Title
Auditory Sentence Processing in Unimpaired and Impaired Adult Listeners: The Influence of Structure, Prosody, and Thematic Fit

Author
Sheppard, Shannon Brooke MacKenzie

Publication Date
2016

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA, SAN DIEGO

SAN DIEGO STATE UNIVERSITY

Auditory Sentence Processing in Unimpaired and Impaired Adult Listeners: The Influence of Structure, Prosody, and Thematic Fit

A dissertation submitted in partial satisfaction of the requirements for the degree
Doctor of Philosophy

in

Language and Communicative Disorders

by

Shannon Brooke MacKenzie Sheppard

Committee in charge:

University of California, San Diego

Professor Seana Coulson
Professor Jeanne Townsend

San Diego State University

Professor Lewis P. Shapiro Chair
Professor Phillip J. Holcomb, Co-Chair
Professor Tracy Love
Professor Katherine J. Midgley

2016

The Dissertation of Shannon Brooke MacKenzie Sheppard is approved, and is acceptable in quality and form for publication on microfilm and electronically:

Co-Chair

Chair

University of California, San Diego

San Diego State University

2016

DEDICATION

To my husband James - your unconditional love, friendship, and encouragement, mean the world to me.

To my Mom and Dad – thank you for your constant love and for fostering and encouraging my desire, curiosity, and aspiration for knowledge.

To my brother Chad – thank you for always being there for me.

EPIGRAPH

Language, that most human invention, can enable what,
in principle, should not be possible. It can allow all of us,
even the congenitally blind, to see with another person's eyes.

Oliver Sacks

There is nothing like looking, if you want to find
something. You certainly usually find something, if you
look, but it is not always quite the something you were after.

J.R.R. Tolkien

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

First I would like to thank my mentors, Dr. Lew Shapiro and Dr. Tracy Love, for all of the guidance and mentorship you have provided over the past five years. You both have offered unwavering support and have taught me to be a thoughtful, careful and critical scientist. This dissertation would not have been possible without the many hours you spent discussing study designs and theoretical implications, reading countless drafts of various manuscripts, listening to numerous practice talks over the years, and offering invaluable career advice. Thank you also for providing me with so many research, training, and teaching opportunities. It has truly been a privilege to be your doctoral student.

I would also like to thank Dr. Phil Holcomb and Dr. Katherine Midgley for your mentorship and for giving me the incredible opportunity to start a project with you when you were starting up your lab at SDSU. Thank you for teaching me everything I know about ERPs and for never hesitating to answer my questions, of which there were many. The training you provided was invaluable, and I consider myself very fortunate to have had the opportunity to learn from and work with you both.

Thank you to my other committee members Dr. Seana Coulson and Dr. Jeanne Townsend for serving on my committee. I very much appreciate your feedback and helpful comments throughout this process.

I also want to thank all current and former members of the Language and Neuroscience Group Lab (LANG), the NeuroCognition Lab, the JDP, and SDSU

School of Speech, Language, and Hearing Sciences. First, to the my fellow JDP students, Natalie Sullivan, Sam Engel, Kristi Hendrickson, and Stephanie DeAnda, thank you for your friendship and moral support. You have made grad school much more fun, interesting and entertaining. Also, to former LANG doctoral students Roberto Gutierrez, Michelle Gravier, and Dorothy Yang, thank you all for your help and advice particularly in the early stages of grad school. I learned a great deal from all of you about what it takes to get a study up and running and how to maneuver the many, and sometimes confusing, requirements of the JDP. Special thanks to Dr. Matthew Walenski for so many thoughtful discussions ranging from theoretical linguistics and statistics to studying language in dolphins. Thank you to the members of the NeuroCognition lab, and especially Megan Mott and Kurt Winsler. Thank you both for the interesting conversations and for always being happy to help me run participants. Thank you as well to the countless research assistants in both the LANG and Neurocognition labs who have helped me with everything from stimuli development, to running participants. I could not have done this research without your help.

Thank you Dr. Sonja Pruitt, Linda Schmitz and Sharron Turner for guiding me through my clinical training. I learned so much from you all and greatly appreciate all of the time you spent mentoring and training me.

I am also exceptionally grateful to Dr. Schandler and the late Dr. Flowers who were my mentors when I was an undergraduate student. I am very thankful to you both for all of the time you spent mentoring me and teaching me about the world of research. You were instrumental in my decision to pursue graduate school and I certainly could not have done it without the influence of your thoughtful guidance. I will always be thankful to you both and will strive to use your examples in the future when I will also hopefully have the opportunity to mentor young students.

I also want to express my sincere gratitude to my dear friends Nancy Boyd and Kristi Pine. Thank you for your friendship, support, and guidance that you have provided over the years. I also want to thank Laura Kinney for your friendship. I am grateful for such a supportive and fun study partner. I am also sincerely grateful to Michelle Bernstein for your unwavering encouragement and friendship. I am so privileged to be friends with such a strong and wonderful woman.

I also want to express my heartfelt gratitude to my wonderful family: my parents Beverly and Donald, and to my brother Chad. You have always encouraged me to follow my heart and my dreams. You instilled in me a sense of curiosity about the world, and the drive to pursue my goals, without which I would not have sought a PhD. Thank you for always being there for me and supporting me in everything I do. Thank you as well to my new family: Michael, Pauline, Simon, and Nicholas. I am so lucky to be able to call you my family. Thank you for everything. Finally, I am sincerely grateful to my husband James for your endless love and support. I truly could not ask for a more encouraging, supportive, and caring husband. Thank you for being so incredible, I could not have done this without you.

Chapter 3, in full, is a reprint of the material as it appears in the Journal of Speech, Language, and Hearing Research. Sheppard, S.M., Walenski, M., Love, T., Shapiro. L.P. (2015). The auditory comprehension of wh-questions in aphasia: Support for the intervener hypothesis. *Journal of Speech, Language and Hearing Research, 58,* 781-797, 10.1044/2015_JSLHR-L-14-0099. Preparation of this manuscript was supported by National Institute on Deafness and Other Communication Disorders Grants R01DC009272, R01DC000494, and T32DC007361. The dissertation author was the primary investigator and the primary author of this paper. We thank our research assistants and our participants and their families for their time.

Chapter 4 has been submitted for publication and appears as it is intended for publication of the material as it may appear in Sheppard, S.M., Midgley, K.J., Love, T., Holcomb, P.J., Shapiro, L.P. (*Submitted*) Electrophysiological Evidence for the Interaction of Prosody and Thematic Fit Information During Sentence Comprehension. *Neuropsychologia.* The dissertation author was the primary investigator and the primary author of this paper. Preparation of this manuscript was supported, in part, by National Institute on Deafness and Other Communication Disorders Grants (NIDCD) R01 DC009272, R01 DC000494, and T32 DC007361, and by HD25889. We are very grateful to our research assistants and our participants and their families for their time.

Chapter 5 is being prepared for submission for publication of the material. Sheppard, S.M., Love, T., Midgley, K.J., Holcomb, P.J., Shapiro, L.P. (*in preparation*). Influence of Prosody and Thematic Fit on Syntactic Ambiguity Resolution in Broca's Aphasia: Evidence from ERPs. The dissertation author was the primary investigator and the primary author of this paper. Preparation of this manuscript was supported, in part, by National Institute on Deafness and Other Communication Disorders Grants (NIDCD) R01 DC009272, R01 DC000494, and T32 DC007361, and by HD25889. We are very grateful to our participants and their families for participation in this investigation. We also thank members of the Language and Neuroscience Group (San Diego State University) and the NeuroCognition (San Diego State University) laboratories for their help with stimuli development and preparation, and data collection.

VITA

EDUCATION

Ph.D. San Diego State University/ University of California, San Diego — 2016
Language and Communicative Disorders

B.A. Chapman University, *Summa Cum Laude* — 2007
Psychology

RESEARCH EXPERIENCE

Doctoral Student — 2011-2016
San Diego State University
Language and Neuroscience Group Laboratory
NeuroCognition Laboratory

Research Assistant — 2005-2007
Chapman University
Cognitive Psychophysiology Laboratory

FIELDS OF STUDY

Major field: Language and Communicative Disorders

Sentence Processing in Aphasia
Sentence Processing in Neurologically Unimpaired Populations
Professors Lewis Shapiro and Tracy Love

Electrophysiology of Language Processing
Professors Phillip Holcomb and Katherine Midgley

ACADEMIC HONORS AND AWARDS

NIH Predoctoral Training Grant — 2011-2016
Neurocognitive Approaches to Communication Disorders
NIH/NIDCD T3DC007361

SDSU Center for Clinical & Cognitive Neuroscience Student Travel Award — 2016

2015

American Speech-Language Hearing Foundation New Century
Scholars Doctoral Scholarship

NIMH Funding to attend the 2015 ERP Boot Camp Training, UC Davis Center for Mind and Brain — 2015

Student Fellowship, Saffran Student Scholar Award Program to attend the 10th Annual Eleanor M. Saffran Cognitive Neuroscience Conference — 2015

NIDCD Student Fellowship to attend and present at the 43rd Clinical Aphasiology Conference — 2015

SDSU Student Travel Fund Award — 2013

Outstanding Senior in Psychology Award, Chapman University — 2007

Provost's List, Chapman University — 2002-2007

PUBLICATIONS (PEER REVIEWED)

Sheppard, S.M., Love, T., Midgley, K.J., Holcomb, P.J., Shapiro, L.P. (*in preparation*). Electrophysiology of Prosodic and Lexical-Semantic Processing in Aphasia.

Sheppard, S.M., Midgley, K.J., Love, T., Holcomb, P.J., Shapiro, L.P. (*Submitted*). The impact of prosodic and semantic cues in syntactic ambiguity processing: Evidence from event-related brain potentials. *Neuropsychologia.*

Sheppard, S.M., Walenski, M., Love, T., Shapiro. L.P. (2015). The auditory comprehension of wh-questions in aphasia: Support for the intervener hypothesis. *Journal of Speech, Language and Hearing Research, 58,* 781-797.

CONFERENCE PRESENTATIONS

Sheppard, S.M., Midgley, K.J., Love, T., Shapiro, L.P., & Holcomb, P.J. (2016). *Interaction of Prosodic and Plausibility Cues During Sentence Processing: Evidence from ERPs.* Poster presented at the 23rd Annual Meeting of the Cognitive Neuroscience Society, New York, NY.

Sheppard, S.M., Midgley, K.J., Love, T., Yang, D., Holcomb, P.J., & Shapiro, L.P. (2015). *Electrophysiology of Sentence Processing in Aphasia: Prosodic*

Cues and Thematic Fit. Poster presented at the 53rd Annual Meeting of the Academy of Aphasia, Tucson, AZ.

Shapiro, L.P., Love, T., **MacKenzie, S.**, & Sullivan, N. (2015). *Sentence Comprehension in Aphasia: The Intervener Hypothesis.* Oral presentation at the Experimental Psycholinguistics Conference, Madrid, Spain.

MacKenzie, S., Walenski, M., Love, T., Ferrill, M., Engel, S., Sullivan, N., Harris Wright, H. & Shapiro, L.P. (2014). *The Impact of Similarity-based Interference in Processing Wh-questions in aphasia.* Poster presented at the 52nd Annual Meeting of the Academy of Aphasia, Miami, FL.

Sullivan, N., Walenski, M., **MacKenzie, S.**, Ferrill, M., Love, T. & Shapiro, L. (2014). *The Time-course of Lexical Reactivation of Unaccusative Verbs in Broca's Aphasia.* Poster presented at the 52nd Annual Meeting of the Academy of Aphasia, Miami, FL.

Ferill, M., Love, T., Sullivan, N., **MacKenzie, S.**, & Shapiro, L. (2014). *The Effect of Syntactic and Semantic Cues on Lexical Access in Broca's Aphasia.* Poster presented at the 52nd Annual Meeting of the Academy of Aphasia, Miami, FL.

Sullivan, N., **MacKenzie, S.,** Walenski, W., Love, T. & Shapiro, L. (2014). *The Auditory Processing of Unaccusative Verbs in Individuals with Aphasia.* Poster presented at the 44th Clinical Aphasiology Conference, St. Simons, GA.

MacKenzie, S., Walenski, M., Love, T., & Shapiro, L. (2013). *The Auditory Comprehension of Who and Which-NP Questions in Aphasia: Support for the Intervener Hypothesis.* Poster presented at the 5th Annual Society for the Neurobiology of Language Conference, San Diego, CA.

MacKenzie, S., Gutierrez, R., Walenski, M., Love, T., & Shapiro, L. (2013). *The Auditory Comprehension of Who and Which-NP Questions in People with Aphasia: Which Account do the Data Support?* Poster presented at the 43rd Clinical Aphasiology Conference, Tucson, AZ.

MacKenzie, S., Gutierrez, R., Walenski, M., Love, T., & Shapiro, L. (2013). *The Auditory Comprehension of Who and Which-NP Questions in Neurologically Unimpaired Listeners: Which Account do the Data Support?* Poster presented at the 11th International Symposium of Psycholinguistics, Tenerife, Spain.

TEACHING EXPERIENCE

Instructor 2016

Graduate level Acquired Neurogenic Language and Cognitive Disorders II (SLHS 609B), San Diego State University

Instructor 2014

Undergraduate level Language Development and Disorders (SLHS 513), San Diego State University

Graduate Assistant (Course Instructor: Dr. Lewis Shapiro) 2014

Undergraduate level Introduction to Language Science (SLHS 300), San Diego State University

Instructor 2012

Introduction to Psychology, Academic Connections, UC San Diego

PROFESSIONAL TRAINING

ERP Boot Camp 2015

UC Davis, Center for Mind and Brain, Davis, CA

Analysis of Functional NeuroImages (AFNI) Training 2013

National Institutes of Health (NIH); Bethesda, MD

E-Prime Training 2012

Psychology Software Tools; Philadelphia, PA

GRADUATE CLINICAL EXPERIENCE SPEECH-LANGUAGE PATHOLOGY

Clinical Internship 2014-2015

San Diego Speech Language and Hearing Clinic, San Diego, CA

Clinical Externship 2015

El Camino Creek Elementary School, Carlsbad, CA

Clinical Externship 2015

Sharp Grossmont Hospital, La Mesa, CA

ABSTRACT OF THE DISSERTATION

Auditory Sentence Processing in Unimpaired and Impaired Adult Listeners: The Influence of Structure, Prosody, and Thematic Fit

by

Shannon Brooke MacKenzie Sheppard

Doctor of Philosophy in Language and Communicative Disorders

University of California, San Diego, 2016
San Diego State University, 2016

Professor Lewis Shapiro, Chair
Professor Phillip Holcomb, Co-Chair

Auditory sentence processing is astonishingly complex and involves the rapid processing and integration of many different forms of information. While this is seemingly effortless for neurologically unimpaired listeners, it is clear from the literature that brain damage can cause the normal language system to be disrupted in specific and testable ways. One major goal of this dissertation is to describe how the system is fractionated in aphasia by focusing on the time-course

of using specific information types that appear to be involved in the unimpaired language system.

A series of sentence processing studies are presented exploring the impact of syntactic structure in neurologically unimpaired listeners and in listeners with Broca's aphasia (Chapter 3), the impact of thematic fit and prosody in college-age adults (Chapter 4) and individuals with aphasia along with a group of age-matched healthy controls (Chapter 5).

Chapter 2 reviews research on sentence processing, and accounts of the sentence comprehension deficit in aphasia are also discussed. Chapter 3 provides evidence that similarity-based interference, which results from certain syntactic structures, contributes to the sentence comprehension deficit in aphasia. Chapter 4 examines how thematic fit/plausibility and prosody impacted syntactic structure building in college-age adults using event-related potentials (ERPs). Results revealed that the parser was able to use thematic fit/plausibility information to predict upcoming syntactic structure before the critical verb. Syntactic reanalysis was triggered at the critical verb in sentences with incongruent prosody and no plausibility cue. Chapter 5 examined how individuals with Broca's aphasia and age-matched controls use plausibility and prosodic cues. The results from the age-matched controls were nearly identical to the college-age adults (Chapter 4). However, the group of individuals with aphasia with a less severe comprehension deficit could predict upcoming syntactic structure when provided with a plausibility cue, but without a plausibility cue had difficulty integrating prosody with syntactic structure. Those with a more severe comprehension deficit had difficulty integrating prosodic and lexical-semantic cues with syntactic structure. Thus, similarity-based interference, lexical-semantic processing and prosody are all implicated in the sentence comprehension deficit seen in individuals with Broca's aphasia.

CHAPTER 1:

Introduction

1.1 Introduction

While comprehending sentences may seem to be automatic and simple, at least to a native speaker of a language, an abundance of research has demonstrated that successful sentence comprehension requires many complex operations to all be performed at an extremely rapid pace. Listeners and speakers must possess syntactic knowledge – how words and phrases are 'put together' to form sentences, knowledge of the lexicon – the collection of knowledge about word forms, including the phonology (the speech sounds that form to make words), semantics (the meanings of words and sentences), lexical-category information (the part-of-speech), and grammatical constraints (not all verbs, for example, yield well-formed sentences when combined with all types of phrases).

Several different types of sentence processing models exist that attempt to explain how the human brain is able to rapidly perform such complex operations. These sentence processing models vary in the importance they place on linguistic (e.g., syntactic) and extra-linguistic (e.g., probabilistic) information, as well as on the cognitive resources such as attention and memory that may underlie sentence processing. While sentence processing is largely unproblematic for the majority of the neurologically unimpaired population, the same cannot be said for individuals with Broca's aphasia. Historically, Broca's aphasia, which typically results from brain damage to the inferior frontal gyrus in the brain's left hemisphere (Brodmann areas 44 & 45), was believed to be a disorder of language production rather than comprehension. This is because individuals diagnosed with Broca's aphasia have a very apparent production deficit, typically present with halting non-fluent speech, while also appearing to retain language comprehension abilities, particularly in everyday situations. However, a seminal study by Caramazza and Zurif (1976) revealed that individuals with Broca's aphasia have little difficulty understanding sentences that conform to 'canonical' word order (subject-verb-object order in English) yet they have considerable difficulty understanding sentences that have been characterized as more complex, that is, not conforming to canonical order (see also Zurif, Swinney, Prather, Solomon & Bushell, 1993; Love, Swinney, Walenski, Zurif, 2008 and references therein).

Because individuals with Broca's aphasia as a group appear to understand syntactically simple but not complex sentences, much of the research in this area has focused on investigating syntactic processing, where complexity is defined in terms of the syntactic operations required to process a sentence. Even so, there is considerable research exploring the role of working memory in the sentence comprehension deficits found in aphasia. Working memory is the type of memory that allows the brain to temporarily hold and manipulate several pieces of information. There is a long-standing debate in the field regarding the nature of working memory involved in sentence comprehension, and in fact some researchers discount the notion altogether. Yet, new research is emerging demonstrating that when a sentence contains multiple noun phrases (NPs), particularly those that are similar in structure, the reader/listener can become confused as to "who did what to whom." Thus interference within working memory for sentences can have a negative impact on sentence processing and comprehension, particularly for subjects who are language-impaired.

1.2 Overview of Dissertation

Many elements are involved in sentence processing, and the primary goal of this dissertation is to examine *how* and *when* particular elements interact with one another on-line, in both neurologically unimpaired populations and in individuals with aphasia. This goal will have important implications for theories and accounts of sentence processing. A series of three studies investigating sentence processing in these populations is described in this work. The first study in the series, reported in Chapter 3, discusses whether similarity-based interference can account for the sentence comprehension deficits seen in some patients with Broca's aphasia. This study examined the processing of four types of *Wh*-questions in a group of college-age adults and a group of patients with Broca's aphasia using an eye-tracking while listening method:

1.	Yesterday afternoon, two mailmen and a fireman got into a fight.	(Discourse Sentence)
1a.	Who__ pushed the fireman yesterday afternoon?	(Subject-extracted *Who)*
1b.	Which mailman __ pushed the fireman yesterday afternoon?	(Subject-extracted *Which)*
1c.	Who did the fireman push__ yesterday afternoon?	(Object-extracted *Who*)
1d.	Which mailman did the fireman push__ yesterday afternoon?	(Object-extracted *Which*)

Three hypotheses were examined, each of which would predict a different pattern of processing difficulty across these four *Wh*-question sentence types (1a-1d). The Word Order hypothesis predicted that object-extracted sentences would be more difficult to process relative to their subject-extracted counterparts because previous research has found that non-canonical word order is typically more difficult to process than canonical word order (Bates, Friederici, & Wulfeck, 1987; O'Grady, Yamashita, & Lee, 2005). The Discourse Hypothesis predicted that *Which*-questions would result in more processing difficulty than *Who*-questions because *Which*-questions are required to refer to entities that were previously mentioned in discourse (e.g., (1)), yet *Who*-questions are not (e.g., Avrutin, 2000, 2006; Burkhardt, 2005; Shapiro, 2000). Finally, the Intervener Hypothesis stated that sentence constructions containing an intervening element (a lexical NP) between a displaced NP (*which mailman* in (1d)) and its gap site results in a significant processing disadvantage relative to sentences without interveners. Note that there are two object-extracted sentence types (1c) and (1d) yet only the object-extracted *which*-question contains two fully specified lexical Noun Phrases (NPs) (*the mailman*, *the fireman*) that must be held in working memory prior to being integrated with the verb (*pushed*). Thus, the Intervener Hypothesis predicted processing difficulty in object-extracted *Which*-questions relative to the other three sentence types.

Whereas the study presented in Chapter 3 focuses primarily on the impact of syntactic structure and the possible influence of similarity-based interference that can result from certain structures, the studies presented in Chapters 4 and 5 examine how prosody and thematic fit can influence sentence comprehension. Event-related potentials (ERPs) were used to examine how prosody, thematic fit, and the potential interaction of prosody and thematic fit impacts sentence processing in college-age adults (Chapter 4), and individuals with aphasia and their age-matched controls (Chapter 5). The same materials were used in both studies. Participants were presented with sentences containing temporary syntactic ambiguities. Consider:

2. While the band played the song pleased all the customers.

In (2), the verb *played* is optionally transitive so it is initially unclear whether the subsequent NP (*the song*) is the direct object of *played* (incorrect interpretation) or the subject of the main clause (correct interpretation). Understanding how the parser interprets the temporarily ambiguous NP (*the song*), and what factors influence that initial interpretation can help answer many questions about sentence processing. For example, if a pause is inserted after the verb *played*, intuitively it seems likely that the listener would form the correct interpretation, where *the song* is the subject of the upcoming main clause. In fact, many studies have found that syntactic boundaries can serve to disambiguate temporary syntactic ambiguities (Nagel, Shapiro, & Nawy, 1994; Schafer, Speer, Warren, & White, 2000; Speer, Warren, & Schafer, 2003; Warren, Schafer, Speer, & White, 2000).

However, prosody is not the only factor at play. Consider:

3. While the band played the beer pleased all the customers.

While *the song* in (2) is a plausible direct object for the subordinate verb *played, the beer* in (3), is not capable of being *played.* It is possible that the parser is sensitive to this plausibility information, which is referred to as thematic fit. Thematic fit refers to the combination of a verb with its arguments. Some NPs are more plausible continuations of particular verbs relative to others. If the parser immediately capitalizes on thematic fit information, it may be more likely to predict the correct syntactic structure where *the beer* is not the direct object of *played.* Hence, the studies presented in Chapters 4 and 5 examine how and to what extent prosody and thematic fit influence syntactic processing, and also investigates whether they interact during this process. Chapter 4 examines these questions in a group of college-age neurologically unimpaired adults. Chapter 5 examines whether and how this process is altered in patients with aphasia relative to a group of age-matched controls. Finally, Chapter 6 concludes with a discussion of the implications of the results from each of these studies. Future directions as well as the potential future impact of the findings from these studies will be discussed.

Prior to delving into the three research studies, Chapter 2 will provide a general overview of psycholinguistics and sentence processing models. It will include information on various elements of sentence processing, and in particular syntax and the effects of similarity-based interference, lexical-semantic information, and prosody – all of which are of particular importance to the studies presented in this dissertation. It will also include information about the comprehension deficit seen in patients with Broca’s aphasia.

References

Avrutin, S. (2000). Comprehension of discourse-linked and non-discourse-linked questions by children and Broca's aphasics. *Language and the brain: Representation and processing*, 295-313.

Avrutin, S. (2006). Weak syntax. In Y. Grodzinsky & K. Amunts (Eds.), *Broca's Region* (pp. 49-62). Oxford, UK: Oxford University Press.

Bates, E., Friederici, A., & Wulfeck, B. (1987). Comprehension in aphasia: A cross-linguistic study. *Brain and Language, 32*(1), 19-67.

Burkhardt, P. (2005). *The syntax-discourse interface: Representing and interpreting dependency* (Vol. 80): John Benjamins Publishing.

Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language, 3*(4), 572-582.

Love, T., Swinney, D., Walenski, M., & Zurif, E. (2008). How left inferior frontal cortex participates in syntactic processing: Evidence from aphasia. *Brain and Language, 107*(3), 203-219.

Nagel, H. N., Shapiro, L. P., & Nawy, R. (1994). Prosody and the processing of filler-gap sentences. *Journal of Psycholinguistic Research, 23*(6), 473-485.

O'Grady, W., Yamashita, Y., & Lee, S.-Y. (2005). A note on canonical word order. *Applied linguistics, 26*(3), 453-458.

Schafer, A. J., Speer, S. R., Warren, P., & White, S. D. (2000). Intonational disambiguation in sentence production and comprehension. *Journal of Psycholinguistic Research, 29*(2), 169-182.

Shapiro, L. (2000). Some recent investigations of gap filling in normal listeners: Implications for normal and disordered language processing. In L. Shapiro, Y. Grodzinsky, & D. Swinney (Eds.), *Language and the brain:*

Representation and processing (pp. 357-376). San Diego, CA: Academic Press.

Speer, S., Warren, P., & Schafer, A. (2003). *Intonation and sentence processing.* Paper presented at the Proceedings of the Fifteenth International Congress of Phonetic Sciences, Barcelona, Spain.

Warren, P., Schafer, A. J., Speer, S. R., & White, S. D. (2000). Prosodic resolution of prepositional phrase ambiguity in ambiguous and unambiguous situations. *UCLA Working Papers in Phonetics*, 5-34.

Zurif, E., Swinney, D., Prather, P., Solomon, J., & Bushell, C. (1993). An on-line analysis of syntactic processing in Broca′s and Wernicke′s aphasia. *Brain and Language, 45*(3), 448-464.

CHAPTER 2:

Elements of Sentence Processing

2.1 Linguistic Considerations

2.1.1 Phrase Structure

Rather than simply stringing words together, sentences are formed by building a hierarchical structure. Individual categories of words (e.g., nouns, verbs, prepositions) yield higher-order phrasal categories (e.g., noun phrases (NPs), verb phrases (VPs), prepositional phrases (PPs)) using the *Merge* operation (Chomsky, 1995). Sentences are then derived from a series of Merge operations. For example, in Figure 2-1A a Determiner (*the*) and Noun (*girl*) merge to form a higher-order constituent, a Determiner Phrase (DP)[1].

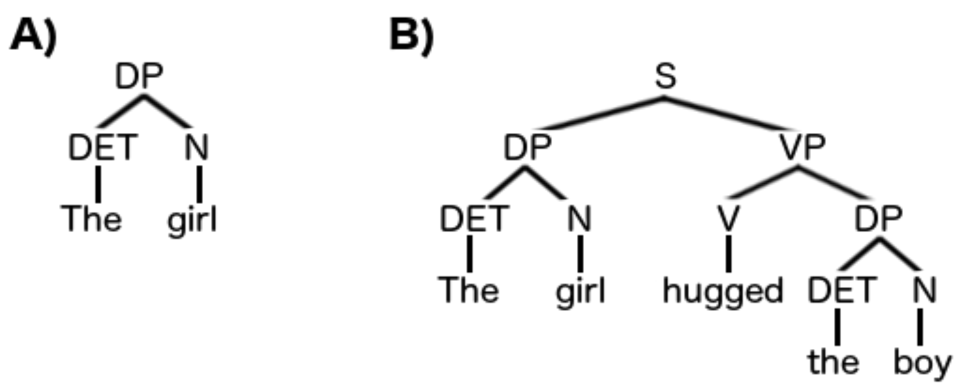


Figure 2-1. (A) Showing the *Merge* operation combining a determiner (*the*) and noun (*girl*) to form a higher-order NP. (B) Syntactic phrase structure tree for *"the girl hugged the boy,"* demonstrating phrase structure.

Furthermore and as demonstrated in Figure 2-1B, phrasal categories like NPs and VPs combine in a hierarchical fashion to form a sentence. Phrasal categories always contain at least one lexical category of the same type; for example, DPs must contain a Determiner, NPs must contain a Noun (N). The lexical category

---

[1] In the remainder of this paper, I resort to using noun phrases (NPs) instead of Determiner Phrases, as a simplification.

[2] We also conducted analyses with a traditional 100ms pre-stimulus baseline

(e.g., N) that projects to form the phrasal category (e.g., NP) is the head of the higher-order phrase such that the noun in an NP is referred to as the head of the NP, a verb is the head of a VP and so on.

2.1.2 Argument Structure and Thematic Roles

Verb phrases are a particularly important phrasal category because they contain features that restrict both the syntax and meaning of sentences. Sentences by definition are composed of at least one verb (i.e., predicate) and the verb's arguments. The verb describes the action or event and the arguments denote the participants in that event. Consider the following sentences:

1a. James slept.

1b. *James slept the bed.

2a. James hugged the girl.

2b. * James hugged.

3a. James placed the book on the shelf.

3b. *James placed the book.

Verbs select their arguments. For example, the verb *slept* requires one and only one argument (the NP *James* in (1a)) and is thus referred to as a one-place predicate or <u>intransitive</u>. Thus if the verb is used in a sentence with more than one argument, the sentence is ungrammatical (1b). The verb *hugged* is a two-place predicate because it selects for two arguments, a subject NP (*James*) and an object NP (*the girl*). Thus, with a two-place verb, an ungrammatical sentence results when the two arguments are not present (2b). Verbs that take at two arguments are transitive verbs. Another example is the verb *placed* (3a), which selects for three arguments and is sometimes referred to as a ditransitive verb. Some verbs can be optionally transitive and have the option of taking a direct object argument or not (e.g., *eat*, as in "James ate (Sushi)").

Argument structure, then, can be described in terms of the number of arguments a verb takes, and in terms of the sentence, the number of argument slots that must be available for the sentence to be grammatical. Argument structure, therefore, is a constraint on the well-formedness of sentences. Yet argument structure can also be defined in terms of the 'semantics' of the arguments, which is described in terms of Thematic Roles. A well-known constraint is that every argument of a verb must be assigned one and only one thematic role. Some common thematic roles include Agent, Theme, Goal, and Experiencer. An Agent is an argument that causes an event while a Theme is the argument that undergoes the effect of the event or action. The Goal is the location or entity in the direction of which something moves and the Locative is the specification of the place where the action/event is situated. Consider the following:

4. James placed the book on the shelf.
5. James gave the book to the girl.

The verb *placed* is a three-place predicate and thus requires three argument positions in the sentence. As shown in (4), the subject argument position is filled by the NP *James*, which fulfills the Agent role, the direct object argument position is filled by the NP *the book*, which plays the role of the Theme, and the indirect object argument position is filled by the NP *the shelf*, which plays the Locative role. There are also three thematic roles required for the verb *give* in (5), where the third argument position if filled by the NP *the girl,* and which fulfills the thematic role of Goal. In (6) below the subject NP, *Chad,* plays the role of Experiencer for the verb *love*; the Experiencer role describes the entity undergoing a cognitive or emotional experience.

6. Chad loves horses.

It has been proposed that both of these properties, argument structure requirements and thematic role features, are stored in a verb's lexical entry. A verb assigns thematic roles to its argument positions through a process called theta-marking (Chomsky, 1981). When a verb merges with an NP to form a VP, the verb assigns the appropriate thematic role to the argument slot in the sentence. Consider:

7. James hugged the girl.

When the verb *hugged* merges with the object NP, *the girl,* to form the VP (*hugged the girl*) the verb assigns the thematic role of Theme to the NP. Similarly, when the VP merges with the subject NP, *James,* the verb assigns the thematic role of Agent to the subject NP. Thus, one important way to characterize a sentence is in terms of predicate-argument structure, where every verb has a particular set of required arguments and associated thematic roles. If a sentence contains too few or too many arguments for the specified number of thematic roles specified in the verb's lexical entry, the sentence is rendered ungrammatical.

Predicate-argument structure is not only a notion important to linguistic theory. Research by Shapiro and colleagues (Shapiro, Brookins, Gordon, & Nagel, 1991; Shapiro, Zurif, & Grimshaw, 1987; Shapiro, Zurif, & Grimshaw, 1989) examined how argument structure impacts sentence processing. Briefly here, results revealed that verbs with multiple argument structure possibilities required significantly more processing 'load' than those with only one possibility. Their findings suggest that listeners automatically activate all possible argument structure configurations when encountering a verb, setting up a syntactic skeleton that allows for further processing operations.

2.1.3 Long-Distance Dependencies

Another consideration for sentence processing is that sentences can contain several types of 'syntactic' dependencies that listeners must process to yield successful comprehension. Long-distance dependencies refer to sentences where two associated elements are located in non-adjacent syntactic positions. Consider:

8. The coach watched the game.

9. The coach who was wearing a blue jersey watched the game.

The simple sentence in (8) becomes a long-distance dependency in (9) when the relative clause is inserted between the subject NP (*the coach*) and the verb (*watched*). Another type of long-distance structure involves what psycholinguists refer to as filler-gap dependencies:

10. [The mom] hugged [the child].
11. It was [the child]$_i$ that the mom hugged [____]$_i$.
12. [Which child]$_i$ did the mom hug [____]$_i$?

The verb *hugged* is transitive and thus requires both a subject (the person giving the hug) and an object (the person receiving the hug) to be present in the representation. In (10) the sentence is in canonical word order for English (Subject–Verb–Object). However, in English and in many other languages NPs can be displaced from their canonical (or base-generated) positions and still yield grammatical sentences. For example, in (11) and (12) the object NP (*the child*) occurs before the verb, and thus the sentence has non-canonical word order in English. In some linguistic theories, when a direct object is displaced from its original canonical position after the verb (where it is 'base-generated'), it leaves behind a copy of itself, (sometimes referred to as a *trace*), which is linked to the displaced NP through the syntax. In psycholinguistic terminology the *trace* or position from where the NP has been displaced is known as a *gap*, and the displaced NP is referred to as its *filler.* In order to comprehend a sentence containing a filler-gap dependency, listeners must be able to compute the relationship between the two non-adjacent positions. A significant amount of literature shows that listeners do in fact (re)access the displaced NP at the gap (Balogh, Zurif, Prather, Swinney, & Finkel, 1998; Love & Swinney, 1996; Nicol & Swinney, 1989; Osterhout & Swinney, 1993).

Another type of dependency occurs with anaphora, where a word is substituted to refer to another word located earlier in the sentence or in another clause. For example, when a personal pronouns is used, it must co-refer with a referential entity located in another clause. Consider:

13. *The girl* got a new job that made *her* very happy.

Here, the personal pronoun (*her*) refers to the NP *the girl* (called the antecedent). Note that the pronoun and antecedent are in different clauses; indeed, a well-known syntactic constraint is that personal pronouns cannot refer to an antecedent in its same clause. This constraint also allows for the situation where the antecedent is mentioned in the discourse and not in the sentence itself, as in:

14. The girl said that the teacher likes him.

where the personal pronoun, *him,* refers to someone likely mentioned in the discourse.

2.1.4 Prosody

Prosody is also important consideration in sentence processing. Prosody is the stress, rhythm, and intonation in speech and can be described using measures of pitch, amplitude and duration. Prosody conveys non-linguistic information such as the gender, age, or emotional state of the speaker. It also conveys macro-linguistic information including whether a sentence is a question, a statement, or a command. Emotional prosody, which communicates the emotional state of the speaker, and linguistic prosody express two distinct types of information. Of particular interest to this dissertation however is linguistic prosody. Specifically, the research presented in this dissertation examines the interaction of prosody and syntax during sentence processing. The fundamental interest here is how prosody disambiguates structural syntactic ambiguities.

2.1.4.1 Theory of Prosodic Structure

Prosody can broken down into prosodic constituents, just as sentences can be broken into constituents such as noun phrases, verb phrases, nouns, and verbs (Nespor & Vogel, 1986; Selkirk, 1986). Prosodic constituents can be arranged in a hierarchical manner, and in order from highest to lowest unit they include: the utterance, the intonational phrase, the phonological phrase, and the prosodic word. This hierarchical structure is demonstrated in Figure 2-2A (Ferreira, 1993).

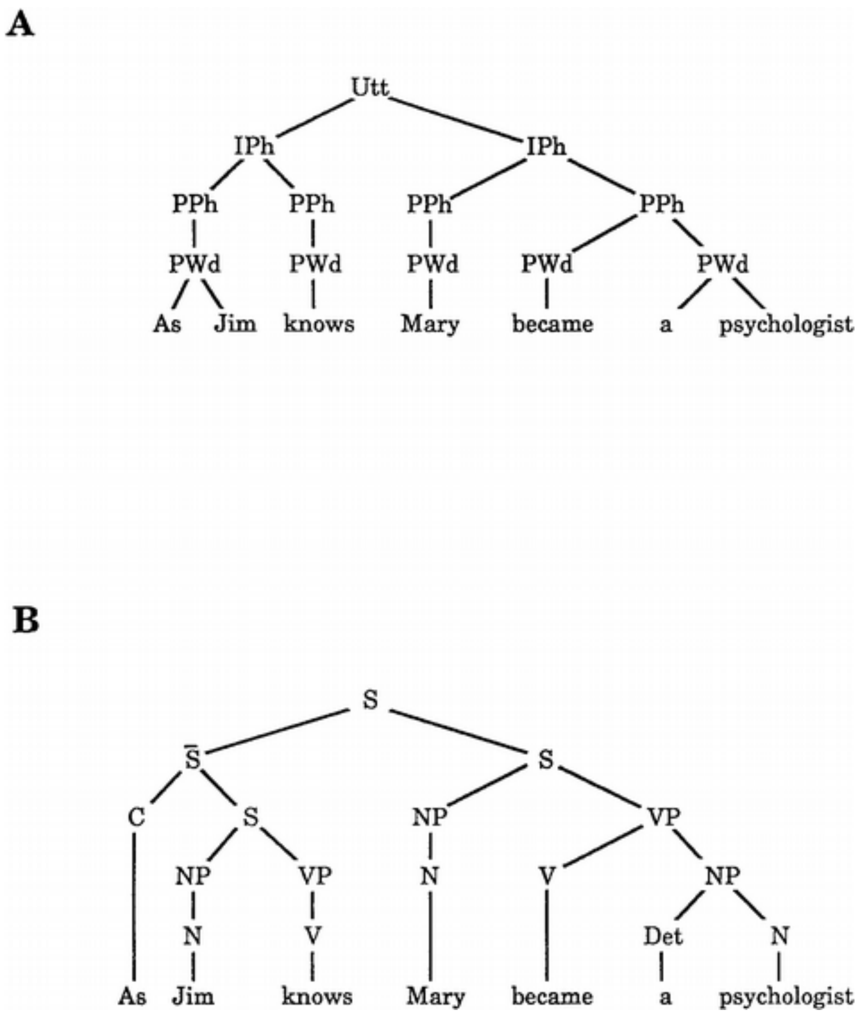


Figure 2-2. Prosodic (A) and syntactic structures (B) for the sentence As Jim knows, Mary became a psychologist (Ferreira, 1993). (Utt = utterance; IPh = intonational phrase; PPh = phonological phrase; PWd = prosodic word; S = sentence-bar; S = sentence; NP = noun phrase; VP = verb phrase; N = noun; V = verb; Det = determiner; C = complementizer.)

In the sentence *As Jim knows Mary became a psychologist,* the utterance is the largest unit in the prosodic structure. An utterance can consist of just a sentence; however multiple sentences can form one utterance when forming a higher-level sentence (Selkirk, 1978; Shattuck-Hufnagel & Turk, 1996). The next highest level is the intonational phrase (IPh), and intonational phrases are characterized by a decline in pitch over the course of the phrase. Intonational phrases end with either a high or low boundary tone, and are often further distinguished by the addition of a pause after the intonational phrase (Cutler & Clifton, 1999; Nespor & Vogel, 1986). As shown in in Figure 2-2A, the sentence is divided into two intonational phrases, *As Jim knows*, and, *Mary became a psychologist*.

Below the intonational phrase is the phonological phrase, which is comprised of all the words in a syntactic phrase that lead up to the right boundary of that syntactic phrase (Nespor & Vogel, 1986; Selkirk, 1986). Figure 2-2B demonstrates that the right boundary of the syntactic noun phrase, *Mary,* ends at *Mary.* Thus, the noun phrase *Mary* consists of one phonological phrase (see Figure 2-2A). However, the right boundary of the verb phrase, *became a psychologist*, does not end until the noun, *psychologist*, thus the full verb phrase represents a phonological phrase. Finally, the prosodic word constitutes the last prosodic structure level. A prosodic word consists of a content word as well as any function words that are attached to that content word. Content words (open class words) are those that express semantic information such as nouns, verbs, adverbs and adjectives, and they are 'open' because over time new elements can be added to the category (e.g., *hardwire* is a relatively new Verb, while *hardwiring* is a relatively new Noun). In contrast, function words (closed class words) provide grammatical information, and they include determiners, prepositions, pronouns, and conjunctions; typically, such vocabulary are 'closed' because new elements are rarely added.

2.1.4.2 Prosody in Sentence Comprehension

A great deal of research has also demonstrated that speakers naturally use prosodic cues when producing sentences (Cooper & Paccia-Cooper, 1980; Nagel, Shapiro, & Nawy, 1994; Nagel, Shapiro, Tuller, & Nawy, 1996), and these cues used by listeners to understand the intended meaning of the sentence (Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991). As mentioned previously, an intonational phrase boundary, or a prosodic break, can be indicated by a pause, lengthening of the word preceding the pause, as well as a boundary tone at the pre-pause word. Prosodic breaks tend to occur at major syntactic boundaries (Cooper & Paccia-Cooper, 1980; Nagel et al., 1994; Price et al., 1991). Thus, prosodic boundaries can help a listener determine the underlying syntactic structure of a sentence. Many researchers have found that prosodic boundaries convey important information to a listener such that prosodic information congruent with sentence structure facilitates sentence comprehension and incongruent prosodic information disrupts comprehension (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2013; Carlson, Frazier, & Clifton, 2009; Kjelgaard & Speer, 1999; Pauker, Itzhak, Baum, & Steinhauer, 2011; Pynte & Prieur, 1996; Schafer, Speer, Warren, & White, 2000; Steinhauer, Alter, & Friederici, 1999).

Prosody can also be used to help disambiguate syntactic ambiguities. For example, consider:

15. The girl with the flower was touched.

Sentence (15) contains an ambiguous prepositional phrase attachment. There are two possible underlying syntactic structures for this sentence. In the low attachment structure, *the girl*, who was in possession of a flower, *was touched*. In the high attachment structure, *the flower* was used to touch the girl. Prosodic cues provided by the speaker can successfully disambiguate between these two possible meanings (Snedeker & Casserly, 2010).

Importantly, prosodic cues can also potentially disambiguate temporary syntactic ambiguities. Consider:

16. While the band played the song pleased all the customers.

Moving 'left-to-right', (16) contains a temporary syntactic ambiguity where the verb *played* is optionally transitive and consequently it is initially unclear whether the subsequent NP (*the song*) is the direct object of *played* (e.g., "…the band played <u>the song</u>") or the subject of the main clause (e.g., "<u>the song</u> pleased all the customers"). Yet, if the sentence is presented aurally, a prosodic break inserted after the word *played* can signal the presence of a syntactic boundary and potentially disambiguate the temporary syntactic ambiguity (Nagel et al., 1994; Schafer et al., 2000; Speer, Warren, & Schafer, 2003; Warren, Schafer, Speer, & White, 2000).

Both online and offline methods have been used to examine the impact of prosody on sentence processing. The listener's final interpretation of a sentence can be measured using offline methods, whereas online methods allow for the examination of moment-by-moment processing that occurs prior to final interpretation. Online methods offer a distinct advantage over offline methods when examining when prosodic information influences sentence processing. Yet few studies have examined prosody using online methods. Some of these studies have used cross-modal naming tasks. Participants listen to a syntactically ambiguous sentence fragment and then they are presented with a visual target probe word that serves as a continuation of the sentence. Participants are required to read the probe word as quickly as possible. Processing interference is indicated by lower accuracy and longer response times. The results of studies using the cross-modal naming method have intimated that the syntactic structure of a sentence is immediately influenced by prosodic cues (Kjelgaard & Speer, 1999; Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992; Speer, Kjelgaard, & Dobroth, 1996).

As an example, Kjelgaard and Speer (1999) found that early closure sentences properly marked with a prosodic boundary were processed faster than sentences with either neutral prosody or with conflicting prosody, where the prosodic boundary conflicted with the underlying syntactic structure. The study concluded that prosodic cues influence the syntactic parsing mechanism. While compelling, the findings of these studies are limited because the cross-modal naming method requires participants to switch from an auditory to a visual processing modality mid-sentence, which likely requires the subject to focus their attention on integrating the probe word into the sentence. Such conscious focus makes the task unlikely to reveal processing routines that are more immediate and online.

Other studies have used self-paced listening tasks to examine the influence of prosody on sentence processing (DeDe, 2010; Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996b). In this method, listeners are presented with sentences in a word-by-word (or phrase-by-phrase) fashion, and must press a button to reveal the next aurally presented segment. Listening times via button press are recorded and longer listening times are equated to processing difficulty/interference. The results of studies using this method also have provided evidence that prosody influences processing of temporary syntactic ambiguities (DeDe, 2010; Ferreira et al., 1996b). Yet, in self-paced listening studies, the listener must consciously reflect on each segment of the sentence. Such conscious reflection does not allow for an unfettered examination of online behavior, which as suggested above, is necessary to reveal the underlying nature of sentence processing. Finally, the self-paced listening method interrupts some aspects of prosody (Ferreira, Anes, & Horine, 1996a), making it difficult to examine how and when prosody influences processing moment-by-moment. The role of prosody in sentence processing will be further discussed in the next section on sentence processing models.

