand average, but is still meaningful for language ability.

4.9.3.1 The N400 Correlates with Auditory Working Memory and Phonological Segmentation

The N400 response was related to measures of memory. Lower scores on auditory memory, including sentence memory were associated with smaller N400s. The relationship between memory and N400 amplitude in these children speaks to the importance of memory demands in generating an N400 effect. The amplitude of the N400 reflects difficulty of integrating a newly heard lexical item into the previously heard sentence context. Ease of integration with a previous context likely interacts with an individual's memory ability such that children with better memory would be expected to have an easier time integrating new information. This would present as a less negative response to inconsistent semantic information than the response in children with poorer memory ability.

The difference in ERP amplitude after a semantic violation and ERP amplitude after correct semantics is also correlated with phonological segmentation abilities. This relationship likely exists because phonological segmentation is strongly supported by memory ability. Phonological segmentation and general auditory memory abilities were significantly correlated, $r = 0.38$, $p < 0.05$. It is possible that components of working memory ability that were captured by the measure of phonological segmentation are driving this correlation.

These results are consistent with previous work relating the N400 in older children to behavioral abilities. Wray & Weber-Fox, 2013 found that a more adult-like (smaller amplitude) N400 was associated with working memory ability. This study and the present study provide converging evidence for a relationship between working memory and the development of the cognitive processes that underlie semantic processing.

It is important to note that this correlation was driven not only by children who had a smaller N400 effect, but also children with a more *positive* response to anomalous as compared to canonical semantics showed better scores on behavioral assessments of language ability. Whether these children with relationships in the unexpected direction represent noise in the data or a real relationship that is not related to the N400 effect as it is understood in a grand average across participants remains an open question.

4.9.3.2 The Anterior Negativity Correlates with Phonological Blending and Memory

The earlier portion of the AN is related to word memory and phonological blending and the later portion of the AN is related to number memory forward. Better scores on word memory, number memory, and phonological blending were associated with a greater difference between response to a syntactic violation vs. correct syntax. This means that children who were better at these skills also had a more negative response to incorrect syntax as compared to their response to correct syntax. The ability to maintain individual words in short term memory likely supports a child's ability to determine if incoming syntactic information is consistent with a permissible syntactic structure or if the sentence has been rendered syntactically anomalous.

Previous ERP work that found a relationship between the presence of P600 vs. AN ERP effects and syntax mastery as measured behaviorally (Schipke et al., 2012) adds credence to this result. While all children showed a P600-like effect to incorrect syntax, only children who demonstrated better than chance performance in selecting the picture that matches the syntactic relationship described in a sentence showed an anterior negativity. It appear that results from this study and the present study implicate the AN as a marker of efficient, more mature language processing.

The relationship between the ERP response to syntax and phonological blending skills, but not other phonological skills, is more difficult to interpret. This effect may be an artifact of age-related correlations. Both the anterior negativity effect and phonological blending ability correlate with age, $r = -0.36$, $p < 0.5$ and $r = 0.40$, $p < 0.05$, respectively. It is likely that the correlation between phonological blending and the anterior negativity is driven by the fact that increased age leads to better phonological blending and a larger AN effect, and not a relationship between phonological blending ability and the AN that is at all independent of maturation.

As with measures of the N400 described above, some children show a relationship between response to syntactic anomaly vs. correct syntax that goes in the opposite direction of the negative effect visible in the grand average. However, the direction of effects present in all correlations between response to syntax and behavioral measures of language skill suggest that a more mature AN– a larger negativity to incorrect as compared to correct syntax – is associated with better language skill.

4.9.3.3 The Variability in the N1 Response Correlates with Receptive Language

Variability in magnitude of the N1 response to auditory onsets correlates with receptive language in general, including the processing of complex syntax (elaborated phrases) such that increased variability in the N1 response is related to better performance on these tasks. When balanced for acoustic properties, attended auditory onsets elicit a larger N1 response than ignored auditory onsets in five-year-old children (Astheimer & Sanders, 2012; Sanders & Zobel, 2012). It is possible that larger variability in the N1 response across a long period of time – which necessarily includes periods of time where attention lapses and is then reestablished – reflects a larger difference between the N1 response while attending to speech vs. the N1 response when inattentive. In other words, children with more variability in the N1 response may be doing a better job of using selective attention to facilitate auditory processing. This would then suggest an entirely logical relationship between greater auditory processing facilitation while attending and better processing of language.

Alternatively, these results may provide evidence that a more sensitive N1 allows for better language comprehension. More variability in the N1 response is likely reflecting more accurate tracking of the speech signal, which is highly variable. It appears that this more accurate tracking facilitates better receptive language skills.

4.9.3.4 Story Comprehension Correlates with Behavioral Measures of Phonological Processing and Mastery of Grammatical Morphemes

Accuracy of comprehension question responses was related to phonological processing, specifically word discrimination, and the ability to understand grammatical morphemes. The word discrimination task required children to listen to 32 pairs of words and determine if the word pair was two identical words or two different words. This task likely taps into not only phonological processing, but also basic low-level auditory processing and, given the large number of word pairs, ability to maintain sustained auditory attention. All of these factors appear to support the ability to comprehend a narrative and answer questions about that narrative. Unsurprisingly, receptive language, specifically of phrases and sentences that rely on knowledge of grammatical morphemes in order to support comprehension, also supports the ability to accurately answer questions about a narrative. The comprehension questions were designed to minimize working memory demands and tap into simple comprehension of the most recently heard sentences. A lack of correlation with any measures of memory suggest that this goal was achieved.

4.9.3.5 Lack of Relationship Between ERP Measures and Nonverbal Intelligence

Nonverbal intelligence was not correlated with any ERP measures or accuracy on comprehension questions. ERP measures capture variability in language ability that cannot also be explained by nonverbal intelligence. This makes ERPs uniquely suited to investigate processing specific to language, without contamination of intelligence and other unwanted factors that contribute to scores on behavioral measures like response selection and understanding of task instructions.

These results differ from what was found by Wray & Weber-Fox, 2013. This study not only found that nonverbal intelligence was uncorrelated with grammatical ability and verbal working memory as measured behaviorally, but that greater nonverbal intelligence was related to a more adult-like N400 and P600 (Wray & Weber-Fox, 2013). These findings may be explainable due to slight differences in behavioral task used to measure nonverbal intelligence – the present study used the PTONI while Wray & Weber-Fox used the Columbia Mental Maturity Scale. It is also possible that there is a differential reliance of nonverbal skills to support language ability across development, as these authors found a lack of relationship between behavioral measures of nonverbal intelligence and behavioral measures of language skill in older children than the population that participated in the present study. Relationships between nonverbal intelligence and ERP measures may have been present in the Wray & Weber-Fox dataset due to task differences between the ERP paradigm used with these children and the paradigm in the present study. While the present study asked questions about the plot, a behavioral task that likely encouraged comprehension, Wray & Weber-Fox asked children to monitor for incorrect sentences, likely encouraging metalinguistic processes. It is possible that asking children to monitor for errors engages the same types of skills that are necessary for children to complete other tasks where they provide specific judgment about the correctness of something. For example, a nonverbal intelligence task asking children to determine which image is an anomaly compared to the others that are present may engage these same processes, explaining the relationship found between them.