2.2 Sentence Processing Models

There are several types of sentence processing accounts that attempt to explain how the human brain initiates and keeps track of this complex information to rapidly form and understand sentences. These accounts typically fall within three general camps: restricted, unrestricted, and resource-based models. In restricted models information is processed serially and in two general phases, where the first phase consists of creating a syntactic structure based on the syntactic category (e.g., noun, verb, adjective) of the words in the sentence and the syntactic skeleton formed by the verbs argument requirements (e.g., if a verb requires two arguments, there needs to be two argument positions to fill those arguments) (Shapiro & Hestvik, 1995; Shapiro, Hestvik, Lesan, & Garcia, 2003). Only after the syntactic information has been parsed does the second phase of processing begin, where non-syntactic sources of information, such as semantics and plausibility information (and probabilistic information), interact and affect the initial parse. In these types of models, the simplest syntactic structure is built initially. As the listener encounters additional words they are placed into the ongoing structure and if a word is encountered that does not fit into the original structure, the sentence will need to be reanalyzed and a new syntactic structure is constructed. This model is in contrast to unrestricted models (constraint-based), which assume that different types of information (e.g., semantic, contextual, syntactic, probabilistic) interact with one another throughout the sentence comprehension process. In these types of models it is assumed that multiple syntactic structures are built and the listener selects the best one based on, for example, probabilistic information (MacDonald, Pearlmutter, & Seidenberg, 1994). Another group of sentence processing models are resource-based, focusing on the non-linguistic aspects of processing that purportedly underlies sentence processing, including memory and attention. I now turn to a more detailed description of restricted, unrestricted, and resource-based accounts of sentence processing, and the evidence supporting each.

2.2.1 Restricted Accounts

Frazier's Garden-path model (1987) is the prototypical example and indeed the forerunner of a restricted account. Frazier claims that sentence processing occurs in two distinct stages. First, the human sentence processor (parser) constructs the simplest syntactic structure possible, using only syntactic category information gleaned from phrasal and lexical categories. The parser only analyzes non-syntactic information like semantics, world knowledge, and plausibility in the second stage, where reanalysis is required if the syntactic structure built in the first stage is incongruent with the new information. Models like this one are based on the notion that limited cognitive resources are available for sentence processing. To save this limited resource, the initial structure is computed based on restricted information. Extra cognitive resources are only required when the parser is faced with information in the second stage that would require reanalysis.

Much of the evidence for restricted accounts comes from processing sentences containing structural (i.e., syntactic) ambiguities. Consider:

17. The woman saw the man with binoculars.

This sentence can have two possible interpretations: one is that the woman used binoculars to see the man, or the woman saw a man who was holding binoculars. The two distinct interpretations stem from where the Prepositional Phrase (PP) is attached in the syntactic configuration. The PP *with the binoculars* can attach either to the verb (*saw*) or to the noun phrase (*the man*). When it attaches to the verb (verb attachment) it gives rise to the first, and most common, interpretation, where the woman used binoculars to see the man. If the PP attaches to the noun phrase (noun attachment) it takes on the second interpretation, where the man is holding the binoculars.

According to restricted accounts, when faced with this type of ambiguity the system will yield the simplest analysis. In the garden-path model it is assumed that the parser initially uses principles that only refer to the phrase structure configuration of the sentence; these include *Minimal Attachment*, *Late Closure* and the *Most Recent Filler Strategy.* The principle of *minimal attachment* states that material entering the phrase structure will be constructed using the fewest nodes possible while being consistent with the well-formedness rules of the language. The principle of *late closure* states that whenever possible, lexical items will be attached into the clause or phrase currently being processed. The *most recent filler* strategy hypothesizes that when the parser encounters a gap it will assume that the most recent potential filler is the correct filler. In sentences where this is not the case, re-analysis will be triggered.

As seen in Figure 2-3, the verb attachment option yields the simplest hierarchical structure with the smallest number of nodes. Thus, according to the garden-path model, listeners will assume the verb attachment option, unless they are faced with information later in the sentence that suggests this initial analysis is incorrect. Sentences that mislead readers or listeners to initially parse an incorrect structure that must later be reanalyzed are often called “garden-path” sentences. When this occurs the reader or listener is said to have been “garden-pathed.”

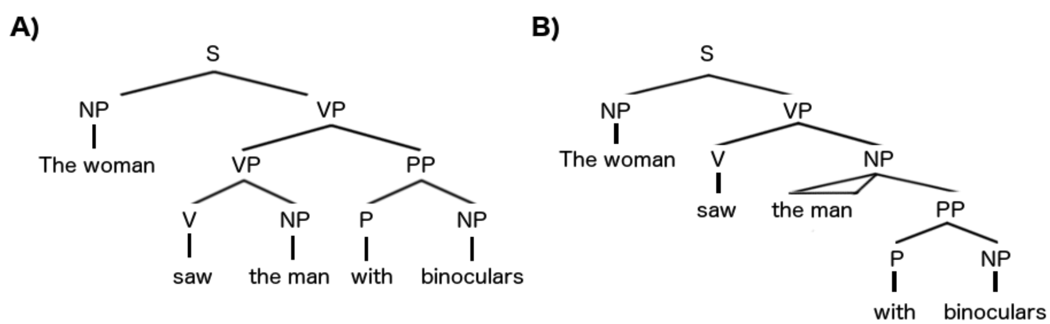


Figure 2-3. A) Tree structure demonstrating the minimal verb attachment of the PP. B) Tree structure demonstrating non-minimal noun attachment.

Similarly, consider when the lexical information inside the PP is slightly different, as in:

18. The woman saw the man with the dog.

The PP, containing the NP *the dog* (instead of *the binoculars*) now clearly steers the parser toward the more complicated NP attachment option, as it is quite unlikely to see ‘with a dog’. Even so, a strict modular garden-path account will still construct the simplest syntactic structure (verb attachment) during the first stage of processing, and only in the second stage will lexical information (such as the semantics of the NP) be taken into account and thus will trigger a reanalysis.

There is a significant amount of research supporting the principles of this garden-path account, though much of this support is based on relatively early studies (Fodor, 1983; Frazier, 1987; Frazier & Rayner, 1982; Just & Carpenter, 1980; Rayner, Carlson, & Frazier, 1983). For example, Frazier and Rayner (1982) presented subjects with sentences like:

19.	The city council argued the mayor's position…	
19a.	The city council argued the mayor's position <u>forcefully</u>.	(Minimal Attachment)
19b.	The city council argued the mayor's position <u>was incorrect</u>.	(Non-minimal Attachment)

This sentence contains a temporary direct object (DO)/sentential complement (SC) ambiguity because the verb (*argued*) is optionally transitive so the reader/listener does not initially know whether the structurally ambiguous NP (*the mayor's position*) is the direct object of the verb *argued* or whether it is the subject of the sentential clause (e.g., *the mayor's position was incorrect*). According to the principles of *minimal attachment* and *late closure*, the temporarily ambiguous NP (*the mayor's position*) will be interpreted initially as the direct object of the verb *argue* because this analysis yields the simplest structure. Thus, when presented with (19b) readers would be forced to reanalyze the sentence. Using their eye tracking-while-reading method, reanalysis would be indicated by longer reading times per character, more regressive eye movements (to the position in the sentence where reanalysis must begin), and increased average fixation duration in the disambiguiating region (underlined in (19a) and (19b)). It is important to note that longer reading times are equated with increased processing load.

Direct support for the garden-path account was revealed, as shorter reading times were found in sentences that conformed to the principle of minimal attachment (19a), indicating that more processing was required in sentences violating these principles (19b). Also, the average reading time per character was longer in (19b) relative to (19a). Finally, when comparing average fixation duration in the disambiguating region relative to the ambiguos region earlier in the sentence, increased average fixation duration was only found in (19b). The authors interpreted these findings to mean that readers initially constructed the simplest structure because increased processing was only observed in (19b). If both syntactic structures were constructed and the best was chosen, as would be predicted in an unrestricted account, then increased processing in (19b) relative to (19a) would not have been observed.

Frazier, Clifton, and Randall (1983) provided evidence in support of another strategy of the *garden-path account, the Most Recent Filler* (MRF) strategy, which predicts that when a gap is detected during sentence processing it is quickly linked to the most recently encountered filler. In this sentence comprehension study subjects were presented with sentences like the following:

20a. This is the girl$_1$ the teacher$_2$ wanted ______$_2$ to talk to ______$_1$. (Recent Filler)

20b. This is the girl$_1$ the teacher wanted ______$_1$ to talk. (Distant Filler)

The MRF strategy predicts that (20a) should be easier to process than (20b) because the first gap was meant to be filled by the most recently encountered NP (*the teacher*), as in (20a) but not in (20b), where it should be filled by the first NP in the sentence (*the girl*). If the MRF strategy is correct, then (20a) would be processed with relative ease, but in contrast, once the reader or listener reached the end of the sentence in (20b) and realized there was not a second gap to fill with the first NP (*the girl*), reanalysis would be triggered. The results indicated that the recent filler sentences (20a) were processed significantly faster than distant filler sentences (20b), thus supporting the MRF strategy.

More recently, the garden-path model has been extended to the *construal hypothesis* (Frazier & Clifton, 1996; Frazier & Clifton, 1997). According to this hypothesis, an immediate fully determined syntactic analysis is only made initially for primary phrases (subject and main predicate of any finite clause) and primary relations, which are defined as complements or obligatory costituents of primary phrases. While a complete syntactic analysis is completed for primary phrases and primary relations, only an incomplete underspecified analysis is completed for non-primary relations (e.g., relative clauses, adverbial clauses, etc.) in a process called *construal*. In this way the *construal hypothesis* makes a distinction between primary and non-primary phrases. In this two stage model, primary phrases are parsed in the constituent structure module while non-primary phrases are assigned to the thematic processing domain which works in parallel to check that the structure is properly built for the verb's argument structure. The constituent structure module uses only syntactic information, while the thematic processing module uses all of the available information (e.g., semantic information, contextual cues, plausibility). In this way, syntactic information is processed separately from non-syntactic information but relevant non-syntactic information does impact sentence processing in the early stages.

As evidence for the *construal hypothesis* the authors cite a study by Clifton, Frazier, Rapoport, and Rado (1996) that compared the processing of sentences with primary phrase ambiguity or non-primary phrase ambiguity in a self-paced reading task. According to *construal,* the parser should be garden-pathed when ambiguity is present within the primary phrase but not when ambiguity is present in a non-primary phrase since these phrases do not receive a determinate analysis. When comparing reading times at the site of disambiguation, Clifton et al. (1996) found evidence of significant disruption in garden-path sentences containing primary phrase ambiguity but not in those with non-primary phrase ambiguity, thus supporting the *construal hypothesis*.

The garden-path model proposes that a complete, detailed, and accurate representation is generated for every sentence that enters the language processor. The *construal hypothesis,* which extended the garden-path hypothesis, claimed that primary phrases receive a complete representation and non-primary phrases receive an incomplete representation. Similarly, another account, the *Good-Enough Approach* (Ferreira, Bailey, & Ferraro, 2002), suggests that language processing sometimes results in partial and incomplete representations. This approach is based on studies that found that information from schemas stored in long-term memory can interfere with sentence processing. For example, sentences such as *the dog was bitten by the man* are often misinterpreted as meaning the more likely scenario (e.g., the man was bitten by the dog) (Ferreira & Stacey, 2000). Ferreira and colleagues also cite evidence that the initial incorrect representation of garden-path sentences interferes with the final interpretation of the sentence (Christianson, Hollingworth, Halliwell, & Ferreira, 2001).

2.2.2 Unrestricted Accounts

Unrestricted accounts, which are often constraint-based, differ from restricted accounts in several important ways. First, unrestricted models typically claim that processing occurs within one stage where all types of information (e.g., lexical-semantic, syntactic, plausibility, context) interact with one another throughout the entire process. Crucially, because syntactic information is processed along with every other type of information in the same stage, syntax does not play a privileged role as it does in restricted accounts. Instead, syntactic constraints regarding how words merge to form higher-order categories and how verbs, for example, select for their arguments, are specified in each word's lexical entry and are thus available to a listener/reader when the verb is encountered (and sometimes even before, particularly in verb-final languages). These accounts claim that words consist of multiple properties, and syntactic constraints are simply one of these. Furthermore, unrestricted accounts assume that as words of a sentence are presented to a listener, the language processor assesses all of the possibilities permitted by the individual words and the features of those words. These possibilities are tracked and ranked by probability and as the processor encounters more words, revealing further constraints, the probabilities are constantly changing relative to one another. If multiple interpretations exist by the time the end of the sentence is reached, the parser uses frequency information to choose the most likely interpretation. Note that parallel processing occurs here because multiple possibilities are being computed simultaneously. This mechanism is very different from restricted models where only one structure is built at a time, and that initial structure is only revised when an error is detected.

Unrestricted accounts first emerged in the 1970s (Marslen-Wilson, 1973, 1975) in reaction to restricted accounts (i.e., modularity) that were being proposed. Instead of the modular, syntax-driven accounts that researchers like Frazier and colleagues had proposed, the unrestricted accounts proposed a highly interactive model of language comprehension that was detailed in a treatise by Marslen-Wilson and Tyler (1980). In this essay it was argued that context plays a more important role than structure in the early stages of sentence processing.

To lend support to their claims, Marslen-Wilson and Tyler (1980) cited evidence from an experiment where subjects were tasked with monitoring for word-targets (e.g., *lead*) at different positions within Normal Prose (21), Semantically Anomalous Prose (22) and Scrambled Prose (23) sentences, as in the following examples:

21.	The church was broken into last night. Some thieves stole most of the *lead* off the roof.	(Normal Prose)
22.	The power was located into great water. No buns puzzle some in the *lead* off the text.	(Semantically Anomalous Prose)
23.	Into was power water the great located. Some the no puzzle buns in *lead* text the off.	(Scrambled Prose)

The Anomalous Prose condition was designed to differ from the Normal Prose condition in terms of lacking semantic organization, while also preserving syntactic and prosodic structure. The Scrambled Prose condition was designed to lack both syntactic and semantic organization. The sentences were either presented with a lead-in sentence (as written) or without the lead-in sentence. The study found that participants responded significantly faster to word-targets in the Normal Prose condition relative to the Semantically Anomalous and the Scrambled condition. Additionally, the inclusion of the lead-in sentence resulted in faster reaction times in the Normal Prose condition but not the other conditions.

The authors interpreted these results to mean that context plays a vital role in the early stages of sentence processing. Yet, these results should be interpreted with much caution. Consider that word-monitoring tasks require the listener to 'hold' the to-be-monitored sentence in memory as the sentence is unfolding over time, essentially requiring the listener to consciously reflect on and check if each incoming word matches the to-be-monitored word. Conscious reflection almost certainly is sensitive to context, so it is not surprising that context effects emerge. Furthermore, the dual-task nature of this method also requires participants to divide their attention between sentence processing and the memory task. Thus it is unlikely that this method is measuring on-line sentence processing without requiring interference from other information or processes.

The most prominent unrestricted account has been the *constraint-satisfaction model* (MacDonald et al., 1994), which claims that the principle of *minimal attachment* has a different basis than the one presented in the *garden-path* model. They propose instead that the weighting of probabilistic and grammatical constraints can explain the garden-path effects found by many researchers. These claims were tested, for example, in a self-paced reading task (MacDonald, 1994) where subjects were presented with sentences such as:

24. The rancher knew that the nervous cattle *pushed/moved/driven* into the crowded pen were afraid of the cowboys.

These sentences contain a potential main verb/reduced relative clause (MV/RR) ambiguity where it is initially unclear whether the verb (*pushed, moved*) is the main verb or whether it is part of the reduced relative clause. Reduced relative clauses are so named because the relative pronoun or complementizer (e.g. *who, which, that*) that often introduces relative clauses (a dependent clause that functions like an adjective) can be omitted in English. Yet the omission of the pronoun or complementizer often results in a temporary syntactic ambiguity. This ambiguity occurs because for many verbs in English the past tense form (used in the main verb interpretation) is morphologically the same as the past participle form (used in the reduced relative clause version). MacDonald (1994) examined how probabilistic constraints would impact the processing of sentences containing the MV/RR ambiguity. Specifically, the argument structure frequency (e.g., whether the verb is more likely to be used transitively or intransitively) of the verbs was manipulated. Subjects were presented with transitively-biased verbs (e.g., *pushed*), intransitively-biased verbs (e.g., *moved*), and unambiguous control verbs (e.g., *driven*). Note that the control verbs are unambiguous because the past tense version of the verb (*drove*) is morphologically different from the past participle form (*driven*). Because the RR interpretation requires a transitive argument structure, it was predicted that transitively-biased verbs would be processed faster than intransitively-biased verbs. And indeed, when compared to the unambiguous condition, reading times were significantly longer for intransitively biased verbs, but no difference was found between the unambiguous and transitively biased conditions. These results were interpreted as providing strong support for the *constraint-satisfaction* approach, as frequency impacted the interpretation of temporarily ambiguous sentence structures.

Furthermore, using the constraint-satisfaction approach, Trueswell and Tanenhaus (1994) described the role that lexical representations play in sentence processing. According to their account, thematic fit information (whether an NP is a ‘good’ Agent or Patient) is available in the early stages of processing to resolve structural ambiguities like the following:

25a. The fossil examined…

25b. The archeologist examined…

The verb *examined* is structurally ambiguous because it can either be the past tense version or the passive participle form. In the past tense form of the verb, the fragment is the main clause and the first NP takes on the thematic role of Agent. However, in the passive participle form the verb is at the beginning of a reduced relative clause. In these constructions the first NP is the object of the verb and takes on the thematic role of Theme. Thus, in terms of frequency, when a verb like *examined* is preceded by an NP that would be a good Agent it is more likely that the verb is part of a main clause, and when it is preceded by an NP that would be a good Theme it is more likely that the verb is part of a reduced relative clause. In this account, then, it is assumed that thematic fit information is immediately available to the parser and is used in initial structure-building, which differs from restricted two-stage models where syntactic information is the only information used in initial processing stages.

Trueswell, Tanenhaus, and Garnsey (1994) conducted a seminal experiment which provided evidence to support the constraint-satisfaction approach. In this eye tracking-while-reading experiment subjects were presented with sentences like the following:

26a. The defendant examined by the lawyer turned out to be unreliable.

26b. The evidence examined by the lawyer turned out to be unreliable.

26c. The defendant that was examined by the lawyer turned out to be unreliable.

26d. The evidence that was examined by the lawyer turned out to be unreliable.

Here sentences (26a) and (26b) are initially structurally ambiguous because they contain reduced relative clauses (where the optional complementizer *that* which indicates the beginning of the relative clause has been removed) and sentences (26c) and (26d) are unambiguous relative clauses. The first NP was manipulated so that it was either animate (*the defendant*) or inanimate (*the evidence*). Animate NPs possess semantic properties that make them good Agents, while inanimate NPs possess properties that make them good Themes. Recall that when presented with an NP that makes a good Agent, an animate NP, the verb is more likely to be part of a main clause rather than a reduced relative clause. Thus, it was predicted that readers would be less likely to be garden-pathed when presented with temporarily ambiguous sentences containing inanimate NPs, as in (26b), relative to those with animate NPs, as in (26a). This prediction differs from the *garden-path account* which would predict that readers would be garden-pathed regardless of the semantic properties associated with the NPs because the system would automatically build the simplest syntactic structure (the main verb structure). A garden-path effect would be indicated by significantly more regressive eye movements at the point of disambiguation, *by the lawyer*, in the sentences containing the reduced relative clause (26a) and (26b) compared to the unreduced relative clauses (26c) and (26d).

Eye-movements were recorded and first-pass (eye movements occurring within a region of interest if the subject had not read that region previously, and ending when the subject either made regressive eye movements to a prior region or a forward movement to the next region) and second-pass reading times were recorded during different regions of the sentences. Reduced relative clauses with animate NPs (26a) yielded significantly longer first- and second-pass reading times compared to those with inanimate NPs (26b). Also, there were significantly longer reading times in the reduced relative clauses with animate NPs (25a) compared to unreduced relative clauses with animate NPs (26c), yet this distinction was not found between reduced (26b) and unreduced clauses (26d) containing inanimate NPs. Thus these results appear to show clear support for a lexically based constraint-based approach.

2.2.3 Resource-Based Accounts

Another set of accounts focus on the cognitive resources that underlie sentence processing, including memory and attention. One example is a cue-based retrieval mechanism for sentence processing (Lewis & Vasishth, 2005; Lewis, Vasishth, & Van Dyke, 2006; Van Dyke & Lewis, 2003). This model suggests that as a word in a sentence is processed, some of the word's properties are encoded into working memory, such as its category (e.g., NP, VP) and number (e.g., singular, plural) as well as the lexical requirements for the item it is expected to join (e.g., verb, noun, third person singular); these features remain in working memory until they are retrieved later in the sentence. Retrieval cues are provided by grammatical heads (e.g., the head of an NP is a Noun; the head of a VP is a verb; and so on) and are used to access items that have been previously stored.

Consider the following:

27. The student with the large backpack forgot the exam.

The NP, *the student*, is encoded with certain features (*noun, singular*) and the features of the item it expects to join later in the sentence (*verb, third person singular*). These features remain in working memory until the verb, *forgot*, is reached. Features of the verb along with the features of the item it is expected to integrate with (the *noun* that can act as a subject) act as retrieval cues for the NP, *the student.* At this point the verb is integrated with the noun. Processing difficulty can occur if these features decay in working memory. Processing difficulty can also occur when items with similar features are required to be temporarily stored in working memory – resulting in similarity-based interference – which will be discussed in detail later in this paper.

Another resource-based account is grounded in expectation-based syntactic comprehension (Levy, 2008). Here the key element is the notion of *surprisal*, the likelihood that a given word will be encountered in various contexts. Similar to constraint-based accounts, parallel processing occurs where multiple possibilities are computed and are ranked based on their probability. Cognitive resources are allocated to these different interpretations and processing difficulty occurs when these resources are improperly allocated. Thus, the relative ease of integrating a new word into a sentence directly corresponds to whether it fits with a highly ranked or a lower ranked possibility. If it corresponds with a lower ranked structure then re-ranking will be required, resulting in the expenditure of valuable processing resources.

It is clear that conflicting information often exists when sentences are processed for comprehension. Recently, researchers have discussed the need for unifying accounts of sentence processing. In a review, Ferreira (2005) explained that many psycholinguistics have become disenchanted with generative grammar since it is difficult to adapt to processing models, and on Ferreira's view generative grammar is based on a weak empirical foundation. As a solution, Ferreira proposes that formal linguists begin to link their work more closely with the field of cognitive science, as Jackendoff (2002) has suggested. One account that attempts to do this is the *Parallel Architecture* account (Jackendoff, 2007, 2011). According to this constraint-based theory, the grammar consists of phonology, syntax and semantics as independent generative components, which are linked by interface rules. These components are built-in parallel and contain constraints that will immediately impact processing. Structure-building is claimed to be non-directional in that it can occur in a top-down, bottom-up or left-to-right direction. Both syntactic rules and the properties of words can yield potential structures, which are held in working memory and are in direct competition with one another. As linkages are made between lexical information, potential structures are eliminated from working memory. Thus, in this model an attempt has been made at unifying generative grammar, constraint-based and resource-based processing. Unfortunately, there is little in the way of experiments that have directly tested this account.

2.2.4 Recent Approaches to Incorporate Prosody into Sentence Processing Models

Prosody has a limited role in early models of sentence processing since many of these models were based on findings from reading studies, rather than studies of auditory sentence processing. However, more recently researchers have attempted to incorporate prosody into sentence processing models. Researchers in this area typically distinguish between prosodic grouping/phrasing and prosodic prominence. Prosodic grouping refers to temporal changes and boundary tones thought to group words syntactically. In contrast, prosodic prominence (conveyed by pitch, duration, and intensity) impacts other types of processing such as pronoun and reference resolution.

As an example, Carlson et al. (2009) investigated two hypotheses with distinctive predictions about how prosody and intonation impacts language processing. The prosodic packaging hypothesis claimed material is packaged into perceptual and memory units. This hypothesis would predict that listeners should have difficulty accessing material that was processed and packaged earlier in the sentence relative to material encountered later in sentence. However, the specialized role hypothesis suggested that prosodic boundaries (e.g., slowing, pausing) and boundary tones constrain parsing possibilities by aiding grouping decisions during hierarchical structure building. In this hypothesis prosodic boundaries determine hierarchical structure but do not impact accessibility to sentence material, whereas pitch accents are influential in determining accessibility. In a series of experiments where reaction times and final comprehension tasks were used to investigate the role of prosody, they found support for the specialized role hypothesis.

Similarly, Speer and colleagues (Speer, Crowder, & Thomas, 1993; Speer & Ito, 2009; Speer, Warren, & Schafer, 2011) acknowledge that prosodic form is determined in part by the syntactic structure of a sentence, but they also point out that prosody simultaneously reflects multiple components of linguistic structure. In addition to conveying syntactic information, prosody can express phonological, semantic, pragmatic, sociolinguistic information. For example, pitch accents and other types of cues can convey emphasis and topicalization (establishes an expression as the topic of the clause or sentence). They also propose that prosodic structure aids in the organization of linguistic information in working memory, allowing for the more efficient use of working memory resources. As well, Frazier, Carlson, and Clifton (2006) claim that the prosodic representation of a sentence holds linguistic representations in memory during processing. Specifically, they claim that prosody forms a skeleton that helps retain an utterance in memory during processing by holding different syllables together and organizing items across phonological, syntactic, and semantic representations.

While it is clear that prosody is an essential component of sentence processing that must be incorporated into models of sentence processing, there is much work to be done. Many studies have used offline tasks, where the impact of prosody on the final comprehension of sentences is measured, rather than online tasks, which measure processing as the sentence unfolds. Offline tasks do not provide the temporal sensitivity that online tasks offer and thus are limited in their ability to provide information about when prosody impacts sentence processing.

With this attempt to describe sentence processing accounts, I now move to a description of accounts of sentence comprehension deficits in Broca's aphasia, including grammar-oriented, lexically-based, and cognitive accounts.

2.3 Accounts of Sentence Comprehension Deficits in Broca's Aphasia

Broca's aphasia is characterized by effortful, halting, nonfluent speech. Often, individuals with Broca's aphasia produce speech where grammatical function words (i.e., prepositions, articles, auxiliary verbs, pronouns, and conjunctions) and grammatical inflections (indicating tense, gender, number, and agreement) are omitted relative to content words (i.e., nouns, verbs, and adverbs). Thus, individuals with Broca's aphasia are often characterized as producing 'agrammatic' speech. Paul Broca (1861) was the first scientist to attribute this type of language disorder to damage to left hemisphere inferior frontal gyrus (LIFG). He described a patient who had severe language production difficulties who could only produce a single word (*tan*), yet his language comprehension appeared to be spared. As a result of these findings, Broca's aphasia was originally described as a language disorder where speech production was impaired while comprehension remained intact. This characterization remained until more recent times. One seminal article, Caramazza and Zurif (1976), described a study which revealed that individuals with Broca's aphasia had difficulty understanding sentences in non-canonical word order with semantically reversible NPs, like (28):

28. The cat that the dog is biting is black.

In (28) both NPs (*the boy* and *the girl*) are capable of performing the action of *biting.* However, the participants with Broca's aphasia did not have trouble understanding sentences like:

29. The book that the girl is reading is yellow.

In sentences like (29), only the animate NP, *the girl*, is capable of performing the action of *reading*. Thus participants had difficulty understanding non-canonical sentence structures where semantic information (e.g., animacy) was not sufficient to determine which NP was performing the action and which was receiving the action. Since this discovery, researchers have explored sentence comprehension abilities using several different sentence types to better understand the underlying nature of comprehension deficits that exist in this population (e.g., Friedmann & Shapiro, 2003; Grodzinsky, 1989, 2000; Love et al., 2008; Schwartz et al., 1987).

Not surprisingly, several different accounts of the language deficits in Broca's aphasia have been proposed. One class of accounts, referred to as *grammar-oriented accounts,* propose that the impairment in Broca's aphasia must be described in terms of the grammar, and these are often syntactic-centric. There are also lexically-based accounts, which claim that lexical access is delayed in Broca's patients which ultimately results in what appears to be impaired syntactic processing. Finally, more cognitively-based theories allege that reduced cognitive resources are the primary cause of comprehension deficits in Broca's aphasia. I review these accounts below.

2.3.1 Grammar-Oriented Accounts

According to Caplan and Futter (1986), participants with Broca's aphasia are unable to properly assign thematic roles. Instead of building a hierarchical syntactic structure, individuals with Broca's aphasia engage in a linear Agent-first strategy where the first NP encountered in a sentence is always assigned the thematic role of Agent and the second NP is thus assigned the role of Patient or Theme. As discussed by Grodzinsky (1986), this account would predict that any reversible sentence not conforming to canonical word order (S-V-O, or Agent-Verb-Patient) would always be misinterpreted; evidence suggests that this prediction is too strong. Furthermore, Grodzinsky objected to Caplan and Futter's assumption that hierarchical structure-building was completely impaired in Broca's patients because this impairment would be quite severe. Instead, Grodzinsky (1986, 1995, 2000, 2006, and others) proposed the *trace deletion hypothesis,* which claims that comprehension deficits in Broca's patients results from the deletion of traces in the representation of sentences.

Recall from the *Long- Distance Dependencies* Section 2.1.3 (p. 16) that in non-canonical word-order sentences, NPs are displaced from their original base-generated positions (e.g., *the child* in (30) below), leaving behind a gap (in psycholinguistic terminology) or copy/trace (in linguistic terminology) that must be linked with the displaced constituent in order for the listener to properly assign thematic roles and understand the sentence. Consider:

30. It was [the child]$_i$ that the mom hugged [____]$_i$.

The verb, as the head of the VP, assigns thematic roles to its argument positions in the sentence. The Agent is assigned to the subject NP slot (*the mom*) and the Theme role is assigned to the object NP slot, now occupied by the trace. The trace and its displaced constituent, the NP *the mom*, form a syntactic chain, and the thematic role is assigned to the chain. Thus, the displaced NP inherits the Theme role. According to the *trace deletion hypothesis,* individuals with Broca's aphasia delete traces from the linguistic representation and are thus unable to assign thematic roles to the displaced NP. Thus, listeners are able to correctly assign the Agent role because no trace is involved, but are unable to assign the Theme role to the displaced NP. Consequently, according to this account the displaced NP does not receive a thematic role and the language parser defaults to a non-linguistic agent-first strategy and assigns the role of Agent to the first NP in the sentence, *the child.* Thus two NPs receive the role of Agent, one grammatically and one through the Agent-first heuristic. An individual with Broca's aphasia is then left to guess which NP is the Agent. In a simple sentence-picture matching task with two pictures (one conforming to the appropriate Agent-Theme representation, and one reversing that relationship; e.g., Mom hugged Child vs. Child hugged Mom), participants with Broca's aphasia perform at chance levels.

Another grammar-oriented account is the *slow syntax hypothesis* (Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008; Piñango, 2000; Piñango & Burkhardt, 2005). This account argues that syntactic structure formation is delayed as a result of limited processing capacity in the syntactic system. Specifically, the account suggests that the *Merge* operation, where two syntactic objects are combined to form a larger syntactic constituent, is delayed in Broca's patients during sentence processing (note that it is unclear why Merge is disrupted and why Merge requires considerable processing resources). In unimpaired listeners and as discussed in Section 2.1.1 (p. 12), on some accounts (and the one that is assumed in this dissertation) *Merge* operations occur before the assignment of thematic roles. Therefore, as a result of the syntactic processing delay predicted by the *slow syntax hypothesis*, semantic information is available before the fully realized syntactic structure is built, and thus semantic information is required to drive the assignment of thematic roles. This impairment results in two competing thematic role interpretations: one from semantic information and the other from the delayed syntactic analysis. This competition results in comprehension deficits.

2.3.2 Lexical Processing Accounts

Lexical processing accounts suggest that comprehension deficits found in Broca's aphasia are primarily a consequence of lexical processing impairments. One such account is the *delayed lexical activation hypothesis* (DLA; Love et al., 2008), which claims that slowed lexical activation is the fundamental basis for the comprehension deficits observed in Broca's patients. Love et al. (2008) presented evidence in support of this hypothesis in a series of cross-modal lexical priming (CMLP) experiments. In CMLP tasks, participants are instructed that they will be performing two tasks. First, they are presented with sentences aurally and told that they need to listen to the meaning of each sentence. At the same time and during the unfolding of each uninterrupted sentence, they are to monitor a computer screen for a visual probe. Upon presentation of the visual probe (a letter string that does or does not form a word), participants are asked to make a binary lexical decision (e.g. WORD/NON WORD), during which accuracy and reaction times are recorded. The visual probe is presented at a particular point in the sentence, and it is either related or unrelated to the constituents in the sentence. Consider, for example:

31. The audience liked [the wrestler]$_i$ ^{*1} that the ^{*2}parish priest condemned _____$_i$ ^{*3} for ^{*4} foul ^{*5} language.

Here, if one is interested in the time course of lexical activation for the NP *the wrestler*, reaction times to words related to that NP (e.g., fighter) are compared to an unrelated probe (e.g., pigment) immediately at the offset of that NP (*1). A priming effect (significantly faster reaction times to related relative to unrelated probes) is interpreted as an indication that the word of interest (e.g., *wrestler*) has been activated at that specific point in the sentence. Multiple probe points can be investigated within an experiment, however only a single probe is presented with each sentence, offering a snapshot in time of the processing system. In this way, researchers can determine whether participants are activating lexical items at various positions in the sentence, including during the immediate occurrence of the lexical item, and at the gap, where it is assumed that a remnant of the displaced NP is represented.

Love et al. (2008) presented both unimpaired subjects and subjects with Broca's aphasia with sentences like (31), above. The results revealed that neurologically unimpaired participants accessed the direct object of the verb *condemned, the wrestler*, both at its displaced position (*1) and at the gap (*3), its original base-generated position. Yet importantly, evidence of lexical activation in the Broca's group was found downstream from these two positions, at probe points (*2) and (*4). Hence, the Broca's patients were able to engage in lexical activation and syntactic structure-building, but in a manner that was delayed relative to the unimpaired group. A corollary of the DLA suggests that because lexical activation and re-activation (at the gap) is delayed, fast-acting syntactic processing is no longer synchronized with lexical access, yielding what appears to be a syntactic processing deficit in Broca's aphasia.

Several studies using various methods have corroborated Love et al.'s (2008) results (Choy, 2011; Swaab, Brown, & Hagoort, 1997). For example, Swaab et al. (1997) used event-related potentials to investigate language processing in individuals with aphasia. In experiments using event-related potentials, participants wear an electrode-cap, which records neural electrical activity, while being presented with visual or auditory stimuli. The ERP technique has the advantage of recording data with millisecond precision, without requiring the participant to engage in a secondary task. ERP components are examined by calculating a time-locked average of several events. Swaab et al. (1997) were particularly interested in examining the N400, a negative-going ERP component that typically peaks between 380-440 ms after stimulus onset. In unimpaired participants semantically incongruent words result in a larger N400 than congruent words and this difference in amplitude between semantically congruent and incongruent stimuli is referred to as the N400 effect. The N400 effect is believed to reflect lexical integration processes (Brown & Hagoort, 1993; Holcomb, 1993; Kutas & Hillyard, 1980). In the Swaab et al. (1997) study, a group of unimpaired participants and a group of individuals with Broca's aphasia were presented aurally with sentences in Dutch. In one condition the sentence-final word was congruent with the preceding context and in the other the sentence-final word was incongruent. The resulting N400 effect was present in the Broca's group, yet it was reduced in amplitude and delayed relative to the unimpaired group. Thus both the Love et al. (2008) and Swaab et al. (1997) results provide evidence that delayed lexical access may account for the comprehension deficits seen in patients with Broca's aphasia.

2.3.3 Working Memory/Resource Allocation Deficit Accounts

Another set of theories suggests that comprehension deficits in individuals with Broca's aphasia results from the impairment of certain cognitive abilities, particularly within the working memory system. These theories are referred to as working memory or resource allocation deficit accounts. Before the role of working memory deficits in Broca's aphasia can be discussed, a description of the role of working memory in sentence processing in neurologically unimpaired individuals will be provided. I follow this with a section detailing resource allocation deficit theories as a potential explanation for comprehension deficits in participants with Broca's aphasia.

2.3.3.1 Working Memory Overview

Working memory is a type of memory that allows a person to temporarily hold and manipulate information for use in many complex cognitive processes. Although there are several models of working memory, one of the earliest and best known is Baddeley's Working Memory Model (Figure 3) (Baddeley, 1986, 2000). This model consists of a central executive and three "slave" systems including the visuospatial sketchpad, the phonological loop, and the episodic buffer. The central executive is responsible for directing the activities of these three systems and is responsible for shifting and focusing attention to these three components. It is also thought to have a limited capacity. The visuospatial sketchpad processes visuospatial information and has both storage and rehearsal components, while the phonological loop processes phonological encoding and rehearsal. The episodic buffer is the least well-understood system and is responsible for linking visual, spatial, and verbal information as well as allowing Long Term Memory (LTM) to interact with the other components of the model.

This model describes a reciprocal relationship between working memory (fluid systems) and long-term memory (crystallized systems) (Figure 2-4).

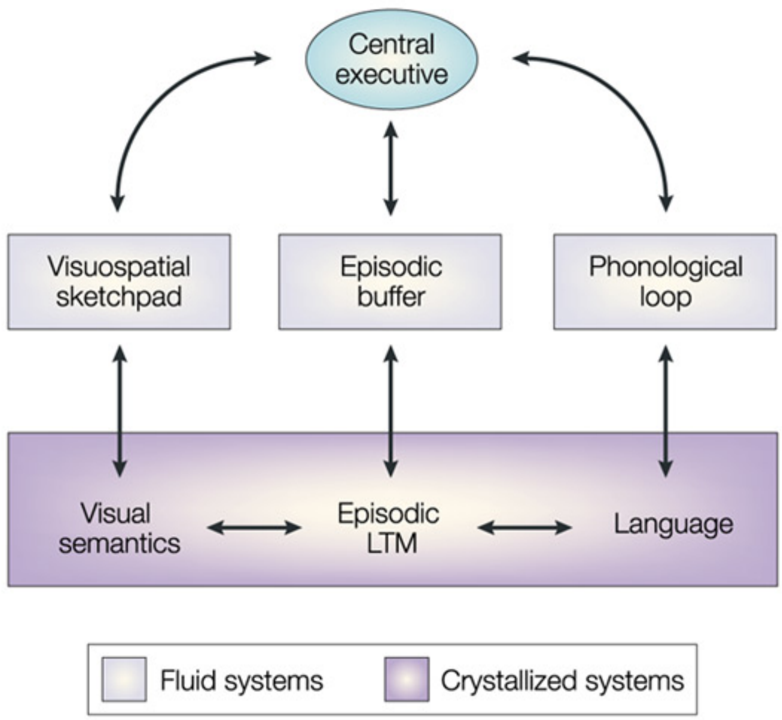


Figure 2-4. Working Memory Model. [From Baddeley (2003)].

Intuitively it is likely that working memory is involved in sentence processing as it allows a listener to "hold" the elements in the sentence until those elements are needed for interpretation. The idea of working memory being used during sentence comprehension was first discussed by Miller and Chomsky (1963) who described doubly center-embedded sentences like the following:

32. The rat the cat the dog chased bit ate the cheese.

Sentences like (32) are difficult if not impossible for listeners to comprehend. Miller and Chomsky (1963) pointed out that comprehending sentences like this increases memory load as listeners must hold multiple NPs in their memory before the NPs can be properly integrated with their respective verbs. Sentences containing long-distance dependencies, then, would also suggest an increase in memory load.

To review, long-distance dependencies refer to sentences where two elements associated with each other are located in non-adjacent positions. Consider:

33. The coach watched the game.

34. The coach who was wearing a blue jersey watched the game.

The simple sentence (33) becomes a long-distance dependency (34) when the relative clause is inserted between the subject (*the coach*) and the verb (*watched*). Another type of long-distance structure is a filler-gap dependency:

35. [The mom] hugged [the child].

36. It was [the child]$_i$ that the mom hugged [____]$_i$.

37. [Which child]$_i$ did the mom hug [____]$_i$?

Because the verb *hugged* is transitive it requires both a subject (the person giving the hug) and an object (the person receiving the hug) to be present in the representation. In (35) the sentence is in canonical word order for English (Subject–Verb–Object), yet in (36) and (37) the object NP (*the child*) occurs before the verb. Recall from the *Long-Distance Dependencies* Section 2.1.3 (p.16) that sentences where NPs are displaced from their base-generated positions create filler-gap dependencies, as in sentences (36) and (37) above.

It is thus likely that some aspect of working memory is involved in the process of comprehending simple sentences and even more so when processing sentences containing long-distance dependencies, where multiple NPs must be held in working memory prior to integration with the verb. Yet, the notion that sentence comprehension requires working memory is one of the most contentious areas in language processing. There are numerous reasons for this debate. For example, the capacity limits of working memory are not fully understood and thus complicates the implications for sentence processing and comprehension. Furthermore, there is debate about the modularity of working memory, i.e., whether there exists a separate working memory system devoted only to language processing. Researchers generally agree that visuo-spatial information and verbal information are processed separately in working memory (Baddeley & Hitch, 1974; Hanley, Young, & Pearson, 1991; Jonides et al., 1993). However, whether verbal working memory can be sub-divided into one process specifically for linguistic processing and one for non-linguistic verbal cognitive tasks is unknown.

Some researchers (Just & Carpenter, 1992; King & Just, 1991; MacDonald, Just, & Carpenter, 1992) take the position that there is only one verbal working memory capacity that is used for both sentence processing and verbal-mediated cognitive tasks. According to Just and Carpenter's (1992) *capacity theory* of language processing, there is a limited set of processing resources available in verbal working memory and it can be measured using an external working memory task like the Daneman and Carpenter (1980) reading-span task. In this task participants are asked to read a set of sentences and recall the last word of every sentence. Just and Carpenter claim that individuals with low working memory capacity (low-span readers) as compared to high-span readers have difficulty processing and comprehending object-relative sentences that contain syntactic dependencies. However, other researchers take the view that syntactic processing in sentence comprehension is processed via a separate working memory from non-linguistic verbally-mediated tasks like the Daneman and Carpenter reading-span task (Caplan & Waters, 1999; Lewis, 1996). In an extensive review of the literature Caplan and Waters (1999) distinguish between *interpretive processing,* the extraction of meaning from the linguistic signal, and *post-interpretive processing,* which is used for storing information in long-term memory, reasoning, planning and other similar functions. *Interpretive processing* involves several operations including recognizing words, constructing syntactic and prosodic representations, and assigning thematic roles.

Specifically, Caplan and Waters (1999) argue that because the reading-span task is a dual-task it requires participants to divide their attention. Thus, the poor comprehension of low-span readers reported by Just and Carpenter (1992) may be due to difficulty with dividing attention, and shifting resources between two separate tasks, rather than a problem with syntactic processing. Caplan and

Waters (1999) also took issue with the statistical analyses used by Just and Carpenter (1992) and King and Just (1991) because interactions between group type, syntactic complexity, and sentence region were not reported. Waters and Caplan (1996) compared the ability of low-span and high-span readers to comprehend different types of garden-path sentences and found no differentiation between groups in terms of sentence processing ability. Moreover Caplan and Waters (1999) cite work from different patient populations, including patients with auditory verbal short-term memory impairments and Broca's patients, to demonstrate that two separate verbal working memory loci must exist.

Much of the work in this area has focused on how manipulating the number of items in a dual-task impacts sentence processing. Yet, some scientists have turned toward examining interference that results from similar items being held in working memory during sentence processing. This work views working memory as part-and-parcel of the language and cognitive processing system (that is, on this account there is no such thing as an independent "working memory system"), and hence it may be erroneous to test working memory capacity with external tasks such as the reading and listening span tasks (see, for example, MacDonald,1992). Instead, the properties of the sentence itself are what matters. In the next section I review what I believe to be the most interesting and important set of studies that are relevant to the notion of working memory and sentence comprehension; these suggest that similarity-based interference is at the root of sentence processing and its potential impairments.

2.3.3.1.1 Similarity-Based Interference within Working Memory

Similarity-based interference during sentence comprehension occurs when the demands on storage and retrieval during sentence comprehension are increased as a result of NPs in a sentence that have similar representations (Gordon, Hendrick, & Johnson, 2001, 2004; Gordon, Hendrick, Johnson, & Lee, 2006; Van Dyke, 2007; Van Dyke & McElree, 2011). By examining the nature of similarity-based interference we can gain a better understanding of the sentence characteristics that increase complexity and processing demands for comprehension.

The concept of similarity-based interference first arose in traditional memory research (Shulman, 1970) where it was noted that target items in a list of words are more quickly forgotten when followed by distractor items that share similar characteristics. Also, Bever (1974) observed that the accurate comprehension of double center-embedded sentences was greatly increased when different types of NPs are used (38) relative to when the same type of NPs are used (39):

38. The professor everyone I met loves gave great advice.

39. The professor the student the woman met loves gave great advice.

Several studies have since been conducted to identify the specific characteristics of NPs that contribute to similarity-based interference and to better understand the mechanism of interference as it relates to sentence processing (Fedorenko, Gibson, & Rohde, 2006; Gordon et al., 2001, 2004; Gordon et al., 2006; Gordon, Hendrick, & Levine, 2002; Sheppard, Walenski, Love, & Shapiro, 2015; Van Dyke & Lewis, 2003; Van Dyke & McElree, 2006). The findings from these studies have led some to a cue-based approach of sentence processing (Lewis & Vasishth, 2005; Van Dyke & Johns, 2012), where interference results from difficulty retrieving the head NP from memory. Difficulty occurs when there is a high degree of similarity between NP1 and NP2, indicated by the two NPs sharing similar retrieval cues, making it easy to confuse them in memory. In the following I first review studies examining similarity-based interference in neurologically unimpaired populations, followed by a discussion of the work examining interference in individuals with aphasia.

One of the first to examine this process was Gordon et al. (2001), who presented subjects with sentences containing subject-extracted (40) and object-extracted (41) relative clauses:

40. The banker that praised [the barber / Joe / you / everyone] climbed the mountain.

41. The banker that [the barber / Joe / you / everyone] praised climbed the mountain.

The first NP within each sentence remained the same in the different conditions, and was always a descriptive NP. However, the type of critical noun phrase (the second NP) present within both sentence types was manipulated such that some sentences contained NPs that were descriptions of human roles (e.g. “the barber”), a proper name (e.g. “Joe”) or a pronoun (e.g. “you” and “everyone”). Subjects completed a self-paced reading task followed by a true-false question about the previous sentence.

In sentences where both the first and second NPs were descriptive NPs, significantly longer reading times and lower accuracy in the object-extract relatives were observed compared to the subject-extracted condition, which corroborated the findings of many previous research studies (Gibson, 1998; MacWhinney & Pléh, 1988). However, very different results were found when the first and second NPs were from different classes. The processing advantage of subject- versus object-extracted sentences virtually disappeared when the second NP was a proper name or pronoun.

Participants were also presented with subject- (42) and object-extracted (43) clefts to determine the impact of having two proper names (i.e., matched condition) in a sentence:

42. It was [the barber / John] that saw [the lawyer / Bill] in the parking lot.

43. It was [the barber / John] that [the lawyer / Bill] saw in the parking lot.

The researchers found that the processing discrepancy between subject and object clefts was reduced when the sentences contained mismatched NPs relative to sentences with matched NPs. However, the difference between the two conditions was not completely eliminated as it was in the sentences containing relative clauses. Also, both types of matched NP sentences, description-description matches and name-name matches, resulted in the same findings, suggesting that there is not an invariant characteristic of names that reduces processing difficulty or interference. The difference found between relative clauses and clefts was attributed to several factors. One factor is that names and pronouns cannot easily be modified by a relative clause, unlike clefts, thus when a sentence with a relative clause contains a description NP and a name or pronoun, the reader is given a cue about which NP is being modified. The combination of reduction in interference and the added cue may serve to completely reduce the subject-extracted relative clause processing advantage. These findings also could be due to the fact that the head of a relative clause operates as a semantic argument of two verbs whereas the head of a cleft operates as a semantic argument of one verb. Thus the reader is given an additional cue about the position of the head in a relative clause compared to the cleft sentence.

This work was extended by Gordon et al. (2004) in another series of self-paced reading experiments to determine the characteristics of NPs that contribute to similarity-based interference effects. Specifically, the semantic characteristics of the NP in the embedded clause of sentences containing both subject-extracted and object-extracted clauses were manipulated to have characteristics of subjects and objects that were either be more or less common, based on corpora data. These manipulations were based on literature showing that subjects in a sentence tend to have certain properties, including that they are definite NPs that refer to human entities, and are often pronominal. Thus, it is possible that the findings from the previous Gordon et al. (2001) study were due to the fact that pronouns are prototypical subjects and the pronoun served as the object in the subject-extracted condition (40), resulting in more processing difficulty, and as the subject in the object-extracted condition (41), resulting in less processing difficulty. This potential confound may have contributed to reducing the processing differences between subject- and object-extracted sentences.

In one experiment from Gordon et al. (2004), NPs were either paired with a definite article (e.g., “the”) or an indefinite article (e.g., “a”/“an”), and the processing differences between sentences with subject- (43) and object-extracted (44) relative clauses were compared:

43. The salesman that contacted [the/an] accountant spoke very quickly.

44. The salesman that [the/an] accountant contacted spoke very quickly.

Since subjects are more likely to be definite rather than indefinite NPs (Givón, 1984), the subject-object difference should yield smaller effects with the definite rather than the indefinite NP. Conversely, if similarity-based interference is sensitive to NP definiteness then the subject-object difference would be smaller with an indefinite second NP, as the first NP was always definite. Results revealed significantly longer reading times for object-extracted relative to subject-extracted sentences with no evidence that definiteness impacted reading times.

In another experiment, the second NP was manipulated to either be definite (e.g. “the accountants”) or generic (e.g. “accountants”) as shown in (45) and (46) since according to their corpus analysis generics are non-prototypical subjects and prototypical objects. This comparison was also interesting because generics are quantified expressions, thus allowing the researchers to examine the role of quantification in similarity-based interference.

45. The salesman that [the accountants/accountants] contacted spoke very quickly.

46. The salesman that contacted [the accountants/accountants] spoke very quickly.

Relative to subject-extracted sentences, object-extracted sentences evinced significantly longer reading times, and the presence of a generic second NP significantly increased reading times in both subject- and object-extracted conditions. Importantly, the subject-object difference was not affected by using definite versus generic second NPs.

In a third experiment, rather than manipulating structural semantic characteristics of NPs (i.e., definite vs. indefinite, and definite vs. generic), Gordon et al. (2004) manipulated the lexical- semantic characteristics of the embedded NP. This was accomplished by manipulating the lexical-semantics of the second NP to either convey rich information such as a specific role descriptor (e.g. “accountant”) or lean information (e.g. “person”) indicating only number and humanness.

47. The [salesman/person] that the [accountant/person] contacted spoke very quickly.

48. The [salesman/person] that contacted the [accountant/person] spoke very quickly.

The results showed no impact of lexical "richness" on subject- and object-extracted reading times. These results suggest that similarity-based interference does not operate at the level of lexical-semantics. Taken together the experiments in Gordon et al. (2004) suggest that the semantic characteristics of embedded NPs, including definiteness, whether the NP is generic, and whether the NP conveys semantically rich or lean information, do not mediate similarity-based interference effects.

While the Gordon et al. (2001; 2004) studies served to enrich our understanding of similarity-based interference during sentence processing, they did not give us information about the time course of interference. Therefore, the authors conducted an additional study (Gordon et al., 2006) using an eye tracking-while-reading method to provide more information about the time course of interference. This study was also designed to provide more information regarding how and to what extent linear proximity between NPs contributes to interference effects.

Similar to the past Gordon et al. (2001; 2004) studies, subjects were presented with sentences containing subject- and object-extracted clauses where the two NPs were either matched for type (both definite descriptor NPs such as "the banker") or mismatched (one definite descriptor and one proper name). Significantly longer reading times were revealed for object-extracted relative clauses compared to subject-extracted. Importantly, significantly longer total reading time duration, increased gazes and increased re-reading time during the relative clause and matrix verb regions in the matched compared to the mismatched conditions were exhibited. These patterns suggest that similarity-based interference occurs at the time of memory retrieval – when the NPs must be integrated with the matrix verb. Also, the fact that interference effects were observed during initial processing (i.e., at the relative clause and the matrix verb) as well as later processing (indicated by increased rereading times) suggests that similarity-based interference results in either delayed or incomplete integration of the NPs with the matrix verb. Another important finding from this study was that linear proximity between the critical NPs did not mediate interference effects.

Taken together, the combined findings of et al. (2001, 2004, 2006) suggest that sentence processing is vulnerable to interference when NPs from the same referential class are required to be held in working memory prior to being integrated with the verb – when the memory representations are active in working memory (see also, Van Dyke & McElree, 2006). However, it is important to keep in mind that all but one of these studies examined reading rather than auditory processing, thus the results may not necessarily generalize to sentences presented aurally. Thus many questions are left to be answered regarding the impact of similarity-based interference in auditory on-line sentence processing. Chapter 3 of this dissertation details a study investigating the impact of similarity-based interference using an eye-tracking while listening method in a group of college-age neurologically unimpaired adults and a group of individuals with Broca's aphasia.

2.3.3.2 Working Memory Deficits in Broca's Aphasia

As discussed earlier in this paper there are several types of accounts for the comprehension deficits observed in individuals with Broca's aphasia. These include grammar-oriented and lexical-processing accounts. However, there is another group of theories based on resource allocation deficits, which propose that comprehension deficits result from a lack of sufficient cognitive resources. According to these theories, complex sentences require more working memory resources, which is why comprehension deficits are often seen in complex but not simple sentences. Examining the role of working memory in sentence processing in Broca's patients – who typically have syntactic but not purely cognitive deficits - can aid in our understanding of whether separate verbal working memory resources exist for linguistic processing and non-linguistic verbal cognitive tasks. For example, Caplan and Waters (1996) conducted a study using a sentence-picture matching task with individuals with aphasia who had syntactic processing difficulties. The participants were asked to complete the task either without interference or while recalling a series of digits that was equal to or one less than their span. While subjects showed poorer performance in conditions with larger digit loads, the effect of syntactic complexity was not modulated by the size of the digit load.

In an exhaustive set of studies, Caplan, DeDe, and Michaud (2006), and Caplan, Waters, DeDe, Michaud, and Reddy (2007) studied the comprehension of eleven syntactic structures examining three aspects of syntactic processing:

relating a reflexive pronoun to the antecedent, interpreting passive structures and interpreting subject- and object-extracted relative clauses in 42 patients with aphasia (six of these patients met the criteria for Broca's aphasia and 11 met the criteria for fluent aphasia) using a combined self-paced listening and sentence-picture matching task. Caplan et al. (2006, 2007) aimed to discriminate between resource allocation deficit hypothesis and a syntactic hypothesis. Off-line performance data was obtained using sentence-picture matching, object manipulation and grammaticality judgment tasks where sentences were presented aurally. On-line performance was also measured in two self-paced listening tasks accompanying a sentence-picture matching and grammaticality judgment task. Analyses were conducted to determine patterns of impairment within individuals and within groups of patients using the three syntactic processes of interest.

The results of these studies yielded a lack of stable deficits in individual patients, as analyses revealed that patients who performed well on a specific linguistic operation (i.e. interpreting passive structures) in one task, often performed poorly on the same operation in another task, and vice versa. Also, overall, patients exhibited normal on-line patterns on correctly performed tasks, but aberrant on-line patterns for tasks performed incorrectly. Caplan et al. interpreted this particular finding to mean that the participants were not merely guessing correctly in accurate trials; they were correctly processing these sentence structures. Furthermore, the results did not support the *trace deletion hypothesis* (TDH), which would predict above chance performance in the Broca's group on sentences without linguistic traces; Broca's patients as a group performed at chance on sentences that did not contain linguistic traces.

Furthermore, the Broca's group had difficulty comprehending sentences containing reflexive pronouns even when a trace was not present (see also Caplan, Michaud and Hufford , 2013). Caplan et al. (2006; 2007) suggested that with reduced resources the parser can sometimes work correctly, but breaks down occasionally, and importantly breakdowns do not always occur during the same linguistic operation. Thus, these studies suggest that comprehension deficits in aphasia result from reduced resources as well as pathological variability caused by brain damage, rather than a breakdown to a specific linguistic or syntactic process. However, these studies should be interpreted with caution because a self-paced listening task was used to measure on-line performance. In this method, listeners are presented with sentences in a word-by-word (or phrase-by-phrase) fashion, and must press a button to reveal the next aurally presented segment. Listening times via the button press are recorded and longer listening times are equated to processing difficulty/interference. The self-paced listening task results in multiple interruptions throughout the sentence, thus it is not the ideal method to investigate unimpeded on-line sentence processing.

2.3.3.2.1 Similarity-Based Interference in Broca's Aphasia

Only a few studies have investigated whether similarity-based interference can explain the comprehension deficit observed in Broca's aphasia. For example, Friedmann and Gvion (2012) tested the impact of similarity-based interference in four participants with Broca's aphasia using a sentence-picture matching task. Instead of *wh*-questions subject- and object-extracted relative clauses were tested. Within each extraction type there was an intervener and a non-intervener condition, which is allowed in Hebrew sentence structure. Comprehension was revealed to be significantly above chance in the non-intervener conditions but no better than chance in the intervener conditions, regardless of whether it was in a subject- or object-extracted sentence. The authors attributed these results to the participants' inability to build a fully realized syntactic tree when an intervening NP was encountered between a filler and its gap.

Hickok and Avrutin (1996), and Thompson, Tait, Ballard, and Fix (1999) also investigated *who*- and *which*-question comprehension in individuals with Broca's aphasia. However, these studies were not specifically designed to test effects of similarity-based interference. Hickok and Avrutin investigated four types of *Wh*-questions, including subject- and object-extracted *who*- and *which*-questions:

49a.	Who___ chased the dog?	(Subject-extracted *Who*)
49b.	Which cat___ chased the dog?	(Subject-extracted *Which*)
49c.	Who did the dog chase___?	(Object-extracted *Who*)
49d.	Which cat did the dog chase___?	(Objected-extracted *Which*)

Only the object-extracted *which*-questions (49d) would be susceptible to similarity-based interference because two NPs (*which cat*, and, *the dog*) must be held within working memory prior to being integrated at the gap after the verb *chase.* They found that subject-extracted which-questions were comprehended significantly better than object-extracted which-questions, yet there was no difference in comprehension between subject- and object- extracted who-questions. This pattern of results suggests that similarity-based interference may contribute to the comprehension deficit seen in patients with Broca's aphasia.

Thompson et al. (1999) replicated Hickok and Avrutin's (1996) results, using a figure manipulation and picture pointing task, in only one of the four participants with Broca's aphasia. Yet, when the Thompson et al. (1999) data (N = 4) was combined with new data collected by Salis and Edwards (2008) yielding a N = 11, the results demonstrated the same pattern of results revealed in Hickok and Avrutin (1996).

Even though some of the studies reviewed in this section were not specifically designed to test similarity-based interference effects, they do lend support to the notion that it may contribute to comprehension impairments in aphasia. It is clear that more work needs to be done in this area to distinguish between similarity-based interference effects and possible alternative hypotheses. This work can be accomplished by examining the on-line processing of additional sentence structures that contain, by hypothesis, interveners. It should also be noted that all of the reviewed studies (Friedmann & Gvion, 2012; Hickok & Avrutin, 1996; Salis & Edwards, 2008; Thompson et al., 1999) examining this topic used off-line methods. However, Chapter 3 will present a study where an on-line method, eye-tracking while listening, was used to examine the impact of similarity-based interference in both neurologically unimpaired participants and individuals with Broca's aphasia.

The discrepancy between the findings in the Hickok and Avrutin (1996) and Thompson et al. (1999) studies demonstrates the importance of conducting further research in this area, as this population exhibits significant inter-subject variability. While the Thompson et al. study was the only one reviewed in this section that did not find a strong intervener effect across participants, it only included data from a small number of participants (N=4), and the Salis and Edwards (2008) study demonstrated that combining the Thompson et al. and Hickok and Avrutin data with their new data (resulting in a total N of 11), revealed significant intervener effects. Finally, similar to the Gordon et al. (2001; 2002; 2004; 2006) studies in neurologically unimpaired populations, it will be important to investigate the specific features of NPs that could result in similarity-based interference in this population.

Goals of the Dissertation

This dissertation seeks to investigate the *how* and *when* particular sentence processing elements interact with one another on-line, in both neurologically unimpaired populations and in individuals with aphasia. The three elements of particular interest in this dissertation are syntax, prosody, and thematic fit. Chapter 3, to follow, reports on a study investigating the impact of syntax, and the possible influence of similarity-based interference that may arise in certain syntactic structures in both unimpaired listeners and individuals with Broca's aphasia. This study seeks to determine whether similarity-based interference can account for a portion of the sentence comprehension deficits seen in some patients with Broca's aphasia. As discussed previously, the research investigating similarity-based interference effects has used off-line methods. Thus, this study used an on-line method, eye-tracking while listening, that allowed for a precise measure of sentence processing throughout the entire sentence.

The studies presented in Chapters 4 and 5 examine how prosody and thematic fit can influence sentence comprehension and the resolution of temporary syntactic ambiguities. The influence of prosody, thematic fit, and the interaction of these two sentence elements were investigated in college-age adults (Chapter 4), and individuals with aphasia and their age-matched controls (Chapter 5). Past research examining the interaction of prosody and thematic fit has used off-line methods that do not allow for the examination of precisely when prosody and thematic fit influence processing. Thus, event-related potentials (ERPs) were chosen for the current studies, because they allow for unimpeded data collection as sentences unfold with millisecond accuracy. Chapter 6 concludes with a discussion of how these studies inform our knowledge of sentence comprehension in unimpaired populations as well as our understanding of the sentence comprehension deficit in Broca's aphasia. Future directions for work in this field are also discussed.

References

Baddeley, A. (1986). *Working memory*. Oxford, UK: Clarendon Press.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature Reviews Neuroscience, 4*(10), 829-839.

Baddeley, A., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *The Psychology of Learning and Motivation: Advances in Research and Theory* (Vol. 8, pp. 47-89). New York: Academic Press.

Balogh, J., Zurif, E., Prather, P., Swinney, D., & Finkel, L. (1998). Gap-filling and end-of-sentence effects in real-time language processing: Implications for modeling sentence comprehension in aphasia. *Brain and Language, 61*(2), 169-182.

Bever, T. (1974). The ascent of the specious, or there's a lot we don't know about mirrors. *Explaining Linguistic Phenomena*, 173-200.

Bögels, S., Schriefers, H., Vonk, W., Chwilla, D. J., & Kerkhofs, R. (2013). Processing consequences of superfluous and missing prosodic breaks in auditory sentence comprehension. *Neuropsychologia, 51*(13), 2715-2728.

Broca, P. (1861). Remarks on the seat of the faculty of articulated language, following an observation of aphemia (loss of speech). *Bulletin de la Société Anatomique, 6*, 330-357.

Brown, C., & Hagoort, P. (1993). The processing nature of the N400: Evidence from masked priming. *Journal of Cognitive Neuroscience, 5*(1), 34-44.

Burkhardt, P., Avrutin, S., Piñango, M. M., & Ruigendijk, E. (2008). Slower-than-normal syntactic processing in agrammatic Broca's aphasia: Evidence from Dutch. *Journal of Neurolinguistics, 21*(2), 120-137.

Caplan, D., DeDe, G., & Michaud, J. (2006). Task-independent and task-specific syntactic deficits in aphasic comprehension. *Aphasiology, 20*(9), 893-920.

Caplan, D., & Futter, C. (1986). Assignment of thematic roles to nouns in sentence comprehension by an agrammatic patient. *Brain and Language, 27*(1), 117-134.

Caplan, D., Michaud, J., & Hufford, R. (2013). Dissociations and associations of performance in syntactic comprehension in aphasia and their implications for the nature of aphasic deficits. *Brain and Language, 127*(1), 21-33.

Caplan, D., & Waters, G. (1999). Verbal working memory and sentence comprehension. *Behavioral and Brain Sciences, 22*, 77-126.

Caplan, D., Waters, G., DeDe, G., Michaud, J., & Reddy, A. (2007). A study of syntactic processing in aphasia I: Behavioral (psycholinguistic) aspects. *Brain and Language, 101*(2), 103-150.

Caplan, D., & Waters, G. S. (1996). Syntactic processing in sentence comprehension under dual-task conditions in aphasic patients. *Language and Cognitive Processes, 11*(5), 525-551.

Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language, 3*(4), 572-582.

Carlson, K., Frazier, L., & Clifton, J., Charles. (2009). How prosody constrains comprehension: A limited effect of prosodic packaging. *Lingua, 119*(7), 1066-1082.

Chomsky, N. (1981). Knowledge of language: Its elements and origins. *Philosophical Transactions of the Royal Society B: Biological Sciences, 295*(1077), 223-234.

Chomsky, N. (1995). Bare phrase structure. MIT Occasional Papers in Linguistics 5 In G. Webelhuth (Ed.), *Government and Binding Theory and the Minimalist Program*. Oxford: Blackwell.

Choy, J. (2011). *Effects of Lexical Processing Deficits on Sentence Comprehension in Agrammatic Broca's Aphasia.* Northwestern University.

Christianson, K., Hollingworth, A., Halliwell, J., & Ferreira, F. (2001). Thematic roles assigned along the garden path linger. *Cognitive Psychology, 42*(4), 368-407.

Clifton, C., Frazier, L., Rapoport, T., & Rado, J. (1996). Adjunct predication: Attachment or construal. *Unpublished manuscript (quoted by Frazier & Clifton, 1997)*.

Cooper, W. E., & Paccia-Cooper, J. (1980). *Syntax and speech*: Harvard University Press.

Cutler, A., & Clifton, C. (1999). Comprehending spoken language: A blueprint of the listener. *The neurocognition of language*, 123-166.

Daneman, M., & Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450-466.

DeDe, G. (2010). Utilization of Prosodic Information in Syntactic Ambiguity Resolution. *Journal of psycholinguistic research, 39*(4), 345-374.

Fedorenko, E., Gibson, E., & Rohde, D. (2006). The nature of working memory capacity in sentence comprehension: Evidence against domain-specific working memory resources☆. *Journal of Memory and Language, 54*(4), 541-553.

Ferreira, F. (1993). Creation of prosody during sentence production. *Psychological Review, 100*(2), 233.

Ferreira, F. (2005). Psycholinguistics, formal grammars, and cognitive science. *The Linguistic Review, 22*(2-4), 365-380.

Ferreira, F., Anes, M. D., & Horine, M. D. (1996a). Exploring the use of prosody during language comprehension using the auditory moving window technique. *Journal of Psycholinguistic Research, 25*(2), 273-290.

Ferreira, F., Bailey, K., & Ferraro, V. (2002). Good-enough representations in language comprehension. *Current Directions in Psychological Science, 11*(1), 11-15.

Ferreira, F., Henderson, J. M., Anes, M. D., Weeks, P. A., & McFarlane, D. K. (1996b). Effects of lexical frequency and syntactic complexity in spoken-language comprehension: Evidence from the auditory moving-window technique. *Journal of Experimental Psychology: Learning, memory, and cognition, 22*(2), 324.

Ferreira, F., & Stacey, J. (2000). The misinterpretation of passive sentences. *Michigan State University*.

Fodor, J. (1983). *The modularity of mind: An essay on faculty psychology*: MIT press.

Frazier, L. (1987). Sentence processing: A tutorial review *Attention and Performance, XII: The Psychology of Reading*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Frazier, L., Carlson, K., & Clifton, C. (2006). Prosodic phrasing is central to language comprehension. *Trends in Cognitive Sciences, 10*(6), 244-249.

Frazier, L., & Clifton, C. (1996). *Construal*. Cambridge, MA: MIT Press.

Frazier, L., Clifton, C., & Randall, J. (1983). Filling gaps: Decision principles and structure in sentence comprehension. *Cognition, 13*, 187-222.

Frazier, L., & Clifton, J., C. (1997). Construal: Overview, motivation, and some new evidence. *Journal of Psycholinguistic Research, 26*(3).

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology, 14*(2), 178-210.

Frazier, L., & Rayner, K. (1987). Resolution of syntactic category ambiguities: Eye movements in parsing lexically ambiguous sentences. *Journal of Memory and Language, 26*, 505-526.

Friedmann, N., & Gvion, A. (2012). *Intervention and locality in agrammatic aphasia*. Siena, Italy: CISCLWorking Papers.

Friedmann, N., & Shapiro, L. (2003). Agrammatic Comprehension of Simple Active Sentences With Moved ConstituentsHebrew OSV and OVS Structures. *Journal of Speech, Language, and Hearing Research, 46*(2), 288-297.

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition, 68*(1), 1-76.

Givon. (1984). *Syntax. A functional-typological introduction.* (Vol. 1). Philadelphia: John Benjamins Publishing.

Gordon, P., Hendrick, R., & Johnson, M. (2001). Memory interference during language processing. *Journal of Experimental Psychology: Learning, Memory and Cognition, 27*(61), 1-13.

Gordon, P., Hendrick, R., & Johnson, M. (2004). Effects of noun phrase type on sentence complexity. *Journal of Memory and Language, 51*(1), 97-114.

Gordon, P., Hendrick, R., Johnson, M., & Lee, Y. (2006). Similarity-based interference during language comprehension: Evidence from eye tracking during reading. *Journal of Experimental Psychology: Learning, Memory and Cognition, 32*(6), 1304-1321.

Gordon, P., Hendrick, R., & Levine, W. (2002). Memory-Load Interference in Syntactic Processing. *Psychological science, 13*(5), 425-430.

Gordon, P., & Lowder, M. (2012). Complex sentence processing: A review of theoretical perspectives on the comprehension of relative clauses. *Language and Linguistics Compass, 6*(7), 403-415.

Grodzinsky, Y. (1986). Language deficits and the theory of syntax. *Brain and Language, 27*(1), 135-159.

Grodzinsky, Y. (1989). Agrammatic comprehension of relative clauses. *Brain and Language, 37*(3), 480-499.

Grodzinsky, Y. (1995). A restrictive theory of agrammatic comprehension. *Brain and Language, 50*(1), 27-51.

Grodzinsky, Y. (2000). Overarching agrammatism *Language and the brain: retation and processing - Studies presented to Edgar Zurif on his 60th birthday* (pp. 73-86). San Diego: Academic Press.

Grodzinsky, Y. (2006). A blueprint for a brain map of syntax. In Y. Grodzinsky & K. Amunts (Eds.), *Broca's Region* (pp. 83-107). New York: Oxford University Press.

Hanley, J., Young, A., & Pearson, N. (1991). Impairment of the visuo-spatial sketch pad. *The quarterly Journal of Experimental Psychology, 43*(1), 101-125.

Hickok, G., & Avrutin, S. (1996). Comprehension of wh-questions in two Broca's aphasics. *Brain and Language, 52*(2), 314-327.

Holcomb, P. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology, 30*(1), 47-61.

Jackendoff, R. (2002). *Foundations of language: Brain, meaning, grammar, evolution*: Oxford University Press.

Jackendoff, R. (2007). A parallel architecture perspective on language processing. *Brain Research, 1146*, 2-22.

Jackendoff, R. (2011). What is the human language faculty?: Two views. *Language, 87*(3), 586-624.

Jonides, J., Smith, E., Koeppe, R., Awh, E., Minoshima, S., & Mintun, M. (1993). Spatial working-memory in humans as revealed by PET. *Nature, 363*, 623-625.

Just, M., & Carpenter, P. (1980). A theory of reading: from eye fixations to comprehension. *Psychological Review, 87*(4), 329.

Just, M., & Carpenter, P. (1992). A capacity theory of comprehension: individual differences in working memory. *Psychological Review, 99*(1), 122.

King, J., & Just, M. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30*(5), 580-602.

Kjelgaard, M., & Speer, S. (1999). Prosodic facilitation and interference in the resolution of temporary syntactic closure ambiguity. *Journal of Memory and Language, 40*(2), 153-194.

Kutas, M., & Hillyard, S. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203-205.

Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition, 106*(3), 1126-1177.

Lewis, R. (1996). Interference in short-term memory: The magical number two (or three) in sentence processing. *Journal of Psycholinguistic Research, 25*(1), 93-115.

Lewis, R., & Vasishth, S. (2005). An activation ‐ based model of sentence processing as skilled memory retrieval. *Cognitive Science, 29*(3), 375-419.

Lewis, R., Vasishth, S., & Van Dyke, J. (2006). Computational principles of working memory in sentence comprehension. *Trends in Cognitive Sciences, 10*(10), 447-454.

Love, T., & Swinney, D. (1996). Coreference processing and levels of analysis in object-relative constructions; demonstration of antecedent reactivation with the cross-modal priming paradigm. *Journal of Psycholinguistic Research, 25*(1), 5-24.

Love, T., Swinney, D., Walenski, M., & Zurif, E. (2008). How left inferior frontal cortex participates in syntactic processing: Evidence from aphasia. *Brain and Language, 107*(3), 203-219.

MacDonald, M. (1994). Probabilistic Constraints and Syntactic Ambiguity Resolution. *Language and Cognitive Processes, 9*(2), 157-201.

MacDonald, M., Just, M., & Carpenter, P. (1992). Working memory constraints on the processing of syntactic ambiguity. *Cognitive Psychology, 24*(1), 56-98.

MacDonald, M., Pearlmutter, N., & Seidenberg, M. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review, 101*(4), 676-703.

MacWhinney, B., & Pléh, C. (1988). The processing of restrictive relative clauses in Hungarian. *Cognition, 29*(2), 95-141.

Marslen-Wilson, W. (1973). Linguistic structure and speech shadowing at very short latencies. *Nature, 244*, 522-523.

Marslen-Wilson, W. (1975). Sentence Perception as an Interactive Parallel Process. *Science, 189*, 226-228.

Marslen-Wilson, W., & Tyler, L. (1980). The temporal structure of spoken language understanding. *Cognition, 8*(1), 1-71.

Marslen-Wilson, W. D., Tyler, L. K., Warren, P., Grenier, P., & Lee, C. S. (1992). Prosodic effects in minimal attachment. *The quarterly Journal of Experimental Psychology, 45*(1), 73-87.

Miller, G., & Chomsky, N. (1963). Finitary models of language users. In R. D. Luce, R. R. Bush, & E. Galanter (Eds.), *Handbook of Mathematical Psychology* (Vol. 11, pp. 419-491). New York: Wiley.

Nagel, H. N., Shapiro, L. P., & Nawy, R. (1994). Prosody and the processing of filler-gap sentences. *Journal of Psycholinguistic Research, 23*(6), 473-485.

Nagel, H. N., Shapiro, L. P., Tuller, B., & Nawy, R. (1996). Prosodic influences on the resolution of temporary ambiguity during on-line sentence processing. *Journal of Psycholinguistic Research, 25*(2), 319-344.

Nespor, M., & Vogel, I. (1986). Prosodic phonology. Dordrecht: Foris.

Nicol, J., & Swinney, D. (1989). The role of structure in coreference assignment during sentence comprehension. *Journal of Psycholinguistic Research, 18*(1), 5-19.

Osterhout, L., & Swinney, D. (1993). On the temporal course of gap-filling during comprehension of verbal passives. *Journal of Psycholinguistic Research, 22*(2), 273-286.

Pauker, E., Itzhak, I., Baum, S., & Steinhauer, K. (2011). Effects of cooperating and conflicting prosody in spoken English garden path sentences: ERP evidence for the boundary deletion hypothesis. *Journal of Cognitive Neuroscience, 23*(10), 2731-2751.

Piñango, M. (2000). Canonicity in Broca's sentence comprehension: the case of psychological verbs. *Language and the Brain*, 327-350.

Piñango, M., & Burkhardt, P. (2005). Pronominal interpretation and the syntax-discourse interface: Real-time comprehension and neurological properties *Anaphora processing: Linguistic, cognitive and computational models* (pp. 221-238). Amsterdam: John Benjamins.

Price, P. J., Ostendorf, M., Shattuck‐Hufnagel, S., & Fong, C. (1991). The use of prosody in syntactic disambiguation. *the Journal of the Acoustical Society of America, 90*(6), 2956-2970.

Pynte, J., & Prieur, B. (1996). Prosodic Breaks and Attachment Decisions in Sentence Parsing. *Language and Cognitive Processes, 11*(1-2), 165-192.

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning and Verbal Behavior, 22*(3), 358-374.

Salis, C., & Edwards, S. (2008). Comprehension of wh-questions and declarative sentences in agrammatic aphasia: The set partition hypothesis. *Journal of Neurolinguistics, 21*(5), 375-399.

Schafer, A. J., Speer, S. R., Warren, P., & White, S. D. (2000). Intonational disambiguation in sentence production and comprehension. *Journal of Psycholinguistic Research, 29*(2), 169-182.

Schwartz, M., Linebarger, M., Saffran, E., & Pate, D. (1987). Syntactic transparency and sentence interpretation in aphasia. *Language and Cognitive Processes, 2*(2), 85-113.

Selkirk, E. (1978). On prosodic structure and its relation to syntactic structure. In T. Fretheim (Ed.), *Nordic Prosody II*. Trondheim: TAPIR.

Selkirk, E. (1986). On derived domains in sentence phonology. *Phonology, 3*(01), 371-405.

Shapiro, L., Brookins, B., Gordon, B., & Nagel, N. (1991). Verb effects during sentence processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*(5), 983.

Shapiro, L., & Hestvik, A. (1995). On-line comprehension of VP-ellipsis: Syntactic reconstruction and semantic influence. *Journal of Psycholinguistic Research, 24*(6), 517-532.

Shapiro, L., Hestvik, A., Lesan, L., & Garcia, A. R. (2003). Charting the time-course of VP-ellipsis sentence comprehension: Evidence for an initial and independent structural analysis. *Journal of Memory and Language, 49*(1), 1-19.

Shapiro, L., Zurif, E., & Grimshaw, J. (1987). Sentence processing and the mental representation of verbs. *Cognition, 27*(3), 219-246.

Shapiro, L., Zurif, E., & Grimshaw, J. (1989). Verb processing during sentence comprehension: Contextual impenetrability. *Journal of Psycholinguistic Research, 18*(2), 223-243.

Shattuck-Hufnagel, S., & Turk, A. E. (1996). A prosody tutorial for investigators of auditory sentence processing. *Journal of Psycholinguistic Research, 25*(2), 193-247.

Sheppard, S., Walenski, M., Love, T., & Shapiro, L. (2015). The Auditory Comprehension of Wh-Questions in Aphasia: Support for the Intervener Hypothesis. *Journal of Speech, Language, and Hearing Research*, 1-17.

Shulman, H. (1970). Encoding and retention of semantic and phonemic information in short-term memory. *Journal of Verbal Learning and Verbal Behavior, 9*(5), 499-508.

Snedeker, J., & Casserly, E. (2010). Is it all relative? Effects of prosodic boundaries on the comprehension and production of attachment ambiguities. *Language and Cognitive Processes, 25*(7-9), 1234-1264.

Speer, S., Warren, P., & Schafer, A. (2003). *Intonation and sentence processing.* Paper presented at the Proceedings of the Fifteenth International Congress of Phonetic Sciences, Barcelona, Spain.

Speer, S. R., Crowder, R. G., & Thomas, L. M. (1993). Prosodic structure and sentence recognition. *Journal of Memory and Language, 32*(3), 336.

Speer, S. R., & Ito, K. (2009). Prosody in first language acquisition–Acquiring intonation as a tool to organize information in conversation. *Language and Linguistics Compass, 3*(1), 90-110.

Speer, S. R., Kjelgaard, M. M., & Dobroth, K. M. (1996). The influence of prosodic structure on the resolution of temporary syntactic closure ambiguities. *Journal of Psycholinguistic Research, 25*(2), 249-271.

Speer, S. R., Warren, P., & Schafer, A. J. (2011). Situationally independent prosodic phrasing. *Laboratory Phonology, 2*(1), 35-98.

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

Swaab, T., Brown, C., & Hagoort, P. (1997). Spoken sentence comprehension in aphasia: Event-related potential evidence for a lexical integration deficit. *Journal of Cognitive Neuroscience, 9*(1), 39-66.

Thompson, C., Tait, M., Ballard, K., & Fix, S. (1999). Agrammatic aphasic subjects' comprehension of subject and object extracted wh questions. *Brain and Language, 67*(3), 169-187.

Trueswell, J., & Tanenhaus, M. (1994). Toward a lexical framework of constraint-based syntactic ambiguity resolution. In C. Clifton, L. Frazier, & K. Rayner (Eds.), *Perspectives on Sentence Processing* (pp. 155-180). Hillsdale, NJ: Erlbaum.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: Use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language, 33*(3), 285-318.

Van Dyke, J. (2007). Interference effects from grammatically unavailable constituents during sentence processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(2), 407.

Van Dyke, J., & Johns, C. (2012). Memory interference as a determinant of language comprehension. *Language and Linguistics Compass, 6*(4), 193-211.

Van Dyke, J., & Lewis, R. (2003). Distinguishing effects of structure and decay on attachment and repair: A cue-based parsing account of recovery from misanalyzed ambiguities. *Journal of Memory and Language, 49*(3), 285-316.

Van Dyke, J., & McElree, B. (2006). Retrieval interference in sentence comprehension. *Journal of Memory and Language, 55*(2), 157-166.

Van Dyke, J., & McElree, B. (2011). Cue-dependent interference in comprehension. *Journal of Memory and Language, 65*(3), 247-263.

Warren, P., Schafer, A. J., Speer, S. R., & White, S. D. (2000). Prosodic resolution of prepositional phrase ambiguity in ambiguous and unambiguous situations. *UCLA Working Papers in Phonetics*, 5-34.

Waters, G., & Caplan, D. (1996). Processing resource capacity and the comprehension of garden path sentences. *Memory & Cognition, 24*(3), 342-355.

CHAPTER 3:

The Auditory Comprehension of *Wh*-Questions in Aphasia: Support for the Intervener Hypothesis

Preface

As established in Chapter 2, some studies have found evidence that syntactic structures may cause similarity-based interference that can impact sentence processing in neurologically unimpaired populations, as well as processing and ultimate comprehension in people with Broca's aphasia. However, these studies have all used off-line methods that do not offer precise information about *how* and *when* this interference influences processing. This study examined the processing of four types of *Wh*-questions, subject- and object-extracted *who*- and *which*-questions using eye-tracking while listening. Reaction data and accuracy data were also collected. Three competing hypotheses were compared, each of which predicted a different pattern of results among the four *Wh*-question types. This study served two purposes: first to chart the time-course of *Wh*-question processing and possible interference effects in a group of college-age neurologically unimpaired participants to serve as a baseline comparison for the group of participants with Broca's aphasia. Second, to examine whether similarity-based interference could account for sentence processing deficits in Broca's aphasia.

JSLHR

Research Article

The Auditory Comprehension of *Wh*-Questions in Aphasia: Support for the Intervener Hypothesis

Shannon M. Sheppard,[a,b] Matthew Walenski,[a] Tracy Love,[a,b] and Lewis P. Shapiro[a,b]

Purpose: This study examines 3 hypotheses about the processing of *wh*-questions in both neurologically healthy adults and adults with Broca's aphasia.
Method: We used an eye tracking while listening method with 32 unimpaired participants (Experiment 1) and 8 participants with Broca's aphasia (Experiment 2). Accuracy, response time, and online gaze data were collected.
Results: In Experiment 1, we established a baseline for how unimpaired processing and comprehension of 4 types of *wh*-question (subject- and object-extracted *who*- and *which*-questions) manifest. There was no unambiguous support found for any of the 3 hypotheses in Experiment 1. In Experiment 2 with the Broca's participants, however, we found significantly lower accuracy, slower response times, and increased interference in our gaze data in the object-extracted *which*-questions relative to the other conditions.
Conclusions: Our results provide support for the intervener hypothesis, which states that sentence constructions that contain an intervener (a lexical noun phrase) between a displaced noun phrase and its gap site result in a significant processing disadvantage relative to other constructions. We argue that this hypothesis offers a compelling explanation for the comprehension deficits seen in some participants with Broca's aphasia.

We describe an investigation of the time course of processing *wh*-questions during sentence comprehension in a group of neurologically healthy adult participants and a group of participants with neurological impairment, specifically aphasia. To begin, consider this declarative sentence:

1. A fireman pushed the policeman.

Sentence 1 is in subject-verb-object (S-V-O), canonical word order. The verb *push* requires two arguments, one playing the thematic role of agent and the other playing the theme role. In Sentence 1, the agent role is assigned to the subject position occupied by the noun phrase (NP) *a fireman*, and the theme is assigned to the direct object position occupied by the NP *the policeman*.

In various linguistic and psycholinguistic accounts, *wh*-questions are derived from their S-V-O counterparts by extracting (and fronting) the questioned element (see Sentence 2 below). The similarities (and differences) across structures can be captured generally by how thematic roles are assigned by the verb or verb phrase to its argument positions. Consider the following:

2. Two firemen and a policeman got into a fight.
   a. Which fireman pushed the policeman?
   b. Which fireman did the policeman push <~~which fireman~~>?

Thematic role assignment in the subject-extracted *which*-question (Sentence 2a) is similar to that of the canonical declarative sentence in Sentence 1. In the object-extracted question (Sentence 2b), the *which*-phrase has been displaced from its underlying direct object position to a position before the verb, yielding noncanonical word order. Although the theme role is assigned to the direct object position as it is in Sentences 1 and 2a, that position is occupied by an unpronounced copy (or trace/gap) of the displaced *wh*-phrase; the thematic role is transferred to the displaced *wh*-phrase via a chain that connects the copy to its displaced element, forming a dependency relationship between the two positions (Chomsky, 1981, 1995).

Object-extracted questions, such as Sentence 2b, both intuitively and empirically, are more difficult to understand

[a]San Diego State University, CA
[b]University of California, San Diego, CA
Correspondence to Shannon M. Sheppard: SBM.Sheppard@gmail.com
Editor: Rhea Paul
Associate Editor: Jessica Richardson
Received April 9, 2014
Revision received July 8, 2014
Accepted January 10, 2015
DOI: 10.1044/2015_JSLHR-L-14-0099

Disclosure: The authors have declared that no competing interests existed at the time of publication.

than their subject-extracted counterparts (Sentence 2a). One simple explanation for this processing difference is a general word order hypothesis: In English, listeners expect and prefer sentences in S-V-O order, and thus, these structures yield a processing advantage over sentences that do not conform to S-V-O order, such as object-extracted structures (Bates, Friederici, & Wulfeck, 1987; O'Grady, Yamashita, & Lee, 2005). The word order hypothesis requires generalization to similar constructions (as would any hypothesis). Consider, then, subject- and object-extracted *who*-questions (Sentences 3a and 3b, respectively):

3a. Who pushed the policeman?

3b. Who did the policeman push <~~who~~>?

Similar structural and thematic role considerations apply. Thus, the word order hypothesis makes no distinction between these question types, that is, between *who*- and *which*-questions.

Yet there are linguistic and processing differences between these question types. One involves the syntax-discourse interface. *Which*-questions are discourse-linked (D-linked) because they must refer to an individual from a set of individuals in the discourse as in Sentence 2, and *who*-questions are not necessarily D-linked. It has been suggested that D-linked constructions are more difficult to process because interface conditions are more resource intensive (e.g., Avrutin, 2000, 2006; Burkhardt, 2005; Rothman & Slabakova, 2011; Shapiro, 2000). It is interesting that the distinction between these two question types has been observed even when a relevant discourse was presented for both *which*- and *who*-questions (e.g., Donkers & Stowe, 2006; Salis & Edwards, 2005; Shapiro, 2000). Thus, the D-linked hypothesis predicts a processing advantage for *who*-questions relative to *which*-questions. Note that D-linking should predict similar patterns for both subject- and object-extracted questions although Avrutin (2000) suggests that the combination of filling a gap and D-linking depletes the limited processing resources of people with Broca's aphasia, leading to difficulty with object-extracted *which*-questions. We return to this suggestion in the Discussion.

The intervener hypothesis is the primary focus of our study. Computing the dependency relationship between the displaced NP and its gap in both Sentences 2b and 3b requires crossing over another argument—the policeman—which we call the intervener. There is no such intervener in the subject-extracted examples in Sentences 2a and 3a. The intuition here is that the intervener interferes with computing the dependency relationship because it is a possible element in the dependency chain, rendering a processing disadvantage to such structures over those that don't contain an intervener. To be more formal, this hypothesis stems from Rizzi's relativized minimality account (1990; see also Grillo, 2005, 2009). Relationships among arguments in a sentence are constrained by a locality condition:

4. Given a structure: . . .X. . .Z. . .Y. . ., Y is in a local (minimal) configuration with X if and only if there is no Z that has the following properties:

   a. Z is of the same structural type as X, and

   b. Z intervenes between X and Y.

In other words, computing the dependency relationship between two elements becomes more difficult because the structurally similar intervener is a potential site for one of the elements in the dependency (e.g., see Friedmann, Belletti, & Rizzi, 2009). We suggest that some adults with a language disorder are particularly vulnerable to interveners during sentence processing perhaps because they are susceptible to interference among similarly structured NPs.

One issue for the intervener account is what *the same structural type* means. One possibility is that the intervener is restricted to a lexically specified NP (e.g., *the policeman* in Sentence 2b) that is similar in structure to the displaced phrase (e.g., *which fireman*), as opposed to, for example, a pronoun or proper name. This constraint suggests a distinction between *who*- and *which*-questions, in which the latter phrase (i.e., *which*-NP) has the structure of a fully specified NP (i.e., determiner-noun), and the former phrase (i.e., *who*) does not. The intervener hypothesis, then, suggests no distinction between subject- and object-extracted *who*-questions because neither involves an intervener. However, *which*-questions should reveal an asymmetry between subject- and object-extraction given that only the object-extracted *which*-question involves an intervener.

There is some evidence in the adult literature (healthy participants and those who have aphasia) that *who*- and *which*-questions yield different comprehension patterns (e.g., Donkers, Hoeks, & Stowe, 2013; Frazier & Clifton, 2002; Hickok & Avrutin, 1996). For example, Donkers and Stowe (2006) conducted a self-paced reading study with Dutch-speaking participants comparing standard *who*- and *which*-questions as well as a generic *which* condition (which person) that resembled *who*-questions because they were not set-restricted. They found that standard *which*-questions required longer processing times compared to *who*-questions in object-extracted but not subject-extracted constructions. They also discovered that standard *which*-questions required longer processing times compared to the generic *which*-questions. Donkers and Stowe suggested that the longer processing times often associated with *which*-questions may be due to the process of set-restriction that generally accompanies such questions (for similar accounts, see also De Vincenzi, 1991; Frazier & Clifton, 2002; Frazier, Plunkett, & Clifton, 1996).