Results from the present study suggest that the right experimental design can decouple nonverbal intelligence ability from language processing as measured by ERPS.

Removal of these nonverbal factors may prove invaluable in detecting differences between groups of children diagnosed with different language disorders and also differences between individuals diagnosed with the same language disorder. These more specific measures may also explain why certain children benefit from one intervention while others do not, and eventually may be used to predict the kinds of interventions that are best suited for a child's specific language profile.

4.10 Conclusion

The present study represents the most extensive attempt at relating standardized behavioral measures of language and cognitive ability with ERP effects relevant to real-world language processing in five-year-old children. The results presented here provide evidence that electrophysiological measures provide information about language processing that is related to language comprehension as measured behaviorally in a way that suggests relevance to real language ability but also offers greater specificity. This can be concluded because 1) behavioral measures of language skill correlate with one another across domains and ERP measures of language processing do not, 2) behavioral measures of language skill correlate with nonverbal intelligence and ERP measures do not, 3) ERP measures correlate only with behavioral measures that seem to tap abilities that would be directly relevant to the processing necessary for the type of language that the ERP effect is elicited by. It appears that ERPs can provide added information about whether immaturity of individual language subsystems' on-line processing ability is part of a child's language deficit profile.

This seems particularly promising for the processing of syntax and the AN. Relationships between when this ERP effect emerges in development, whether it is long or short in duration, how large the ERP effect is on an individual level, and behaviorally demonstrated mastery of syntactic structure point to the idea that a larger, longer lasting AN to even simple syntactic anomalies is a sign of more adult-like syntactic processing. Results related to semantic processing show a less clear relationship. Smaller N400 amplitude is considered more adult-like and does relate to better language skill, but these relationships exists not just in children with smaller N400s, but in children with a seemingly opposite effect such that the response to correct semantics is more negative than the response to anomalous semantics. Further work needs to be done to determine whether these relationships are noise or a true effect that is unrelated to the N400 effect typically seen in adults and grand average effects across groups of children before this can be used as a marker of language subsystem maturity. Additionally, the age of emergence of a PMN needs investigation in order to hopefully use the strength of this effect as a maker of mature language processing.

For at least the case of syntactic processing, monitoring for changes in ERP response to violations vs. canonicals in a real speech context may be a useful marker of intervention success. A more adult-like AN after intervention would suggest that the intervention may be benefitting the child in a way that is generalizable to on-line syntactic processing. Of particular importance is the fact that these ERPs are elicited in a real communication context, suggesting that the difference in processing is generalizable to the child’s everyday life. Of course, these conclusions would be even stronger if a comprehensive developmental profile of the AN in real speech contexts is established to disentangle gains provided by the intervention per se vs. gains that naturally occur with age.

CHAPTER 5

CONCLUSION

5.1 Making Scientific Progress Through Real-World Relevance

The present study demonstrates that, 1) It is possible to elicit ERPs of language processing using an experimental design that is directly analogous to a real-world communication context, 2) Experimental results differ in important ways across experiments that do and do not encourage natural language processing, and 3) Using real-world experimental methods are particularly important to understand language development.

5.2 ERP Results from Real-World and Artificial Experimental Designs Differ

Results from adult participants show that, particularly for syntactic processing, experimental factors can entirely change the duration of ERP effects, such as the AN (Chapter 2.7.2.2), and the presence of others, such as the P600 (Chapter 2.7.2.2). Comparisons across adults and children, particularly for the N400 effect, show that differences between these two groups may disappear when appropriate experimental contexts are used (Chapter 3.7.1), calling into question previous work that has charted the development of ERP effects in response to less natural experimental protocols. Additionally, clear ERP effects, particularly in the case of the AN (Chapter 3.6.2.2) are visible in children in this natural experimental paradigm despite a lack of clear consensus on the nature of this effect across studies with less natural designs. Further, this design that was likely more familiar to children allowed for retention of 100% of the data, a rate that is dramatically higher than the retention rate of more unnatural tasks (Chapter 3.1).

5.3 Phonological Predictions Support Speech Comprehension

Chapter 2 represents the first successful attempt to identify an ERP response to phonological violations on suffixes in continuous speech. The presence of this effect represents an important contribution to our understanding of how phonological knowledge is used to understand real speech. This effect is evidence that adults use their knowledge of the phonological regularities of English to make specific predictions about upcoming phonemes (Chapter 2.7.2.3). Further work with children is necessary to determine whether children engage in the same kind of predictions, when in development this prediction strategy comes on-line, and what sort of cues children use to confirm or deny their predictions, including how this cue use changes across development.

5.4 Behavioral Measures of Language Ability are Not Specific Enough

Chapter 4.8.1 summarizes results that highlight the highly interrelated nature of commonly used language assessments. Specifically, scores on language tasks could not be disentangled from scores on nonverbal intelligence in the 41 typically developing children included in this sample. Scores across supposedly separate language domains, such as phonological processing and the ability to understand complex syntactic relationships, were also tightly correlated. While there are perfectly valid theoretical reasons for why these two abilities may be related, these strong correlations show that there is room to try to better isolate the component processes that differ between these two skills in order to better understand specifically what supports success in these domains.

5.5 ERP Measures of Language Processing are More Specific

Chapter 4.9.2 shows that ERP effects do not correlate with one another, and Chapter 4.9.3.6 shows that these ERP effects also do not correlate with nonverbal intelligence. Correlations do exist between some language related ERPS and language skill. In general, memory ability is related with both measures of semantic and syntactic processing. This suggests that memory may be a key component process involved in language comprehension that cannot be disentangled. The specificity achieved here opens the door for future work related to when component processes underlying language comprehension come on-line in development, which of these processes is key for specific language disorders, if particular deficits in processing as measured by ERPs could better predict who will benefit from an intervention, if success on interventions can be measured by differences in the ERP response to language, and if better connections can be made between these measures and genetic profiles, experiential factors, and neuroanatomy.

APPENDIX A

EXPERIMENTAL STIMULI

Semantic Experimental Sentences

Birthday Party Story.

The mail truck pulls up and I wave to the mailman/beak.
The mailman sees me at the window and honks his horn/party cheerfully.
Or maybe Mama ordered a birthday present/parrot for me.
A letter with a fancy green envelope/doctor catches my eye.
"Well," Mama says, "Remember Halloween when we got to dress up in costumes of different things or people/paws?
"So we get to carve pumpkins and eat candy/house?" I ask.
I also have a glass of orange juice/car.
Even a real stethoscope and his fancy white coat/battle!
She promises she will let me listen to her heartbeat/bookcase at the party.
I think his plan is an incredible idea/woman!
Then she walks to the bookcase/heartbeat.
Mama always has the best books/wings
We open the book to the first page/eagle, which has mermaids on it.
These are a cross between a fish and a beautiful woman/idea.
I look for a while and realize that they are half lion and half eagle/page!
The animal has beautiful broad wings and a big pointy beak/mailman.
It also has four paws/people.
We buy amazing things to make the wings/books for my griffin costume and to add to the eagle mask.
You are going to be …a beautiful princess/mirror?" He asks as he tickles me making me laugh.
"You look very powerful; I would never win a battle/coat against you!"
"You better start getting ready if you don't want to be late for the party/horn."
I turn around to see myself in the mirror/princess
Mama drives me to David's party and we finally arrive in front of his house/candy
I get out of the car/juice and walk into the house with Mama.
He has an eye patch and a squawking parrot/present on his shoulder!
"Happy birthday David, here is your gift/kitchen!"
Sonali's stethoscope and coat really make her look like a doctor/envelope.
I hear David's mother calling from the kitchen/ gift.