Thus far we have kept to a description of an intervener in structural terms although this hypothesis can be extended to include other properties of the intervener that might affect sentence comprehension. Here we take our initial cue from the work of Gordon and colleagues, who have conducted several studies examining how similar NPs interfere with one another during adult sentence processing (e.g., Gordon, Hendrick, & Johnson, 2004; Gordon, Hendrick, Johnson, & Lee, 2006). This work suggests a similarity-based interference account of memory, according to which the demands on storage and retrieval during sentence comprehension are increased when there are NPs in a sentence that have similar representations. Using tasks such as eye tracking while reading, Gordon and colleagues found that reading times increased when two NPs (e.g., the displaced argument and the subject of a relative clause) were both descriptive (i.e., determiner-noun) relative to when the intervening NP was a proper name or a pronoun. This pattern is consistent with the intervener account (see also Van Dyke, 2007; Van Dyke & McElree, 2011, for a similar interference proposal).

More to the primary purpose of this article, differences between processing *who*- and *which*-questions have also been observed in those patients with Broca's aphasia who evince comprehension deficits. Broca's aphasia is characterized by nonfluent and halting speech and was originally thought to be a disorder of speech production (see Grodzinsky, 2000, for a history of Broca's aphasia). However, research that began in the 1970s has since revealed that a comprehension disorder may also be present although it is not surprising that there is considerable disagreement on the source(s) and generality of the disorder. One ubiquitous result is that these individuals have difficulty comprehending noncanonically ordered sentences in which an argument has been displaced, such as passives, object-extracted relative clauses, and *wh*-questions (e.g., Caramazza & Zurif, 1976; Drai & Grodzinsky, 2006; Grodzinsky, 1990).

Hickok and Avrutin (1996) investigated *who*- and *which*-question comprehension in two patients with Broca's aphasia using untimed sentence–picture matching tasks. Subject-extracted *which*-questions were comprehended significantly better than object-extracted *which*-questions, yet there was no difference in comprehension between subject- and object-extracted *who*-questions (see also Frazier & McNamara, 1995; Salis & Edwards, 2005). Thompson, Tait, Ballard, and Fix (1999) replicated Hickok and Avrutin's results in the comprehension of passivized *wh*-questions, using a figure-manipulation task and a picture-pointing task although in only one of four participants with agrammatic aphasia. Friedmann and Gvion (2012) tested the intervener hypothesis with four participants with agrammatic Broca's aphasia. They tested subject- and object-extracted relative clauses with each relative clause type having both an intervener and nonintervener condition (on the basis of Hebrew structure). They found that performance on nonintervener conditions was above chance, and performance on intervener conditions was no better than chance. These patterns suggest that comprehension success was not on the basis of sentence type (subject- vs. object-relatives) but instead was based on whether or not an NP intervened between the filler and gap (see also Friedmann & Shapiro, 2003, footnote 4). This is an important initial finding, but because offline sentence–picture matching tasks cannot measure how participants arrive at their final interpretation, the evidence that can be used to adjudicate different accounts is limited.

We end this section with a description of some online work that is relevant to our study. Dickey, Choy, and Thompson (2007) used an eye tracking while listening method to investigate processing of *wh*-questions. Participants listened to a story (as in Example 5 below) while their eye movements to pictures of the elements/characters in the story were recorded. The participants were then presented with critical comprehension probes that were either object *who*-questions (Sentence 5a), object clefts (Sentence 5b), or control yes/no questions (Sentence 5c):

5. This story is about a boy and a girl. One day they were at school. The girl was pretty, so the boy kissed the girl. They were both embarrassed after the kiss.
   a. Who did the boy kiss that day at school?
   b. It was the girl who the boy kissed that day at school.
   c. Did the boy kiss the girl that day at school?

Dickey et al. (2007) found that the participants in both the control and aphasia groups demonstrated eye movements indicative of successful online comprehension of the *who*-questions. However, participants with aphasia were significantly less accurate in their responses to the *who*-questions and the object cleft questions (Sentences 5a and 5b, respectively) compared to both the control yes/no questions (Sentence 5c) and the control group's responses to these types of questions. They concluded that agrammatic individuals' online processing of syntactic dependencies in *who*-questions is relatively unimpaired but that comprehension breaks down during the interpretation phase, possibly due to "weakened" syntactic representations.

In a follow up, Dickey and Thompson (2009) examined object-relative clauses and passives with an eye tracking while listening method. Consider their object-relative sentences (Sentence 6a):

6. One day a bride and groom were walking in a mall. The bride was feeling playful, so the bride tickled the groom. A clerk was amused.
   a. Point to who the bride was tickling ___ in the mall.

Once again, convincing evidence was observed for associating the filler to the gap for their participants with aphasia using eye-gaze measures although with a slightly delayed time course relative to control participants. However, the displaced NP was a bare *wh*-phrase. Thus, on the intervener account, there should be no interference among the NPs in the sentence, and normal patterns should emerge. Even so, contrary to the intervener account, the accuracy data clearly showed that the participants with aphasia did not understand these sentence structures; the intervener account predicts reasonably good performance on structures that do not contain interveners.[1]

[1]We note that the participants in the Dickey and Thompson (2009) study were diagnosed as agrammatic primarily on the basis of production measures. We take a different approach as described in our Method section. To be brief, here our participants were selected for their specific sentence-comprehension deficits because comprehension is the focus of our study.

In the current article, we report on two experiments using an eye tracking while listening method to investigate processing differences between four question types: subject- and object-extracted *who*- and *which*-questions. In spite of the offline evidence suggesting processing distinctions between *wh*-question types in unimpaired populations and populations with neurological impairment, no studies we are aware of have used an online method to examine processing differences between different types of *wh*-questions in patients with aphasia, and only two (Dickey et al., 2007; Dickey & Thompson, 2009) used an online method to examine the processing of any types of *wh*-questions in patients with agrammatic Broca's aphasia.

Three different hypotheses described in this introduction were investigated: word order, D-linking, and the intervener hypothesis. As shown in Table 1, investigating the four question types in this study can differentiate the predictions made by these accounts. If object-extracted questions were found to be more difficult than subject-extracted questions regardless of *wh*-type, the word order hypothesis would be supported. If *which*-questions were observed to be more difficult than *who*-questions regardless of extraction type, the D-linked hypothesis would be supported. Last, if the *which* object-extracted condition yielded distinct behavior from the other three question types, then the intervener hypothesis would be supported. We examined offline comprehension of these questions, and we also examined online gaze behavior for different segments in the sentences of interest, allowing us to understand if our participants' gaze behavior supported any of the hypotheses.

Experiment 1: *Wh*-Questions in College-Age Adults

We begin with an experiment testing our hypotheses in a group of neurologically healthy college-age participants. Although we do not expect these participants to evince offline comprehension difficulties with *wh*-questions, at least in terms of accuracy, we may be able to detail the underlying basis for their offline comprehension by charting their eye movements as they listen to sentences. Furthermore, this experiment serves as a baseline for our subsequent Experiment 2 that investigates *wh*-question comprehension in a group of individuals with aphasia, allowing us to determine if any of our hypotheses generalize to both neurologically intact participants and those with aphasia.

Method

Participants

We tested 32 neurologically unimpaired, right-handed, college-age students (24 women, eight men) who were monolingual speakers of American English. Their mean age was 20.2 years old (range 18–30). All had normal or corrected-to-normal self-reported visual and auditory acuity. As indicated by self-report, all participants were neurologically and physically stable at the time of testing with no history of alcohol or drug abuse, psychiatric illness, or other significant brain disorder or dysfunction.

Materials

We created 65 action pictures containing three figures interacting with each other (see Figure 1) to go with 65 discourse sentences describing the figures and the action in the scene. Forty-six of these pictures were experimental stimuli with four question types (see Table 2; *which*-subject, *which*-object, *who*-subject, *who*-object) matched to each experimental picture. The remaining 19 pictures served as fillers; each filler picture was matched with one filler *who*- and one filler *which*-question. In the pictures, the figure on the left was performing an action on the middle figure, who was, in turn, performing that same action on the figure on the right. The figure on the left was always the correct answer for the *who*-subject and *which*-subject questions, the figure on the right was always the correct answer for the *who*-object and *which*-object questions, and the middle figure was always the answer to the filler questions and was never a correct answer for any of the experimental questions. The discourse sentences and questions were recorded by a male speaker at a normal average speaking rate of 4.85 syllables/s.

Design

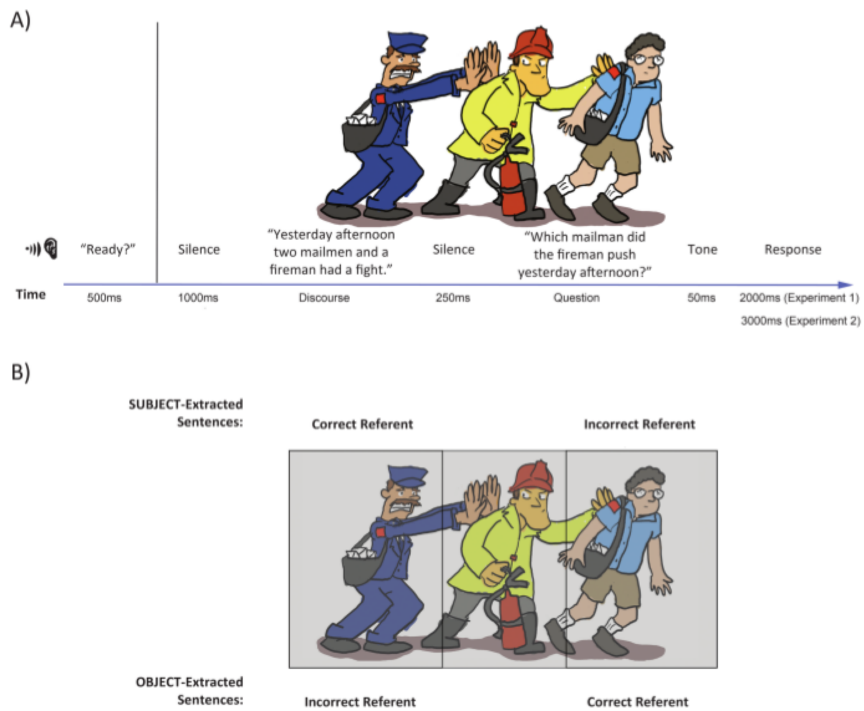
The 46 experimental sets consisting of four sentences each (a total of 184 experimental items) and 19 filler discourse sets consisting of two sentences each (a total of 38 items) were counterbalanced across four presentation lists such that each list contained one of the *wh*-question conditions for each experimental item (i.e., subject- and object-extracted *who*- and *which*-questions); the filler items were rotated through their *who*- and *which*-question versions twice. We used a partially within-subjects design, in which each participant completed two test sessions with one presentation list per session.

Table 1. Hypotheses tested.

Types of questions	Word order hypothesis	Discourse hypothesis	Intervener hypothesis
Who subject-extracted	+	+	+
Who object-extracted	–	+	+
Which subject-extracted	+	–	+
Which object-extracted	–	–	–

Note. + indicates a processing advantage; – indicates a processing disadvantage.

Figure 1. Examples of time course and regions of interest for one trial. (A) An example of the time course of one trial. Participants were presented with the word *Ready?* on the screen for 500 ms, after which the picture appeared and remained throughout the entire trial. Sentences were presented aurally at a normal speech rate, and eye movements were captured throughout the entire trial. The trial ended when the participant made a response, or in the event of no response, it ended after 2 s in Experiment 1 and after 3 s in Experiment 2. (B) Regions of interest for a sample picture. The correct (the figure on the left for the subject-extracted questions and the figure on the right for the object-extracted questions) and incorrect (the figure on the right for the subject-extracted questions and the figure on the left for the object-extracted questions) referents each comprised 40% of the picture with the remaining 20% for the middle referent. The words did not appear on screen but are shown here only to aid the reader. See text for additional details.



Experimental and filler items were presented in the same pseudorandom order for each presentation list and were intermixed such that the same question condition or discourse type (experimental, filler) never occurred more than twice in a row. Experimental sessions were separated by at least 1 week to minimize potential exposure effects.

Procedure

A Tobii eye-tracker with a sampling rate of 60 Hz was used to collect gaze data. The participants sat facing the eye-tracker with their eyes at a distance of 60 cm. The eye-tracker was calibrated for each participant at the beginning of each experimental session. The stimuli were presented with E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). The timing for each trial was as follows (see Figure 1A): A ready screen was presented for 500 ms, then the picture was presented for 1 s before the sentence discourse was presented aurally (the picture remained on the screen for the entire trial). At the end of the discourse sentence, there was a period of 250 ms of silence followed by the question probe; a 50-ms tone signaled the end of the question. Participants were instructed to answer the question using a three-button response box (recording response time [RT] and accuracy) as soon as they heard the tone. After a 2-s response period, the next trial automatically began. The response box had

Table 2. Example experimental sentences by type.

Experimental Sentences	Example
Discourse	Yesterday afternoon two mailmen and a fireman had a fight.
Who subject-extracted	Who ___ pushed the fireman yesterday afternoon?
Who object-extracted	Who did the fireman push ___ yesterday afternoon?
Which subject-extracted	Which mailman ___ pushed the fireman yesterday afternoon?
Which object-extracted	Which mailman did the fireman push ___ yesterday afternoon?
Filler Sentences	**Example**
Discourse	Two waitresses and a golfer met at target practice.
Who subject-extracted	Who ___ shot the waitress at target practice?
Which subject-extracted	Which person ___ shot the waitress at target practice?

three buttons labeled *left*, *middle*, and *right* corresponding to the three figures in each picture. Each participant was given a practice session at the start of each experimental session to insure that they understood the task and were acclimated to the experimental procedure. Eye-gaze location was recorded every 17 ms throughout the entire trial (beginning with the picture presentation and ending with their button-press response).

Results

We begin with our accuracy and the RT data. Analyses of these offline data were conducted using restricted maximum likelihood in mixed-effects regression models separately for each dependent variable. A logit-link function (for binary outcome data) was used for accuracy analyses (SAS 9.3 Proc Glimmix). Button presses corresponding to the wrong answer to the question and no response errors were scored as incorrect. RTs for correct responses were analyzed with SAS 9.3 Proc Mixed. In order to account for by-participant and by-item variance in a single statistical test (i.e., in lieu of separate by-subject and by-item tests), each model included crossed random effects on the intercept of participant and item. Each model also included fixed effects of extraction type (subject vs. object), *wh*-question type (*who* vs. *which*), and their interaction. The models were fit with an unstructured covariance matrix for each random effect. Type III F tests are reported for main effects and interactions. For a priori planned subcontrasts of our fixed effects (e.g., *who*-subject vs. *who*-object), we computed t tests of the differences of the least square means from the full model and report the regression coefficient B (with standard error in parentheses), t statistics, and 95% confidence intervals. All p values are reported two-tailed. Degrees of freedom were computed using the Satterthwaite approximation. Note that the degrees of freedom are large because, in these models, they are based on the number of data points, not the number of participants or items. For further discussion of these statistical methods, see Baayen (2004, 2008) and Littell, Milliken, Stroup, Wolfinger, and Schabenberger (2006). Note also that Barr, Levy, Scheepers, and Tily (2013) argue that random-intercepts-only models are anticonservative, at least when a model with a more maximal random effects structure converges. In our data, the more maximal models frequently failed to converge (even those with only one additional random effect). Thus, we report results for all models with random intercepts only.

For accuracy, there was a significant main effect of extraction type: subject-extracted questions (96.5%) were more accurate than object-extracted questions (93%), $F(1, 2{,}940) = 15.85$, $p < .0001$. A significant main effect of *wh*-question type was also observed, $F(1, 2{,}940) = 9.91$, $p = .002$, with *who*-questions (96%) yielding more accurate performance than *which*-questions (93.5%). The interaction between extraction site and question type did not reach significance, $F(1, 2{,}940) = 3.27$, $p = .07$. Even so, given our hypotheses, we examined if there were significant differences within and across question and extraction types. The object-extracted *which*-questions (92%) were not reliably different from the subject-extracted *which*-questions (95%), B = −0.45 (0.24), $t(2{,}940) = 1.90$, $p = .06$, 95% CI: (−0.91, 0.02). The object-extracted *who*-questions (94%) were answered less accurately than the subject-extracted *who*-questions (98%), B = −1.15 (0.32), $t(2{,}940) = 3.64$, $p = .0003$, 95% CI: (−1.77, −0.53). There was no difference in accuracy between the object-extracted *which*- (92%) and *who*-questions (94%), B = −0.26 (0.22), $t(2{,}940) = 1.19$, $p = .23$, 95% CI: (−0.69, 0.17), but a significant difference was found between the subject-extracted *which*- (95%), and *who*-questions (98%), B = −0.96 (0.32), $t(2{,}940) = 3.00$, $p = .003$, 95% CI: (−1.59, −0.33).

Analysis of the RT data revealed that, overall, there were significant main effects of extraction type, with object-extracted questions (709 ms) evincing slower RTs than subject-extracted questions (669 ms), $F(1, 2{,}683) = 29.69$, $p < .0001$, and *wh*-question type, with *which*-questions (697 ms) yielding longer RTs than *who*-questions (681 ms), $F(1, 2{,}683) = 4.04$, $p = .04$). The interaction between extraction type and *wh*-question type was not significant, $F(1, 2{,}684) = 2.36$, $p = .12$. As with the accuracy data, we analyzed RTs within and across question and extraction types. RTs for object-extracted *which*-questions (723 ms) were significantly slower than the RTs for subject-extracted *which*-questions (671 ms), B = 55 (11), $t(2{,}687) = 4.92$, $p < .0001$, 95% CI: (33, 77). Object-extracted *who*-questions also revealed slower RTs (695 ms) than subject-extracted *who*-questions (667 ms) B = 30 (11), $t(2{,}680) = 2.78$, $p = .006$, 95% CI: (9, 52). The RTs for object-extracted *which*-questions (723 ms) were significantly slower than the RTs for object-extracted *who*-questions (695 ms) B = 28 (11), $t(2{,}689) = 2.49$, $p = .01$, 95% CI: (6, 50). The RTs for subject-extracted *which*-questions did not differ from subject-extracted *who*-questions, B = 4 (11), t(2,677) = 0.33, p = .74, 95% CI: (−18, 25). Note that RT data were screened prior to analysis by removing outliers outside the inner fence of a box plot separately by condition (1.3% of data).

Gaze Analysis and Data

For analysis, each picture was divided into three regions of interest (see Figure 1B), corresponding to the left, middle, and right figures. For all items, we analyzed the mean proportion of gazes in each region of interest during the question portion and response period for each experimental item. We divided each item into multiple time windows, measuring the onset and offset of each window for each item individually, then adding 200 ms to both onset and offset to account for gaze delay (Allopenna, Magnuson, & Tanenhaus, 1998). The subject-extracted sentences were divided into four time windows (*wh*-phrase, verb, object, end of sentence, e.g., which mailman/who | pushed | the fireman | yesterday afternoon) plus the response period (i.e., the period from the end of the sentence until a button press response was made). The object-extracted sentences were divided into five time windows (*wh*-phrase, auxiliary, intervener, verb-gap, end of sentence, e.g., which mailman/who | did | the fireman | push | yesterday afternoon) plus the response period. A gaze was conservatively defined as seven consecutive looks to a particular region of interest (i.e., 102 ms or more gaze duration; see Manor & Gordon, 2003). For each participant and each item, we calculated the proportion of gazes to each region of interest (subject, middle, object) separately for each time window for each condition (*who*-subject, *who*-object, *which*-subject, *which*-object). This proportion (i.e., gazes to the region of interest out of all gazes during the time window) was our dependent variable. Note that the proportion of gazes was treated as a binary variable: Either the gaze was within the region or it wasn't.

We analyzed the gaze data's change over time for each condition separately using restricted maximum likelihood in mixed-effects regression models, using a logit-link function for binomial data. Each model included crossed random effects of participant and item on the intercept and a fixed effect of *wh*-type. Note that due to models frequently failing to converge, the random effect of item was not included in the results reported below (in models that did converge with this random effect, the results were essentially identical to the same model results without this factor). The models were fit with unstructured covariance matrices for each random effect. We report the coefficient (with standard error in parentheses), t statistics, and 95% confidence intervals. Alpha was set to 0.05 for all effects. Analyses were conducted using SAS version 9.3 Proc Glimmix (SAS Institute, Inc.). Given the differences in the linear positions of the time windows, object-extracted and subject-extracted sentences were not directly compared. We examined gazes in separate models for each extraction type in each time window for the correct referent (i.e., the subject in the subject-extracted sentences located to the left of the middle referent and the object in the object-extracted sentences located to the right of the middle referent) and the incorrect referent (i.e., the object in the subject-extracted sentences and the subject in the object-extracted sentences). Gazes to the middle region were not included in analysis as every trial began with a ready screen with the text centered on the screen where the middle figure was subsequently located, biasing gaze position. In addition, the left and right figures were always the same type of referent (i.e., the two mailmen in Figure 1A) whereas the middle figure was always a different type of referent (i.e., the fireman in Figure 1A).

Subject-Extracted Sentences

Gazes to the correct referent (see Figure 2A) revealed that *which*-questions yielded a larger proportion of correct gazes than *who*-questions at the verb time window (25% *which*; 16% *who*), B = 0.57 (0.14), t(1,329) = 4.09, $p < .0001$, 95% CI: (0.30, 0.85), and at the middle NP time window (31% *which;* 20% *who*), B = 0.63 (0.13), t(1,351) = 4.89, $p < .0001$, 95% CI: (0.38, 0.89), but not at the other time windows ($ps > .30$). Gazes to the incorrect referent were not different for *which*- and *who*-sentences at any time window (see Figure 2B; all $ps > .08$).

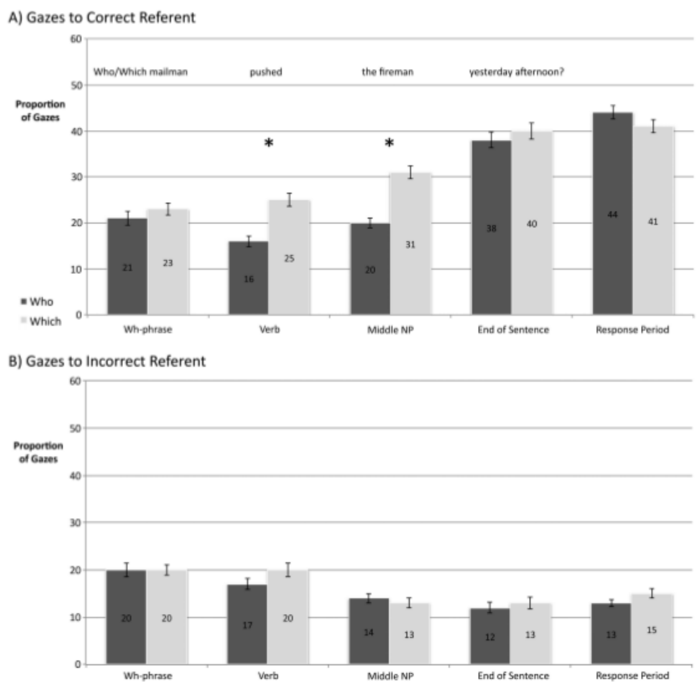
Object-Extracted Sentences

First examining gazes to the correct referent (i.e., the mailman on the right in Figure 1A), the results (see Figure 3A) indicate significant differences in gaze proportion between the *which*- and *who*-questions only for the intervener NP time window (25% *which*; 19% *who*), B = 0.32 (0.13), t(1,352) = 2.36, p = .02, 95% CI: (0.05, 0.58); all other $ps > .17$. For gazes to the incorrect referent (i.e., the mailman on the left in Figure 1A), the results (see Figure 3B) indicate significantly increased gaze proportions for *which*-questions relative to *who*-questions only at the auxiliary time window (25% *which*; 19% *who*), B = 0.41 (0.14), t(1,266) = 2.93, p = .003, 95% CI: (0.14, 0.69), and the intervener NP time window (18% *which*, 13% *who*), B = 0.39 (0.15), t(1,352) = 2.53, p = .01, 95% CI: (0.09, 0.69), all other $ps > .43$.

Discussion

The college-age participants responded with close-to-ceiling accuracy and well above chance in every condition (93%–98%). Responses were less accurate for object-extracted questions than subject-extracted questions (across question type), and less accurate for *which*-questions than *who*-questions (across extraction type). The former result suggests some support for the word order hypothesis (see Table 1) although we note that the effect of extraction was significant in pairwise contrasts only for *who*-questions, not *which*-questions. Likewise, the question-type result suggests support for the discourse hypothesis (see Table 1) although again we note that in pairwise comparisons the effect held only for subject-extracted sentences, not object-extracted sentences. Thus, the support is not strong for either account, and we urge caution

Figure 2. Subject-extracted sentences for Experiment 1 (unimpaired participants): Proportion of gazes for all responses (correctly and incorrectly answered by the participant) by time window to the correct referent (A) and incorrect referent (B) for subject-extracted *who*-questions (dark gray) and *which*-questions (light gray). Error bars represent standard error; * denotes a significant difference at the $p < .05$ level.

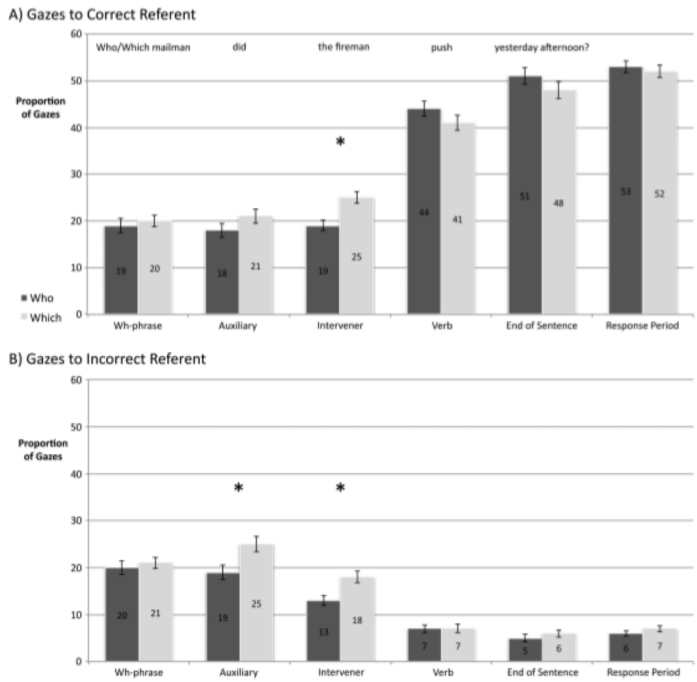


in interpreting these data. It may be that, as indicated by the high performance in all conditions, the task was too easy for our unimpaired participants and so does not discriminate the hypotheses well.

RTs are likely a more sensitive measure of processing when accuracy is at or close to ceiling. For RTs as well, there were main effects for extraction type (object-extracted slower than subject-extracted) and question type (*which*-questions slower than *who*-questions). The effect of question type suggests some support for the discourse hypothesis although this effect held only for the object-extracted sentences in pairwise comparisons, limiting support for this hypothesis. The extraction effect appears to more clearly support the word order hypothesis as here the effect of longer RTs for object-extracted questions held both for *which*-questions and for *who*-questions. Yet the object-extracted *which*-questions yielded significantly longer RTs than object-extracted *who*-questions. Only the intervener account predicts this pattern. However, the lack of a significant interaction weakens support for this hypothesis. It is also worth considering that the RT results—although perhaps more clear than the accuracy results—were also likely affected by the ease of the task for our college-age participants.

For our gaze data, we examined the proportion of gazes to the correct and incorrect referent during specified time windows as well as during the response period between the end of the sentence and the button-press response. For the subject-extracted questions, *which*-questions had increased gazes to the correct referent relative to *who*-questions at the verb and the middle NP. It's not clear what this signifies as the subject extracted *who*-questions actually had higher response accuracy than the subject-extracted *which*-questions. The two question types did not differ in gazes to the incorrect referent at any point in the sentence or response period.

Figure 3. Object-extracted sentences for Experiment 1 (unimpaired participants): Proportion of gazes for all responses (correctly and incorrectly answered by the participant) by time window to the correct referent (A) and incorrect referent (B) for object-extracted *who*-questions (dark gray) and *which*-questions (light gray). Error bars represent standard error; * denotes a significant difference at the $p < .05$ level.



For the object-extracted questions, gazes to the correct referent were greater for *which*-questions than *who*-questions only in the intervening NP time window, in which there were also more gazes to the incorrect referent for *which*-questions. This latter finding suggests greater difficulty for the *which*-questions. However, this effect starts before the intervening NP, at the auxiliary time window, although given the small number of data points contributing to this (very short) time window, we think this result should not be given much weight. However, there were no effects observed at the gap and beyond, where the intervener hypothesis would predict difficulties in computing the dependency relationship.

Thus, in this experiment, none of the three hypotheses were unambiguously supported by our data although RT patterns suggest some support for the word order hypothesis. We now move to our second experiment, in which we examine *wh*-question comprehension in a group of participants with aphasia.

Experiment 2: *Wh*-Questions in Aphasia

Our second experiment tested our hypotheses on participants with Broca's aphasia who have sentence-comprehension deficits. Here we used the same eye tracking while listening method as Experiment 1 and examined accuracy, RT, and gaze data.

Method

Participants

Eight adults with aphasia participated in the study (see Table 3). All participants experienced a single unilateral left

Table 3. Aphasia participant information.

Participant	Group	Sex	BDAE	Years poststroke	Lesion location	Age at testing (years)	Education level	SOAP: Canonical	SOAP: Noncanonical
LHD009	Broca	M	3	12	Large L lesion involving inferior frontal gyrus (BA44, 45)	52	1 year grad school	75%	55%
LHD101	Broca	M	2	6	Large L lesion involving posterior inferior frontal gyrus (BA44) with posterior extension	63	Ph.D.	95%	35%
LHD130	Broca	M	4	5	L IPL with posterior extension sparing STG	60	4 years college	75%	55%
LHD132	Broca	M	4	8	Large L lesion involving inferior frontal regions with extension to the anterior two thirds of STG & MTG	49	4 years college	85%	55%
LHD140	Broca	F	2	13	L MCA infarct secondary to occlusion of L proximal CA	38	4 years college	80%	30%
LHD138	Broca	M	2	14	L MCA infarct	35	Some college	70%	25%
LHD158	Broca	F	2	4	L CVA	56	4 years college	65%	25%
LHD159	Broca	F	3	3	L MCA infarct	60	College	100%	70%

Note. BDAE = Boston Diagnostic Aphasia Examination; L = left; BA = Brodmann area; IPL = inferior parietal lobule; STG = superior temporal gyrus; MTG = middle temporal gyrus; MCA = middle cerebral artery; CA = cerebral artery; CVA = cerebrovascular accident.

hemisphere stroke, were monolingual native speakers of English, and had normal or corrected-to-normal visual and auditory acuity. At the time of testing, all participants were neurologically and physically stable (i.e., at least 6 months postonset) with no reported history of alcohol or drug abuse, psychiatric illness, or other significant brain disorder or dysfunction.

Participants were diagnosed as having Broca's aphasia with specific sentence-comprehension deficits. Diagnosis of aphasia was based on the convergence of clinical consensus and the results of the Boston Diagnostic Aphasia Examination (version 3; Goodglass Kaplan, & Barresi, 2000). Sentence-comprehension deficits were defined as at- or below-chance performance on sentences not conforming to S-V-O order (e.g., passives and object-extracted relative clauses) along with above-chance performance on sentences with S-V-O word order (e.g., actives and subject-extracted relatives) via the SOAP Test of Sentence Comprehension (Love & Oster, 2002). Each participant was tested in four 1-hr sessions at least 1 week apart at the Language and Neuroscience Group Laboratory located at San Diego State University and was compensated $15 per session.

Design and Procedure

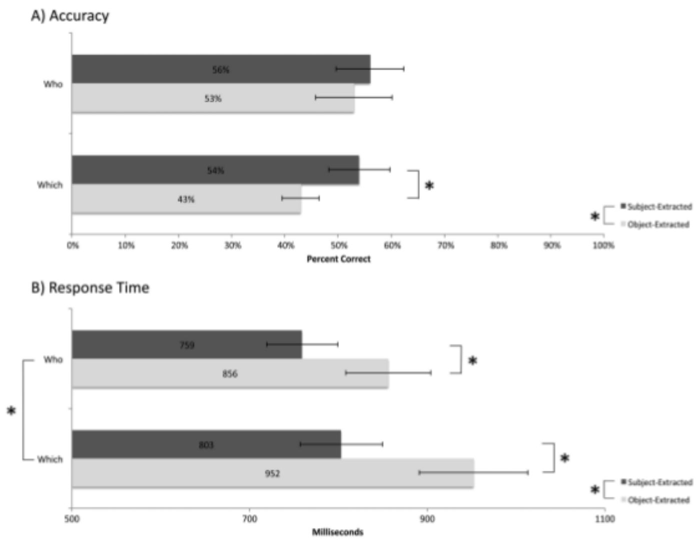
The design and procedure for Experiment 2 were nearly identical to those of Experiment 1 except that this design was fully within-subjects with participants completing all four lists across four sessions. In order to control for referent order effects, we created a duplicate set of pictures with the direction of action reversed with the action moving from right to left. In these reversed right-to-left pictures, the figure on the right was the correct choice for object-extracted questions and the figure on the left the correct choice for subject-extracted questions. In two sessions, participants saw pictures with the action moving left to right and in two sessions saw the pictures depicting the action moving right to left. In this way, each participant received every condition for each picture over the four sessions. In addition, Experiment 2 used fewer items (40 blocks each consisting of four experimental sentences for a total of 160 experimental items and 15 blocks each consisting of two filler sentences for a total of 30 filler items) and a longer response period (3 s).

Results

Offline Analysis and Data

We used the same data analysis procedures described in Experiment 1. Turning to the results from our accuracy data first (see Figure 4A), overall there was a significant main effect of extraction type: subject-extracted questions (55%) yielded more accurate performance than object-extracted questions (48%), $F(1, 1{,}196) = 7.79$, $p = .005$. A nearly significant main effect of *wh*-question type was observed: *which*-questions (48%) yielded poorer performance than *who*-questions (54.5%), $F(1, 1{,}196) = 3.67$, $p = .06$. The interaction did not reach significance, $F(1, 1{,}196) = 2.51$, $p = .11$. On further analysis, we found that accuracy for the object-extracted *which*-questions (43%) was lower than that for the object-extracted *who*-questions (53%), B = −0.43 (0.18), $t(1{,}196) = 2.46$, $p = .01$, 95% CI: (−0.78, −0.09), lower than subject-extracted *which*-questions (54%), B = −0.54 (0.18), $t(1{,}196) = 3.08$, $p = .002$, 95% CI: (−0.89, −0.20), and lower than subject-extracted *who*-questions (56%), B = −0.58 (0.18), $t(1{,}196) = 3.31$, $p = .0009$, 95% CI: (−0.93, −0.24). The latter three conditions did not differ from one another (all $ps > .39$). It is important that only object-extracted *which*-questions (43%) did not differ from chance performance (33%): $t(7) = 1.73$, $p = .13$. Note that participants pressed the middle button 12.5% of the time on average across all conditions, suggesting that they were in fact using all three buttons to respond, and so it is therefore appropriate to set chance at 33%.

Figure 4. Experiment 2 (participants with aphasia): Mean accuracy (A) and response time (B) across the four experimental conditions. Error bars represent standard error; * denotes a significant difference at the $p < .05$ level.



Consistent with this accuracy pattern, RTs (see Figure 4B) for the object-extracted *which*-questions (952 ms) were slower than for object-extracted *who*-questions (856 ms), B = 118 (62), $t(609) = 1.92$, $p = .06$, 95% CI: (−3, 239), subject-extracted *which*-questions (803 ms), B = 201 (61), $t(603) = 3.30$, $p = 0.001$, 95% CI: (81, 320), and for subject-extracted *who*-questions (759 ms), B = 249 (62), $t(601) = 4.04$, $p < .0001$, 95% CI: (128, 369). Among the latter three conditions, only object-extracted *who*-questions differed from subject-extracted *who*-questions, B = 130 (59), $t(609) = 2.22$, $p = .03$, 95% CI: (15, 246); the others did not differ from one another ($ps > .15$). Overall, the interaction between extraction type and *wh*-question type was not significant, $F(1, 609) = 0.69$, $p = .41$, but there were significant main effects of extraction type (object-extracted had slower RTs than subject-extracted), $F(1,602) = 15.31$, $p = .0001$, and *wh*-question type (*which*-questions had slower RTs than *who*-questions), $F(1, 599) = 3.88$, $p = .05$. RTs were screened as in Experiment 1 except using the outer fence of the box plot, removing 3.3% of data.

Gaze Analysis and Data

Gaze data were analyzed as described for Experiment 1 with the exception that all models converged when both random effects for participant and item were included, so results are reported with both random effects included.

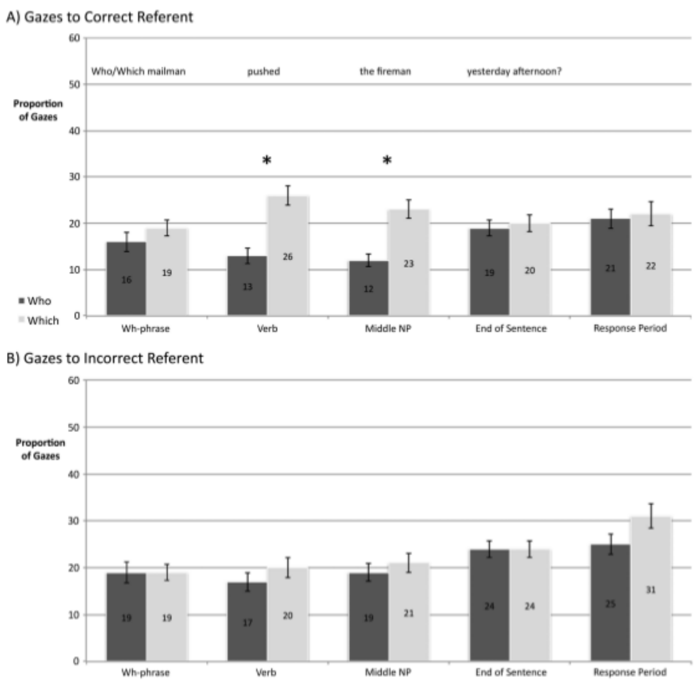
Subject-Extracted Sentences

For the subject-extracted sentences, gazes to the correct referent (see Figure 5A) revealed that *which*-questions (26%) produced a larger proportion of correct gazes than *who*-questions (13%) at the verb, B = 0.90 (0.23), $t(549) = 3.87$, $p = .0001$, 95% CI: (0.44, 1.36) and the middle NP time windows (*which*: 23%; *who*: 12%), B = 0.82 (0.24), $t(562) = 3.46$, $p = .0006$, 95% CI: (0.35, 1.28), but not at the other time windows ($ps > .40$). Gazes to the incorrect referent were not different for *which*- and *who*-questions at any time window (see Figure 5B; all $ps > .12$).

Object-Extracted Sentences

Gazes to the correct referent (see Figure 6A) revealed no significant differences in gaze proportion between the *which*- and *who*-questions for any time window (all $ps > .07$). However, gazes to the incorrect referent revealed an intriguing pattern (see Figure 6B). Beginning at the verb-gap region, *which*-questions (17%) yielded a higher proportion of gazes to the incorrect referent than *who*-questions (9%), B = 0.68 (0.26), $t(548) = 2.59$, $p = .01$, 95% CI: (0.16, 1.19). This difference continued through the end of the sentence (*which*: 16%; *who*: 9%), B = 0.68 (0.27), $t(570) = 2.54$, $p = .01$, 95% CI: (0.15, 1.21), and through the response period (*which*: 20%;

Figure 5. Subject-extracted sentences for Experiment 2 (participants with aphasia): Proportion of gazes for all responses (correctly and incorrectly answered by the participant) by time window for the correct referent (A) and incorrect referent (B) for subject-extracted *who*-questions (dark gray) and *which*-questions (light gray). Error bars represent standard error; * denotes a significant difference at the $p < .05$ level.

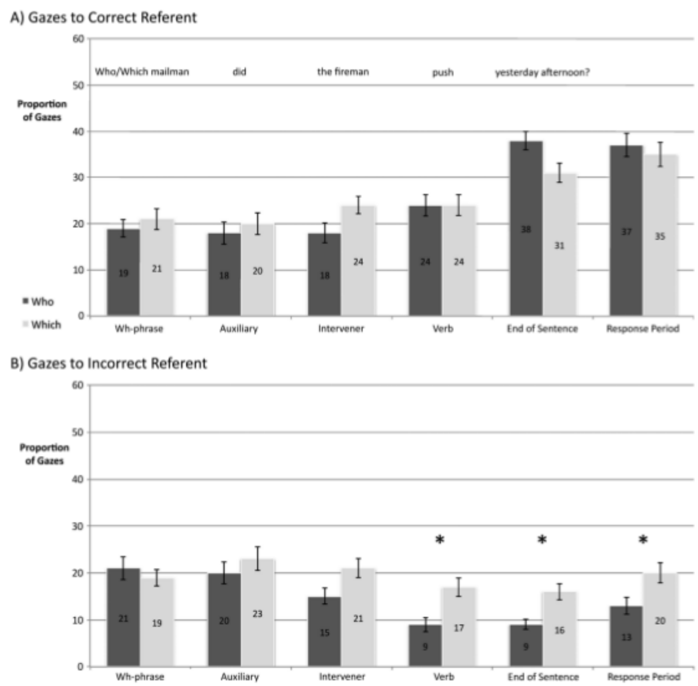


who: 13%), B = 0.53 (0.24), $t(509) = 2.17$, $p = .03$, 95% CI: (0.05, 1.01). Prior to the verb-gap region, there were no significant differences in gazes to the incorrect referent (all $ps > .08$).

We examined this apparent interference in more detail prospectively by analyzing if the proportion of gazes to either referent for an item predicted response accuracy for that item at any point in the sentence (see Table 4). That is, we examined if gazes to the incorrect referent (e.g., the agent-mailman) at any point in the sentence predicted a decreased likelihood of a correct response and, correspondingly, if the proportion of gazes to the correct referent (e.g., the theme-mailman) predicted an increased likelihood of a correct response. We used similar regression analyses as above with a logit link function for binary responses and crossed random effects of participant and item except that accuracy (correct vs. incorrect) was the dependent variable and proportion of gazes in the region of interest (object or subject in separate analyses) was the (continuous) fixed effect.

Two patterns are apparent (see Table 4). First, interference was evident for the *which*-sentences (black shading with white text): Increased gazes to the incorrect referent corresponded to an increased likelihood of an incorrect response. Of note, this pattern held from the verb to the end of the sentence and through the response period, exactly those time windows in which the comparison against the *who*-sentences also suggested interference. For the *who*-sentences, no such interference was found until the response period. Second, increased gazes to the correct referent (over all items) corresponded to an increased likelihood of a correct response (gray shading in Table 4), starting at the verb in the *which*-sentences (and continuing through the response period) and somewhat later for the *who*-sentences, starting

Figure 6. Object-extracted sentences for Experiment 2 (participants with aphasia): Proportion of gazes for all responses (correctly and incorrectly answered by the participant) by time window for the correct referent (A) and incorrect referent (B) for object-extracted *who*-questions (dark gray) and *which*-questions (light gray). Error bars represent standard error; * denotes a significant difference at the $p < .05$ level.



at the end of the sentence window and continuing for the response period.

Discussion

The participants with aphasia performed well on the task with above-chance accuracy for three of the four conditions. Indeed, the object-extracted *which*-question condition (43%) was the only condition that was not significantly different from chance (33%) and was significantly worse than performance on each of the other three types of questions. Accuracy in the other three conditions was not different from each other. Despite the lack of a significant interaction, this pattern is consistent with the predictions of the intervener hypothesis and is not predicted by the other two hypotheses we examined.

With respect to the other hypotheses, there was a main effect of extraction type with performance for object-extracted sentences worse than for subject-extracted sentences. This is consistent with the predictions of the word order hypothesis although in pairwise contrasts the effect was found only for *which*-questions, not for *who*-questions, limiting support for this hypothesis as no differences between question types are expected on this view. We also observed a nearly significant effect of question type with poorer performance for *which*-questions than *who*-questions, consistent with the discourse hypothesis. However, this effect was found only for the object-extracted questions in pairwise contrasts. Note that it has been suggested that object-extracted *which*-questions might be particularly problematic on the D-linking hypothesis (Avrutin, 2000, 2006). The reasoning is that more processing resources are required to fill a gap with an antecedent that is D-linked and that some

Table 4. Experiment 2 object-extracted sentences, the regression coefficient (B) with significance (*t*, *p*) for the analysis examining if gazes to the correct or incorrect referent predicted button-press response accuracy.

	Looks to correct referent			Looks to incorrect referent		
Time window	**B**	***t***	***p***	**B**	***t***	***p***
Which-sentences						
Wh-phrase	0.33	0.82	.41	0.24	0.52	.61
Auxiliary	0.34	0.98	.33	0.06	0.17	.87
Intervener	0.74	1.94	.05	–0.59	1.37	0.17
Verb	**0.92**	**2.61**	**.01**	<u>–1.60</u>	<u>3.40</u>	<u>.0008</u>
End of sentence	**1.21**	**3.13**	**.002**	<u>–1.98</u>	<u>3.43</u>	<u>.0007</u>
Response	**1.53**	**4.50**	**< .0001**	<u>–1.81</u>	<u>3.94</u>	<u>.0001</u>
Who-sentences						
Wh-phrase	–0.66	1.73	0.08	–0.48	1.29	.20
Auxiliary	–0.38	1.05	0.29	–0.20	0.57	.57
Intervener	–0.67	1.55	0.12	0.25	0.53	.60
Verb	–0.69	1.71	0.09	0.32	0.62	.54
End of sentence	**0.94**	**2.35**	**0.02**	–1.37	1.72	.09
Response	**1.36**	**3.62**	**0.0004**	<u>–1.57</u>	<u>2.87</u>	<u>.004</u>

Note. A significant positive coefficient indicates that an increased proportion of gazes predicts greater accuracy (bold); a significant negative coefficient indicates that an increased proportion of gazes predicts reduced accuracy (i.e., interference; underline).

people with aphasia have depleted resources to compute an accurate representation of such structures. Ignoring the thorny issue of what is meant by *processing resources* in this account, there is considerable linguistic and processing evidence that even subject-extracted relative clauses and *wh*-questions contain a copy/trace of a displaced (subject) NP (see, for example, Zurif, Swinney, Prather, Solomon, & Bushell, 1993) and thus there is no theoretical reason for the D-linking hypothesis to distinguish subject- from object-extraction.