Pancake Story

I came straight home from school and I haven't had a snack / batter yet.
Mama says it is because I am a growing girl / pan.
She is sitting in her favorite chair /fridge reading a book.

Sometimes she'll read me stories/ ingredients as well.
I have started to read books too, but I need Mama's help with bigger words/ pancakes
Now she notices me and looks up from her book /mixer.
I want to eat some pancakes / words!"
We always use the same big plastic bowl / steam
Our cabinets are pretty tall so Mama has to fetch some of the ingredients/ stories for me.
She sets up the mixer/book.
I think I can remember that we need flour, eggs / cats and milk.
Every morning for breakfast I have my favorite cereal / counter.
Before I know it, the milk is tumbling out of the fridge / chair, bringing the egg carton down with it.
Mama scoops me up in her arms / butter and tells me everything is ok.
"For this recipe, we need to measure some flour/stove," Mama says.
She shakes it a bit so that the extra flour falls back into the bag / fruit.
She's really careful and checks that no eggshell got in the batter/snack.
Next, she adds baking powder and milk/table.
My favorite animals are cats/ eggs.
Before we can start cooking, we need to take out a pan/girl.
I pull a frying pan out of the cupboard/syrup.
She begins to melt some butter/arms in the frying pan.
"This is a very hot stove/ flour!"
They are in a place I can reach – the counter/cereal!
Our favorite thing to add to pancakes is fruit/bag.
As the pancake cooks, I start to see floating steam/bowl in the air
We set out our plates and then Mama places the stack of steaming pancakes in the middle of the table / milk.
She laughs, passes me the maple syrup / cupboard and then we both dig in.

Kitten Story

The sky is overcast with dense grey clouds /legs.
The dark clouds and rain make for a very scary looking sky/engine.
I stare out the window/face for a long time
I start to close my eyes/jackets.
I get to do the best job/deck in the world – I am an astronaut
They all run around looking for shelter and dart under a deck /job.
As he is running, he nearly takes a dip into a very deep looking puddle/store.
It seems so dangerous outside because of the terrible weather/den.
I hear very loud thunder/stray roaring from the sky.
I don't like the scary thunder and lightning/room
The person hops in the car and puts the key in the ignition, starting the engine / sky.
He is getting so miserable and wet from the never-ending rain/princess.
What if he is sick and needs to go to the veterinarian/telephone
He is probably hungry if he is a stray/thunder.
We can give him some clean water/family too!
We need to stay dry so we grab our boots and jackets/eyes.
The kitten notices me and rubs up against my legs /clouds .
His poor little whiskers/people are drooping

The kitty is very scared because he is in a strange place with strange people/whiskers.
My friend Sonali got a kitten for Christmas/tail last year.
All of a sudden, my cat Fluffy runs into the den/weather.
She is always acting so fancy so we call her the princess/rain of the house.
Mama hears the commotion and runs into the room/lightning
Fluffy moves her face / window closer to the kitten and sniffs.
He hops around and swishes his tail/Christmas.
To order the pizza, Mama needs to find her purse and get her telephone/veterinarian.
Mama promises we can go to the pet store/puddles tomorrow morning.
I am so happy that the kitten has joined our family/water !

Syntactic Experimental Sentences

Pancake story

The time is 4 o'clock pm and I feel(s) very hungry.
I like strawberries, but I want(s) something warm to eat.
I think(s) pancakes sound so yummy
She always looks so serious when she's reading but I know(s) it's just because she is so interested in the story.
I skip(s) over and give her a hug.
I start(s) getting out what we will need.
I love(s) when the bowl comes out because that means we are making something yummy!
I struggle(s) to reach one of the cupboards.
I look(s) up as she grabs the flour and the electric mixer.
I start(s) to giggle because I remember the last time we cooked we got flour all over the counter and floor
Suddenly I remember(s) that I can reach the milk all by myself.
I struggle(s) to open the fridge because the door is stuck.
I look(s) around in the fridge.
I grab(s) the front of the milk carton and pull.
I just want(s) to cry.
I feel(s) so relieved that she's not angry with me.
I lean(s) down to look at the carton on the ground.
I skip(s) around the kitchen.
I give(s) mama a big hug and then my stomach growls again
I give(s) them to her and watch as she carefully fills the cup with flour.
I love(s) this part.
The pan is very heavy, but I pick(s) it up and hand it to Mama.
I remember(s) the last time it happened and it was awful!
I lean(s) closer to get a better look.
I know(s) I can get those!
I grab(s) the strawberries and hand them to Mama.
I think(s) I can try!
Mama lets me choose the first pancake and I pick(s) the biggest one there.

Birthday Party Story

All of a sudden, I hear(s) some brakes squeal.
I wonder(s) if I will get a card from Grandma.
We put on our coats and I run(s) to the mailbox.
I think(s) I can make out some of the words.
I see(s) my name on it!
I say(s) I need some help and ask her to read it to me.
I love(s) dressing up for Halloween so much.

It is bedtime and I lay(s) in bed for a long time thinking about what I should dress up as.
Then, I ride(s) the bus with my friends Sonali and Andre.
I beg(s) to try out the stethoscope.
I wonder(s) what a heartbeat actually sounds like through a stethoscope.
I agree(s) that the bookworm is a better idea.
I need(s) to come up with something clever.
I explain(s) that I love they are because they are strong and heroic.
Just like how I want(s) to be when I grow up
I think(s) I like griffins.
“Mama, I want(s) to be a griffin!
I agree(s) with Mama, we need to pick a cool gift for David’s birthday party.
I ride(s) in the car with Mama to go to the toy store.
I beg(s) Mama to go to the craft store with me so we can buy things to make my costume spectacular
I hear(s) the front door open.
I run(s) to my dad and give him a big hug
“How do I look?” I say(s) to my parents.
I lay(s) in bed and wonder what my friends might think about my griffin costume.
I love(s) how I look in it.
I see(s) so many different costumes through the car window and I’m so happy to finally be here.
I need(s) to find David to give him his gift.
I explain(s) to them that I am a griffin, the most incredible creature of all.

Kitten Story

I look(s) out the window.
I hear(s) the raindrops tapping on the window.
I look(s) at the clock to check the time.
I look out the window and I spot(s) something moving.
I feel(s) so worried about this poor cat!
I think(s) the cat might be able to take shelter under a parked car.
I worrie(s) he will drown!
I glance(s) towards the umbrella lying on my windowsill.
I feel(s) so sad for him!

I decide(s) I will ask my Mama if we can do something.
I wonder(s) if we can bring the kitten inside
I step(s) onto our porch, never taking my eyes off the kitten.
I step(s) very slowly.. I pick(s) him up gently and look into his wide eyes.
First, I need(s) to calm him down.
I start(s) to pet him gently and offer him some milk.
I spot(s) something moving out of the corner of my eye.
I worry(s) she will be jealous of the poor kitten.
I hear(s) a gentle whimpering.
I begin(s) to cry.
I pick(s) up the mouse and wave it around in front of the kitten.
Now I begin(s) to laugh.
I start(s) to wonder if the kitten might like to stay with us forever.
I glance(s) out the window and notice it is still raining.
I need(s) to know he will stay safe."
I wonder(s) if we can have pizza.
I decide(s) to name our new kitten Pumpkin.
I think(s) we will all be very happy together.

Phonological Experimental Sentences

Pancake Story

It has been three whole hour/s/ since I ate lunch!
She tells me storie/s/ from when she was little and always hungry.
Her favorite food when she was younger was strawberrie/s/.
She sits with her ankle/s/ crossed on top of the foot rest.
She gets so absorbed in her storie/s/, that sometimes she doesn't hear me.
"It feels like I haven't eaten in day/s/!
Last time we used the bowl we made Christmas cookie/s/.
We went to visit her for 3 day/s/ for vacation so I brought her the cookies.
Grandma loves when we bring her cookie/s/.
My favorite pies are the ones with apple/s/ and cinnamon.
She reaches to the top of the cabinet to get the beater/s/ for the mixer.
Then she walks to the laundry room to get us some clean dishtowel/s/.
I pull hard on the handle/s/ and the fridge pops open.
My ankle/s/ wobble.
She laughs and says, "That's why I brought the dishtowel/s/."
Then we clean up the puddle/s/ of egg with the towels.
Can you hand me that measuring cup and one of the spoon/s/?"
The beater/s/ spin fast to turn everything into a smooth white batter.
I know I can usually pick up bigger pans by the handle/s/.
Mama says that without the butter the pancakes stick and then the bottom/s/ will burn.
I watch as Mama pours the batter into the pan and bubble/s/ begin to form
"Let's add some strawberrie/s/!
Last time we had cinnamon apple/s/ on our pancakes and I loved it.

She says you can tell when a pancake needs to be flipped because it will have lots of bubble/s/.
We don’t want to burn the bottom/s/!
By now it’s been four hour/s/ since I last ate and my stomach is growling.
We set the table with forks, spoon/s/, and knives.
I pour some huge puddle/s/ of syrup onto my plate and dig in.

Birthday Party Story

I grab all the letters/s/ and look at them.
I also love partie/s/.
Her dad is a doctor and she gets to borrow all of the things real doctor/s/ wear.
“She helped me go online to look at pictures of worm/s/ to decide what the costume should look like.”
I really love animal/s/, so I think I want my costume to be an animal.
I think eagle/s/ are so graceful.
But lion/s/ are so strong.
I tell my Mama about my two idea/s/.
“It’s all about mythical creature/s/.”
“Don’t they look like such pretty ladie/s/?
We could make you a tail and add some sparkly gem/s/,”
Let’s look at some more creature/s/.
The next page has pictures of beautiful unicorn/s/.
These are magical horse/s/ that can fly.
“Look at how incredible their colorful horn/s/ look,” Mama says
I have so many idea/s/ for what to get David. I want to make the wings sparkly with gem/s/.
I am happy to get to be as strong and heroic as lion/s/.
Being able to wear wings like majestic eagle/s/ is just so exciting.
I am never late to partie/s/!
She joins the other ladie/s/ who are chatting and watching TV.
I see a few unicorn/s/ running around playing.
They really do look like colorful and magical horse/s/.
I love how pretty their horn/s/ look.
They are one of the few guests who are not dressed as animal/s/.
She has a clipboard with many letter/s/ on it.
David says she would fit right in with all the doctor/s/ at the hospital.
He is dressed as a book covered with fake worm/s/!

Kitten Story

The wheel/s/ crunch over moon rocks.
I love kitten/s/ so much!
The kitten is dodging puddle/s/ while he runs.

Someone is running towards the car, jingling their key/s/.
I can hear the person stepping on puddle/s/.
The car pulls away slowly and the kitten stays safe, untouched by the car’s big wheel/s/.
His little paw/s/ are soaked in mud.
I feel tear/s/ streaming down my face.
We can also warm him up with some towel/s/.
Maybe we can even give him big bowl/s/ of food.
Mama looks at me with a huge smile on her face, her eye/s/ crinkling in the corners.
Mama grabs the key/s/.
I know animal/s/ can be very easy to startle.
His claw/s/ are not even out.
His paw/s/ are soaking wet.
His ear/s/ are quite wet.
Mama helps me warm him up with some towel/s/.
Fluffy used to live in the alley/s/ around our neighborhood before Mama rescued her.
She looked just as pitiful as the kitten/s/ that were outside in the rain earlier.
I can see that Fluffy has her claw/s/ out.
Her ear/s/ relax as she realizes the intruder is only a tiny, frightened kitten.
I realize the kitten and Fluffy will get along fine and I dry my tear/s/.
Mama looks at my worried eyes/s/.
She knows I love animal/s/.
She hands me two bowl/s/, one for Fluffy and one for my new kitten.
I want to take this kitten to play around the alley/s/ with Fluffy.

APPENDIX B

COMPLETE STORIES

Complete Stories

This appendix includes the stories in their entirety. Superscript numbers indicate which experimental group heard the error version of the sentence. Comprehension questions that were asked by the research assistant during the EEG session are in italics. Following each question, answer choices are in the following order: correct answer, plausible answer, familiar answer, nonsense answer.

Pancake Story

It is late in the afternoon and I was at school all day. It was raining earlier today and I got to jump in all the puddles. *What did she play in? Puddles;Trees;Sun;Vase* I look at the clock to check what time it is. I just learned how to read the hands on the clock this past school year. The time is 4 o'clock pm and I feel(s) very hungry[1]. It has been three whole hour/s/ since I ate lunch![2] It is a Friday and I just got off the school bus. *What did she just get off of? School Bus; Rollercoaster; Clock; Lion* I came straight home from school and I haven't had a snack / batter yet[2]. I am hungry all the time. The other night I ate two whole pieces of pizza. *What did she eat the other night? Pizza; Bread; Rain cloud; Money* Mama says it is because I am a growing girl / pan[2]. She jokes that I could eat an entire cake and still be hungry. She tells me storie/s/ from when she was little and always hungry[1]. Her favorite food when she was younger was strawberrie/s/[2]. I like strawberries, but I want(s) something warm to eat[1]. I think(s) pancakes sound so yummy[2]. I decide to ask Mama if we can make them. *What does she want to eat? Pancakes; Banana; School Bus; High heeled shoe*

I go into the living room to find Mama. She is sitting in her favorite chair /fridge reading a book[1]. When she reads, she puts on her reading glasses. *What does Mama have on? Glasses; Coat; Pizza; Leaf* She sits with her ankle/s/ crossed on top of the foot rest[1]. She doesn't look up when I come in. She gets so absorbed in her storie/s/, that sometimes she doesn't hear me[2]. She always looks so serious when she's reading but I know(s) it's just because she is so interested in the story[2]. Mama just loves to read books. *What is Mama doing? Book; Television; Puddle; Snowflake* Sometimes she'll read me stories/ ingredients as well[1]. I have started to read books too, but I need Mama's help with bigger words/ pancakes[2]. I can read a book about the tooth fairy all by myself though. I love fairies. I even dressed up as one for Halloween last year. *What did she dress as for Halloween? Fairy; Dog; Strawberries; Collar*

I call out to Mama, but she doesn't answer. I skip(s) over and give her a hug[2]. Now she notices me and looks up from her book /mixer[1]. "Hi Mama," I say. "It feels like I haven't eaten in day/s/![1] I want to eat some pancakes / words!"[1] She smiles and says "Of course!". We head to the kitchen. *Where are they going? Kitchen; Church; Chair; Nail* I am finally big enough that I get to help make pancakes with Mama. I've watched her do it before, so I know just where to start.