In terms of our RT data, the object-extracted *which*-questions (952 ms) were significantly slower than the RTs for the subject-extracted *who*- (759 ms) and *which*- (803 ms) questions and the object-extracted *who*-questions (856 ms). Thus, the RT patterns basically conformed to the accuracy data described above with RTs for object-extracted *which*-questions significantly slower than for the other three conditions. Again, this pattern is only predicted by the intervener hypothesis and not the other accounts, albeit again without a significant interaction. There was a significant main effect of extraction type (object-extracted slower than subject-extracted), which held in pairwise contrasts both for the *which*-questions and for the *who*-questions, consistent with the word order hypothesis. Yet the worse performance for object-extracted *which*-questions relative to the object-extracted *who*-questions is not expected on this view. We also found a main effect of *wh*-type (*which*-questions slower than *who*-questions), consistent with the discourse hypothesis although pairwise comparisons revealed that this pattern only held for the object-extracted questions. Therefore, although there may be some support for the word order and discourse hypotheses, the observation that the object-extracted *which*-questions clearly stand out from the other three question types provides stronger support for the intervener hypothesis.

For the online gaze data, we compared the proportion of gazes to the correct and incorrect referents within extraction type; the two subject-extracted conditions were compared to each other, and the two object-extracted conditions were compared to each other. For the subject-extracted sentences, the patients showed precisely the same pattern as the unimpaired controls did in Experiment 1. There was an increase in gazes to the correct referent for *which*-questions relative to *who*-questions during the verb and middle NP time windows. This pattern suggests that the participants with aphasia are processing these sentences similarly to the control participants even if it may not be entirely clear precisely what kind of process this signifies (see discussion to Experiment 1). Moreover, as with the control participants, there were no differences between *which*-questions and *who*-questions with respect to gazes to the incorrect referent.

For the object-extracted sentences, a clearer pattern emerges. There were no differences between *which*-questions and *who*-questions in gazes to the correct referent, but unlike what was observed for our control participants in Experiment 1, here we observed consistently more gazes to the incorrect referent for *which*-questions from the verb-gap region through the end of the sentence and the response period. Moreover, the gaze behavior through these regions predicted response accuracy for the *which*-questions but not for the *who*-questions, which showed only a more restricted relationship between gaze location and accuracy.

This pattern in the gaze data suggests that only the object-extracted *which*-questions were problematic for the participants with aphasia to process, consistent with the predictions of the intervener hypothesis but not the other hypotheses. Our results are also consistent with those of prior offline studies. Hickok and Avrutin (1996) found a subject-object asymmetry only for *which*- and not for *who*-questions. Friedmann and Gvion (2012) report results consistent with an intervener effect for object-extracted relative clauses. In addition, Dickey et al. (2007) found on-time gazes at the gap for object-extracted *who*-questions, suggesting that their participants with Broca's aphasia were able to process these sentences. The present study corroborates this finding. Yet we have gone further and observed that not all *wh*-questions are treated similarly. The patients with Broca's aphasia who also have comprehension deficits in the present study had significantly more offline and online difficulty with questions containing an intervener (object-extracted *which*-questions) compared to those questions that did not (object-extracted *who*-questions, subject-extracted *wh*-questions).

General Discussion

We argue that the results from our participants with aphasia support the intervener hypothesis. In terms of the *wh*-questions we investigated, an intervener is a fully specified NP that occurs between a gap and its displaced *wh*-phrase.

The intervener interferes with computing the dependency relationship because it is a possible element in the dependency chain, rendering a processing disadvantage to such structures over those that don't contain an intervener. We suggest that some adults with a language disorder are particularly vulnerable to interveners during sentence processing, perhaps because they are susceptible to interference among similarly structured NPs.

To be sure, there are several unanswered questions that are raised by our findings. One question is whether the intervener hypothesis is specific to individuals with aphasia. Our results suggest this may be the case as only Experiment 2 found relatively strong support for the account in terms of accuracy, RTs, and gaze data. Yet the theoretical basis for the account comes not only from the linguistic literature (i.e., relativized minimality), but also from the processing literature using neurologically intact adult participants. For example, Friedmann and Gvion (2012) specifically couched their intervener results in terms of a linguistic deficit. In their view, participants with agrammatic Broca's aphasia cannot construct fully realized syntactic trees, and thus, locality comes to the rescue if the syntax cannot provide a structure to connect a verb to its (displaced) arguments. In terms of processing, Gordon and colleagues (Gordon, Hendrick, & Johnson, 2004; Gordon, Hendrick, Johnson, et al., 2006) have suggested a similarity-based interference account of normal memory, in which the demands on storage and retrieval during sentence comprehension are increased when there are NPs that have similar representations. The idea is that interference is mediated by a direct-access retrieval mechanism that is sensitive to different cues, including semantic, pragmatic, and syntactic ones. Because we found intervener effects only for our participants with aphasia, perhaps their linguistic deficit stems from an increased sensitivity to similarity because of memory processing limitations.

An additional account, the trace-deletion hypothesis (TDH; Grodzinsky, 1995; Grodzinsky & Finkel, 1998), bears mention here. The TDH claims that individuals with Broca's aphasia delete traces in syntactic representations, leaving displaced arguments without a grammatically specified thematic role. A nonlinguistic agent-first heuristic (assume that the first NP in a sentence is the agent) is used to interpret an argument that is left without a grammatically specified thematic role. Skipping details, this heuristic leads to chance performance on offline sentence–picture matching tasks with sentences containing displaced direct object arguments. However, because the TDH suggests that only referential NPs (those that refer to an individual from a set of individuals) are input to the agent-first heuristic, only questions headed by a *which*-phrase should be affected. The TDH therefore makes the same predictions as the intervener hypothesis for offline measures, namely that object-extracted *which*-questions should have the lowest accuracy. Even so, the TDH requires both the deletion of traces and the use of a nonlinguistic heuristic to explain offline patterns, and the intervener account suggests a single mechanism: interference from similarly structured NPs. Furthermore, the TDH has relied solely on offline measures; online predictions from eye tracking for the TDH are not clear. Thus our view is that the intervener hypothesis may be a simpler account of sentence comprehension performance in Broca's aphasia relative to the TDH, and this is also buttressed by support from our online eye gaze measurements. Further experimentation can resolve this issue by examining other constructions that do (and do not) contain interveners and on which the two accounts make distinct predictions.

Last, there is the possibility of a general language-processing impairment, such as that proposed by a delayed lexical access account (Ferrill, Love, Walenski, & Shapiro, 2012; Love, Swinney, Walenski, & Zurif, 2008) or a delayed syntactic processing account (Avrutin, 2006; Burkhardt, Avrutin, Piñango, Ruigendijk, 2008; Piñango, 2000). The delayed lexical access hypothesis predicts that patients with Broca's aphasia have delayed gap filling due to delayed access to lexical information. The delayed syntactic processing account likewise predicts slower-than-normal gap filling due to slowed syntactic processing. However, because we observed clear differences between the object-extracted *who-* and *which*-questions, both requiring gap filling, we did not find support for either of these hypotheses.

We end our discussion with a note on variability. As is well known in the literature, variability in behavior across participants with aphasia is a continuing concern and often interferes with interpreting the results from different studies. In particular, this issue has often targeted the syndrome of Broca's aphasia (see, for example, Drai & Grodzinsky, 2006). Our tactic here and in other studies is to select our participants with aphasia on the basis of specific theoretical issues. The issue that we addressed in this study is about the underlying deficit in comprehension in aphasia. In the present work, then, we selected our participants on the basis of their comprehension profiles, including only participants with Broca's aphasia on standard testing who also revealed at- or below-chance performance on noncanonically ordered sentences (e.g., passives and object-extracted relatives) relative to good performance on S-V-O ordered sentences (e.g., actives and subject-extracted relatives). It remains to be seen whether or not other types of aphasia—those that also involve a comprehension deficit—would reveal similar results.

To conclude, the present study found strong evidence to support the intervener hypothesis of sentence comprehension in aphasia. If this work is confirmed and extended (e.g., to other intervener-type constructions), treatment programs could be developed that focus on the similarity of NPs in sentences that yield good versus poor comprehension. Thus, this line of research could have far-reaching implications and benefits for patients with aphasia.

Acknowledgments

The work reported in this article was supported by National Institute on Deafness and Other Communication Disorders Grants R01DC009272 (awarded to Tracy Love and Lewis P. Shapiro), R01DC000494 (awarded to Lewis P. Shapiro), and T32DC007361 (awarded to Lewis P. Shapiro). We thank our research assistants and our participants and their families for their time.

References

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38,* 419–439.

Avrutin, S. (2000). Comprehension of discourse-linked and non-discourse-linked questions by children and Broca's aphasics. In Y. Grodzinsky, L. P. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing* (pp. 295–313), San Diego, CA: Academic Press.

Avrutin, S. (2006). Weak syntax. In Y. Grodzinsky & K. Amunts (Eds.), *Broca's region* (pp. 49–62). Oxford, UK: Oxford University Press.

Baayen, R. H. (2004). Statistics in psycholinguistics: A critique of some current gold standards. *Mental Lexicon Working Papers, 1*(1), 1–47.

Baayen, R. H. (2008). *Analyzing linguistic data* (Vol. 505). Cambridge, UK: Cambridge University Press.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68,* 255–278.

Bates, E., Friederici, A., & Wulfeck, B. (1987). Comprehension in aphasia: A cross-linguistic study. *Brain and Language, 32,* 19–67.

Burkhardt, P. (2005). *The syntax-discourse interface: Representing and interpreting dependency* (Vol. 80). Philadelphia, PA: John Benjamins.

Burkhardt, P., Avrutin, S., Piñango, M. M., & Ruigendijk, E. (2008). Slower-than-normal syntactic processing in agrammatic Broca's aphasia: Evidence from Dutch. *Journal of Neurolinguistics, 21,* 120–137.

Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language, 3,* 572–582.

Chomsky, N. (1981). *Lectures on government and binding*. Dordrecht, the Netherlands: Foris.

Chomsky, N. (1995). *The minimalist program* (Vol. 28). Cambridge, MA: MIT Press.

De Vincenzi, M. (1991). *Syntactic parsing strategies in Italian: The minimal chain principle* (Vol. 12). Dordrecht, the Netherlands: Springer.

Dickey, M., Choy, J. W., & Thompson, C. K. (2007). Real-time comprehension of *wh*-movement in aphasia: Evidence from eye tracking while listening. *Brain and Language, 100,* 1–22.

Dickey, M., & Thompson, C. (2009). Automatic processing of *wh*- and NP-movement in agrammatic aphasia: Evidence from eye tracking. *Journal of Neurolinguistics, 22,* 563–583.

Donkers, J., Hoeks, J., & Stowe, L. (2013). D-linking or set-restriction? Processing *which*-questions in Dutch. *Language and Cognitive Processes, 28,* 9–28.

Donkers, J., & Stowe, L. (2006). *Wh-questions and the nature of D-linking: A processing perspective*. Presented at the International Conference on Linguistic Evidence, University of Tübingen, Germany.

Drai, D., & Grodzinsky, Y. (2006). A new empirical angle on the variability debate: Quantitative neurosyntactic analyses of a large data set from Broca's Aphasia. *Brain and Language, 96,* 117–128.

Ferrill, M., Love, T., Walenski, M., & Shapiro, L. P. (2012). The time-course of lexical activation during sentence comprehension in people with aphasia. *American Journal of Speech-Language Pathology, 21,* S179–S189.

Frazier, L., & Clifton, C. (2002). Processing "d-linked" phrases. *Journal of Psycholinguistic Research, 31,* 633–659.

Frazier, L., & McNamara, P. (1995). Favor referential representation. *Brain and Language, 49,* 224–240.

Frazier, L., Plunkett, B., & Clifton, C. (1996). Reconstruction and scope. *University of Massachusetts Occasional Papers in Linguistics, 19,* 239–260.

Friedmann, N., Belletti, A., & Rizzi, L. (2009). Relativized relatives: Types of intervention in the acquisition of A-bar dependencies. *Lingua, 119,* 67–88.

Friedmann, N., & Gvion, A. (2012). Intervention and locality in agrammatic aphasia. In *Enjoy Linguistics! Papers Offered to Luigi Rizzi on the Occasion of His 60th Birthday* (pp. 1–13). Siena, Italy: CISCLWorking Papers.

Friedmann, N., & Shapiro, L. P. (2003). Agrammatic comprehension of simple active sentences with moved constituents: Hebrew OSV and OVS structures. *Journal of Speech, Language, and Hearing Research, 46,* 288–297.

Goodglass, H., Kaplan, E., & Barresi, B. (2000). *Boston Diagnostic Aphasia Examination (3rd Ed.)*. Philadelphia, PA: Taylor & Francis.

Gordon, P. C., Hendrick, R., & Johnson, M. (2004). Effects of noun phrase type on sentence complexity. *Journal of Memory and Language, 51,* 97–114.

Gordon, P. C., Hendrick, R., Johnson, M., & Lee, Y. (2006). Similarity-based interference during language comprehension: Evidence from eye tracking during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 1304–1321.

Grillo, N. (2005). Minimality effects in agrammatic comprehension. In S. Blaho, L. Vicente, & E. Schoorlemmer (Eds.), *Proceedings of ConSOLE XIII* (pp. 106–120). Leiden, the Netherlands: Leiden University.

Grillo, N. (2009). Generalized minimality: Feature impoverishment and comprehension deficits in agrammatism. *Lingua, 119,* 1426–1443.

Grodzinsky, Y. (1990). *Theoretical perspectives on language deficits.* Cambridge, MA: The MIT Press.

Grodzinsky, Y. (1995). A restrictive theory of agrammatic comprehension. *Brain and Language, 50,* 27–51.

Grodzinsky, Y. (2000). The neurology of syntax: Language use without Broca's area. *Behavioral and Brain Sciences, 23,* 1–71.

Grodzinsky, Y., & Finkel, L. (1998). The neurology of empty categories: Aphasic's failure to detect ungrammaticality. *Journal of Cognitive Neuroscience, 10,* 281–292.

Hickok, G., & Avrutin, S. (1996). Comprehension of *wh*-questions in two Broca's aphasics. *Brain and Language, 52,* 314–327.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberger, O. (2006). *SAS for linear mixed models* (2nd ed.) Cary, NC: SAS Institute.

Love, T., & Oster, E. (2002). On the categorization of aphasic typologies: The SOAP (a test of syntactic complexity). *Journal of Psycholinguistic Research, 31,* 503–529.

Love, T., Swinney, D., Walenski, M., & Zurif, E. (2008). How left inferior frontal cortex participates in syntactic processing: Evidence from aphasia. *Brain and Language. 107,* 203–219.

Manor, B. R., & Gordon, E. (2003). Defining the temporal threshold for ocular fixation in free-viewing visuocognitive tasks. *Journal of Neuroscience Methods, 128,* 85–93.

O'Grady, W., Yamashita, Y., & Lee, S. Y. (2005). A note on canonical word order. *Applied Linguistics, 26,* 453–458.

Piñango, M. M. (2000). On the proper generalization for Broca's aphasia comprehension pattern: Why argument movement may not be at the source of the Broca's deficit. *Behavioral and Brain Sciences, 23,* 48–49.

Rizzi, L. (1990). *Relativized minimality*. Cambridge, MA: MIT Press.

Rothman, J., & Slabakova, R. (2011). The mind-context divide: On acquisition at the linguistic interfaces. *Lingua, 121,* 568–576.
Salis, C., & Edwards, S. (2005). Discourse linking, canonicity, and comprehension of *wh*-questions in agrammatism. *Brain and Language, 96,* 86–87.
Shapiro, L. P. (2000). Some recent investigations of gap filling in normal listeners: Implications for normal and disordered language processing. In Y. Grodzinsky, L. P. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing* (pp. 357–376). San Diego, CA: Academic Press.
Thompson, C. K., Tait, M. E., Ballard, K. J., & Fix, S. C. (1999). Agrammatic aphasic subjects' comprehension of subject and object extracted *wh*-questions. *Brain and Language, 67,* 169–187.
Van Dyke, J. A. (2007). Interference effects from grammatically unavailable constituents during sentence processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 407–430.
Van Dyke, J. A., & McElree, B. (2011). Cue-dependent interference in comprehension. *Journal of Memory and Language, 65,* 247–263.
Zurif, E., Swinney, D., Prather, P., Solomon, J., & Bushell, C. (1993). An on-line analysis of syntactic processing in Broca's and Wernicke's aphasia. *Brain and Language, 45,* 448–464.

Chapter 3, in full, is a reprint of material as it appears in Sheppard, S.M., Walenski, M., Love, T., Shapiro, L.P. (2015). The auditory comprehension of Wh-questions in aphasia: Support for the intervener hypothesis. *Journal of Speech, Language, and Hearing Research, 58(3)*, 781-797. The dissertation author was the primary investigator and author of this paper.

CHAPTER 4:

Electrophysiological Evidence for the Interaction of Prosody and Thematic Fit Information During Sentence Comprehension

ELECTROPHYSIOLOGICAL EVIDENCE FOR THE INTERACTION OF PROSODY AND THEMATIC FIT INFORMATION DURING SENTENCE COMPREHENSION

Shannon M. Sheppard[1,2], Katherine J. Midgley [1], Tracy Love [1,2], Lewis P. Shapiro [1,2], and Phillip J. Holcomb [1,2]

1 San Diego State University

2 University of California, San Diego

Preface

While Chapter 3 focused on the impact of syntax and the resulting similarity-based interference that may result in certain syntactic constructions, Chapters 4 and 5 focus on two different elements in sentence processing: prosody and thematic fit. As discussed in Chapter 2, both prosody and thematic fit are essential components of sentence processing, yet many studies investigating these two components have used off-line methods. Here we examine how prosody and thematic fit influence sentence processing, and in particular how they impact the resolution of temporary syntactic ambiguities. Event-related potentials (ERPs) were used as they allowed for the investigation of specific ERP components, the Closure Positive Shift, the N400, and the P600, which are each elicited by different aspects of language processing. Specifically, the CPS indexes the processing of intonational phrase boundaries, the N400 measures semantic integration, and the P600 syntactic repair/reanalysis. Measuring each of these components at key points in experimental sentences allowed for the examination of how and when prosody and thematic fit interacted during processing, and what specific aspect of language processing was influenced by this interaction. Chapter 4 details the investigation of these processing elements in a group of college-age adults, and Chapter 5 discusses the same study conducted in a group of participants with aphasia and their age-matched controls.

Abstract

In the present study we used event-related potentials (ERPs) to examine the impact and interaction of prosody and thematic fit/plausibility information on the processing of sentences containing temporary early closure (correct) or late closure (incorrect) syntactic ambiguity. We examined ERPs in a group of college-age adults to early closure sentences with congruent and incongruent prosody where the temporarily ambiguous NP was either a plausible or an implausible continuation for the subordinate verb (e.g., "While the band played the song/the beer pleased all the customers."). It was hypothesized that an implausible NP in sentences with incongruent prosody may provide the parser with a cue about the correct underlying structure. The implausible NP Three ERP components, the Closure Positive Shift (CPS), N400, and P600, were examined at critical points in each sentence type. The results revealed that prosodic and thematic fit/plausibility cues interact immediately (indexed by an N400-P600 complex) at the implausible NP (*the beer*), when it is paired with incongruent prosody. Results also indicated that incongruent prosody paired with a plausible NP (*the song*) results in garden-path effects a (N400-P600 complex) at the critical verb (*pleased*).

4.1. Introduction

In this paper we describe a study examining how prosody and plausibility are used to resolve structural ambiguities during on-line sentence processing. Consider:

1. While the band played the song pleased all the customers.

Moving 'left-to-right', (1) contains a temporary syntactic ambiguity where the verb *played* is optionally transitive and thus it is initially unclear whether the subsequent NP (*the song*) is the direct object of *played* (e.g., "…the band played the song") or the subject of the main clause (e.g., "the song pleased all the customers"). Yet, if the sentence is presented aurally, the addition of a pause after the word *played* can potentially disambiguate the subsequent temporary syntactic ambiguity by signaling the presence of a syntactic boundary (Nagel, Shapiro, & Nawy, 1994; Schafer, Speer, Warren, & White, 2000; Speer, Warren, & Schafer, 2003; Warren, Schafer, Speer, & White, 2000). Prosodic boundaries congruent with syntactic structure have been found to enhance processing, while incongruent boundaries obstruct processing (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2010, 2013; Carlson, Frazier, & Clifton, 2009; Kjelgaard & Speer, 1999; Nagel et al., 1994; Pauker, Itzhak, Baum, & Steinhauer, 2011; Pynte & Prieur, 1996; Schafer et al., 2000; Steinhauer, Alter, & Friederici, 1999). These findings lend support to a constraint-based sentence processing approach since prosodic cues appear to constrain sentence processing by interacting with syntactic information. In such an account, syntactic and non-syntactic information interact immediately and throughout the sentence comprehension process (MacDonald, Pearlmutter, & Seidenberg, 1994; McRae & Spivey-Knowlton, 1998; Trueswell & Tanenhaus, 1994; Trueswell, 1996).

In addition to prosodic cues, other information, such as lexical-semantic cues, may also interact with syntax during sentence processing. For example, consider (2):

2. While the band played the beer pleased all the customers.

Here, the NP immediately following the verb *played* (the beer) appears to constrain the initial parse; the NP is more easily integrated into the sentence as the subject of the ensuing clause rather than the object of *played*, since people typically don't "play beer". The combination of a verb with its arguments is often called "thematic fit" because, in this case, some NPs are better continuations of particular verbs than others. Neurologically unimpaired participants are sensitive to verb transitivity and thematic fit (Staub, 2007) such that processing is momentarily disrupted when a transitive-biased verb is followed by an implausible direct object. Yet, because much psycholinguistic research has been conducted using reading rather than listening, questions remain regarding the role of prosody and its interaction with, for example, thematic fit.

Consider again:

3. While the band played the song pleased all the customers.

In (3) the post-verb NP can either serve as the direct object of the first clause (termed 'late closure' (LC)) or the subject of the second clause (early closure (EC)). Reading studies have demonstrated a preference for LC, that is, to attach the NP to the verb, the phrase being processed, rather than close off the initial parse at the verb *played*. When subsequent information is encountered (e.g., the verb *pleased*), listeners/readers have been "garden-pathed" – they have been led down the garden path and mis-analyzed the sentence. Yet, studies examining the effect of lexical cues suggest that the lexical-semantic content of the NP can lessen or eliminate the garden-path effect, as in:

4. While the band played the beer pleased all the customers.

Here, the NP *the beer* is a poor fit as a direct object for the verb *played*, unlike *the song* in (3), and thus the preference for LC is reduced, and so too is the garden-path effect.

It remains unclear how prosody interacts with other types of non-syntactic information – for example, thematic fit – to influence "garden-path" effects. Only a few studies have examined this issue. In the following, we briefly describe the literature that underlies our approach. We begin with a brief discussion of how prosodic information is used during sentence processing and follow that with a discussion of how lexical-semantic plausibility cues impact processing. We then briefly discuss the literature examining how these cues interact, and move to a description of our study.

Prosodic Cues in Sentence Processing

Prosody is the stress, timing, and intonation in speech and can be described using pitch, amplitude and duration measures. A prosodic break, or intonational phrase boundary, can be indicated by a pause, lengthening of the word preceding the pause, as well as a boundary tone at the pre-pause word. Prosodic breaks tend to occur at major syntactic boundaries (Cooper & Paccia-Cooper, 1980; Nagel et al., 1994; Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991). Thus, prosodic boundaries can help a listener determine the underlying syntactic structure of a sentence. Many researchers have found that prosodic boundaries convey important information to a listener such that prosodic information congruent with sentence structure facilitates sentence comprehension and incongruent prosodic information disrupts comprehension (Bögels et al., 2013; Carlson et al., 2009; Kjelgaard & Speer, 1999; Pauker et al., 2011; Pynte & Prieur, 1996; Schafer et al., 2000; Steinhauer et al., 1999).

Both online and offline methods have been used to examine the impact of prosody on sentence processing. Offline methods measure the listener's final interpretation of a sentence while online methods examine moment-by-moment processing that occurs prior to final interpretation. Distinguishing how and when prosodic information impacts processing requires precise temporal information, thus online methods offer a significant advantage over offline methods. Yet few studies have examined prosody using online methods. Some of these studies have used cross-modal naming tasks. Participants listen to a syntactically ambiguous sentence fragment and then they are presented with a visual target probe word that serves as a continuation of the sentence. Participants are required to read the probe word as quickly as possible. Both accuracy and response times are recorded, and lower accuracy and longer response times indicate processing interference. The results of studies using the cross-modal naming method have suggested that the syntactic structure of a sentence is immediately influenced by prosodic cues (Kjelgaard & Speer, 1999; Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992; Speer, Kjelgaard, & Dobroth, 1996).

As an example, (Kjelgaard & Speer, 1999) found that early closure sentences properly marked with a prosodic boundary were processed faster than sentences with either neutral prosody or with conflicting prosody, where the prosodic boundary conflicted with the underlying syntactic structure. The study concluded that prosodic cues influence the syntactic parsing mechanism. While compelling, the findings of these studies are limited because the cross-modal naming method requires participants to switch from an auditory to a visual processing modality mid-sentence, which likely requires the subject to focus their attention on integrating the probe word into the sentence. Such conscious focus makes the task unlikely to reveal processing routines that are more immediate and online.

Other studies have used self-paced listening tasks to examine the influence of prosody on sentence processing (DeDe, 2010; Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996b). Recall that in this method, listeners are presented with sentences in a word-by-word (or phrase-by-phrase) fashion, pressing a button to reveal the next aurally presented segment, and listening times via the button press are recorded. Longer listening times are equated to processing difficulty/interference. The results of studies using this method also have provided evidence that prosody influences processing of temporary syntactic ambiguities (DeDe, 2010; Ferreira et al., 1996b). Yet, self-paced listening, like its reading analogue, requires the listener to consciously reflect on each segment before moving on to additional segments. Again, such conscious reflection does not allow for an unfettered examination of online behavior, which as suggested above, is necessary to reveal the underlying nature of sentence processing. Finally, by nature of the method, self-paced listening disrupts of some aspects of prosody (Ferreira, Anes, & Horine, 1996a), making it difficult to examine how and when prosody influences processing moment-by-moment.

Lexical Cues in Sentence Processing

Several studies have examined the impact of thematic fit on the processing of structural ambiguities. For example, Ferreira and Clifton (1986) presented participants with sentences like:

5. The defendant examined by the lawyer turned out to be unreliable.

6. The evidence examined by the lawyer turned out to be unreliable.

These sentences have a reduced relative clause and thus contain a temporary syntactic ambiguity (where the optional complementizer *that was*, which indicates the beginning of the relative clause, has been removed). The first NP was manipulated so that it was either animate (*the defendant*) or inanimate (*the evidence*). Animate NPs possess semantic properties that make them good subjects, while inanimate NPs possess properties that make them good direct objects. The verb is more likely to be part of a main clause rather than a reduced relative clause when the first NP would make a good subject. Yet regardless of animacy, readers initially preferred the main clause interpretation. These results were viewed as evidence for a syntax-driven account of sentence processing. However, in response to the Ferreira and Clifton study, Trueswell, Tanenhaus, and Garnsey (1994) conducted a similar study and found the opposite: that animacy had an immediate impact on parsing. Readers had greater difficulty processing reduced relative clauses with animate NPs compared to those with inanimate NPs. Thus, when the first NP served as a poor subject but a good direct object of the verb, the reduced relative clause interpretation was preferred over the main clause interpretation. Trueswell and colleagues interpreted these results to provide evidence in support of a constraint-based approach, given that the content of the NP, and not just the syntax of the sentence, influenced parsing decisions. Thus, as these two seminal studies show, there is conflicting evidence about whether lexical cues/thematic fit information has an immediate impact on parsing decisions.

Interaction of Prosodic and Lexical Cues in Sentence Processing

Only a few studies have examined the interaction of prosodic and lexical cues in sentence processing (Blodgett, 2004; DeDe, 2010; Pynte & Prieur, 1996; Snedeker & Yuan, 2008) and they have shown different patterns of results. For example, (Pynte & Prieur, 1996) used a word detection task to examine the interaction of prosodic and lexical cues in sentences containing ambiguous prepositional phrases like these:

7. The spies informed the guards of the palace

8. The spies informed the guards of the conspiracy.

Here, the prepositional phrase *of the palace/of the conspiracy* could be attached to the noun phrase (7) or the verb phrase (8). Along with the type of preposition (NP-attached or VP-attached), the verb type (monotransitive – requiring a direct object, or ditransitive – requiring a direct and an indirect object), and the prosodic break (present or absent) prior to the preposition were manipulated. The results revealed effects of prosody only when the argument structure cues conflicted with ambiguity resolution. No prosodic effects were found when the lexical cues were consistent with the disambiguation of the sentence. These results were interpreted to mean that lexical cues (verb bias) play a role in building the initial syntactic structure, and prosody is only used to revise that analysis when reanalysis is required. However, word detection or monitoring – a secondary task – is not well suited to examine initial effects of ongoing processing because it requires the listener to consciously reflect on every word encountered in the sentence (Shapiro, Swinney & Borsky, 1998).

Snedeker and Yuan (2008), using the visual world method, also examined the effects of lexical and prosodic cues with sentences containing ambiguous prepositional phrases. The location of the prosodic break (intonational phrase break after the verb - biased toward the NP interpretation, or an intonational phrase break after the noun – biased toward the VP interpretation) and the type of verb (biased toward the NP interpretation, biased toward the VP interpretation, or no bias) were manipulated. Unlike Pynte and Prieur (1996), Snedeker and Yuan found evidence that both of these cues interacted early in sentence processing and are used to resolve structural ambiguities.

Researchers have also examined the interaction of these cues in sentences containing early vs. late closure temporary syntactic ambiguities. For example, using a self-paced listening task, DeDe (2010) examined the impact of conflicting lexical and prosodic cues in the processing of early closure sentences such as the following:

9a. While the parents watched the child sang a song with her grandmother.

9b. While the parents danced the child sang a song with her grandmother.

In these sentences it is initially unclear whether they have early closure, where the NP *the child* is the subject of the main clause, or late closure, where the NP *the child* is the object of the subordinate verb *watched/danced.* Verb transitivity bias and plausibility were manipulated, providing a lexical cue, and the prosodic contour was also manipulated to either be present (pause after the verb *watched/danced*) or absent (no clear prosodic bias toward an early closure or late closure interpretation). Results revealed that processing times were short at the structurally ambiguous NP (*the child*) and at the disambiguating main verb (*sang*) when both lexical and prosodic cues matched the correct early closure interpretation. However, when the lexical and prosodic cues matched the incorrect late closure interpretation, processing times were short at the ambiguous NP but were long at the disambiguating verb (*sang*). These findings suggest that lexical and prosodic cues interact at the subordinate verb (*watched/danced*) and that plausibility has an immediate impact on sentence processing. Thus, both DeDe (2010) and Snedeker and Yuan (2008) found evidence that prosodic and plausibility cues interact and influence structure building. We have already discussed why self-paced listening (DeDe, 2010) might not be the best method for measuring initial effects during real-time language processing. Snedeker and Yuan used eye-tracking, which allows for on-line data collection without the conscious reflection required in self-paced listening. Yet even eye-tracking has its limitations regarding how lexical-semantic and prosodic cues might interact during ambiguity resolution. Therefore, in our study we use event-related brain potentials (ERPs) during listening to measure on-line sentence processing. ERPs offer an advantage over eye-tracking because they allow for the examination of specific language related components that allow for differentiating prosodic, lexical-semantic, and syntactic processing routines.

Accounts of Prosody and Sentence Processing

The studies discussed above propose several conflicting accounts of how prosodic cues are used in sentence processing. One account suggests that prosodic cues take precedence over other types of cues (Kjelgaard & Speer, 1999), another suggests that lexical cues take precedence over prosodic cues (Pynte & Prieur, 1996), and the last claims that prosodic and lexical cues interact (Dede, 2010; Snedeker & Yuan, 2008). Our study aimed to distinguish among these three accounts and address how and when prosodic and lexical-semantic cues influence sentence processing by using event-related brain potentials.

Event-Related Brain Potentials in Sentence Processing

Event-related brain potentials (ERPs) are extracted from electroencephalography (EEG) data, which are recorded using electrodes placed on participants' scalp while the participant is performing a cognitive task. The EEG is time-locked to brain activity impacted by a stimulus event of interest, and a large number of trials of the same type are averaged together to generate the ERP waveform. ERPs are believed to be generated from the summed activity of postsynaptic potentials in large numbers of cortical pyramidal neurons (Peterson, Schroeder, & Arezzo, 1995). ERPs offer several benefits to studying sentence processing when compared to other tasks, including millisecond-level temporal resolution of online brain processes. In addition, they can be elicited without a participant performing a secondary task that would distract from the primary task of language processing. Different experimental conditions can be compared by examining differences in ERP waveform amplitudes, latencies, and scalp distributions.

There are three language-related ERP components that are of particular interest for the current study: the Closure Positive Shift (CPS), the N400, and the P600. Each component reflects a different aspect of sentence processing.

The Closure Positive Shift (CPS) Component

The CPS component is an important ERP component to investigate in auditory sentence processing studies. Steinhauer et al. (1999) first described the CPS component which is elicited in spoken sentences at prosodic phrase boundaries and is characterized by a large positive-going waveform with a bilateral distribution and a duration of about 500-700ms (Steinhauer, 2003; Steinhauer et al., 1999). It is sensitive to pauses in speech along with other types of acoustic boundary markers such as constituent lengthening and boundary tones (Steinhauer, 2003), and is believed to reflect the decoding of intonational phrasing. It has been identified in several languages including German, Dutch and Japanese (Kerkhofs, Vonk, Schriefers, & Chwilla, 2007; Steinhauer et al., 1999; Wolff, Schlesewsky, Hirotani, & Bornkessel-Schlesewsky, 2008). Only one study has examined this component in English prosody-driven garden-path sentences (Pauker et al., 2011), underscoring the importance of examining this component in the current study.

The N400 Component

The impact of plausibility when manipulating thematic fit can be examined using the N400 component. The N400 component is a negative-going wave that peaks around 400ms post-stimulus onset. It typically has a slightly right-lateralized centro-parietal scalp distribution. This component was first discovered by Kutas and Hillyard (1980) who compared sentences with expected endings (10) to those with anomalous endings (11):

10. I shaved off my mustache and beard.

11. I take my coffee with cream and dog.

The amplitude of the N400 is linked to semantic processing such that sentence-final words with high cloze probability yield an N400 component with a smaller amplitude (i.e., (10) above) relative to sentence-final words with low cloze probability (i.e., (11) above). The N400 is also sensitive to other factors such as word frequency, where infrequent words manifest a larger N400 amplitude than highly frequent words. There is an ongoing debate regarding the specific neural processes underlying the N400. For example, some researchers suggest that it reflects the integration of lexical information (Brown & Hagoort, 1993; Hagoort, Baggio, & Willems, 2009) while others claim it is an index of access to semantic memory (see Kutas & Federmeier (2011) for a review). However, it is generally agreed that the N400 serves as an index for semantic processing difficulty.

The P600 Component

Another important language ERP component is the P600 component, which is a positive-going component that typically peaks around 600ms after stimulus onset. The P600 is elicited by syntactic violations (Osterhout &

Holcomb, 1992) and appears when participants have difficulty integrating a word into the ongoing sentence structure. Evidence suggests that the P600 reflects syntactic reanalysis (Friederici, 2011) or possibly the effort and time required to build the syntactic structure of the sentence (Hagoort, 2003). It is reliably found in garden-path sentences at the point of disambiguation - the point where it becomes clear that the incorrect syntactic structure has been predicted or formed.

Typically, the P600 has a centro-parietal distribution. However, P600 effects with a broad frontal distribution have also been observed. Some researchers have argued the posterior P600 and the frontal P600 index different aspects of syntactic processing. Kaan and Swaab (2003) suggest that while the posterior P600 is an indication of syntactic revision processes the frontal P600 is a measure of ambiguity resolution or possibly an increase in discourse processing complexity. Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (2007) found evidence of a frontal positivity to unexpected, but plausible words, in sentences with strongly constraining contexts. Similarly, Coulson and Wu (2005) compared ERPs to probe words that were either related or unrelated to a one sentence joke preceding the probe and found evidence of a frontal positivity to unrelated probe words. The authors suggested this frontal positivity may reflect processes of selective retrieval of information from semantic memory. It is unclear at this time whether the frontal positivities discovered in these various studies reflect the same or distinct linguistic processes.

The P600 has also been elicited in sentences containing thematic violations (Geyer, Holcomb, Kuperberg, & Perlmutter, 2006; Kuperberg, 2007; Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003). For example, Kuperberg et al. (2003) presented participants with sentences like:

12. Every morning at breakfast the boys would only eat toast and jam.

13. Every morning at breakfast the eggs would only eat toast and jam.

In both cases the verb *eat* assigns the thematic role of Agent to the NP in the subject role. In (12) the NP, *the boys*, is animate and a proper subject for the verb *eat*, and thus no thematic role violation occurs. However, (13) contains an inanimate subject NP, *the eggs,* that is not a proper subject for the verb and thus is a thematic role violation. These violations elicited a significant posterior P600 effect at the critical verb, which was thought to result from a mismatch between the expected thematic role of Theme that is typically associated with an inanimate NP like *the eggs,* and the role of Agent that was actually assigned to *the eggs* by the verb *eat.* This P600 effect reflects the reanalysis or repair of the structure being built online that was triggered when the verb was encountered. More specifically, Kuperberg and colleagues attributed their findings to the presence of semantic associations between the verbs and their arguments.

ERP Garden-Path Effects – N400-P600 Complex

In ERP studies of garden-path sentences a biphasic N400-P600 complex is often found at the disambiguating word in the sentence because garden-path effects can interfere with both lexical-semantic and syntactic integration. Several studies have found that a mismatch between prosody and syntax can lead to a prosody-driven garden path effect, which is reflected by N400-P600 (Bögels et al., 2010; Pauker et al., 2011; Steinhauer et al., 1999). For example, Steinhauer et al., 1999 discovered an N400-P600 complex at the disambiguation point in prosody-driven garden path sentences. The N400 component claimed to reflect lexical re-access, which was necessary due to the violation of verb argument structure. The P600 was claimed to reflect structural revisions. Pauker et al. (2011) also found evidence of an N400-P600 complex in prosody-driven garden path sentences. Specifically, the results revealed that incongruent prosodic cues, including either the absence of a prosodic boundary or the insertion of an incongruent boundary, resulted in a larger N400-P600 complex relative to sentences containing congruent prosodic cues. However, sentences missing prosodic boundaries were easier to process (as indicated by smaller N400-P600 effects and a higher participant acceptability rating) relative to those with incongruent boundaries. They concluded that while listeners may prefer the simpler LC over an EC structure, this preference is quickly overridden when prosodic information leads the listener to another conclusion.

Conversely, several studies have reported finding an N400 but no P600 at the disambiguation point (Bögels et al., 2010; Friederici, von Cramon, & Kotz, 2007). This pattern of results was argued to depend upon whether the specific tasks performed by participants resulted in syntactic revision processes (indicated by the presence of a P600) or not (indicated by only an N400). Given these multiple distinct waveforms, ERPs allow researchers to measure sentence processing as a function of the presence of a prosodic boundary, semantic interference, and syntactic interference while the sentence is being processed. These various measures offer a distinct advantage over self-paced listening and reading studies, where it is difficult to determine whether performance is due to the presence of a prosodic boundary, a semantic violation, or a syntactic violation. Yet, no studies to date of which we are aware have used ERPs to examine the interaction between thematic fit plausibility cues and prosodic cues on the processing of garden-path sentences.

4.1.1 Current Study

The current experiment seeks to understand the role of prosodic and lexical-semantic (thematic fit) cues during the processing of garden-path sentences using event-related brain potentials. Consider the sentences in Table 4-1.

Table 4-1. Example Experimental Sentences

Sentence	Prosody (Pr)	Plausibility / Thematic Fit (TF)	Condition
14a. **[**While the band played**]** **[**the song pleased all the customers.**]**	Congruent (+)	Plausible (+)	*Pr+TF+*
14b. **[**While the band played**]** **[**the beer pleased all the customers.**]**	Congruent (+)	Implausible (-)	*Pr+TF-*
14c. **[**While the band played the song**]** **[**pleased all the customers.**]**	Incongruent (-)	Plausible (+)	*Pr-TF+*
14d. **[**While the band played the beer**]** **[**pleased all the customers.**]**	Incongruent (-)	Implausible (-)	*Pr-TF-*

Each sentence contains a temporary syntactic ambiguity because the first verb in each sentence (*played*) is optionally transitive, thus it has the option of taking a direct object or not. Thematic fit was manipulated such that the NP following the optionally transitive verb was either a plausible (14a, 14c) or implausible (14b, 14d) direct object. Prosody was also manipulated to either be congruent or incongruent with the syntactic structure. These manipulations yielded a 2 (Sentence Type: plausible thematic fit, implausible thematic fit) x 2 (Prosody: congruent, incongruent) design as shown in Table 4-1.

Predictions of Current Study

4.1.1.1 Predictions at the Prosodic Break

CPS components were investigated in this study by comparing the point of the prosodic break in one condition to the same point in the counterpart condition that did not contain a prosodic break. Based on previous research we predicted that participants would perceive the prosodic break in each condition, as evinced by a CPS component.

Predictions at Ambiguous NP

First, we predicted that processing the NP *the beer* in condition *Pr-TF-* (14d) would result in semantic integration difficulty, while processing the NP *the song* in condition *Pr-TF+* (14c) would not, given that latter is a 'good' direct object/Theme for the verb *played* while the former is not. Thus, we predicted an N400 effect when comparing the waveforms time locked to *the beer* versus *the song.* This pattern would suggest that listeners initially attempted to parse the structurally ambiguous NP as the direct object of the verb *played* as they did not consider the NP *the beer* to be a good thematic fit with *played*. If we do not find differences in these ERP conditions, then this pattern would suggest that listeners did not immediately attempt to parse the ambiguous NP as the direct object of *played* and that they were not sensitive to the plausibility manipulation.

We also predicted that poor thematic fit between the subordinate verb *played* and the potential direct object *the beer,* would signal the parser that syntactic reanalysis was required at the ambiguous NP, *the beer* - before the disambiguation point at the critical verb *pleased* was reached. Thus, we predicted we would find a P600 at the ambiguous NP *the beer* in condition *Pr-TF-* (14d) compared to the ambiguous NP *the song* in condition *Pr-TF+* (14c). Specifically, we predicted we would find a P600 at the ambiguous NP in *Pr-TF-* (14d), but not until the critical verb *pleased* in condition *Pr-TF+* (14c). The P600 was evaluated using difference waves to avoid any potential differential effects due to clause position.

Predictions at Critical Verb (Point of Disambiguation)

We examined prosodic garden-path effects due to congruent/incongruent prosody as indicated by the N400-P600 complex at the point of disambiguation (*pleased*) across all four conditions. The presence of an N400-P600 complex in the conditions with incongruent [*Pr-TF+* (14c) and *Pr-TF-* (14d)] relative to congruent prosody [*Pr+TF+* (14a) and *Pr+TF-* (14b)] would indicate that incongruent prosody yielded a garden-path effect. Recall that the plausible NP, *the song,* does not contain a plausibility cue to help predict structure, while the implausible NP, *the beer,* does contain a plausibility cue. Any differences in the N400-P600 complex between the condition with incongruent prosody and a plausible NP, *Pr-TF+* (14c), and the condition with incongruent prosody and an implausible NP, *Pr-TF-* (14d), would indicate that plausibility information immediately interacts with syntactic structure building.

We expected to find a classic garden path effect as indicated by the presence of the N400-P600 complex in the comparison between conditions with a plausible NP [*Pr+TF+* (14a) compared to the *Pr-TF+* (14c)]. However, because we expected to find a P600 at the ambiguous NP, *beer*, in *Pr-TF-* (14d), we did not anticipate finding an N400-P600 complex in the comparison between conditions with an implausible NP [*Pr+TF-* (14c) compared to *Pr-TF-* (14d)].

4.2. Materials and Methods

Participants

We tested 25 college-age students (19 females, mean age = 21 years) who were right-handed monolingual speakers of American English. As indicated by self-report, all participants had normal or corrected-to-normal visual and auditory acuity, and were neurologically and physically stable at the time of testing with no history of psychiatric illness, drug or alcohol abuse, or other significant brain disorder or dysfunction.

Materials

Sentences (14a-14b) were recorded using naturally produced early closure prosody. The following prosodic control sentences were recorded using naturally produced late closure prosody:

14e. [While the band played the song] [the beer pleased all the customers.]

14f. [While the band played the beer] [the song pleased all the customers.]

Sentences (14c-14d) were formed using a waveform editor (Adobe Audition) to cut the initial portions of (14e-14f) up to the ambiguous NP (*the song/the beer*) and spliced to replace the same portion in (14a-14b). Sentences (14e-14f) served as prosodic controls in this experiment. These manipulations allowed us to determine whether prosody can bias listeners toward a specific parse even when the lexical cues (whether the NP is a plausible or implausible direct object) conflict with the argument structure of the verb. NPs were counterbalanced across the different verbs used in our materials. Sixty of each type of sentence (14a-14f) were created yielding a total of 360 sentences. All sentences were recorded at a regular rate of speech (4-6 syllables/second) in a soundproofed environment.

Procedure

The participants were fitted with an electrode cap and were presented with sentences over headphones while sitting in a comfortable chair in a dimly lit sound-attenuated room. Simultaneous with the onset of each word in a sentence, a code specifying the condition of the word was sent to the computer digitizing the EEG data. This allowed for precise time-locking of the EEG with word onset across the various conditions. For each trial the start of the sentence was accompanied by a fixation cross in the center of the screen, which disappeared 1000ms post-sentence offset and was replaced by a question mark signaling the participant to make an acceptability judgment about the sentence they just heard by button press (Figure 4-1). Once the response was made the experiment advanced to the next trial. Participants were presented with all 360 sentences in one data collection session. Before the experiment began, each participant was presented with a block of 10 practice items to familiarize them with the procedure.

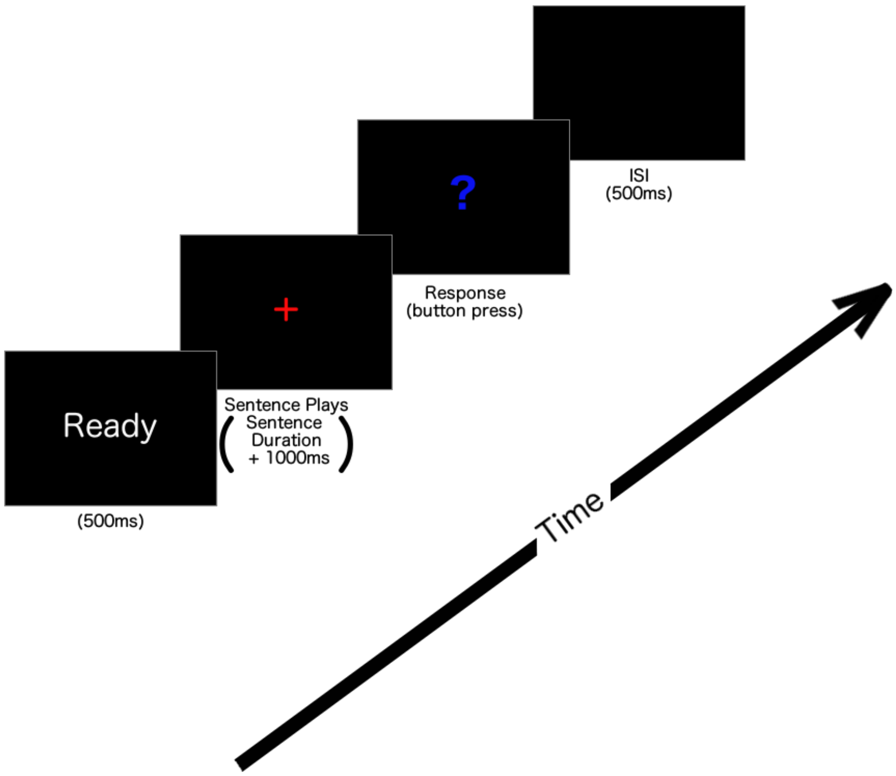


Figure 4-1. Schematic of one trial. Participants were presented with the word "Ready" in the center of the screen to signal the beginning of a new trial. Next, a red cross was presented in the center of the screen, which corresponded with the sentence playing. The red cross remained on the screen throughout the sentence duration up to 1000ms after the sentence ended. A blue question mark was presented to signal that the participant could make their acceptability response by button press. The question mark disappeared once a response was selected.

Behavioral Data Analysis

The percentage of accepted sentences in each condition were computed from the subject acceptability ratings. Next, the accuracy of responses was defined and compared across conditions using a subject-based repeated measures

ANOVA with the factors Prosody (Congruent, Incongruent) and Plausibility/Thematic Fit (Plausible, Implausible). An "Acceptable" rating was considered an accurate response for conditions *Pr+TF+* and *Pr+TF-*, and an "Unacceptable" rating was an accurate response for conditions *Pr-TF+* and *Pr-TF-*.

EEG Recording Procedure

The electroencephalogram (EEG) was recorded from 29 active tin electrodes at the scalp (Electrode-Cap International). Additional electrodes were attached below the left eye (LE, used to monitor blinks), to the side of the right eye (HE, to monitor horizontal eye movements), over the right mastoid bone, and the left mastoid bone (A1, reference electrode). The eye electrode impedances were maintained below 10 kΩ, with the remaining electrode impedances maintained below 5 kΩ. The EEG signal was amplified by a Neuroscan Synamp RT system using Curry data acquisition software. Recording bandpass was DC to 200 Hz and the EEG was continuously sampled at a rate of 500 Hz throughout the duration of the experiment. ERPs were averaged from artifact free trials time-locked to critical target word onset with a 1200ms epoch.

ERP Data Analysis

ERPs were time-locked to critical points in each sentence (details will be provided in the Results section). All EEG trials with eye-blinks, eye-artifacts, and muscle movement artifacts were rejected from analysis (3.93% of trials on average). Participants with rejection rates above 20% were rejected. We excluded one participant's data for exceeding this rejection rate. Our ERPs were averaged from the trials remaining after artifact rejection and were bandpass filtered at .03-15 Hz. A subset of 12 of the 29 scalp sites (Figure 4-2) were selected to be included in data analyses. Average waveforms were produced for the two levels of Prosody (Congruent vs. Incongruent), two levels of Plausibility (Plausible vs. Implausible), three levels of Laterality (left, midline, right), and four levels of Anteriority (frontal, central, parietal, occipital). Mean voltages were calculated in several time windows (see details in Results section) and were analyzed using separate repeated measures analyses of variance (ANOVAs). The Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom in the numerator in order to address violations of sphericity.

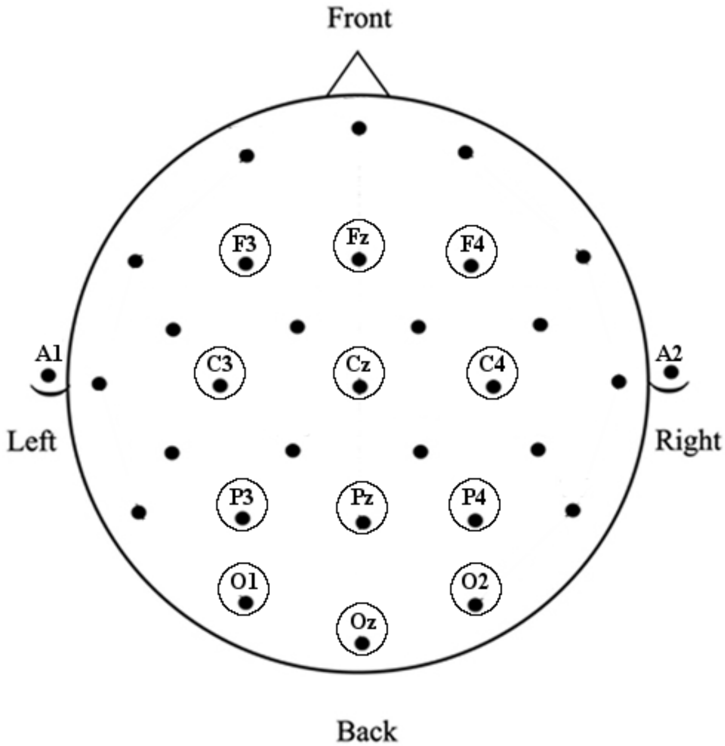


Figure 4-2. The circled electrodes indicate the 12 electrodes used in data analyses.

4.3. Results

4.3.1 Acoustic Measurements

To confirm that each condition's prosody varied as expected in their acoustic properties, we conducted word duration and pitch analyses. We anticipated significantly longer durations at the clause final word relative to its non-clause final counterpart (e.g., we expected *played* to be longer in *Pr+TF+* where it is the clause final word, than in its counterpart sentence, *Pr-TF+*, where it is not the clause final word). Thus, we expected *played* to be longer in *Pr+TF+* (14a) and *Pr+TF-* (14b) where it is the clause final word, compared to *played* in *Pr-TF+* (14c) and *Pr-TF-* (14d) where it is in a clause medial position. We also anticipated the ambiguous NP, *the song/beer,* to be longer in *Pr-TF+* (14c) and *Pr-TF-* (14d) where *song/beer* is in a clause final position relative to *Pr+TF+* (14a) and *Pr+TF-* (14b) where the ambiguous NP is clause medial. Moreover, we expected to find a significantly longer pause after the verb in the conditions with congruent prosody [*Pr+TF+* (14a)*, Pr+TF-* (14b)] compared to those with incongruent prosody. Similarly, we predicted the pause after the ambiguous NP would be longer in the conditions with incongruent prosody [*Pr-TF+* (14c)*, Pr-TF-* (14d)] compared to those with congruent prosody [*Pr+TF+* (14a), *Pr+TF-* (14b)]. The data were subjected to a 2 x 2 ANOVA with Prosody (Congruent, Incongruent) and Plausibility/Thematic Fit (Plausible, Implausible) as factors.

We also conducted pitch analyses and anticipated significantly lower minimum $F_{ø}$ measures at the clause final word compared to the same word in the counterpart sentence at a different position in the clause. These expectations were based on pitch analyses from similar experiments (Kjelgaard & Speer, 1999). Therefore, we expected *played* to have a lower minimum $F_{ø}$ in *Pr+TF+* (14a) where it is the clause final word compared to its counterpart sentence, *Pr-TF+* (14c)*,* where *played* is in a clause medial position. Similarly, we expected the ambiguous NP *the song/beer* to have a significantly lower minimum $F_{ø}$ in *Pr-TF+* (14c) and *Pr-TF-* (14d) where it is the clause final word, compared to *Pr+TF+* (14a) and *Pr+TF-* (14b) where it is in a clause initial position (the beginning of the main clause). We did not expect to find differences at the critical verb. We compared minimum $F_{ø}$ measures at the first verb (*played*), the ambiguous NP (*song/beer*), and the critical verb. The data were analyzed with a 2 x 2 ANOVA with the factors Prosody (Congruent, Incongruent) and Plausibility/Thematic Fit (Plausible, Implausible).

The results revealed in Table 2 corresponded with our predictions. We found evidence of significant pre-boundary lengthening of the first verb followed by a pause in conditions with congruent prosody relative to those with incongruent prosody, as indicated by a main effect of prosody at the subordinate verb (*played*) (F (1, 239) = 138.2, $p < .001$) and Pause 1 (F (1, 239) = 1151.4, $p < .001$). Similarly our results revealed significant pre-boundary lengthening of the ambiguous NP (F (1, 239) = 116.3, $p <.001$) followed by a pause (F (1, 239) = 1776.3, $p <.001$) in conditions with incongruent prosody relative to those with congruent prosody, as signified by a main effect of prosody at both points in the sentence. The duration of the critical verb did not differ significantly between conditions.

Table 4-2. Mean Duration Measurements for Each Condition

	Mean Durations (ms)				
	Verb 1 (*played*)	Pause 1	Ambiguous NP (*song/beer*)	Pause 2	Critical Verb (*pleased*)
Congruent Prosody					
Plausible NP (*Pr+TF+*)	521.8 (10.6)	206.0 (8.9)	475.9 (11.98)	1.0 (.6)	384.1 (15.6)
Implausible NP (*Pr+TF-*)	515.4 (12.1)	223.4 (8.7)	478.9 (13.9)	1.2 (.8)	384.2 (15.1)
Incongruent Prosody					
Plausible NP (*Pr-TF+*)	357.6 (12.7)	1.9 (.7)	604.8 (13.1)	294.0 (10.2)	369.8 (15.8)
Implausible NP (*Pr-TF-*)	391.4 (13.4)	1.7 (1.2)	651.9 (16.6)	153.4 (10.6)	373.1 (16.1)

** Parentheses contain standard error values.*

Furthermore, our pitch analyses revealed support for our predictions since we discovered evidence of pitch differences at the clause final word as determined by prosody (See Table 3). Specifically, the mean minimum $F_{ø}$ at Verb 1 was significantly lower in conditions with congruent prosody relative to those with incongruent prosody (F (1, 239) = 14.9, p <.001). The mean minimum $F_{ø}$ at the Ambiguous NP was significantly lower in conditions with incongruent relative to congruent prosody (F (1, 239) = 156.8, p <.001). No significant differences were found at the critical verb.

Table 4-3. Mean Minimum $F_{ø}$ Measurements for Each Condition

	Mean Minimum $F_{ø}$ (Hz)		
	Verb 1 (*played*)	Ambiguous NP (*song/beer*)	Critical Verb (*pleased*)
Congruent Prosody			
Plausible NP (*Pr+TF+*)	161.0 (4.5)	202.9 (4.3)	170.2 (2.9)
Implausible NP (*Pr+TF-*)	160.3 (5.0)	189.9 (5.5)	166.7 (3.7)
Incongruent Prosody			
Plausible NP (*Pr-TF+*)	214.3 (3.3)	146.3 (3.0)	171.6 (2.9)
Implausible NP (*Pr-TF-*)	214.3 (4.5)	144.7 (2.8)	170.0 (3.9)

** Parentheses contain standard error values.*

4.3.2 Behavioral Results

Recall that we examined the accuracy of responses in each condition, where "Acceptable" was the correct response for conditions *Pr+TF+* and *Pr+TF-*, and "Unacceptable" was the correct response for conditions *Pr-TF-* and *Pr-TF-*. Both conditions with congruent prosody had similar acceptance ratings. Condition *Pr+TF+* had an acceptance rating of 84% and condition *Pr+TF-* had an acceptance rating of 85%, while both conditions *Pr-TF+* and *Pr-TF-*, with incongruent prosody, had very low acceptability ratings (13% and 10% respectively). These results demonstrate that our prosodic manipulation was successful. These analyses show that participants were relatively accurate at identifying each condition as acceptable or not. No significant differences were found in accuracy between conditions as our analyses did not reveal any significant main effects or interactions (all *F < 1.3).* Thus, the participants were able to identify the acceptability of each condition equally well.

4.3.3 ERP Results

Onset of the Prosodic Break in Conditions with Congruent Prosody– CPS Effects

Recall that we predicted finding a CPS effect at the prosodic break and in conditions with congruent prosody this corresponds with the offset of the subordinate verb, *played*. Waveforms were time locked to the offset of *played* using a 100ms pre-stimulus baseline to investigate for CPS effects in the 0-600ms epoch in conditions with congruent prosody (*Pr+TF+*, *Pr+TF-*) relative to those with incongruent prosody (*Pr-TF+*, *Pr-TF-*). Waveforms were compared using a subject-based repeated measures ANOVA with two levels of Prosody (Congruent vs. Incongruent), three levels of Laterality (left, middle right), and four levels of Anteriority (frontal, central, parietal, occipital). A main effect of Prosody (F (1, 24) = 46.15, p < .001) as well as significant interactions of Prosody x Anteriority (F (3, 72) = 11.26, p < .001) and Prosody x Anteriority x Laterality (F (6, 144) = 9.57, p < .001) revealed that waveforms in conditions with congruent prosody were significantly more positive-going than those with incongruent prosody. This difference was largest at right-hemisphere central and parietal electrodes. These results indicate that participants were sensitive to the prosodic break in our materials.

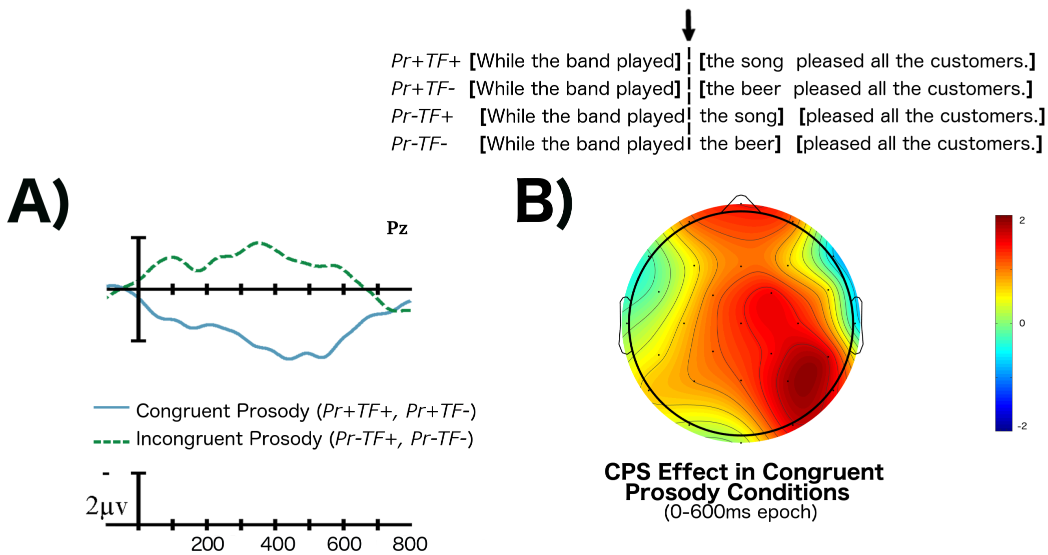


Figure 4-3. CPS effects in the 0-600ms epoch. Corresponding to the prosodic break at the offset of the subordinate verb, *played*, in conditions with congruent prosody (*Pr+TF+* and *Pr+TF-*) relative to those with incongruent prosody (*Pr-TF+* and *Pr-TF-*). Conditions with incongruent prosody do not have a prosodic break at this point. A) Waveforms showing significant CPS effect in conditions with congruent prosody B) Voltage map showing the difference between conditions with congruent and incongruent prosody, revealing that the CPS effect is largest at right-hemisphere central and parietal electrodes.

Onset of Temporarily Ambiguous NP (song/beer)

In order to determine whether participants were sensitive to the plausibility manipulation we examined N400 effects in the 200-500ms epoch in *Pr-TF+* vs. *Pr-TF-* (plausible vs. implausible NP) at the onset of the temporarily ambiguous NP (*song* vs. *beer*). We predicted a significant N400 effect in *Pr-TF-* relative to *Pr-TF+*. We found a main effect of Plausibility (F (1, 24) = 4.89, p =.037) where waveforms in *Pr-TF-* were more negative-going than those in *Pr-*

TF+. This result provides evidence that participants were sensitive to the plausibility manipulation.

Difference Wave Comparison [(Pr-TF+) – (Pr+TF+) vs. (Pr-TF-) – (Pr+TF-)]) at Offset of the Ambiguous NP (song/beer)

Recall that *the beer* in conditions *Pr+TF-* and *Pr-TF-* is a poor thematic fit for the subordinate verb *played* so likely will not serve as the direct object We hypothesized this plausibility information would result in a P600 at the offset of the ambiguous NP in the *Pr-TF-* condition, due to the plausibility cues in the ambiguous NP *beer*. A P600 at this point in the sentence would indicate that the plausibility information is immediatley interacting with structure building. We used difference waves for this analysis in order to equate for differences in clause position. We examined the 500-1000ms epoch for P600 effects and found a main effect of Plausibility (F (1, 24) = 6.57, p =.017) indicating the difference wave with an implausible NP, *beer*, ([*Pr-TF-*] - [*Pr+TF-*]) was significantly more positive-going across the scalp than the difference wave with a plausible NP, *song,* ([*Pr-TF+*] – [*Pr+TF+*]) (See Figure 4-4).

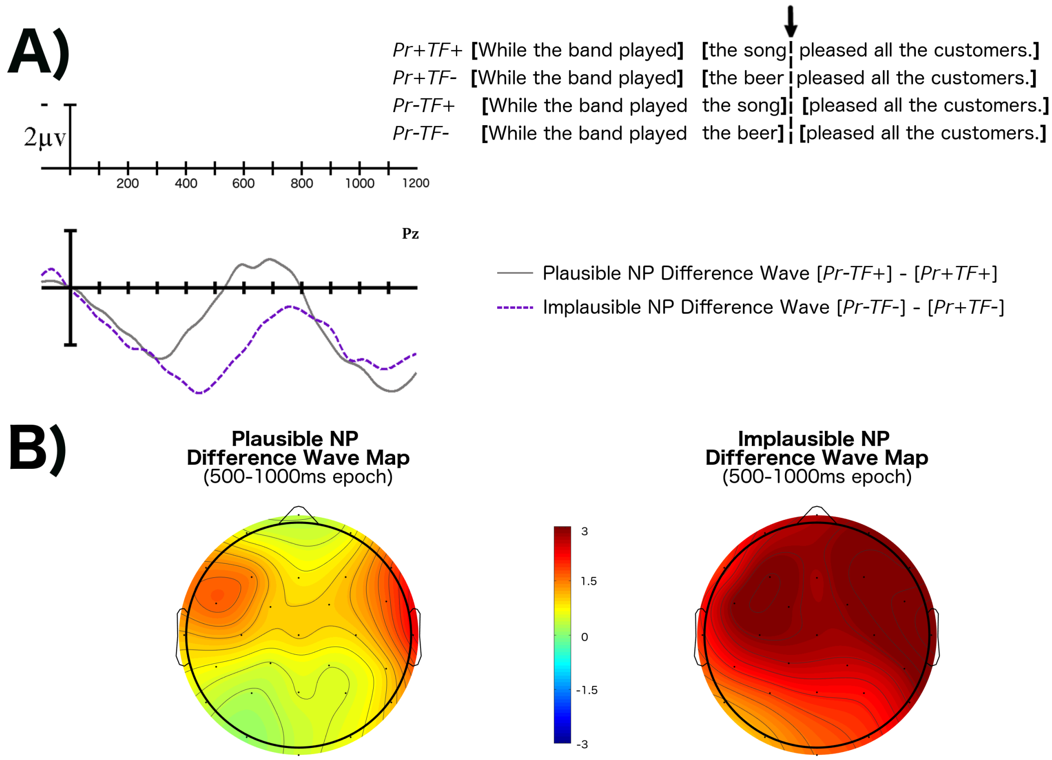


Figure 4-4. Comparison of difference waves in conditions with plausible NPs [(Pr-TF+) – (Pr+TF+)] and implausible NPs [(Pr-TF-) – (Pr+TF-)] timelocked to the offset of the ambiguous NP, which corresponds to the pause in conditions with incongruent prosody. A) Comparison of plausible NP and implausible NP difference waves showing evidence of a P600 effect in the 500-1000ms epoch in implausible NP difference wave. B) Voltage maps of 500-1000ms epoch showing the distribution of the difference waves across the scalp. The voltage map of the Implausible NP difference wave demonstrates a P600 with a wide distribution across the scalp, particularly at frontal sites.

Prosodic Garden-Path Effects at Critical Verb (pleased):

Garden-path effects driven by incongruent prosody were examined by comparing waveforms time-locked to the second verb (*pleased*), which was the disambiguation point in all four experimental conditions. N400 effects were examined in the 200-500ms time window and P600 effects in the 500-1000ms time window. A 200ms post-stimulus baseline interval was used to compensate for the large positivity in condition *Pr-TF-,* described in the section above, that immediately preceded the critical verb. If we used a pre-stimulus baseline, comparisons became difficult because the positivity at the ambiguous NP *beer* in *Pr-TF-* pulled down the effect.[2]

[2] We also conducted analyses with a traditional 100ms pre-stimulus baseline and the results did not fundamentally differ from the effects reported here.

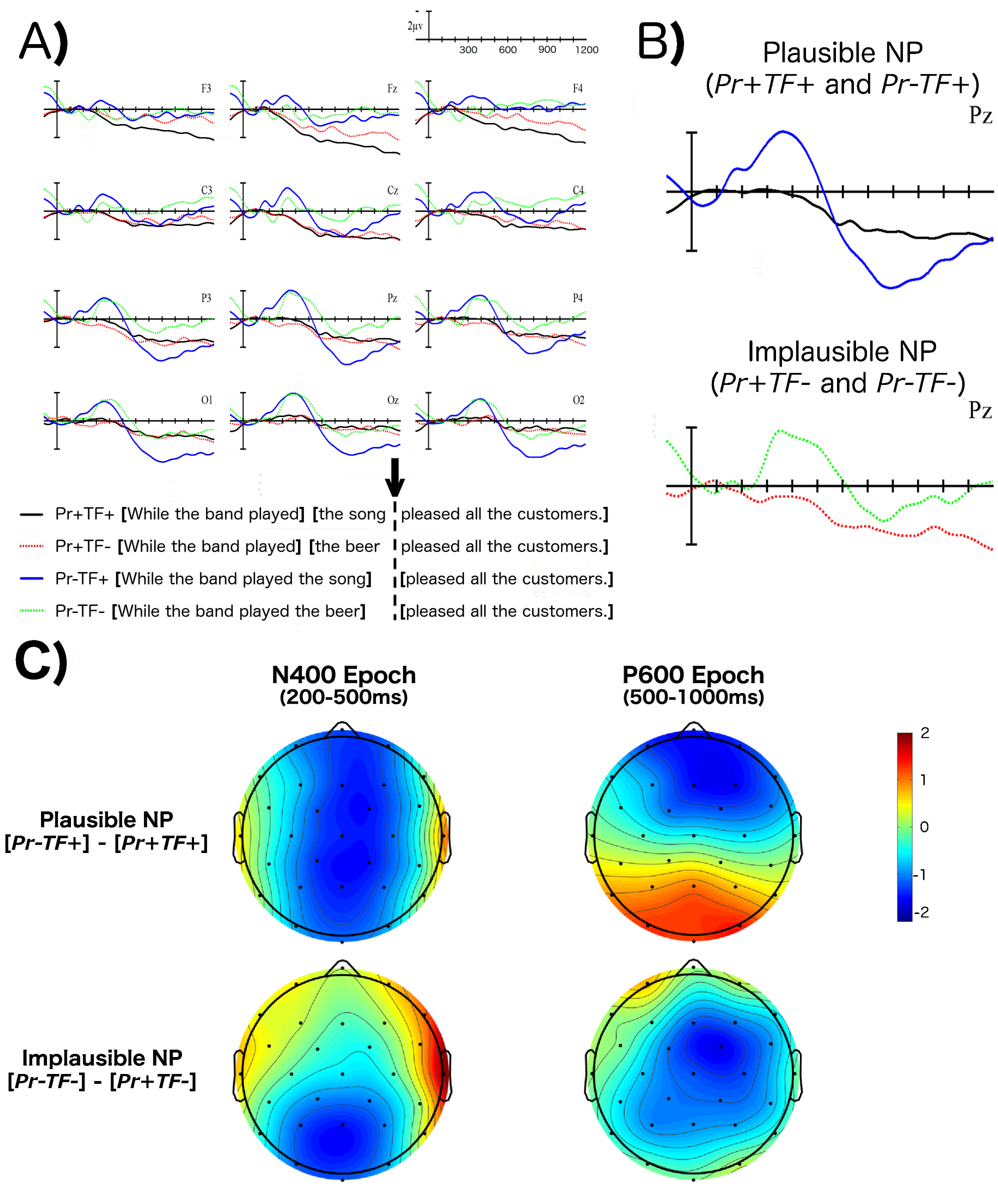


Figure 4-5. ERPs time locked to the critical verb (*"pleased*") in all conditions. **A)** Grand-average ERPs of all conditions time locked to the critical verb (*"pleased"*) illustrating prosodic garden path effects in conditions *Pr-TF+* and *PR-TF-*. **B)** Grand-average ERPs at Pz site comparing conditions *Pr+TF+* and *Pr-TF+* (both with a plausible NP) to one another, and conditions *PR+TF-* and *Pr-TF-* (with implausible NP) to one another. Demonstrates the P600 effect in the comparison containing a plausible NP (*Pr+TF+* vs. *Pr-TF+*) but not in the comparison with an implausible NP (*PR+TF- vs. Pr-TF-*). **C)** Voltage maps of the N400 and P600 epochs shows the presence of an N400 and a P600 effect in conditions with a plausible NP ([*Pr-TF+*] – [*Pr+TF+*]) and an N400 but no P600 effect in the comparison with an implausible NP implausible NP ([*Pr-TF-*] – [*Pr+TF-*]).

N400 Effects at Critical Verb (pleased)

Visual inspection of the waveforms in Figure 4-5 show that both conditions with congruent prosody (*Pr+TF+* and *Pr+TF-*) patterned together throughout the epoch, and both conditions with incongruent prosody (*Pr-TF+* and *Pr-TF-*) were more negative-going in the N400 time window than the congruent prosody counterparts. Our analyses revealed at the point of disambiguation (*pleased*) there was a main effect of Prosody (F (1, 24) = 12.3, p =0.002) and a Prosody x Laterality F (2, 48) = 6.98, p =0.006 interaction. These results indicated that conditions with incongruent prosody (*Pr-TF+* and *Pr-TF-*) were more negative-going than those with congruent prosody (*Pr+TF+* and *Pr+TF-*) in the N400 epoch, particularly at central and right-hemisphere sites. Additionally, there was an interaction between prosodic and plausibility effects that differed as a function of anteriority (Prosody x Plausibility x Anteriority interaction (F (3, 72) = 7.1, p = .007)). This pattern reflected more negative-going waveforms in conditions with plausible NPs (*Pr+TF+* and *Pr-TF+*) particularly at anterior sites. This pattern appeared to be driven primarily by the negative-going waveform in condition *Pr-TF+*.

P600 Effects at Critical Verb (pleased)

Inspection of the P600 epoch in Figure 4-5 shows that incongruent prosody resulted in a P600 effect at the critical verb, and this effect appeared to be modulated by the plausibility of the ambiguous NP. Specifically, the P600 in condition *Pr-TF+* (plausible NP) appears to be more positive-going than the waveform in condition *Pr-TF-* (plausible NP). These findings were supported by our analyses. First, there was a significant main effect of Plausibility (F (1, 24) = 4.62, p = .042); conditions with plausible NPs (*Pr+TF+*, *Pr-TF+*) are more positive-going than those with an implausible NP (*Pr+TF-*, *Pr-TF-*). There was also a three-way interaction of Prosody x Plausibility x Anteriority (F (3, 72) = 5.08, p = .026), where items with correct prosody (*Pr+F+*, *Pr+TF-*) patterned similarly to each other, and items with incorrect prosody (*Pr-TF+*, *Pr-TF-*) were more positive-going particularly at parieto-occipital sites. However, the items with incorrect prosody and a plausible NP (*Pr-TF+*) were more positive-going than items with incorrect prosody and an implausible NP (*Pr-TF-*). There was also a Prosody x Anteriority (F (3,72) = 18.19, p =0.001), and a Prosody x Anteriority x Laterality (F (6,144) = 7.73, p < 0.001) interaction. These interactions reflect more positive-going waveforms in conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) particularly at left-lateralized posterior sites.

Pairwise comparisons of the two conditions containing a plausible NP (*Pr+TF+* and *Pr-TF+*) reveal an interaction of Prosody x Anteriority (F (3, 72) = 19.88, p < .001) and an interaction of Prosody x Anteriority x Laterality (F (6, 144) = 3.75, p =.012) representing a significantly more positive-going waveform in *Pr-TF+* than in *Pr+TF+* at left-hemisphere and midline, parieto-occipital sites. Pairwise comparisons of the two conditions containing an implausible NP (*Pr+TF-* and *Pr-TF-*) revealed a significant Prosody x Anteriority x Laterality interaction (F (6, 144) = 6.3, p < .001) reflecting that waveforms in *Pr+TF-* were more positive-going than those in *Pr-TF-* except at occipital midline and right-hemisphere sites. These pairwise comparisons provide evidence of a significant P600 effect in sentences with incongruent prosody and a plausible NP (*Pr-TF+*) but not in sentences with incongruent prosody and an implausible NP (*Pr-TF-*).

4.4 Discussion

We argue that our results support an account of sentence processing where prosodic and plausibility cues interact with each other and immediately impact structure-building processes. First, we discuss the implications of our ERP results across different points in the sentence (i.e.*,* at the onset of the prosodic break, at the onset and offset of the temporarily ambiguous NP, and at the critical verb). Finally, we examine how these results relate to one another and what directions future research should take.

Discussion of ERP Results at Prosodic Break – CPS Effects

CPS effects were present at the onset of the prosodic break in each of the four conditions. This confirms that participants were sensitive to the prosodic manipulation in this experiment.

ERP Results at Ambiguous NP Onset – N400 Effect

Waveforms were compared at the onset of the ambiguous NPs in conditions with incongruent prosody (*Pr-TF+* and *Pr-TF-*):

15. [While the band played the song] [pleased all the (*Pr-TF+*)

customers.]

16. [While the band played the beer] [pleased all the customers.] (*Pr-TF-*)

We predicted a significant N400 effect at the onset of the implausible NP *beer* (16) relative to the plausible NP *song* (15), thus signifying semantic processing difficulty at *beer* but not *song***.** Our results confirmed our predictions as a significant N400 effect was found at *beer.* These results demonstrate that participants were sensitive to the plausibility/thematic fit manipulation, independent of any potential prosody effect.

Discussion of ERP Results at Ambiguous NP Offset – P600 Effect

Recall that even though the prosodic contour in (16) would likely bias a listener toward a late closure interpretation, we expected participants would be less likely to be garden-pathed in (16) compared to (15), because *the beer* in (16) is an implausible direct object for the verb. Specifically, we expected participants would engage in an early syntactic reanalysis at *the beer,* before hearing the disambiguating verb *pleased.* In contrast, we did not anticipate finding evidence of a P600 effect in (15), with the plausible ambiguous NP *the song*, until hearing *pleased.* The offset of the ambiguous NP in (15) and (16) (*Pr-TF+* and *Pr-TF-*) corresponded with the prosodic break, hence we used a difference wave analysis to isolate CPS from P600 effects (See results section 3.3.2.1). Our predictions were confirmed as we discovered evidence of a P600 effect at *the beer* in (16)

(*Pr-TF-*) but not *at the song* in (15) (*Pr-TF+*). This P600 effect was noted to have a broad distribution across the scalp, including frontal sites.

The P600 effect found at the ambiguous NP in the implausible NP difference wave [(*Pr-TF-*) – (*Pr+TF-*)] but not the plausible NP difference wave [(*Pr-TF+*) – (*Pr+TF+*)] indicates that prosodic and lexical-semantic cues interact throughout sentence processing. The combination of incongruent prosodic contour and the plausibility/thematic fit cue at *the beer* in the *Pr-TF-* condition (16) resulted in a P600 effect before the disambiguation point (*pleased*). This P600 effect could be interpreted in several different ways. One possibility is that this P600 reflects syntactic reanalysis of the sentence to resolve the garden-path effect prior to hearing the critical verb *pleased.* Another possibility is this is a similar P600 effect to the one found by Kuperberg and colleagues (Geyer et al., 2006; Kuperberg, 2007; Kuperberg et al., 2003) and it reflects an attempt to reassign thematic roles. In this interpretation, the parser initially attempts to assign the role of Theme to the NP immediately following *played* but because *the beer* lacks the lexical properties that would make it a good Theme for *played* it immediately triggers a reanalysis to assign a new role of Agent for a predicted upcoming main clause. It is important to note that the sentences in the present study have a different syntactic structure from the sentences examined by Kuperberg and colleagues; recall that they compared ERPs to the critical verb (*eat*) in sentences like:

17. Every morning at breakfast the boys would only eat toast and jam.

18. Every morning at breakfast the eggs would only eat toast and jam.

There are several differences between their sentences and the ones used in the current study. In (17) and (18) the parser encounters the NP before the critical verb where the P600 effect was observed. In our study the parser encounters the verb before the temporarily ambiguous NP *beer* where we found the P600 effect. Also, once the parser encounters *eat* in (17) and (18) (where the P600 effect occurred) it is not possible for the upcoming context to result in a plausible sentence. However, in our study the P600 effect occurs at *beer* and it is still possible at this point in the sentence that another verb will be encountered where *beer* can serve as a plausible argument. Also, recall that an important factor that distinguishes the thematic P600 discovered by Kuperberg and colleagues is that it is only elicited in situations where there is a semantic association between the verb and its argument (i.e., *eggs* is semantically associated with *eat*). In our study the initial verb *played* is not necessarily semantically related to the temporarily ambiguous NP *beer*; however other context cues available in the initial portion of the sentence could possibly provide a semantic association between *played* and *beer.* For example, when the listener hears "While the band played the beer" it is likely that beer would be associated with a place where a band is playing.

Yet another important distinction between the thematic P600 reported by Kuperberg and colleagues and the one we found in the present study is the difference in distribution across the scalp. The thematic P600 had a posterior distribution while the P600 here was broadly distributed across the scalp including at frontal sites. Recall that several studies have reported a broadly distributed frontal P600 (Kaan & Swaab, 2003, Federmeier et al., 2007, Coulson & Wu, 2005). Both Federmeier et al. (2007) and Coulson and Wu (2005) reported a frontal positivity to words that were semantically unrelated based on contextual information. For example, Federmeier et al. presented subjects with strongly constraining sentences like:

19. The children went outside to play.

20. The children went outside to look.

In (19) the final word, *play,* has a higher cloze probability than the final word *look* (20). They discovered an anterior positivity to the final word in (20) relative to (19). This positivity was interpreted as possibly reflecting the need to suppress a strong expectation for a different word. Note that while *look* is an unexpected ending it is a plausible ending for (20). Therefore, it cannot be directly compared to our results where we discovered a frontal positivity at the implausible word *beer* in *Pr-TF-* . Consider again:

21. **[**While the band played the beer**]** **[**pleased all the customers.**]** (*Pr-TF-*)

Because *beer* is a poor thematic fit for *played*, the parser would be expecting a direct object with very different lexical properties. Thus, it is possible that the frontal positivity discovered in this study at *beer* in *Pr-TF-* reflects a similar process to the one described by Federmeier et al. of having to override a strong prediction for a different word. In future work it will be important to explore the specific properties that elicit and modulate a thematic P600 in sentences similar to (21) where the verb and arguments are not necessarily semantically related, but the sentence provides context cues that support a possible semantic association between them.

In light of these considerations, it is unclear whether the P600 found at the implausible ambiguous NP (*the beer*) in (21) in our study is similar to the thematic violation P600 described by Kuperberg and colleagues. Alternatively it could be more similar to a traditional P600 effect found at the critical verb in garden path sentences, or to the frontally distributed P600 described by Federmeier et al. (2007), Coulson and Wu (2005) and others (e.g., Kaan and Swaab (2003)). However, the scalp distribution does indicate that it is more similar to the P600 discovered by Federmeier et al. Regardless, it is apparent that the combination of incongruent prosody and an implausible ambiguous NP immediately impacted sentence processing.

Discussion of ERP Results at Critical Verb Onset – N400-P600 Effects

When comparing our four conditions we anticipated discovering a garden-path effect resulting from incongruent prosody. Consider the four experimental conditions, repeated here:

22. [While the band played] [the song pleased all the customers.] (*Pr*+*TF*+)
23. [While the band played] [the beer pleased all the customers.] (*Pr*+*TF*-)

24. [While the band played the song] [pleased all the customers.] (*Pr-TF+*)

25. [While the band played the beer] [pleased all the customers.] (*Pr-TF-*)

We predicted that the classic garden-path comparison between (22) and its counterpart sentence (24) (both with the plausible NP *the song*) would elicit an N400-P600 effect in (24) relative to (22), due to incongruent prosody in (24). The presence of a biphasic N400-P600 complex in (24) relative to (22) confirmed these predictions.

However, in (25) (*Pr-TF-*) we anticipated that the plausibility cues would result in early syntactic reanalysis at the ambiguous NP *the beer* – before reaching the critical verb. Thus, at the critical verb we did not expect to find an N400-P600 effect when comparing (25) to its counterpart sentence (23). The presence of an N400 effect (without a P600) in (25) relative to (23) bore out these predictions. As previously mentioned, it is possible that the early P600 found in *Pr-TF-* at the ambiguous NP *the beer* (see section 4.3) reflected an early syntactic reanalysis at *beer* so the parser did not need to engage in reanalysis at the critical verb. Our analyses suggested that the N400 effect at the critical verb *pleased* in *Pr-TF-* shared similar characteristics to the N400 found in *Pr-TF+*. Thus, even though the parser engaged in an early syntactic reanalysis in *Pr-TF-* (25) it is likely that the N400 effect reflected some degree of difficulty in integrating *beer* with *pleased* as a result of the incongruent prosody.

Furthermore, the lack of an N400-P600 component in both conditions with congruent prosody [*Pr+TF+* (22) and *Pr+TF-* (23)] confirms that congruent prosody disambiguated sentence structure for the listener in the current study, which conforms with the findings from many studies (Bögels et al., 2010, 2013; Kjelgaard & Speer, 1999; Nagel et al., 1994; Pauker et al., 2011; Schafer et al., 2000; Steinhauer et al., 1999).

4.4.1 Conclusions

To conclude, the present study provides strong evidence that prosodic and lexical-semantic cues interact to influence sentence processing. These results align with Snedeker and Yuan (2008) and DeDe (2010), who also discovered evidence of an interaction between prosodic and plausibility cues. Our study furthers their work through the use of the ERP method, arguably unfettered by the dual-task and self-paced nature of the DeDe method, and allowing for the examination of specific ERP components to differentiate between prosodic, lexical-semantic and syntactic routines. The ERP method allowed us to discover the P600 effect at the ambiguous NP *the beer* containing a plausibility cue (in *Pr-TF-*), confirming that the interaction of prosodic and plausibility cues impacted sentence processing. While, it remains unclear whether this P600 effect reflected syntactic reanalysis, recall that in *Pr-TF-* there was a P600 effect at the ambiguous NP but no P600 effect downstream at the disambiguation point (the critical verb *pleased*). The lack of a P600 effect downstream at the critical verb in the *Pr-TF-* condition suggests that the typical garden-path syntactic reanalysis was not required at the critical verb, thus syntactic structure building processes must have been. The P600 at the ambiguous NP in *Pr-TF-* combined with the discovery of an N400 but no P600 effect at the critical verb *pleased* in *Pr-TF-* suggests that syntactic reanalysis occurred at the ambiguous NP as a result of a mismatch between prosodic and lexical-semantic cues. These findings all converge to provide strong evidence that the parser is immediately influenced by the combination of prosodic and lexical-semantic information when encountering what appear to be temporary syntactic ambiguities.

References

Blodgett, A. R. (2004). *The interaction of prosodic phrasing, verb bias, and plausibility during spoken sentence comprehension.* The Ohio State University.

Bögels, S., Schriefers, H., Vonk, W., Chwilla, D. J., & Kerkhofs, R. (2010). The interplay between prosody and syntax in sentence processing: The case of subject-and object-control verbs. *Journal of Cognitive Neuroscience, 22*(5), 1036-1053.

Bögels, S., Schriefers, H., Vonk, W., Chwilla, D. J., & Kerkhofs, R. (2013). Processing consequences of superfluous and missing prosodic breaks in auditory sentence comprehension. *Neuropsychologia, 51*(13), 2715-2728.

Brown, C., & Hagoort, P. (1993). The processing nature of the N400: Evidence from masked priming. *Journal of Cognitive Neuroscience, 5*(1), 34-44.

Carlson, K., Frazier, L., & Clifton, J., Charles. (2009). How prosody constrains comprehension: A limited effect of prosodic packaging. *Lingua, 119*(7), 1066-1082.

Cooper, W. E., & Paccia-Cooper, J. (1980). *Syntax and speech*: Harvard University Press.

Coulson, S., & Wu, Y. C. (2005). Right hemisphere activation of joke-related information: An event-related brain potential study. *Journal of Cognitive Neuroscience, 17*(3), 494-506.

DeDe, G. (2010). Utilization of Prosodic Information in Syntactic Ambiguity Resolution. *Journal of psycholinguistic research, 39*(4), 345-374.

Federmeier, K. D., Wlotko, E. W., De Ochoa-Dewald, E., & Kutas, M. (2007). Multiple effects of sentential constraint on word processing. *Brain Research, 1146*, 75-84.

Ferreira, F., Anes, M. D., & Horine, M. D. (1996a). Exploring the use of prosody during language comprehension using the auditory moving window technique. *Journal of Psycholinguistic Research, 25*(2), 273-290.

Ferreira, F., & Clifton, C. (1986). The independence of syntactic processing. *Journal of Memory and Language, 25*(3), 348-368.

Ferreira, F., Henderson, J. M., Anes, M. D., Weeks, P. A., & McFarlane, D. K. (1996b). Effects of lexical frequency and syntactic complexity in spoken-language comprehension: Evidence from the auditory moving-window technique. *Journal of Experimental Psychology: Learning, memory, and cognition, 22*(2), 324.

Friederici, A. D. (2011). The brain basis of language processing: from structure to function. *Physiological Reviews, 91*(4), 1357-1392.

Friederici, A. D., von Cramon, D. Y., & Kotz, S. A. (2007). Role of the corpus callosum in speech comprehension: interfacing syntax and prosody. *Neuron, 53*(1), 135-145.

Geisser, S., & Greenhouse, S. W. (1959). On methods in the analysis of profile data. *Psychometrika, 24*(2), 95-112.

Geyer, A., Holcomb, P., Kuperberg, G., & Perlmutter, N. (2006). Plausibility and sentence comprehension. An ERP study. *Cogn. Neurosci. Suppl., Abstract*, 1-1.

Hagoort, P. (2003). How the brain solves the binding problem for language: a neurocomputational model of syntactic processing. *Neuroimage, 20*, S18-S29.

Hagoort, P., Baggio, G., & Willems, R. M. (2009). Semantic unification *The Cognitive Neurosciences* (4th ed., pp. 819-836): MIT press.

Kaan, E., & Swaab, T. (2003). Repair, revision, and complexity in syntactic analysis: An electrophysiological differentiation. *Journal of Cognitive Neuroscience, 15*(1), 98-110.

Kerkhofs, R., Vonk, W., Schriefers, H., & Chwilla, D. J. (2007). Discourse, syntax, and prosody: the brain reveals an immediate interaction. *Cognitive Neuroscience, Journal of, 19*(9), 1421-1434.