I start(s) getting out what we will need[2]. First I get out our red checkered oven mitts. *What did she get out? Oven mitts; Chef's hat; school bus; crying face* We always use the same big plastic bowl / steam[1]. It's blue and the biggest bowl we have. I love(s) when the bowl comes out because that means we are making something yummy![2] Last time we used the bowl we made Christmas cookie/s/[2]. *What did they make last time? Cookies; Sandwich; Book; Dog* We made way too many so I gave the extras to Grandma. We went to visit her for 3 day/s/ for vacation so I brought her the cookies[1]. She was so happy! Grandma loves when we bring her cookie/s/[1]. She says that I am the best baker! She lets me help her make pies. *What does she help make? Pie; Cake; Strawberry; Bull* My favorite pies are the ones with apple/s/ and cinnamon[2].

I want to help with making the pancakes. Maybe I can help Mama get the rest of the things we need. I struggle(s) to reach one of the cupboards[1]. I am too short! After all, I am still growing. Our cabinets are pretty tall so Mama has to fetch some of the ingredients/ stories for me[1]. I look(s) up as she grabs the flour and the electric mixer[1]. She reaches to the top of the cabinet to get the beater/s/ for the mixer[1]. She sets up the mixer/book[2]. Then she walks to the laundry room to get us some clean dishtowel/s/[1]. *What did Mama go get? Towel; Apple; Bowl; Smiling face* "Just in case we make a mess," she says. I start(s) to giggle because I remember the last time we cooked we got flour all over the counter and floor[1]. It was when we tried to make a birthday cake for Mama's birthday. Mama said that it didn't matter because she liked the ice cream better. *What did Mama like better? Ice Cream; Cat; Apple; Snowflake*

We need to find some more ingredients for the pancakes. I think I can remember that we need flour, eggs / cats and milk[1]. Suddenly I remember(s) that I can reach the milk all by myself[1]. Every morning for breakfast I have my favorite cereal / counter[1]. Sometimes when Mama's busy I have to get the milk all by myself. I struggle(s) to open the fridge because the door is stuck[2]. I pull hard on the handle/s/ and the fridge pops open[1]. I look(s) around in the fridge[1]. I have to stand on my tippy-toes but I think I can reach the milk. *What is she trying to reach? Milk carton; mailbox; pancake; raincloud* My ankle/s/ wobble[2]. I grab(s) the front of the milk carton and pull[1]. It seems stuck a bit, so I pull harder. Before I know it, the milk is tumbling out of the fridge / chair, bringing the egg carton down with it[2]. The eggs smash everywhere. I wanted to do it all by myself, but I messed up! I just want(s) to cry[2]. *How does she feel? Face – crying; Face – happy; Milk Carton; Clock* The eggs are scattered across the floor. There were only six eggs left. If all the eggs are broken, we can't make pancakes. Mama scoops me up in her arms / butter and tells me everything is ok[1]. I lean into her and hug her. I'm so disappointed I broke the eggs. She laughs and says, "That's why I brought the dishtowel/s/."[1] I look up to see her face. She's not mad. I feel(s) so relieved that she's not angry with me[1]. I lean(s) down to look at the carton on the ground[2]. When I look more closely I notice something. "Look! One of the eggs is not broken!" *What almost got broken? Egg; Vase, Towel, Leaf* I am so happy I can still have my favorite food. I skip(s) around the kitchen[2]. Mama joins me, waving the dishtowels in the air and we laugh. Then we clean up the puddle/s/ of egg with the towels[2]. I give(s) mama a big hug and then my stomach growls again[1]. Mama hears it and immediately we jump back into making the pancakes.

"For this recipe, we need to measure some flour/stove," Mama says[1]. "We need one cup of flour. Can you hand me that measuring cup and one of the spoon/s/?"[2] I give(s) them to her and watch as she carefully fills the cup with flour[2]. She shakes it a bit so that the extra flour falls back into the bag / fruit[1]. She then hands me the measuring cup. I dump the flour into the bowl. *What are they using? Bowl; Pencil and Paper; Book; Window* Mama cracks the egg into the bowl. She's really careful and checks that no eggshell got in the batter/snack^1. Next, she adds baking powder and milk/table^2. Now it's time to use the mixer. I love(s) this part^2. Whenever Mama gets out the mixer I get excited. It makes a wonderful sound that reminds me of a cat purring. *What does the mixer remind her of? Kitten; Chef's hat; School Bus; Cute worm* My favorite animals are cats/ eggs^1. Mama carefully plugs the mixer in and turns it on. The beater/s/ spin fast to turn everything into a smooth white batter^1.

Now it's time to cook the pancakes! Before we can start cooking, we need to take out a pan/girl^1. That's one more thing I can do all by myself! I pull a frying pan out of the cupboard/syrup^2. I know I can usually pick up bigger pans by the handle/s/^{2}. The pan is very heavy, but I pick(s) it up and hand it to Mama^1. *What did she give Mama? Frying Pan, Gift, Pancake, Rain Cloud* She thanks me, puts the pan on the stovetop, and turns on the heat. She begins to melt some butter/arms in the frying pan^2. Mama says that without the butter the pancakes stick and then the bottom/s/ will burn^2. There is nothing worse than burnt pancakes. They get all charred and black on the bottom and the kitchen starts to smell funny! I remember(s) the last time it happened and it was awful^2!

I watch as Mama pours the batter into the pan and bubble/s/ begin to form^1. Sometimes she'll let me make funny shapes with the batter. My favorite shape to make is a heart. *What shape does she like to make? Heart; Snowflake; Egg; Birthday Party Scene* Then she flips the pancake. It is perfect and golden brown. I lean(s) closer to get a better look^2. "Be careful," Mama says. "This is a very hot stove/ flour!^{1}" We wait a few more minutes for the other side to cook. I watch the clock to see how long it takes. *What is she watching? Clock; TV; heart; mailbox.* I'm proud to show Mama that I can tell time now. When the pancake is done, she flips it onto a plate. *Where did they put the pancake? Plate, Table, Book, Nail (as in hammer and nail).*