Kjelgaard, M., & Speer, S. (1999). Prosodic facilitation and interference in the resolution of temporary syntactic closure ambiguity. *Journal of Memory and Language, 40*(2), 153-194.

Kuperberg, G. R. (2007). Neural mechanisms of language comprehension: Challenges to syntax. *Brain Research, 1146*, 23-49.

Kuperberg, G. R., Kreher, D. A., Sitnikova, T., Caplan, D. N., & Holcomb, P. J. (2007). The role of animacy and thematic relationships in processing active English sentences: Evidence from event-related potentials. *Brain and Language, 100*(3), 223-237.

Kuperberg, G. R., Sitnikova, T., Caplan, D., & Holcomb, P. J. (2003). Electrophysiological distinctions in processing conceptual relationships within simple sentences. *Cognitive brain research, 17*, 117-129.

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event related brain potential (ERP). *Annual Review of Psychology, 62*, 621.

Kutas, M., & Hillyard, S. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203-205.

MacDonald, M., Pearlmutter, N., & Seidenberg, M. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review, 101*(4), 676-703.

Marslen-Wilson, W. D., Tyler, L. K., Warren, P., Grenier, P., & Lee, C. S. (1992). Prosodic effects in minimal attachment. *The quarterly Journal of Experimental Psychology, 45*(1), 73-87.

McRae, K., & Spivey-Knowlton, M. J. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language, 38*, 283-312.

Nagel, H. N., Shapiro, L. P., & Nawy, R. (1994). Prosody and the processing of filler-gap sentences. *Journal of Psycholinguistic Research, 23*(6), 473-485.

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*(6), 785-806.

Pauker, E., Itzhak, I., Baum, S., & Steinhauer, K. (2011). Effects of cooperating and conflicting prosody in spoken English garden path sentences: ERP evidence for the boundary deletion hypothesis. *Journal of Cognitive Neuroscience, 23*(10), 2731-2751.

Peterson, N. N., Schroeder, C. E., & Arezzo, J. C. (1995). Neural generators of early cortical somatosensory evoked potentials in the awake monkey. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section, 96*(3), 248-260.

Price, P. J., Ostendorf, M., Shattuck‐Hufnagel, S., & Fong, C. (1991). The use of prosody in syntactic disambiguation. *the Journal of the Acoustical Society of America, 90*(6), 2956-2970.

Pynte, J., & Prieur, B. (1996). Prosodic Breaks and Attachment Decisions in Sentence Parsing. *Language and Cognitive Processes, 11*(1-2), 165-192.

Schafer, A. J., Speer, S. R., Warren, P., & White, S. D. (2000). Intonational disambiguation in sentence production and comprehension. *Journal of Psycholinguistic Research, 29*(2), 169-182.

Snedeker, J., & Yuan, S. (2008). Effects of prosodic and lexical constraints on parsing in young children (and adults). *Journal of Memory and Language, 58*(2), 574-608.

Speer, S., Warren, P., & Schafer, A. (2003). *Intonation and sentence processing.* Paper presented at the Proceedings of the Fifteenth International Congress of Phonetic Sciences, Barcelona, Spain.

Speer, S. R., Kjelgaard, M. M., & Dobroth, K. M. (1996). The influence of prosodic structure on the resolution of temporary syntactic closure ambiguities. *Journal of Psycholinguistic Research, 25*(2), 249-271.

Staub, A. (2007). The parser doesn't ignore intransitivity, after all. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(3), 550.

Steinhauer, K. (2003). Electrophysiological correlates of prosody and punctuation. *Brain and Language, 86*(1), 142-164.

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

Trueswell, J., & Tanenhaus, M. (1994). Toward a lexical framework of constraint-based syntactic ambiguity resolution. In C. Clifton, L. Frazier, & K. Rayner (Eds.), *Perspectives on Sentence Processing* (pp. 155-180). Hillsdale, NJ: Erlbaum.

Trueswell, J. C. (1996). The role of lexical frequency in syntactic ambiguity resolution. *Journal of Memory and Language, 35*(4), 566-585.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: Use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language, 33*(3), 285-318.

Warren, P., Schafer, A. J., Speer, S. R., & White, S. D. (2000). Prosodic resolution of prepositional phrase ambiguity in ambiguous and unambiguous situations. *UCLA Working Papers in Phonetics*, 5-34.

Wolff, S., Schlesewsky, M., Hirotani, M., & Bornkessel-Schlesewsky, I. (2008). The neural mechanisms of word order processing revisited: Electrophysiological evidence from Japanese. *Brain and Language, 107*(2), 133-157.

Chapter 4 has been submitted for publication and appears as it is intended for publication of the material as it may appear in Sheppard, S.M., Midgley, K.J., Love, T., Holcomb, P.J., Shapiro, L.P. (*Submitted*). Electrophysiological Evidence for the Interaction of Prosody and Thematic Fit Information During Sentence Comprehension. *Neuropsychologia.* The dissertation author was the primary investigator and the primary author of this paper. Preparation of this manuscript was supported, in part, by National Institute on Deafness and Other Communication Disorders Grants (NIDCD) R01 DC009272, R01 DC000494, and T32 DC007361, and by HD25889. We are very grateful to our research assistants and our participants and their families for their time.

CHAPTER 5:

Influence of Prosody and Thematic Fit on Syntactic Ambiguity Resolution in Broca's Aphasia: Evidence from ERPs

Abstract

Event-related potentials (ERPs) were used to examine how individuals with Broca's aphasia and a group of age-matched controls use prosody and thematic fit information in sentences containing temporary syntactic ambiguities. The stimuli had early closure syntactic structure and contained a temporary early closure (correct) / late closure (incorrect) syntactic ambiguity. The prosody was manipulated to either be congruent or incongruent, and the temporarily ambiguous NP was also manipulated to either be a plausible or an implausible continuation for the subordinate verb (e.g., "While the band played the song/the beer pleased all the customers."). It was hypothesized that, an implausible NP in sentences with incongruent prosody may provide the parser with a plausibility cue that could be used to predict syntactic structure. The individuals with aphasia were broken into a group of High Comprehenders and a group of Low Comprehenders depending on the severity of their sentence comprehension deficit. The results revealed that incongruent prosody paired with a plausibility cue resulted in an N400-P600 complex at the implausible NP (*the beer*) in both the controls and High Comprehenders, yet incongruent prosody without a plausibility cue resulted in an N400-P600 at the critical verb (*pleased*) only in healthy controls. A sustained positivity, but no N400, was revealed at each of these points in the Low Comprehenders. These results suggest that High Comprehenders have difficulty integrating prosodic cues with underlying syntactic structure when lexical-semantic information is not available to aid their

parse. Low Comprehenders have difficulty integrating both prosodic and lexical-semantic cues with syntactic structure.

5.1 Introduction

In this paper we describe an experiment that investigates how prosodic and thematic fit information affects sentence processing in individuals with aphasia. Before we do, we describe the relevant sentence processing literature based on neurologically unimpaired adults, setting the stage for a subsequent description of the relevant literature on aphasia.

While comprehending language appears to be immediate and effortless, it actually requires the rapid coordination of a complex set of processes. These processes include building semantic and syntactic representations while also incorporating prosodic information. One important battleground for empirical studies of language processing involves apparent and momentary syntactic ambiguities. Neurologically unimpaired listeners can experience momentary comprehension difficulties when processing sentences containing such ambiguities, yet listeners are typically able to repair and resolve these to ultimately comprehend the sentence. For example, consider:

1. While the band played the song pleased all the customers.

Sentence (1) contains a temporary syntactic ambiguity because it is initially unclear whether the noun phrase (NP) *the song*, once encountered in the speech stream, is the direct object of *played* (incorrect interpretation) or the subject of the main clause (correct interpretation). Once the critical verb *pleased* is subsequently encountered it is clear that *the song* is the subject of the main clause and not the direct object of *played.* Sentence (1) is an example of early closure syntax where the ambiguous NP serves as the subject of a new clause. Sentences like (1) are often called "garden path" sentences because they lead the reader/listener down the "garden path" to misanalysis, and then reanalysis is required to successfully comprehend the sentence.

However, studies examining the impact of lexical-semantic cues have found that they can serve to lessen the garden-path effect. Consider:

2. While the band played the beer pleased all the customers.

Because it is implausible that *the beer* would be *played, the beer* is a poor thematic fit as a direct object or Theme of *played.* Thus, sentences containing an implausible NP like *the beer* in (2) may provide the parser with a lexical-semantic plausibility cue to prefer the correct early closure syntax over the incorrect late closure syntax. In this way lexical-semantic cues may constrain sentence parsing decisions by restricting the array of likely syntactic structures.

Prosody – characterized by pitch, loudness and rhythm of language – can also affect the processing of garden path sentences. Intuitively it seems likely that inserting a pause after *played* and before the introduction to the subsequent NP in (1) would immediately disambiguate the syntactic structure and make it clear to the listener that the NP, *the song,* is the subject of the main clause. Below we will briefly review the literature examining how lexical-semantic and prosodic cues are used by both neurologically unimpaired listeners and persons with aphasia.

Lexical-Semantic and Prosodic Cues in Unimpaired Sentence Processing

Evidence from studies of neurologically unimpaired participants suggests that lexical-semantic plausibility cues such as verb transitivity bias and thematic fit can disambiguate a sentence before the reader/listener is potentially garden-pathed (Altmann, 1999; Altmann & Kamide, 1999; Arai & Keller, 2013; Trueswell, Tanenhaus, & Garnsey, 1994; Van Berkum, Brown, & Hagoort, 1999).

Prosody can also serve as a cue to the underlying syntactic structure of a sentence, because prosodic breaks tend to occur at major syntactic boundaries (Cooper & Paccia-Cooper, 1980; Nagel, Shapiro, & Nawy, 1994; Price, Ostendorf, Shattuck‐Hufnagel, & Fong, 1991). A prosodic break, which can also referred to as an intonational phrase boundary, is designated by pause, preboundary lengthening of the word immediately preceding the pause, and a boundary tone at the word preceding the pause. Studies of neurologically unimpaired participants have found that sentence comprehension is aided by prosodic cues that are congruent with syntax, and obstructed when prosodic cues are incongruent with syntactic structure (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2013; Carlson, Frazier, & Clifton, 2009; Kjelgaard & Speer, 1999; Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992; Pauker, Itzhak, Baum, & Steinhauer, 2011; Pynte & Prieur, 1996; Schafer, Speer, Warren, & White, 2000; Steinhauer, Alter, & Friederici, 1999).

Only a few studies have examined the interaction of lexical-semantic and prosodic cues during sentence processing (Blodgett, 2004; DeDe, 2010; Pynte & Prieur, 1996; Snedeker & Yuan, 2008), but most of these have used off-line methods, which do not allow for the examination of moment-by-moment processing. Recall that the study presented in Chapter 4 (Sheppard et al., submitted) was the only study, to our knowledge, that has examined the interaction of lexical-semantic and prosodic cues using event-related potentials (ERPs). In a group of college-age adults, this study demonstrated that prosodic and lexical-semantic cues interact immediately during syntactic structure building. Incongruent prosody paired with a plausibility cue to help predict the underlying syntactic structure resulted in semantic integration difficulty and subsequent syntactic reanalysis (N400-P600 complex) earlier in the sentence relative to sentences with incongruent prosody and no plausibility cue. Also, results revealed that congruent prosody immediately disambiguated syntactic structure. Thus results from the study presented in Chapter 4 demonstrate that the parser in college-age neurologically unimpaired adults can immediately capitalize on prosodic and lexical-semantic cues to aid syntactic structure building. Yet it is unclear how these potential cues – thematic fit and prosody – are used by individuals with Broca's aphasia to help them comprehend sentences.

Lexical Cues in Aphasia

There is evidence that persons with aphasia are sensitive to plausibility information. For example, Caramazza and Zurif (1976) presented individuals with Broca's aphasia with sentences like the following:

3. The cat that the dog is biting is black.

4. The book that the girl is reading is yellow.

The results revealed that individuals with Broca's aphasia had difficulty understanding sentences in non-canonical word order with semantically reversible NPs like (3) where both NPs (*the cat* and *the dog*) are capable of performing the action of *biting.* However, the participants did not have trouble understanding sentences like (4) which contained only one animate NP (*the girl*) that was capable of performing the action of *reading*. Thus, participants had difficulty understanding non-canonical sentence structures where semantic information (e.g., animacy) was not sufficient to determine which NP was performing the action and which was receiving the action. In a more recent study, using an act-out task Gibson, Sandberg, Fedorenko, Bergen, and Kiran (2015) presented persons with aphasia with sentences such as:

5. The ball kicked the nephew (Implausible active)

6. The daughter was folded by the blanket (Implausible passive)

After each sentence, participants were provided with dolls representing each of the nouns in the sentence they had just heard and were asked to act out the scenario described in the sentence. Compared to the control group, persons with aphasia relied more heavily on plausibility information across all sentence types. However, they were more likely to use plausibility information in non-canonical passive (6) relative to canonical active (5) constructions. Hence, evidence suggests that persons with aphasia rely more on plausibility cues in sentences with non-canonical sentence structure (i.e., object-extracted relative clauses and passive constructions) compared to sentences with canonical structure (i.e., subject-extracted relative clauses and active constructions) (Caramazza & Zurif, 1976; Gibson et al., 2015).

Similarly, Gahl et al. (2003) used an offline plausibility judgment task to examine whether individuals with aphasia reliably use lexical cues to aid in sentence comprehension. The results showed a processing advantage when the sentence structure matched the lexical bias of the main verb relative to sentences where the structure and lexical bias did not match.

Therefore, several studies have demonstrated that persons with aphasia are sensitive to plausibility information. However, these studies used off-line tasks where the ultimate comprehension of the sentence was studied. Off-line tasks cannot provide information about the time course of how and when plausibility cues are used in sentence processing, thus the time course of the underlying processes remains unknown.

Prosodic Cues in Aphasia

Studies examining how and to what extent individuals with Broca's aphasia use prosodic cues in sentence processing have found conflicting results. Some studies using end-of-sentence judgment tasks have found that individuals with aphasia have difficulty identifying prosodic contours in sentences (Pell & Baum, 1997). However, using this same method, Walker, Fongemie, and Daigle (2001) examined how individuals with Broca's aphasia processed sentences containing temporary syntactic ambiguities presented with either congruent, incongruent, or absent prosodic cues. The results revealed that processing was facilitated by the presence of congruent relative to incongruent or absent prosodic cues. Yet, evidence from Baum and Dwivedi (2003) conflict with Walker et al.'s findings. Using a cross-modal lexical decision task, Baum and Dwivedi (2003) presented a group of participants with aphasia with sentences where the prosodic contour was manipulated to either be congruent or incongruent with sentence structure. Slower reaction times in congruent relative to incongruent prosodic boundaries were found in the individuals with aphasia, which was opposite of the pattern found in healthy controls. Hence, the individuals with aphasia were sensitive to prosody, but did not properly use the information to disambiguate the syntactic structure. The authors proposed that perhaps persons with aphasia process prosodic cues but cannot map them onto syntactic structures. Thus, it appears that individuals with Broca's aphasia are sensitive to prosodic information, even though they appear to process it differently than neurologically unimpaired participants. However, these studies are limited because they either do not measure online processing so it is unclear how and when these cues impact processing.

Interaction of Lexical-Semantic and Prosodic Cues in Aphasia

Only one study to date, DeDe (2012), has examined the interaction of lexical-semantic and prosodic cues in persons with aphasia. A self-paced listening task was used. In this method, listeners are presented with sentences in word-by-word (or phrase-by-phrase) segments. Listeners must press a button to reveal the next aurally presented segment, and listening times are recorded for each segment. Longer listening times are associated with processing difficulty/interference. Using this task, Dede (2012) presented participants with early closure sentences where both lexical and prosodic cues were manipulated. Consider:

7a. While the parents danced the child sang a song with her grandmother.

7b. While the parents watched the child sang a song with her grandmother.

The transitivity bias of the verb was manipulated such that intransitively-biased verbs (*danced* in (7a)) were biased toward the correct early closure interpretation and transitively- biased verbs (*watched* in (7b)) were biased toward an incorrect late closure interpretation. Prosody was also manipulated to be biased toward either the early closure or late closure interpretation. The early closure clausal boundary was characterized by the subordinate verb (*danced/watched*) marked with a high pitch accent followed by falling pitch and increased duration of the clause-final syllable. No clear prosodic boundary was present in the late closure biased condition. The results demonstrated that individuals with aphasia showed longer listening times for the ambiguous NP (*the child*) when lexical and prosodic cues conflicted relative to when they were consistent. The control group showed this effect earlier in the sentence (at the subordinate verb *danced/watched*). Both the patient group and the control group showed longer listening times at the main verb (*sang*) when both prosodic and plausibility cues biased the listener toward the incorrect interpretation, which was interpreted as indicating that they engaged in syntactic re-analysis. Dede concluded that while individuals with aphasia are sensitive to prosodic and plausibility cues, they exhibit delayed processing of prosodic and lexical-semantic information. While these results are compelling, self-paced listening requires participants to consciously reflect on each segment of the sentence, which disrupts processing. Hence, it does not allow an unimpeded examination of online processing.

Event-Related Brain Potentials in Sentence Processing

The current study aimed to use event-related brain potentials (ERPs) to study how prosodic and lexical cues impact sentence processing in individuals with aphasia, a method that allows us to investigate online sentence processing with millisecond-level temporal resolution. Moreover, distinct ERP components can be examined, which reflect different aspects of sentence processing. For example, the Closure Positive Shift (CPS) component is a large positive-going waveform that is reliably elicited at intonational phrase boundaries in neurologically unimpaired participants (Steinhauer, 2003; Steinhauer et al., 1999). The CPS is sensitive to prosodic break markers such as lengthening of the pre-pause word, a boundary tone at the pre-pause word, and the presence of a pause.

The N400 component is a negative-going waveform that is sensitive to semantic processing (Kutas, 1993; Kutas & Federmeier, 2011; Kutas & Hillyard, 1980). The amplitude of the N400 is modulated by semantic processing effort such that a larger N400 amplitude indexes more difficulty incorporating the word of interest into the preceding sentence context (Holcomb & Neville, 1990; Kutas, 1993; Van Berkum et al., 1999). Some evidence suggests the N400 reflects processes associated with semantic memory (Kutas & Federmeier, 2000), while other research suggests that the N400 reflects the integration of the semantic information of the current word with the meaning from preceding words in an utterance (Brown & Hagoort, 1993; Hagoort, Baggio, & Willems, 2009; Osterhout & Holcomb, 1992). Also, prior work by Osterhout and Holcomb (1992, 1993) shows that final words in unacceptable sentences elicit an N400 effect relative to final words in sentences judged as acceptable.

In contrast, the P600 component is sensitive to syntactic anomalies (Osterhout & Holcomb, 1992). This positive-going component that typically begins around 600ms after stimulus onset has been suggested to reflect syntactic complexity (Van Berkum et al., 1999) or possibly syntactic integration difficulty (Kaan, Harris, Gibson, & Holcomb, 2000). It is likely the P600 serves as an index of syntactic reanalysis (Friederici, 2011; Friederici & Kotz, 2003; Friederici & Weissenborn, 2007), which is why it is of particular interest in studies examining garden-path sentences. Studies of neurologically unimpaired listeners demonstrate that a combined N400-P600 component is often elicited at the disambiguation point in garden-path sentences, including studies examining prosody-driven garden-path effects (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2010; Pauker et al., 2011; Steinhauer et al., 1999). The biphasic N400-P600 complex reflects how garden-path effects can disrupt both lexical-semantic and syntactic processing.

The P600 has also been elicited in sentences containing thematic violations (Geyer, Holcomb, Kuperberg, & Perlmutter, 2006; Kuperberg, 2007; Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003). For example, Kuperberg et al. (2003) presented participants with sentences like:

8. Every morning at breakfast the boys would only eat toast and jam.

9. Every morning at breakfast the eggs would only eat toast and jam.

In both cases the verb *eat* assigns the thematic role of Agent to the NP (*the boys/the eggs*) in the subject role. In (8) there is no thematic violation because the NP, *the boys*, is animate and is a proper subject for the verb *eat*. However, (9) contains a thematic role violation because an inanimate subject NP, *the eggs,* that is not a proper subject for the verb. Thematic role violations elicited a significant posterior P600 effect at the critical verb. This was attributed to a mismatch between the expected thematic role of Theme that is typically associated with an inanimate NP like *the eggs,* and the role of Agent that was actually assigned to *the eggs* by the verb *eat.* This thematic P600 effect was interpreted as reflecting the reanalysis or repair of the structure being built online that was triggered when the verb was encountered. More specifically, Kuperberg and colleagues attributed their findings to the presence of semantic associations between the verbs and their arguments.

ERPs have successfully been used by researchers to examine the auditory comprehension deficit in aphasia. For example, Kielar, Meltzer-Asscher, and Thompson (2012) examined auditory processing of sentences such as:

10a. Anne visited the doctor and the nurse.

10b. * Anne sneezed the doctor and the nurse.

10c. * Anne visited the doctor and the socks.

No violations were present in (10a), but (10b) contained an argument structure violation since *sneezed* is an intransitive verb and does not take a direct object. Also, (10c) contains a semantic violation at the sentence-final word (e.g., *socks*). In neurologically unimpaired control participants the argument structure violations (10b) elicited a significant N400-P600 complex. However, in participants with aphasia a P600 but no N400 was elicited. The authors interpreted these results to mean that individuals with aphasia have inadequate access to verb lexical information and impaired integration of verb meaning with sentence context. These results were similar to the findings of a study by Friederici, Hahne, and Von Cramon (1998) who examined ERPs to word category violations (e.g., * The friend was in the visited) in a patient with Broca's aphasia. The word category violations elicited a negativity followed by a positivity in healthy controls, yet only a P600 was elicited in the patient with aphasia. The authors suggested that the early negativity reflected fast automatic processing and the P600 reflected secondary syntactic processing. They proposed that while the patient with Broca's aphasia had maintained secondary syntactic processing resources, access to initial fast and automatic semantic processing was lost.

Several ERP studies of sentence comprehension in aphasia have also found that ERPs in this population are modulated by the severity of the comprehension deficit. Wassenaar, Brown, and Hagoort (2004) compared ERPs at the critical verb (e.g., *take/takes*) in sentences like:

11a. The women pay the baker and take the bread home.

11b. * The women pay the baker and takes the bread home.

In the neurologically unimpaired controls, the subject-verb agreement violation in (11b) elicited a P600 effect. However, no P600 effect was found in the individuals with aphasia. In follow-up analyses the authors discovered that the deviations in the P600 effect were most apparent in individuals with a more severe comprehension deficit. The P600 effect was present in most participants with high sentence comprehension scores. In our experiment we also divide our participants with aphasia into low and high comprehension groups to understand if severity is an important factor in determining online sentence comprehension performance.

Several studies have also found that the N400 effect to semantic violations is also modulated by the severity of the comprehension impairment in individuals with aphasia. For example, Swaab, Brown, and Hagoort (1997) compared ERPs elicited in sentences with and without a lexical-semantic violation at the final word. The participants with aphasia were divided into a group of *High Comprehenders* with a mild comprehension deficit and *Low Comprehenders* with a moderate-severe comprehension deficit. The N400 effect in the *High Comprehenders* group was similar to the N400 effect in the control group. However, the N400 effect was smaller and delayed in the Low Comprehenders group which was interpreted as indicating delayed integration of lexical information with the preceding sentence context. Similarly, Hagoort, Brown, and Swaab (1996) compared ERPs in word pairs containing either related or unrelated words. The N400 effect in High Comprehenders was similar to the control group, yet it was significantly reduced in the group of Low Comprehenders.

In sum, ERPs allow researchers to measure the impact of prosodic boundaries (CPS), semantic interference (N400), and syntactic interference (P600) as the sentence is being processed. ERPs thus offer a significant advantage over self-paced listening methods, where it is difficult to determine whether experimental manipulations affect prosodic, semantic, or syntactic processing mechanisms. Yet, no studies to date of which we are aware have used ERPs in individuals with aphasia to examine the interaction between thematic fit plausibility cues and prosodic cues on the processing of garden-path sentences. We remedy this, below.

5.1.1 Current Study

The current experiment seeks to use ERPs to understand how individuals with aphasia process prosodic and lexical-semantic (thematic fit) cues during the processing of garden-path sentences compared to a group of age-matched control participants. Consider the sentences in Table 5-1.

Table 5-1. Example sentences.

Sentence	Prosody (Pr)	Plausibility / Thematic Fit (TF)	Condition
12a. [While the band played] [the song pleased all the customers.]	Congruent (+)	Plausible (+)	*Pr+TF+*
12b. [While the band played] [the beer pleased all the customers.]	Congruent (+)	Implausible (-)	*Pr+TF-*
12c. [While the band played the song] [pleased all the customers.]	Incongruent (-)	Plausible (+)	*Pr-TF+*
12d. [While the band played the beer] [pleased all the customers.]	Incongruent (-)	Implausible (-)	*Pr-TF-*

The first verb in each sentence (*played*) is optionally transitive, thus it has the option of taking a direct object or not. This creates a temporary syntactic ambiguity in each sentence. The thematic fit of the temporarily ambiguous NP following the optionally transitive verb was either a plausible (12a, 12c) or implausible (12b, 12d) direct object. Prosody was also manipulated to either be congruent (12a, 12b) or incongruent (12c, 12d) with the syntactic structure. These manipulations yielded a 2 (Sentence Type: plausible thematic fit, implausible thematic fit) x 2 (Prosody: congruent, incongruent) design as shown in Table 5-1.

5.1.1.1 Predictions of Current Study

Predictions at the Prosodic Break

CPS components were investigated in this study by comparing ERPs time-locked to the point of the first prosodic break in sentences like (12a) and (12b) (offset of “played”) to the same point in the counterpart sentences in sentences like (12c) and (12d) where there was not prosodic break. In prior studies the CPS has reliably elicited at the onset of a prosodic break in studies of college age adults (Pauker et al., 2011; Steinhauer et al., 1999), however CPS effects are not well studied in older adults. Yet, Steinhauer, Abada, Pauker, Itzhak, and Baum (2010) found that in an offline acceptability judgment task older adults were more likely to incorrectly accept sentences with incongruent prosody relative to younger adults. In spite of these behavioral differences between groups, the older adults showed CPS components that were similar in latency to the younger adults. Based on these findings, we predicted that the neurologically unimpaired age-matched control participants would perceive the prosodic break, as indicated by a CPS component.

To our knowledge, no study to date has investigated the CPS component in patients with aphasia. Nevertheless, since evidence from some behavioral studies (Baum & Dwivedi, 2003; DeDe, 2012; Walker et al., 2001) suggests individuals with aphasia are sensitive to prosodic information, we anticipated finding a CPS effect. We also anticipated finding differences in either latency, amplitude or scalp distribution between the CPS effects in the age-matched control and patient groups.

Predictions at Ambiguous NP (*the song/the beer*)

Here sentences with incongruent prosody and an implausible NP (*the beer* in *Pr-TF-*) were compared to sentences with incongruent prosody and a plausible NP (*the song* in *Pr-TF+*). Recall that *the beer* in (12d) is a poor thematic fit for the subordinate verb, *played*, and this poor thematic fit may provide a plausibility cue to aid syntactic processing. Specifically, in the comparison between *Pr-TF-* (12d) with an implausible NP, and *Pr-TF+* (12c) with a plausible NP, the poor thematic fit between *played* and *the beer* in (12d) may trigger syntactic reanalysis at the ambiguous NP. We predicted this would be the case, and thus in the age-matched controls we expected to find a biphasic N400-P600 complex at the ambiguous NP in *Pr-TF-* (12d) vs. *Pr-TF+* (12c). The N400 effect in *Pr-TF-* (*the beer*) relative to *Pr-TF+* (*the song*) would confirm that the incongruent prosody caused the parser to initially attempt to parse the structurally ambiguous NP as the direct object of the verb *played,* but did not consider the NP *the beer* to be a good thematic fit with *played*. Hence, the presence of an N400 in this comparison would indicate semantic integration difficulty in *Pr-TF-* (*the beer*) because *the beer* is an implausible direct object for the subordinate verb *played.* In contrast *the song* is a plausible direct object for *played*, thus we did not anticipate evidence of semantic integration difficulty as evidenced by an N400 effect in *Pr-TF+*. The presence of a P600 effect in *Pr-TF-* (12d) vs. *Pr-TF+* (12c) at the ambiguous NP would indicate that the poor thematic fit between *played* and *the beer* in *Pr-TF-* triggered syntactic reanalysis.

Recall that Dede (2012) manipulated prosody to be biased toward either early or late closure interpretations of sentences such as:

13a. While the parents danced the child sang a song with her grandmother.

13b. While the parents watched the child sang a song with her grandmother.

The subordinate verb (*danced/watched*) was manipulated to either be intransitively biased, providing a plausibility cue biased toward the correct early closure interpretation (13a), or transitively biased, biasing the listener toward the incorrect late closure interpretation (13b). At the critical verb, *sang*, individuals with aphasia showed longer listening times when both plausibility and prosodic cues biased the listener toward the incorrect late closure structure. This was interpreted to be evidence of syntactic reanalysis due to a garden-path effect. However, the self-paced listening task does not allow for the differentiation of processing difficulty resulting from semantic integration difficulty (N400) versus syntactic reanalysis (P600). Thus, in the individuals with aphasia we predicted finding of an N400 or a P600 effect, but likely not the N400-P600 complex that we expect to discover in the age-matched controls. Differences in scalp distribution, amplitude, and latency between the controls and the individuals with aphasia will be discussed

Predictions at Critical Verb (*pleased*)

Garden-path effects can cause interference to both lexical-semantic and syntactic integration, thus many ERP studies find a biphasic N400-P600 effect at the disambiguation point. A mismatch between prosody and syntax can lead to garden-path effects, which is reflected by the presence of an N400-P600 complex (Bögels et al., 2010; Pauker et al., 2011; Steinhauer et al., 1999). Thus, we predicted finding a significant N400-P600 complex in the neurologically unimpaired age-matched control participants in the classic garden-path comparison of *Pr-TF+* (12c) to *Pr+TF+* (12a) where both prosodic and plausibility cues would bias the listener toward the incorrect parse. Since we anticipated finding an N400-P600 complex at the ambiguous NP (prior to the critical verb) in the comparison between conditions with an implausible NP [*Pr-TF-* (12d) vs. *Pr+TF-* (12b)], we did not anticipate finding another N400-P600 complex at the critical verb in this comparison.

Given that the only studies that have examined the interaction of prosodic and thematic cues during sentence processing in patients with aphasia have used behavioral methods such as self-paced listening (Dede, 2012) it is more difficult to predict ERP effects in this group. However, Dede did find longer listening times at the critical verb in participants with aphasia when both prosodic and plausibility cues biased the listener toward the incorrect interpretation. Dede's findings suggest that participants with aphasia were garden-pathed when listening to sentences with prosodic and plausibility cues biased toward the incorrect parse. Thus, we anticipated finding either an N400 or P600 effect in this comparison in participants with aphasia, though we did not expect to find the N400-P600 complex that we anticipated finding in the control group.

Predictions at Final Word (*customers*)

Osterhout and Holcomb (1992; 1993) demonstrated that the final word in garden-path sentences, those deemed to be unacceptable by participants, elicits a sustained N400 effect in neurologically unimpaired participants. Thus, we predicted both conditions with incongruent prosody [(12c, *Pr-TF+*) and (12d, *Pr-TF-*)] would elicit an N400 effect in healthy controls. We also expected individuals with aphasia to be sensitive to the prosody manipulation, and thus anticipated they would also show an N400 effect at the sentence-final word. Though we anticipated it may be attenuated with a shorter latency, and possibly with a different scalp distribution relative to the controls.

5.2 Materials and Methods

Participants

Age-matched Control Participants

The group of age-matched controls was comprised of 20 adults (13 females; mean age = 61 years; range: 41-82 years) who were right-handed monolingual speakers of American English. As indicated by self-report, all participants had normal or corrected-to-normal visual and auditory acuity, and were neurologically and physically stable at the time of testing with no history of psychiatric illness, drug or alcohol abuse, or other significant brain disorder or dysfunction.

Participants with Aphasia

Fifteen adults with Broca's aphasia (5 females; mean age = 55 years; range: 37-77 years) participated in this study (see Table 5-2). All participants experienced a single unilateral left hemisphere stroke, were monolingual native speakers of English, and had normal or corrected-to-normal auditory and visual acuity. All participants were neurologically and physically stable (i.e., at least 6 months post onset) with no reported history of alcohol or drug abuse, psychiatric illness, or other significant neurological disorder or dysfunction. Participants were diagnosed with Broca's aphasia based on the convergence of clinical consensus and the results of the Boston Diagnostic Aphasia Examination (version 3; Goodglass Kaplan, & Barresi, 2000). ERP waveforms can vary in individuals with aphasia based on the severity of the comprehension deficit (Hagoort et al., 1996; Kawohl et al., 2009; Swaab et al., 1997; Wassenaar et al., 2004). Therefore, we analyzed the results of the patients as a whole group, and we also split them into two groups, a *High Comprehenders* group and a *Low Comprehenders* group. Patients were divided into these two groups based on their overall performance on the SOAP Test of Sentence Comprehension (Love & Oster, 2002). Patients with scores significantly better than chance were included in the High Comprehenders group (n = 6), and those with scores that were not significantly better than chance were placed in the Low Comprehenders group (n = 9). The results of each analysis for the entire patient group as a whole, the High Comprehenders and the Low Comprehenders groups are reported.

Table 5-2. Aphasia Participant Information

Participant	Group	Sex	BDAE	Years Post-Stroke	Lesion Location	Age at Testing (Years)	Education Level	SOAP: Overall Score
LHD151	High Comprehender	F	4	6.5	L caudate nucleus, putamen, ventrolateral thalamus & posterior limb of L internal capsule	63.5	College	95%
LHD017	High Comprehender	M	4	17.5	Large lesion involving frontal cortical region & deeper BG structures	58	2 years of college	100%
LHD139	High Comprehender	M	3	16.5	L MCA infarct	40.5	Some college	67.5%
LHD142	High Comprehender	M	4	6	L MCA infarct	76.5	8th grade	72.5%
LHD159	High Comprehender	F	3	5.5	Large L parietal lobe & L frontoparietal lobe	62	College	95%
LHD191	High Comprehender	M	4.5	1.5	L MCA infarct	56	Master's degree	90%
LHD009	Low Comprehender	M	3	15	Large L lesion involving IFG (BA 44, 45)	54	1 yr. grad school	55%
LHD101	Low Comprehender	M	2	9	Large L lesion involving posterior IFG (BA44) with posterior extension	65	Ph.D.	57.5%
LHD130	Low Comprehender	M	4	8	L IPL with posterior extension sparing STG	62	4 years college	65%
LHD138	Low Comprehender	M	2	17.5	L MCA infarct	37	Some college	52.5%
LHD140	Low Comprehender	F	2	15.5	L MCA infarct Secondary to occlusion of L proximal CA	39.5	4 years college	42.5%
LHD169	Low Comprehender	M	1	4	L MCA infarct with small areas of acute infarction at margins of encephalo-malacia	58	High School	60%
LHD175	Low Comprehender	F	3.5	7.5	L MCA infarct	60	Some college	47.5%
LHD176	Low Comprehender	F	3	2	L IFG & L BG	50	College	45%
LHD189	Low Comprehender	M	2	7.5	L MCA infarct	57	Master's degree	25%

Note. BDAE = Boston Diagnostic Aphasia Examination; L = left; BA = Brodmann area; IPL = inferior parietal lobule; STG = superior temporal gyrus; MTG = middle temporal gyrus; MCA = middle cerebral artery; CA = cerebral artery; CVA = cerebrovascular accident; IFG = inferior frontal gyrus.

Materials

The materials were identical to those described in Sheppard et al. (submitted) in Chapter 4. In order to create the materials, sentences (12a-12b) were recorded using naturally produced early closure prosody. The following sentences were recorded using naturally produced late closure prosody:

12e. [While the band played the song] [the beer pleased all the customers.]

12f. [While the band played the beer] [the song pleased all the customers.]

A waveform editor (Adobe Audition) was used to form sentences (12c-12d). The initial portions of (12e-12f) were cut up to the ambiguous NP (*the song/the* beer) and spliced to replace the same portion of the sentence in (12a-12b). Sentences (12e-12f) were used as prosodic controls in this experiment. These manipulations were designed to allow us to determine whether prosody can bias listeners toward a specific parse even when the lexical cues (whether the NP is a plausible or implausible direct object) conflict with the argument structure of the verb. The NPs were counterbalanced across the different verbs. Sixty of each type of sentence (12a-12f) were created yielding a total of 360 sentences. All sentences were recorded in a soundproofed environment at a regular rate of speech (4-6 syllables/second).

Procedure

After the participants were fitted with an electrode cap, they were presented with sentences over headphones while sitting in a comfortable chair in a dimly lit sound-attenuated room. Concurrent with the onset of each word and prosodic break, as well as the offset of each subordinate verb (*played*) and ambiguous NP (*the song/the beer*) in a sentence, a code specifying the condition of the word or prosodic break was sent to the computer digitizing the EEG data. This allowed for precise time-locking of the EEG with word and prosodic break onset across the various conditions. A fixation cross was presented in the center of the screen simultaneous with the start of each sentence. The fixation cross disappeared 1000ms post-sentence offset and was replaced by a question mark signaling the participant to make an acceptability judgment about the sentence they just heard by button press (Figure 5-1). Once the participant selected a response the experiment advanced to the next trial. Participants attended two 1-hour data collection sessions (an average of 2.5 weeks apart), where 180 sentences were presented in each session. Each participant was presented with a block of 10 practice items prior to each experimental session in order to familiarize them with the procedure. Each participant was compensated $15 per hour.

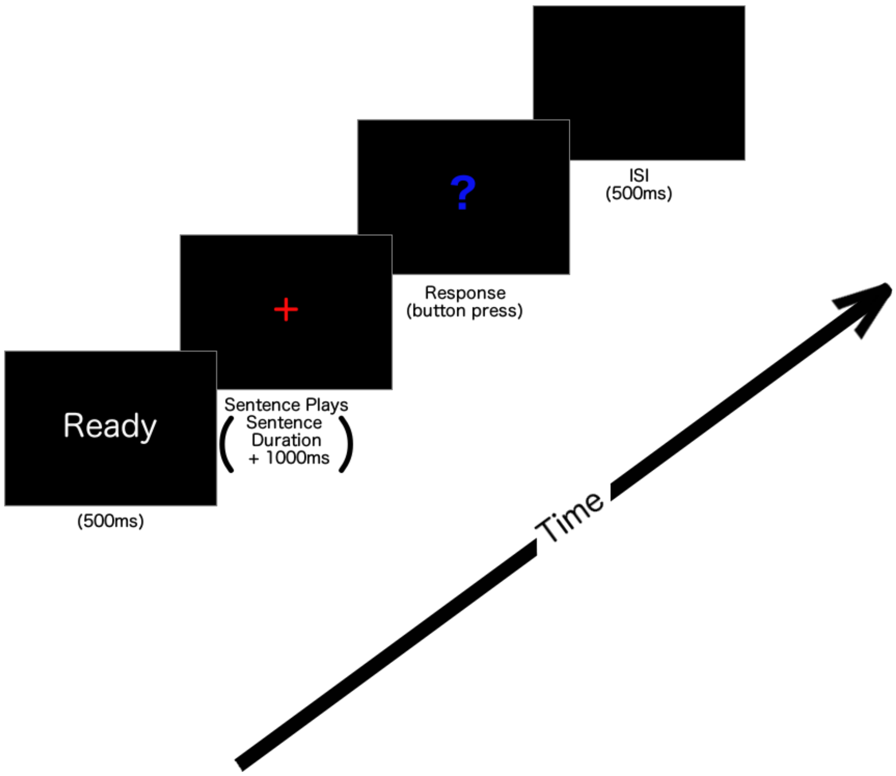


Figure 5-1. Schematic of one trial. Participants were presented with the word "Ready" in the center of the screen to signal the beginning of a new trial. Next, a red cross was presented in te center of the screen, which corresponded with the sentence playing. The red cross remained on the screen throughout the sentence duration up to 1000ms after the sentence ended. A blue question mark was presented to signal that the participant could make their acceptability response by button press. The question mark disappeared once a response was selected.

EEG Recording Procedure

The electroencephalogram (EEG) was recorded from 29 active tin electrodes at the scalp (Electrode-Cap International). Additional electrodes were attached below the left eye (LE, used to monitor blinks), to the side of the right eye (HE, to monitor horizontal eye movements), over the right mastoid bone, and the left mastoid bone (A1, reference electrode). The eye electrode impedances were maintained below 10 kΩ, with the remaining electrode impedances maintained below 5 kΩ. The EEG signal was amplified by a Neuroscan Synamp RT system using Curry data acquisition software. Recording bandpass was DC to 200 Hz and the EEG was continuously sampled at a rate of 500 Hz throughout the duration of the experiment. ERPs were averaged from artifact free trials time-locked to critical target word onset with a 1200ms epoch.

ERP Data Analysis

ERPs were time-locked to critical points in each sentence (details will be provided in the Results section). All EEG trials with muscle movement or amplifier blocking artifacts were rejected from analysis prior to averaging. Independent component analysis (ICA) was performed on continuous data for each participant to correct for blink artifacts (Jung et al., 2000). Participants were only included if they maintained at least 30 trials in each experimental condition for every comparison of interest. Our ERPs were averaged from the trials remaining after artifact rejection and were bandpass filtered at .1-30 Hz. Unless otherwise noted, comparisons were made using a 100ms pre-stimulus baseline.

Analyses were conducted at three points in the sentence: (1) the prosodic break in conditions with congruent prosody [*Pr+TF+* (12a), and *Pr+TF+* (12b)] compared to those with incongruent prosody [*Pr-TF+* (12c), and *Pr-TF+* (12d)]; (2) the ambiguous NP between the two conditions with incongruent prosody, *Pr-*

TF- (12d) versus *Pr-TF+* (12c); and (3) between all four conditions at the critical verb, *pleased.* The analyses in the first comparison at the prosodic break contained two levels of Prosody (Congruent vs. Incongruent). The analyses at the ambiguous NP contained two factors of thematic fit/plausibility (Plausible vs. Implausible). Finally, analyses at the critical verb *pleased* contained factors of two levels of Prosody (Congruent vs. Incongruent) and two levels of Plausibility (Plausible vs. Implausible). Each analysis also contained factors of Anteriority and Laterality as described below.

In order to thoroughly analyze the full montage of 29 scalp sites we used a data analysis approach that was successfully employed in previous studies (Holcomb, Reder, Misra, & Grainger, 2005; Midgley, Holcomb, & Grainger, 2011). In this approach the 29 channel montage is divided into seven columns along the anteroposterior axis of the scalp (see Figure 5-2). Four separate ANOVAs are used to analyze the three pairs of lateral columns as well as the midline column. The analyses for Columns 1, 2, and 3, employed a Laterality electrode site factor (left vs. right hemisphere) and an Anteriority Electrode site factor (three, four, or five levels respectively). The analysis for the midline column used an Anteriority factor with five levels. This approach was chosen because we anticipated differences in scalp distribution when comparing the results from individuals with aphasia to the age-matched controls. This analysis allowed us to acquire a complete statistical description of the data set. While the use of this approach does require an increase in the number of comparisons, this was counterbalanced by obtaining a thorough description of the data.

Mean voltages were calculated and analyzed in separate mixed ANOVAs with Plausibility, Prosody, Laterality, and Anteriority as within-subjects variables and Group (Age-matched Control vs. Individuals with aphasia) as a between-subjects variable. In cases where the mixed ANOVAs indicated differences between groups, follow up analyses were conducted within each participant group with factors of Plausibility, Prosody, Laterality, and Anteriority as described in the Results section. In the participants with aphasia, within group analyses were also conducted for both the High Comprehenders and Low Comprehenders. Between groups analyses were not used to investigate differences between the High and Low Comprehenders groups due to the small group sizes ($n = 6$ in the High Comprehenders; $n = 9$ in the Low Comprehenders), and because the groups were not equal in size. The Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom in the numerator in order to address violations of sphericity.

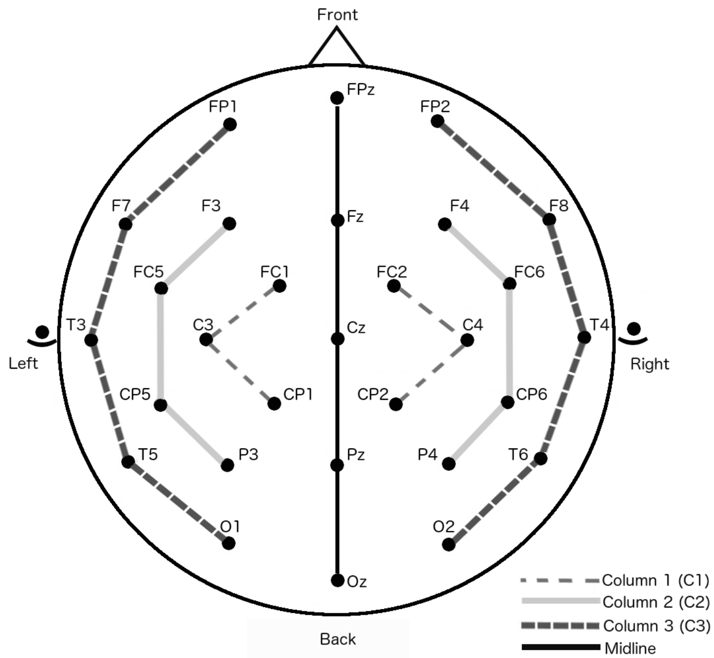


Figure 5-2. Electrode montage. Electrode montage and analysis sites. Electrodes placed in the standard International 10–20 System locations included five sites along the midline (FPz, Fz, Cz, Pz, and Oz) and eight lateral sites, with four in each hemisphere (F3/F4, C3/C4, T3/T4, and P3/P4). Sixteen extended 10–20 sites were also used (Fp1/Fp2, F7/F8, T5/T6, O1/O2, FC1/ FC2, FC5/FC6, CP1/CP2, and CP5/CP6), with eight in each hemisphere. The lines represent the four columns used in analyses (i.e., column 1 (C1), column 2 (C2), column 3 (C3), and midline).