"I know what we should do!" Mama says. "Let's add some strawberrie/s/^{1}! You think you can grab those for us?" I know(s) I can get those^2! They are in a place I can reach – the counter/cereal^2! I grab(s) the strawberries and hand them to Mama^2. *What did she grab? Strawberry, Sandwich, Towel, Sleeping Face* . I am so excited for the strawberries! Our favorite thing to add to pancakes is fruit/bag^2. Last time we had cinnamon apple/s/ on our pancakes and I loved it^1. *What fruit did they have last time? Apple, Grapes, Milk carton, House* Mama slices the strawberries and arranges them on the pancake. Next. Mama melts more butter and pours some more batter into the pan. She says you can tell when a pancake needs to be flipped because it will have lots of bubble/s/^{2}. As the pancake cooks, I start to see floating steam/bowl in the air^1. She flips the pancake after a few minutes. *What did Mama flip? Pancake, Hour Glass; Milk Carton; Sleeping Face* We don't want to burn the bottom/s/^{2}! The pancake is done and it is time to eat. By now it's been four hour/s/ since I last ate and my stomach is growling^2. Something still has to be done though. "We still need to set the table!," Mama says. "Do you think you can do that?" I think(s) I can try^2! *What are they going to do? Fork and knife with plate in the middle, Television, Egg, Bow*

We set the table with forks, spoon/s/, and knives^2. Mama grabs some fancy cloth napkins from the cupboard. "Why not?" she says. Mama shows me a way to fold the napkins so that they look like pretty triangles. *What did they fold? Napkins; Shirt; Bowl; Car* We set out our plates and then Mama places the stack of steaming pancakes in the middle of the table / milk^2. My stomach growls. Mama lets me choose the first pancake and I pick(s) the biggest one there^2. She laughs, passes me the maple syrup / cupboard and then we both dig in^1. I pour some huge puddle/s/ of syrup onto my plate and dig in^2. I am so happy that I got to help and eat pancakes for dinner. *How does she feel? Happy face; Sad Face; Strawberry;* Bread.

Birthday Party Story

I am in the living room looking out the window and daydreaming. All of a sudden, I hear(s) some brakes squeal^1. The mail truck pulls up and I wave to the mailman/beak^1. It's time to get the mail! *What is it time to do? Mailbox with mail in it, Bed, Man, Towel* The mailman sees me at the window and honks his horn/party cheerfully^2. I am so excited to see if he brought anything for me. I wonder(s) if I will get a card from Grandma^1. Last time the card had $5 in it! *What was in the card last time? Money, Letter, Mailbox with mail in it, Shoe* Or maybe Mama ordered a birthday present/parrot for me^1. "Mama! Mama!" I say. "Let's go get the mail!"

It's really cold outside, so we need to bundle up. We put on our coats and I run(s) to the mailbox^1. *What are they wearing? Coat, High heeled shoe, Window, Toy Mouse* I grab all the letters/s/ and look at them^1. I think(s) I can make out some of the words^1. A letter with a fancy green envelope/doctor catches my eye^1. Wait! I see(s) my name on it^2! "Mama?" I ask, "Is this for me?" "Yes, I think it is!" she says. I say(s) I need some help and ask her to read it to me^2. "It's an invitation!" she says. "You are invited to a David's birthday party" *Where is she invited? Birthday party scene/ Church/ Envelope/ Dog* It's a costume party!" "What is a costume party?" I ask. "Well," Mama says, "Remember Halloween when we got to dress up in costumes of different things or people/paws^2? It's like that. You can be anything you want." "So we get to carve pumpkins and eat candy/house^1?" I ask. "I love making jack-o-lanterns!" *What does she love? Jack-o-lantern, Pizza, Coat, Trees* "No," mama says, "just the costume part." I love(s) dressing up for Halloween so much^2. I also love partie/s/^{1}. I am very excited to get to go to something that is both. *How does she feel? Smiley face, Sleeping face, Mailbox with mail in it, Sandwich*

It is bedtime and I lay(s) in bed for a long time thinking about what I should dress up as^1. When I wake up, Mama has breakfast ready for me. It is a waffle, my favorite! *What did she have for breakfast? Waffle, Eggs, Money, Bowl.* I also have a glass of orange juice/car^2. When I am done eating, I help Mama with the dishes. *What are they washing? Dishes, Car, Envelope, Kitten* Then, I ride(s) the bus with my friends Sonali and Andre^1. We are so excited about the party and start taking about it right away! Sonali says she is going to go as a doctor. *What is Sonali going to be? Doctor, Fairy, Jack-o-Lantern, Frying pan.* Her dad is a doctor and she gets to borrow all of the things real doctor/s/ wear^2. Even a real stethoscope and his fancy white coat/battle^2! I beg(s) to try out the stethoscope^1. She promises she will let me listen to her heartbeat/bookcase at the party^2. I wonder(s) what a heartbeat actually sounds like through a stethoscope^1. I think Andre has some great ideas for his costume as well. At first, he wanted to be a cat because he loves them so much. But he loves to read even more. *What does Andre love to do? Book, Television, Mailbox with mail in it, Milk carton* He decided to be a bookworm. I agree(s) that the bookworm is a better idea^1.

"My mom is making the costume," he says. "She helped me go online to look at pictures of worm/s/ to decide what the costume should look like^2." *What pictures did they look at? Worms, Clock, Man, Crying face.* I think his plan is an incredible idea/woman^2! I need(s) to come up with something clever^1. I was a fairy for Halloween, but I want to be something different for the party. *What was she for Halloween? Fairy, Unicorn, Waffle, High Heeled shoe*

I really love animal/s/, so I think I want my costume to be an animal^{2}. I think eagle/s/ are so graceful^{1}. But lion/s/ are so strong^{2}. *What animal does she think is strong? Lion, Bull, Birthday party scene, snowflake* It is so hard to choose! I tell my Mama about my two idea/s/^{2}. I explain(s) that I love they are because they are strong and heroic, just like how I want to be when I grow up^{1}. She smiles at me and gives me a hug. Then she walks to the bookcase/heartbeat^{1}. "I have a book you will like!" she says. *What does Mama have? Book, Towel, Doctor, Cloud with rain drops* "It's all about mythical creature/s/^{2}." Mama always has the best books/wings^{2} "Will you read it to me?!" I ask. "Of course," she says. We open the book to the first page/eagle, which has mermaids on it^{1}. These are a cross between a fish and a beautiful woman/idea^{1}. "Don't they look like such pretty ladie/s/^{2}? We could make you a tail and add some sparkly gem/s/," Mama says^{1}. "Yes," I say, "but I want to be more than beautiful. I want to be strong too!" "That's my girl!" Mama says. Let's look at some more creature/s/^{2}. The next page has pictures of beautiful unicorn/s/^{2}. *What is on the page? Unicorn, Dog, Lion, Kitchen scene* These are magical horse/s/ that can fly^{1}. Each one has a single horn coming out of its head. They also have beautiful feathery wings. They seem very happy, flying over the clouds. *Where are the unicorns flying? Cloud, Trees, Envelope, Rain boots* "Look at how incredible their colorful horn/s/ look," Mama says^{1}. "How about being a unicorn?" "Well," I say, "I don't just want to look incredible, I want to be incredible."

Mama smiles wide and turns the page. This page is covered with amazing looking creatures. I look for a while and realize that they are half lion and half eagle/page^{2}! My two favorite animals! "What is this?" I ask. The animal has beautiful broad wings and a big pointy beak/mailman^{2}. It also has four paws/people^{2}. "It's called a griffin," says Mama. A griffin? I think(s) I like griffins^{1}. "Mama, I want(s) to be a griffin^{1}! They seem strong and incredible and beautiful too." "Great!" Mama says. "We just need one more thing --- we need to pick a gift to bring to the party!" *What do they need? Gift, Vase, Eagle, Sleeping face.*

I agree(s) with Mama, we need to pick a cool gift for David's birthday party^{1}. "Let's go to the toy store, Mama!" I ride(s) in the car with Mama to go to the toy store^{1}. I have so many idea/s/ for what to get David^{2}. Eventually Mama and I find a big remote-control race car for him. *What gift did they buy for him? Race car, television, lion, kitchen scene.* I beg(s) Mama to go to the craft store with me so we can buy things to make my costume spectacular^{1}. It is the only thing I can think about. I can't wait for my friends to see me wearing my costume. We buy amazing things to make the wings/books for my griffin costume and to add to the eagle mask^{2}. I want to make the wings sparkly with gem/s/^{2}. Mama and I start to work on creating the wings for my griffin costume. *What are they working on making? Wings, Nose, Race Car, Chair.*

I hear(s) the front door open^{2}. "Guess who's home!" I run(s) to my dad and give him a big hug^{1}. "Dad, guess what I'm going to be tomorrow!" I shout with excitement. "Let's see. You are going to be …a beautiful princess/mirror^{2}?" He asks as he tickles me making me laugh. *How does her dad make her feel? Face - happy, face - crying, worms (cute), shoe.* "No dad, I'm going to be a griffin!" I tell him. "That is a great costume idea!" My dad exclaims. "A griffin is such an incredible and strong creature. Just like you!"

I go grab the finished wings and try them on. “How do I look?” I say(s) to my parents[2]. “They look amazing!” my mom says. “You look very powerful; I would never win a battle/coat against you[2]!” my dad tells me. We all laugh. I hug both of my parents and then start getting ready for bed. I lay(s) in bed and wonder what my friends might think about my griffin costume[2]. *Where is she? Bed, Church, Doctor, Heart.* I am happy to get to be as strong and heroic as lion/s/[1]. Being able to wear wings like majestic eagle/s/ is just so exciting[2]. My costume is perfect for me. I cannot sleep because I am so excited about the party. Eventually, while imagining how amazing the party will be, I fall asleep.

The next day I wake up and run to my mama to hug her. “Well good morning sweetie! I made you some eggs for breakfast.” *What is for breakfast? Eggs, Milk carton, Eagle, Puddle*. “Mama, you really are the best. Thank you so much for helping me be a griffin for the party. I really hope everyone likes it,” I tell her. “ I am sure everyone will think your costume is amazing,” she says. “You better start getting ready if you don’t want to be late for the party/horn[2].” I am never late to partie/s/[1]! I run upstairs and put on my griffin costume. I turn around to see myself in the mirror/princess I love(s) how I look in it[2].

Now it is time to get in the car. *Where are they? Car, Kitchen scene, book, nail* Mama drives me to David’s party and we finally arrive in front of his house/candy[1]. “Are you ready?” My mama asks me. “More than ever!” I say. I see(s) so many different costumes through the car window and I’m so happy to finally be here[2]. I get out of the car/juice and walk into the house with Mama[1]. She joins the other ladie/s/ who are chatting and watching TV[2]. *What are the ladies doing? TV, Sleeping face, Mailbox with mail in it, Leaf.* I need(s) to find David to give him his gift[1]. While looking around I see so many different costumes. I see a few unicorn/s/ running around playing[2]. *What does she see playing? Unicorns, Dog, Gift, Nail.* They really do look like colorful and magical horse/s/[1]. I love how pretty their horn/s/ look[2]. I walk through the house and find David dressed as a pirate. He has an eye patch and a squawking parrot/present on his shoulder[2]! “Happy birthday David, here is your gift/kitchen[2]! I love your pirate costume,” I say when I see him. *What is David dressed as? Pirate, fairy, Jack-o-lantern, house.* “Thank you so much!” he says.

I see Sonali and Andre walking toward us. They are one of the few guests who are not dressed as animal/s/[1]. Sonali’s stethoscope and coat really make her look like a doctor/envelope[2]. She has a clipboard with many letter/s/ on it[2]. David says she would fit right in with all the doctor/s/ at the hospital[2]. Andre really was a book worm. He is dressed as a book covered with fake worm/s/[1]! He is even wearing fake glasses *What is Andre wearing? Glasses, Coat, Present, Milk carton* “You’re here!” Sonali exclaims. “Your costume looks amazing, but what are you?” David asks me. I explain(s) to them that I am a griffin, the most incredible creature of all[1]. I hear David’s mother calling from the kitchen/ gift[1]. It is time to sing Happy Birthday and eat cake! *What is it time for? Birthday cake, Bed, Eggs, Rain cloud.*

Kitten Story

I love sitting in my room and listening to the rain. I look(s) out the window[1]. It is pouring heavily and rain is fascinating to me. I hear(s) the raindrops tapping on the window[1]. The sky is overcast with dense grey clouds /legs[2]. The sun is completely gone, hidden behind the clouds and pouring rain. *What is the weather like? -Thundercloud with* *rain, -Snowflake, -Window, - Shoe* I look(s) at the clock to check the time^{2}. The big hand and the little hand are nearly on the 12. Even though it is almost noon, it is very dark outside. The dark clouds and rain make for a very scary looking sky/engine^{2}.

I stare out the window/face for a long time. I feel like the sound of the rain will put me to sleep! I start to close my eyes/jackets^{2}. I nod off and begin having a fantastic dream. *What is she doing? Sleeping Face, Party scene, Clock, Trees* In this dream I am finally a grown up. I get to do the best job/deck in the world – I am an astronaut^{1}! I am driving the rover on the surface of the moon. The wheel/s/ crunch over moon rocks^{2}. I could dream about the moon all day long. *What is she dreaming about? Moon, Fairy, Clouds, Bowl* All of a sudden, I hear a loud crash. It is thunder. I jolt awake. I look out the window and I spot(s) something moving^{1}. It is some little kittens. *What animal does she see? –Kitten, - Dog, - Raindrops, - Apple* I love kitten/s/ so much^{1}! They all run around looking for shelter and dart under a deck /job^{2}. One poor kitten is left behind. Instead of running with the others, the kitten is chasing something! He is playing with a leaf blowing in the wind. *What is the kitten playing with? – Leaf – Toy mouse – Window – Crying face* All of a sudden he stops playing and looks around. All of the other kittens are gone! He is all by himself. He desperately searches for shelter from the relentless rain. I feel(s) so worried about this poor cat^{1}! I think(s) the cat might be able to take shelter under a parked car^{2}. Yes, he's running for it! The kitten is dodging puddle/s/ while he runs^{2}. As he is running, he nearly takes a dip into a very deep looking puddle/store^{2}. I worrie(s) he will drown^{2}! He scampers under the car and is able to hide from the downpour. *Where does the kitten hide? –Car, -House, -Puddle, - Man*

I breathe a sigh of relief because the kitten seems safe. Under the car, I see the kitten laying on the ground, away from the rain. Even though he has shelter, I still worry for the kitten. It seems so dangerous outside because of the terrible weather/den^{1}. I hear very loud thunder/stray roaring from the sky^{2}. The sky lights up as lightning flashes. *What does she see in the sky now? -Lightning, -sunshine, -wind, -the kitten* I don't like the scary thunder and lightning/room^{1}. I wonder if the kitten is afraid like I am. I just want to make sure he is safe!

Someone is running towards the car, jingling their key/s/^{1}. It looks like the kitten won't be staying dry for long. I can hear the person stepping on puddle/s/^{1}. The person hops in the car and puts the key in the ignition, starting the engine / sky^{2}. He's going to move his car, and the kitten is still underneath! I hope he doesn't get hurt! The car pulls away slowly and the kitten stays safe, untouched by the car's big wheel/s/^{1}. Rain starts pouring down onto the poor thing again. *What is happening to the kitten now? –Kitten under rain, -Kitten eating, -Car, -Egg* I glance(s) towards the umbrella lying on my windowsill^{2}. I wish I could share it with the kitten! I think about running the umbrella down to the kitten, but I'm afraid Mama wouldn't like that very much. *What does she want to bring down to the kitten? -An umbrella, -A flashlight, -toy mouse -unicorn*

I just can't watch the poor thing suffer anymore. His little paw/s/ are soaked in mud^{1}. He is getting so miserable and wet from the never-ending rain/princess^{2}. The poor kitten runs to hide under another car. What if this car moves too? I feel(s) so sad for him^{1}! I feel tear/s/ streaming down my face^{2}. I decide(s) I will ask my Mama if we can do something^{1}. I head downstairs to try to find her. She is in her favorite chair watching TV. *What is Mama doing? TV, Pencil and Paper, Kitten, Lion* I walk up to her and she smiles at me. I tell her about the kitten I have been watching. I wonder(s) if we can bring the kitten inside^{1}. He really needs someone to be kind to him right now. What if he is sick and needs to go to the veterinarian/telephone^{1}? Even if the rain stops, he still might not be safe. I am worried dogs will chase him! *Who does she think is going to chase the cat? –Dog – Man – Window – Sandwich* We can also warm him up with some towel/s/[2]. Maybe we can even give him big bowl/s/ of food[1]. He is probably hungry if he is a stray/thunder[1]. We can give him some clean water/family too[2]! Mama looks at me with a huge smile on her face, her eye/s/ crinkling in the corners[2]. "Of course, sweetheart," she says. "Let me find the umbrella". *What does Mama want to find? Umbrella, High Heeled Shoe, Lightning, Church*

We need to stay dry so we grab our boots and jackets/eyes[2]. Mama grabs the key/s/[2]. I open the door, and I can barely see because it is raining so hard. I step(s) onto our porch, never taking my eyes off the kitten[2]. "Watch out," Mama says. "It's slippery out here!" I step(s) very slowly[1]. I don't want to fall! My rain boots squeak on the damp wood. *What is she wearing on her feet? – Rain boots – High heeled shoe – Umbrella – Snowflake* I creep up on the kitten very slowly. I know animal/s/ can be very easy to startle[2]. I really don't want to scare him! The kitten notices me and rubs up against my legs /clouds[2]. His claw/s/ are not even out[1]. It seems this kitten is very friendly. I guess I didn't have to worry about scaring him after all. I pick(s) him up gently and look into his wide eyes[2]. *What did she pick up? –Kitten –Toy mouse –Rain –Window*. His paw/s/ are soaking wet[2]. His poor little whiskers/people are drooping[1]. I hope he doesn't get sick.

Mama and I head back to the house. I am so excited to get to play with this kitten! First, I need(s) to calm him down[1]. The kitty is very scared because he is in a strange place with strange people/whiskers[2]. His ear/s/ are quite wet[1]. Mama helps me warm him up with some towel/s/[2]. At first he looks very nervous. I start to sing to him and he relaxes. He looks very sleepy, all wrapped up on the couch. I start(s) to pet him gently and offer him some milk[1]. *What did she give the kitten? – Milk carton – Toy mouse – Fish – Man.* I can tell he is happy because he has started to purr. Maybe he would be happy living with me? I thought I wanted to ask for a puppy for my birthday this year, but now I think I would rather have this kitten. He is just so sweet, and he needs a home. My friend Sonali got a kitten for Christmas/tail last year[2]. Maybe I could ask her what kittens need. I've only ever had grown up cats.

I spot(s) something moving out of the corner of my eye[2]. All of a sudden, my cat Fluffy runs into the den/weather[1]. Fluffy used to live in the alley/s/ around our neighborhood before Mama rescued her[2]. She looked just as pitiful as the kitten/s/ that were outside in the rain earlier[2]. Mama rescued her and nursed her back to health Now Fluffy has beautiful long fur and wears a pretty pink bow. *What is Fluffy wearing? –Bow – Collar – Rain boots – Apple* She is always acting so fancy so we call her the princess/rain of the house[2]. I worry(s) she will be jealous of the poor kitten[1]. She hops up on the couch and begins to hiss. Mama hears the commotion and runs into the room/lightning[2]. I hear(s) a gentle whimpering[2]. The kitten is getting upset all over again! I begin(s) to cry[2]. I just feel so sad for this poor kitten! *How does she feel? – Crying face – Happy face – Bow – Bread* I can see that Fluffy has her claw/s/ out[1]. Mama rushes over to grab Fluffy and get her away from the kitten. At the last second, she stops. Fluffy moves her face / window closer to the kitten and sniffs[1]. Her ear/s/ relax as she realizes the intruder is only a tiny, frightened kitten[1]. Fluffy just can't stay angry any longer. She decides to bring over her favorite toy mouse and share it with the kitten. *What did Fluffy give the kitten? – Toy mouse – Bow – rain cloud – Man* I realize the kitten and Fluffy will get along fine and I dry my tear/s/[1]. Maybe the kitten wants to play. I pick(s) up the mouse and wave it around in front of the kitten[1]. He starts batting at the mouse. He hops around and swishes his tail/Christmas[1]. He is just so cute! Now I begin(s) to laugh[2]. I feel super happy now! *How does she feel? -Happy face, -Crying face, -Dog, -School Bus*

I start(s) to wonder if the kitten might like to stay with us forever[1]. Fluffy would love another friend around the house! I glance(s) out the window and notice it is still raining[1]. "Mama?," I ask. "Can we keep this kitten? I don't want him to have to go back outside. I need(s) to know he will stay safe[1]." She smiles at me and gives me another dry towel. *What did Mama give to her? – Towel –Fish – Milk – Sleeping face* Mama looks at my worried eyes/s/[1]. "I think that would be a great idea," she says. She knows I love animal/s/[1]. She hands me two bowl/s/[1], one for Fluffy and one for my new kitten. "Go grab some cat food from the kitchen!" she says. "I think it's time we all ate." I wonder(s) if we can have pizza[2]. I ask and Mama says yes! *What will Mama serve for dinner? – Pizza – Bowl –Sandwich –Pencil and Paper* To order the pizza, Mama needs to find her purse and get her telephone/veterinarian[2]. I decide(s) to name our new kitten Pumpkin[2]. I want to take this kitten to play around the alley/s/ with Fluffy[1]. First, I need to buy him a collar so everyone knows he belongs to someone. *What does she need? Collar, Backpack, Rain cloud, Pancakes* Mama promises we can go to the pet store/puddles tomorrow morning[1]. I am so happy that the kitten has joined our family/water[1]! I think(s) we will all be very happy together[1].

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