Behavioral Data Analysis

The percentage of accepted sentences in each condition were calculated from the subject acceptability rating data. An “Acceptable” rating was considered an accurate response for conditions with congruent prosody (*Pr+TF+, Pr+TF-*), and an “Unacceptable” rating was an accurate response for conditions with incongruent prosody (*Pr-TF+* and *Pr-TF-*). Acceptability judgment data were analyzed in a mixed 2 (Group: Control vs. Aphasic) x 2 (Prosody: Congruent vs.

Incongruent) x 2 (Plausibility: Plausible vs. Implausible) ANOVA by subjects, with Prosody and Plausibility as within-subjects variables.

5.3 Results

5.3.1 ERP Results

5.3.1.1 Age-Matched Controls vs. Individuals with Aphasia

<u>ONSET OF PROSODIC BREAK – CPS EFFECTS</u>

Subordinate Verb Offset (played) – CPS Effects (0-600ms Epoch)

(Corresponding to prosodic break in Congruent Prosody conditions, *Pr+TF+* and *Pr+TF-*)

In this comparison, CPS effects in conditions with congruent prosody (*Pr+TF+*, *Pr+TF-*) were contrasted with the identical stimuli from conditions without a prosodic break (*Pr-TF+*, *Pr-TF-*). Differences in the ERPs in this contrast would indicate sensitivity to the prosodic break in these two conditions. CPS effects would be designated by positive-going waveforms in the 0-600ms epoch.

Age-Matched Controls vs. Individuals with Aphasia.

A main effect of Prosody was found at all columns, (c1: F (1, 33) = 13.93, p = .001; c2: F (1, 33) = 17.78, p < .001; c3: F (1, 33) = 12.32, p = .001; midline: F (1, 33) = 6.98, p = .013). Also, significant interactions of Prosody x Anteriority were revealed in all columns, (c1: F (2, 66) = 31.91, p < .001; c2: F (3, 99) =

27.77, $p < .001$; c3: F (4, 132) = 20.32, $p < .001$; midline: F (4, 132) = 19.83, $p < .001$), as well as interactions of Prosody x Laterality in Columns 1-3, (c1: F (1, 33) = 5.93, $p = .02$; c2: F (1, 33) = 8.39, $p = .007$; c3: F (1, 33) = 7.20, $p = .011$), and Prosody x Laterality x Anteriority in Column 1, (F (2, 66) = 4.05, $p = .034$). These findings indicate positive-going waveforms in conditions with congruent (*Pr+TF+*, *Pr+TF-*) relative to incongruent prosody (*Pr-TF+*, *Pr-TF-*), especially in right-hemisphere temporal, centroparietal, parietal and occipital sites (see Figure 5-3).

Several effects varied by group, including significant interactions of Group x Prosody x Anteriority in Columns 1-2, (c1: F (2, 66) = 6.41, $p = .008$; c2: F (3, 99) = 6.97, $p = .004$), and a Group x Prosody x Laterality interaction in Column 2 (F (1, 33) = 4.51, $p = .041$). These interactions indicated that that the distribution of the CPS effect differed by group. The CPS effect in the age-matched controls group was significantly larger than the CPS effect in patients with aphasia mainly at left-hemisphere centroparietal, parietal and occipital sites (see Figure 5-3). Follow up analyses were conducted to further examine waveforms within the age-matched control group and the participants with aphasia.

Age-Matched Controls.

The results for the age-matched controls revealed main effects of Prosody at all columns, (c1: F (1, 19) = 10.63, $p = .006$; c2: F (1, 19) = 10.49, $p = .004$; c3: F (1, 19) = 13.93, $p = .001$; midline: F (1, 19) = 6.55, $p = .019$), as well as significant Prosody x Anteriority interactions at all columns, (c1: $F(2, 38) = 51.06$, $p < .001$; c2: $F(3, 57) = 37.23$, $p < .001$; c3: $F(4, 76) = 18.93$, $p < .001$; midline: $F(4, 76) = 22.48$, $p < .001$). These effects revealed a significant CPS effect at the prosodic break in conditions with congruent prosody (*Pr+TF+,* Pr+TF-) relative to conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*), which do not have a prosodic break at this point. As demonstrated in Figure 5-3A, CPS effect was equally distributed across hemispheres and was largest at central, centroparietal, parietal, temporal, and occipital sites.

Individuals with Aphasia.

Main effects of Prosody were discovered in Columns 1-2, (c1: $F(1, 14) = 5.06$, $p = .041$; c2: $F(1, 14) = 7.43$, $p = .016$), which showed a significant CPS effect at the prosodic break in conditions with congruent prosody (*Pr+TF+*, *Pr+TF-*) relative to those with incongruent prosody (*Pr-TF+*, *Pr-TF-*). Additionally, these analyses revealed significant interactions of Prosody x Laterality in Columns 2-3, (c2: $F(1, 14) = 6.15$, $p = .026$; c3: $F(1, 14) = 5.55$, $p = .0340$), Prosody x Anteriority in Columns 3 and midline, (c3: $F(4, 56) = 5.93$, $p = .010$; midline: $F(4, 56) = 3.87$, $p = .044$), and Prosody x Laterality x Anteriority in Column 1, ($F(1, 14) = 5.06$, $p = .041$). The interactions demonstrated that the CPS effect was greatest in right-hemisphere temporal, centroparietal and parietal locations (see Figure 5-3B).

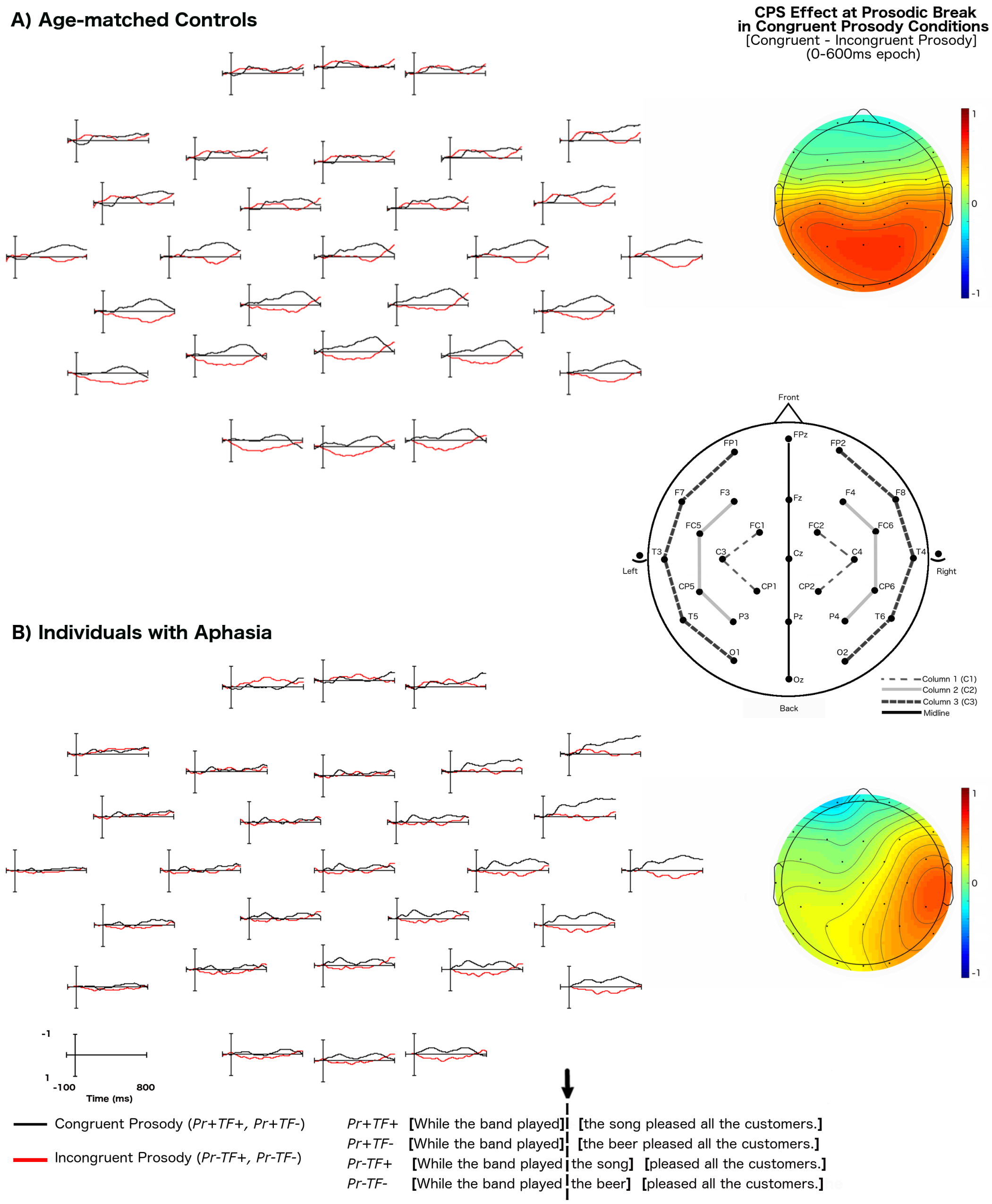


Figure 5-3. Grand average ERPs and voltage maps of the CPS effect at the onset of the prosodic break in conditions with congruent prosody relative to those with incongruent prosody in A) age-matched controls and B) individuals with aphasia. The voltage maps show the scalp distribution of the difference waves (congruent – incongruent) in the 0-600ms epoch. The prosodic break in sentences with congruent prosody (*Pr+TF+*, *Pr+TF-*) elicited a significant CPS effect in both age-matched controls and individuals with aphasia. The CPS effect was distributed across both hemispheres in the controls, while it was primarily distributed in the right-hemisphere in individuals with aphasia.

PLAUSIBILITY-DRIVEN GARDEN-PATH EFFECTS AT ONSET OF AMBIGUOUS NP (*SONG/BEER*)

Here we compared N400 and P600 effects elicited at the ambiguous NP in conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*). A significant N400 effect in sentences with an implausible NP (*the beer* in *Pr-TF-*) relative to sentences with a plausible NP (*the song* in *Pr-TF+*) would indicate that participants were sensitive to the plausibility manipulation in this experiment. A significant P600 effect in this same comparison, between sentences with an implausible NP (*the beer* in *Pr-TF-*) and sentences with a plausible NP (*the song* in *Pr-TF+*), would provide evidence of syntactic reanalysis occurring at the ambiguous NP. Recall that condition *Pr-TF-* contains a plausibility cue, specifically, *the beer* is a poor direct object for *played* so *the beer* is likely to be the subject of a new clause. This plausibility cue could potentially alert the parser to engage in syntactic reanalysis before the critical verb, *pleased.* If this is the case, we would find evidence of a P600 effect in *Pr-TF-* (*the beer*) vs. *Pr-TF+* (*the song*) at the ambiguous NP. The 300-600ms epoch was explored for N400 effects, and the 600-1200ms epoch for P600 effects.

Onset of Ambiguous NP (song/beer) – N400 Effects (300-600ms epoch)

Age-Matched Controls vs. Individuals with Aphasia.

Analyses indicated that waveforms differed significantly by group, with a Group x Plausibility interaction in Column 3 (F (1, 33) = 7.81, p = .009), and a

Group x Plausibility x Laterality x Anteriority interaction in Column 1 (F (2, 66) = 3.23, p = .049). These results revealed a large N400 effect in the *Pr-TF-* vs. *Pr-TF+* comparison. Figure 5-4 suggests that the age-matched controls had a larger and more widely distributed N400 compared to the participants with aphasia. Follow up analyses were conducted within each group to further investigate these interactions.

Age-Matched Controls.

A main effect of Plausibility was discovered in all columns, (c1: F (1, 19) = 7.49 p = .013; c2; (F (1, 19) = 6.23, p = .022; c3: F (1, 19) = 7.39, p = .014; midline: F (1, 19) = 8.10, p = .010). This reflected that sentences with an implausible NP (*Pr-TF-*) were significantly more negative-going relative to sentences with a plausible NP (*Pr-TF+*) (Figure 5-4A). These results suggest that age-matched controls were sensitive to the plausibility manipulation, as a significant N400 effect was found.

Individuals with Aphasia.

The analyses did not reveal evidence of a significant N400 effect in the participants with aphasia (Figure 5-4B).

Onset of Ambiguous NP (song/beer) – P600 Effects (600-1200ms epoch)

Age-Matched Controls vs. Individuals with Aphasia.

A significant P600 effect, distributed primarily in centroparietal, parietal, and occipital sites, was found in *Pr-TF-* (implausible NP) vs. *Pr-TF+* (plausible

NP) (see Figure 5-5). The P600 effect was revealed in significant Plausibility x Anteriority interactions in all columns, (c1: F (2, 66) = 12.39, $p < .001$; c2: F (3, 99) = 15.39, $p < .001$; c3: F (4, 132) = 4.58, $p = .014$; midline: F (4, 132) = 5.67, $p = .006$)

The P600 effect in *Pr-TF-* vs. *Pr-TF+* differed by group as indicated by a significant Group x Plausibility x Anteriority interaction in Columns 1-2 (c1: F (2, 66) = 3.66, $p = .042$; c2: F (3, 99) = 4.00, $p = .03$) and a significant Group x Plausibility x Laterality x Anteriority interaction in Column 1 (F (2, 66) = 4.73, $p = .012$). The P600 effect was larger in the age-matched control group, and was distributed across both hemispheres, at centroparietal, parietal and occipital sites (see Figure 5-4A, 5-4B). Whereas the P600 effect in the participants with aphasia was smaller and distributed across centroparietal, and parietal sites in the left-hemisphere.

Age-Matched Controls.

The implausible NP in *Pr-TF-* vs. *Pr-TF+* elicited a significant P600 effect in the age-matched controls in centroparietal, parietal occipital sites (Figure 5-4A). This was revealed in significant interactions of Plausibility x Anteriority at all columns, (c1: F (2, 38) = 13.20, $p < .001$; c2: F (3, 57) = 18.33, $p < .001$; c3: F (4, 76) = 12.142, $p < .001$; midline: F (4, 76) = 10.28, $p < .001$)

Individuals with Aphasia.

Significant interactions of Plausibility x Laterality x Anteriority at Column 1 (F (2, 28) = 6.97, $p = .006$), reflected a P600 effect at left-hemisphere centroparietal and parietal sites (Figure 5-4B). This is evidence that an implausible NP paired with incongruent prosody in *Pr-TF-* elicited a significant P600 effect in individuals with aphasia.

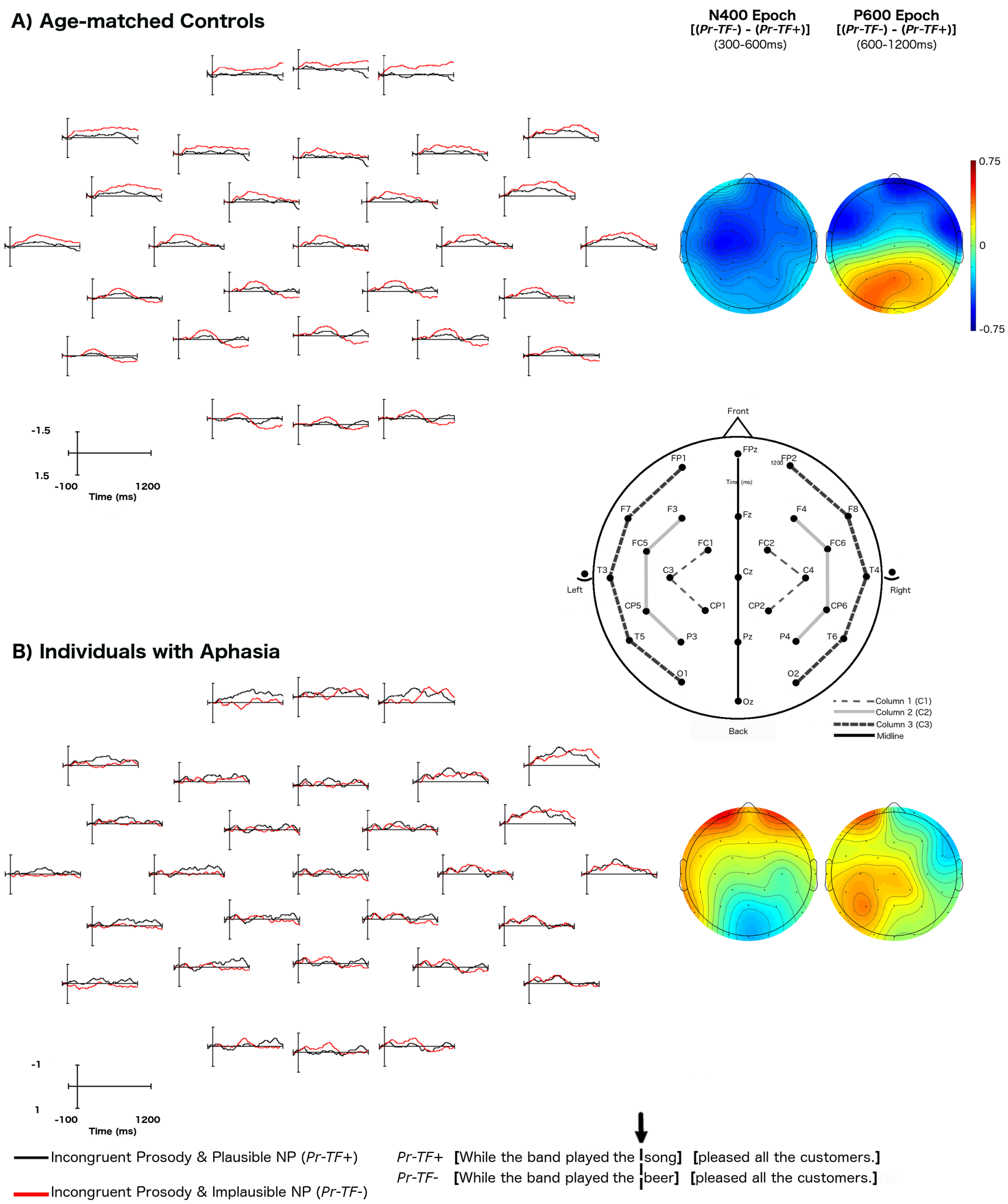


Figure 5-4. Grand average ERPs and voltage maps of the N400 epoch (300-600ms) and P600 epoch (600-1200ms) at the onset of the ambiguous NP (*song/beer*) in conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) in A) age-matched controls, and B) individuals with aphasia. Voltage maps depict the scalp distribution of the difference waves (incongruent – congruent) in each epoch. The plausibility cue present in the implausible NP (*beer*) in *Pr-TF-* vs. *Pr-TF+* elicited a significant N400-P600 complex in age-matched controls. However, evidence of a P600 effect but no N400 effect was found in the individuals with aphasia.

PROSODY-DRIVEN GARDEN-PATH EFFECTS AT DISAMBIGUATION POINT (CRITICAL VERB *PLEASED)*

Waveforms time-locked to the critical verb, *pleased* (the disambiguation point in all four experimental conditions), were compared to examine whether incongruent prosody elicited garden-path effects. N400 effects were examined in the 300-600ms epoch and P600 effects in the 600-1200ms epoch. An N400-P600 complex at the disambiguation point in conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) would indicate the participants were garden-pathed as a result of the prosodic manipulation. A 100 post-stimulus baseline interval was used to compensate for the P600 effect in condition *Pr-TF-,* described in the previous section, that immediately preceded the critical verb. Using a pre-stimulus baseline was not ideal because the positivity at the ambiguous NP *beer* in *Pr-TF-* pulled down the effects of interest so that waveforms could not be adequately compared at the critical verb.[3]

Onset of Critical Verb (pleased) – N400 Effects (300-600ms epoch)

Age-Matched Controls vs. Individuals with Aphasia.

Waveforms in conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) were significantly more negative-going relative to those with congruent prosody (*Pr+TF+*, *Pr+TF-*) at centroparietal, parietal, and occipital regions particularly in the right-hemisphere. These results were revealed in significant interactions of

---

[3] Analyses were also conducted using a traditional 100 pre-stimulus baseline and the effects were very similar to the ones reported here.

Prosody x Anteriority interaction in all four columns, (c1: F (2, 66) = 11.09, $p <$ .001; c2: F (3, 99) = 21.36, $p <$ .001; c3: F (4, 132) = 20.05, $p <$ .001; midline: F (4, 132) = 11.37, $p <$ .001), Prosody x Laterality x Anteriority in Columns 2-3 (c2: F (3, 99) = 8.71, $p <$ .001; c3: F (4, 132) = 7.94, $p <$ .001), and Prosody x Laterality in Column 3 (F (1, 33) = 7.19, p = .011). Also, the N400 effect was larger in *Pr-TF-* (implausible NP) vs. *Pr-TF+* (plausible NP), as evidenced by interactions of Plausibility x Anteriority in Columns 1-2, and a significant Prosody x Plausibility x Anteriority in Column 3 (F (3, 99) = 4.24, p = .033).

The scalp distribution of the N400 effect also differed by group. While the N400 effect had a distribution at centroparietal, parietal and occipital left-hemisphere sites in the age-matched controls, the distribution was centered primarily at centroparietal, parietal, temporal and occipital right-hemisphere sites in the individuals with aphasia. This was indicated by Group x Prosody x Laterality interactions at Columns 1-2, (c1: F (1, 33) = 6.91, p = .013; c2: F (1, 33) = 6.12, p = .019), Group x Prosody x Anteriority interactions at Columns 1-3, (c1: F (2, 66) = 5.59, p = .011; c2: F (3, 99) = 4.56, p = .023; c3: F (4, 132) = 3.40, p = .043), and Group x Prosody x Laterality x Anteriority interaction at Column 3 (F (4, 132) = 3.20, p = .037). Given these between group differences, follow up analyses examining the effects of interest were conducted within each group.

Age-Matched Controls.

A significant Prosody x Anteriority interaction was discovered in all columns, (c1: $F(2, 38) = 19.53$, $p < .001$; c2: $F(3, 57) = 28.08$, $p < .001$; c3: $F(4, 76) = 20.60$, $p < .001$; midline: $F(4, 76) = 12.84$, $p < .001$), signifying significantly more negative-going waveforms in conditions with incongruent (*Pr-TF+*, *Pr-TF-*) relative to congruent prosody (*Pr+TF+*, *Pr+TF-*) at centroparietal, parietal, and occipital sites (Figure 5-5A). Additionally, a Prosody x Laterality interaction in Columns 1-3, (c1: $F(1, 19) = 5.19$, $p = .034$; c2: $F(1, 19) = 8.30$, $p = .01$, c3: $F(1, 19) = 9.90$, $p = .005$), revealed that conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) were significantly more negative-going at left-lateralized sites compared to conditions with congruent prosody (*Pr+TF+*, *Pr+TF-*). The analyses reveal that both conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) elicited significantly larger N400s at the critical verb (Figure 5-5A).

Individuals with Aphasia.

A Prosody x Laterality x Anteriority interaction was revealed at Columns 2-3, c2: $F(3, 42) = 12.76$, $p < .001$; c3: $F(4, 56) = 10.82$, $p < .001$), and a Prosody x Anteriority interaction was also found at Column 3 ($F(4, 56) = 4.48$, $p = .029$). These interactions indicated that conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) were more negative-going than those with congruent prosody (*Pr+TF+*, *Pr+TF-*) especially at right-hemisphere posterior sites (Figure 5-5B). Thus, incongruent prosody resulted in a significant N400 effect in the individuals with aphasia.

Onset of Critical Verb (pleased) – P600 Effects (600-1200ms epoch)

Age-Matched Controls vs. Individuals with Aphasia.

Significant interactions of Prosody x Plausibility were found in all columns, (c1: F (1, 33) = 9.43, p = .004; c2: F (1, 33) = 8.20, p = .007; c3: F (1, 33) = 4.41, p = .044; midline: F (1, 33) = 8.50, p = .006), along with significant Prosody x Plausibility x Anteriority interactions in all columns, (c1: F (2, 66) = 7.45, p = .003); c2: F (3, 99) = 16.71, p < .001; c3: F (4, 132) = 4.70, p = .017; midline: F (4, 132) = 3.58, p = .035). These interactions demonstrate that waveforms in sentences with incongruent prosody and a plausible NP (*Pr-TF+*) were more positive-going than the other three conditions. In contrast, the waveforms in sentences with incongruent prosody and an implausible NP (*Pr-TF-*) were more negative-going than the other three conditions. This difference in *Pr-TF+* (plausible NP) vs. *Pr-TF-* (implausible NP) was largest at central, centroparietal and parietal sites. These results show that sentences with incongruent prosody and a plausible NP (*Pr-TF+*) elicited a significant P600 effect, whereas sentences with incongruent prosody and an implausible NP (*Pr-TF-*) elicited negative-going waveforms.

The P600 effect varied between groups as evidenced by significant interactions of Group x Prosody x Laterality x Anteriority in Columns 2-3, (c2: F (3, 99) = 4.22, p = .019; c3: F (4, 132) = 3.02, p = .039). The distribution of the P600 effect was larger in the age-matched controls and encompassed temporal and occipital sites across both hemispheres that the P600 effect in the individuals with aphasia did not. The P600 effect in individuals with aphasia was primarily centered over left-hemisphere centroparietal and parietal sites.

Age-Matched Controls.

A Prosody x Plausibility interaction was discovered in all columns, (c1: F (1, 19) = 8.24, p = .01; c2: F (1, 19) = 9.83, p = .005; c3: F (1, 19) = 7.91, p = .011; midline: F (1, 19) = 8.87, p = .008), which resulted from the large P600 (see Figure 5-5A) in the condition with incongruent prosody and a plausible NP (*Pr-TF+*) relative to the other three conditions. Additionally, column 2 revealed a Plausibility x Anteriority (F (3, 57) = 5.61, p = .015), and a Prosody x Plausibility x Anteriority (F (3, 57) = 8.68, p = .002) interaction. These interactions at column 2 reflect that the P600 in *Pr-TF+*, with incongruent prosody and a plausible NP, is more positive-going than waveforms in the other three conditions particularly at centroparietal and parietal sites. These combined results describe a significant P600 effect in *Pr-TF+*, with incongruent prosody and a plausible NP (*the song*). However, no P600 effect was apparent in *Pr-TF-*, the condition with incongruent prosody and an implausible NP (*the beer*).

Individuals with Aphasia.

A Prosody x Laterality interaction was found at Column 2 (F (1, 14) = 5.41, p = .036), indicating that at right-hemisphere sites conditions with congruent prosody (*Pr+TF+, Pr+TF-*) had significantly more positive–going waveforms than those with incongruent prosody (*Pr-TF+, Pr-TF-*) (Figure 5-5B). A Plausibility x Laterality x Anteriority interaction at Column 2 (F (2, 28) = 4.43,

p = .028), signifying that waveforms in conditions with a plausible NP (*Pr+TF+*, *Pr-TF+*) were more positive-going than those with an implausible NP (*Pr+TF-*, *Pr-TF-*) at left-hemisphere centro-parietal and parietal sites. Moreover, a Prosody x Plausibility x Laterality interaction at Column 2 (F (1, 14) = 4.98, p = .042), and a Prosody x Plausibility x Anteriority interaction at Columns 1-2 (c1: F (2, 28) = 4.01, p = .035; c2: F (3, 42) = 8.26, p = .004) show that condition *Pr-TF+* (incongruent prosody, and a plausible NP) possessed positive-going electrodes at left-hemisphere anterior (prefrontal, frontal, and central) sites. Thus, we found evidence of a significant positive-going effect especially in *Pr-TF+*.

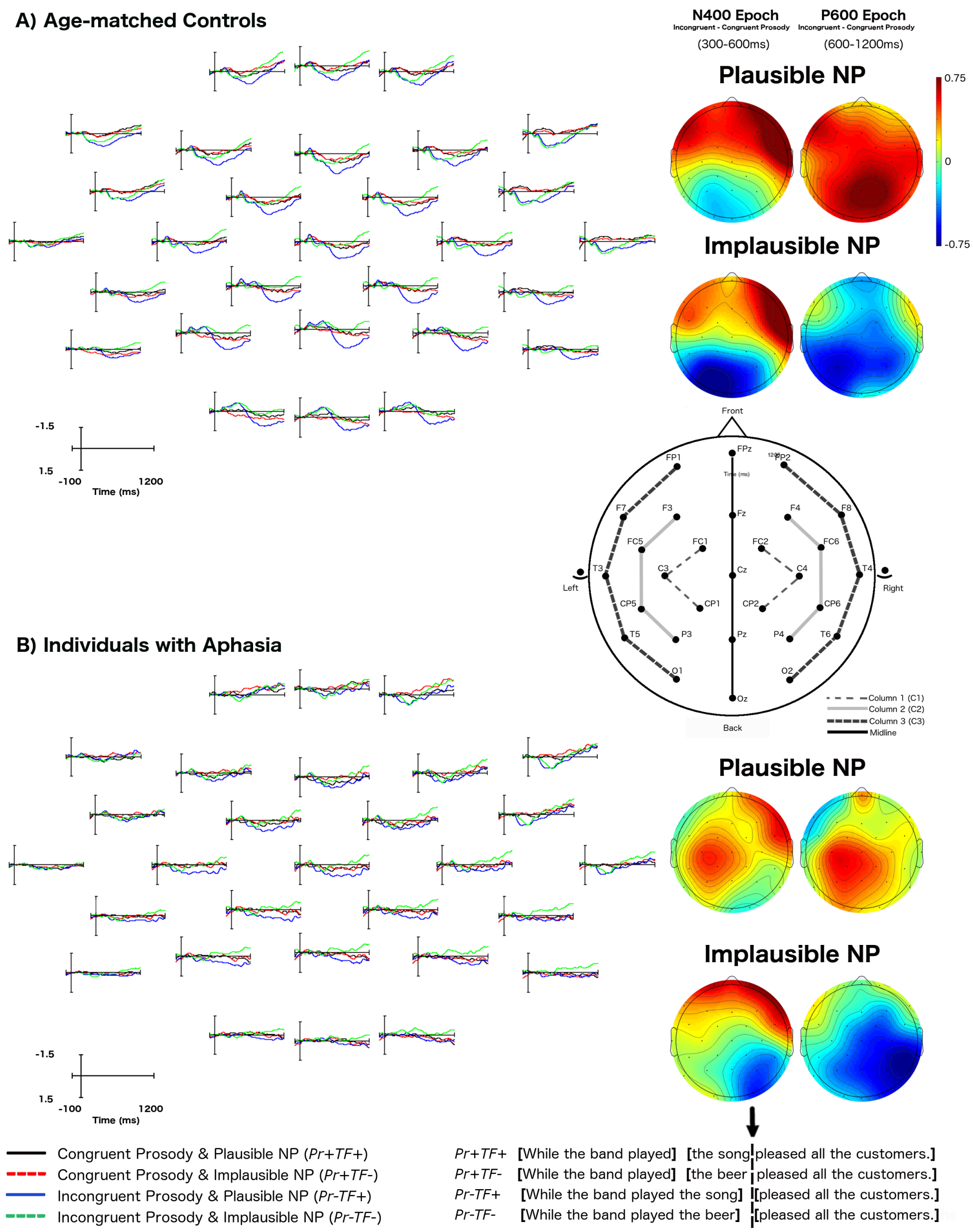


Figure 5-5. Grand average ERPs and voltage maps of the N400 epoch (300-600ms) and P600 epoch (600-1200ms) at the onset of the critical verb (*pleased*) in A) age-matched controls, and B) individuals with aphasia. Voltage maps demonstrate the scalp distribution of the difference waves (incongruent – congruent prosody) in conditions with a plausible NP (*song* in *Pr-TF+* vs. *Pr+TF+*) and an implausible NP (*beer* in *Pr-TF-* vs. *Pr+TF-*) in each epoch. Incongruent prosody elicited an N400-P600 effect at the critical verb in sentences with a plausible NP (*the song*), and an N400 effect in sentences with an implausible NP (*the beer*) in both groups. The N400 effect was left-lateralized in the age-matched control group, but right-lateralized in the individuals with aphasia.

FINAL WORD ANALYSES (*CUSTOMERS)*

ERPs time-locked to the sentence-final word in each condition were compared. Prior research has found that a sustained N400 effect is elicited at the final word in unacceptable sentences in neurologically unimpaired populations (Osterhout & Holcomb, 1992; 1993). Therefore, we anticipated finding N400 effects in both conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) in the healthy controls. The presence of sentence-final word N400 effects sentences with incongruent prosody (*Pr-TF+*, *Pr-TF-*) in individuals with aphasia would indicate they were sensitive to the prosody manipulation. ERPs were compared in both the 300-600ms and 600-900ms epoch because these effects often have a long latency in healthy controls, and also to examine possible differences in latency between the control and aphasia groups.

Onset of Final word (customers) – N400 Effects (300-600ms epoch)

Age-Matched Controls vs. Individuals with Aphasia.

Significant Prosody x Anteriority interactions were revealed at Columns 1,3 and midline, (c1: F (2, 66) = 5.04, p = .022; c3: F (1, 33) = 13.44, p = .001; midline: F (4, 132) = 4.72, p = .019), along with significant Prosody x Laterality x Anteriority interactions in Columns 2-3, (c2: F (3, 99) = 11.41, p < .001; c3: F (4, 132) = 3.62, p = .038), and a Prosody x Laterality interaction in Column 3 (F (1, 33) = 13.44, p = .001). These results describe an N400 effect in sentences with incongruent prosody (*Pr-TF+*, *Pr-TF-*) compared to those with congruent prosody (*Pr+TF+*, *Pr+TF-*), that was distributed primarily in right-hemisphere prefrontal, frontal, central, and temporal sites. Additionally, a Prosody x Plausibility x Laterality x Anteriority in Column 1 (F (2, 66) = 4.48, p = .019), indicated the large N400 effect resulting from incongruent prosody was largest in *Pr-TF-*, with an implausible NP (*the beer*). Finally, a Group x Prosody interaction in Column 1 (F (1, 33) = 4.40, p = .044) demonstrated that while in the healthy controls waveforms were more negative-going in incongruent prosody conditions (*Pr-TF+*, *Pr-TF-*), they were more positive-going in the individuals with aphasia. The waveforms are described within each group below.

Age-Matched Controls.

A main effect of Prosody was found at all columns, (c1: F (1, 19) = 8.36, p = .009; c2: F (1, 19) = 9.76, p = .006; c3: F (1, 19) = 7.10, p = .015; midline: F (1, 19) = 4.49, p = .048), along with significant interactions of Prosody x Anteriority in all columns, (c1: F (2, 38) = 4.63, p = .033; c2: F (3, 57) = 9.55, p = .002; c3: F (4, 76) = 5.53, p = .021; midline: F (4, 76) = 4.96, p = .022). Significant interactions of Prosody x Laterality were also found in Columns 1-3, (c1: F (1, 19) = 7.49, p = .013; c2: F (1, 19) = 15.97, p = .001; c3: F (1, 19) = 11.64, p = .003), as well as significant interactions of Prosody x Laterality x Anteriority in Columns 1-2, (c1: F (2, 38) = 9.04, p = .001; c2: F (3, 57) = 3.78, p = .032).

As shown in Figure 5-6A, these analyses reveal a significant N400 effect distributed primarily at prefrontal, frontal, central, and temporal sites in the right-hemisphere in the 300-600ms epoch in sentences with incongruent prosody (*Pr-TF+*, *Pr-TF-*) compared to those with congruent prosody (*Pr+TF+*, *Pr+TF-*). Moreover, a significant main effect of Plausibility in all Columns, (c1: F (1, 19) = 5.39, p = .032; c2: F (1, 19) = 5.66, p = .028; c3: F (1, 19) = 6.38, p = .021; midline: F (1, 19) = 4.73, p = .042), indicated that the N400 effect was largest in the comparison with an implausible NP. A significant Plausibility x Anteriority interaction in the midline columns demonstrates the implausible NP N400 effect is largest at anterior sites.

Individuals with Aphasia.

A significant Prosody x Laterality x Anteriority (F (4, 56) = 4.52, p = .010) interaction in Column 3 indicated more negative-going waveforms in conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) at right-hemisphere prefrontal, frontal and temporal sites (Figure 5-6B).

Onset of Final word (customers) – Sustained N400 Effects (600-900ms epoch)

Age-Matched Controls vs. Individuals with Aphasia.

The analyses at the final word in the 600-900ms epoch revealed a main effect of Prosody in all columns, (c1: F (1, 33) = 14.63, p = .001; c2: F (1, 33) = 16.50, p < .001); c3: F (1, 33) = 13.13, p = .001; midline: F (1, 33) = 11.04, p = .002). Significant interactions of Prosody x Laterality in Columns 1-3, (c1: F (1, 33) = 5.86, p = .021; c2: F (1, 33) = 13.29, p = .001; c3: F (1, 33) = 10.19, p = .003), and Prosody x Laterality x Anteriority in Columns 1 and 3, (c1: F (2, 66) = 3.46, p = .043; c3: F (4, 132) = 5.47, p = .003) were also discovered. These findings indicate waveforms that were more negative-going in sentences with incongruent prosody (*Pr-TF+*, *Pr-TF-*) relative to congruent prosody (*Pr+TF+*, *Pr+TF-*). This sustained N400 effect was primarily located in the right-hemisphere at prefrontal, frontal, central, and temporal sites.

Furthermore, significant interaction of Group x Prosody x Anteriority in Column 2 (F (3, 99) = 4.77, p = .012) demonstrated that the sustained was largest in anterior sites in the healthy controls, but the effect was largest at posterior sites in the individuals with aphasia. A Group x Prosody x Plausibility x Laterality in Column 2 (F (1, 33) = 7.58, p = .010) also indicated that the sustained N400 effect in the plausible NP comparison (*Pr-TF+* vs. *Pr+TF+*) was distributed primarily in the right-hemisphere in the age-matched controls, but was distributed across both hemispheres in the individuals with aphasia. Even so the sustained N400 effect was smaller in the aphasia group. These differences between groups are explored in detail within each group below.

Age-Matched Controls.

Within the age-matched control group we found a significant main effect of Prosody in all columns, (c1: F (1, 19) = 16.48, p = .001; c2: F (1, 19) = 20.57, p < .001; c3: F (1, 19) = 17.85, p < .001; midline: F (1, 19) = 10.43, p = .004), where incongruent prosody (*Pr-TF+*, *Pr-TF-*) elicited negative-going waveforms relative to congruent prosody (*Pr+TF+*, *Pr+TF-*). This effect was primarily distributed in anterior sites in the right-hemisphere (see Figure 5-6A), as evidenced by significant Prosody x Laterality interactions in Columns 1-3, (c1: F

(1, 19) = 9.16, p = .007; c2: F (1, 19) = 18.07, p < .001; c3: F (1, 19) = 11.23, p = .003), significant Prosody x Anteriority interactions in Column 3 and the midline column, (c3: F (4, 76) = 5.58, p = .005; midline: F (4, 76) = 4.50, p = .016), and a Prosody x Laterality x Anteriority interaction in Column 1 (F (2, 38) = 3.52, p = .049). Additionally, a Plausibility x Anteriority F (3, 57) = 3.51, p = .038 indicated that the sustained N400 was larger in *Pr-TF-* with both incongruent prosody and an implausible NP (Figure 5-6A).

Individuals with Aphasia.

A Prosody x Anteriority interaction in Column 1 (F (2, 28) = 5.57, p = .020), and a Prosody x Laterality x Anteriority interaction in Column 3 (F (4, 56) = 5.54, p = .005) indicated negative-going waveforms at right-hemisphere central, centroparietal, temporal, and occipital sites in sentences with incongruent prosody (*Pr-TF+*, *Pr-TF-*) (Figure 5-6B). Additionally, a Prosody x Plausibility x Laterality F (1, 14) = 7.77, p = .015 indicated this N400 effect was largest in the comparison with the implausible NP (*Pr-TF-* vs. *Pr+TF-*).

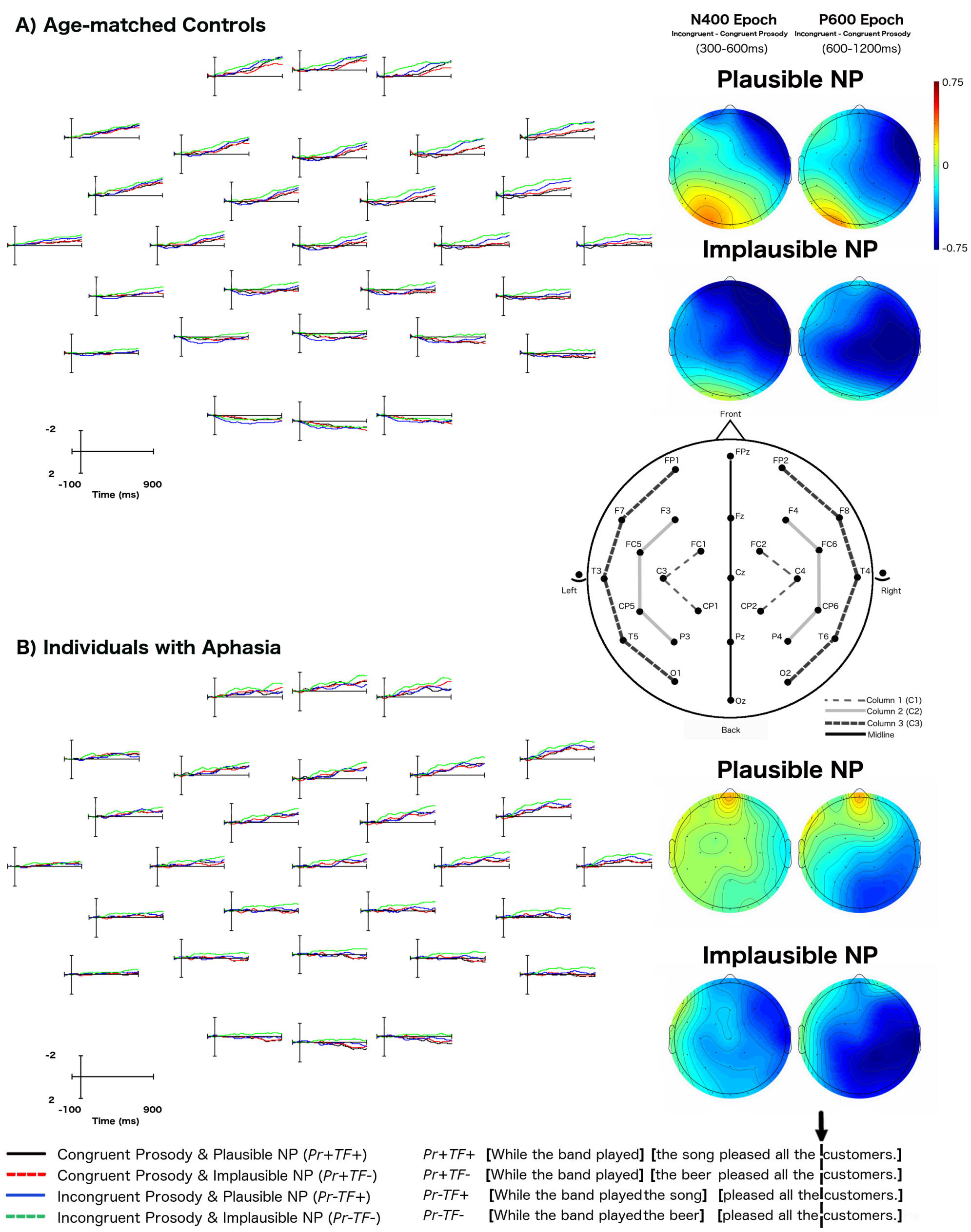


Figure 5-6. Grand average ERPs and voltage maps time locked to the onset of the final word across all four conditions. Two epochs are shown (300-600ms and 600-900ms) in A) age-matched controls, and B) individuals with aphasia. The voltage maps depict the scalp distribution of the difference waves (incongruent – congruent prosody) in conditions with a plausible NP [*song* in (*Pr-TF+*) – (*Pr+TF+*)] and an implausible NP [*beer* in (*Pr-TF-*) – (*Pr+TF-*)] in each epoch. Sentences with incongruent prosody elicited an N400 effect at the final word in both the 300-600ms and 600-900ms epochs in both participant groups. The N400 effect was largest in sentences with incongruent prosody and an implausible NP (*Pr-TF-*).

5.3.1.2 High vs. Low Comprehenders

<u>ONSET OF PROSODIC BREAK – CPS EFFECTS</u>

Subordinate Verb Offset (played) – CPS Effects (0-600ms Epoch)

(Corresponding to prosodic break in Congruent Prosody conditions, *Pr+TF+* and *Pr+TF-*)

High Comprehenders.

A main effect of Prosody was discovered in Columns 2-3, (c2: F (1, 5) = 7.32, p = .043; c3: F (1, 5) = 7.14, p = .044), and a Prosody x Laterality interaction was also found in Column 3 (F (1, 5 = 8.51, p = .033). These findings reflected a significant CPS effect in conditions with congruent (*Pr+TF+*, *Pr+TF-*) vs. incongruent (*Pr-TF+*, *Pr-TF-*) prosody, particularly at right-hemisphere sites (Figure 5-7A).

Low Comprehenders.

A significant Prosody x Anteriority interaction was detected in Column 3 (F (4, 32) = 3.91, p = .050), indicating a CPS effect at posterior sites in conditions with congruent (*Pr+TF+*, *Pr+TF-*) relative to incongruent prosody (*Pr-TF+, Pr-TF-*). Thus, prosodic breaks elicited a significant CPS effect in Low Comprehenders (Figure 5-7B).

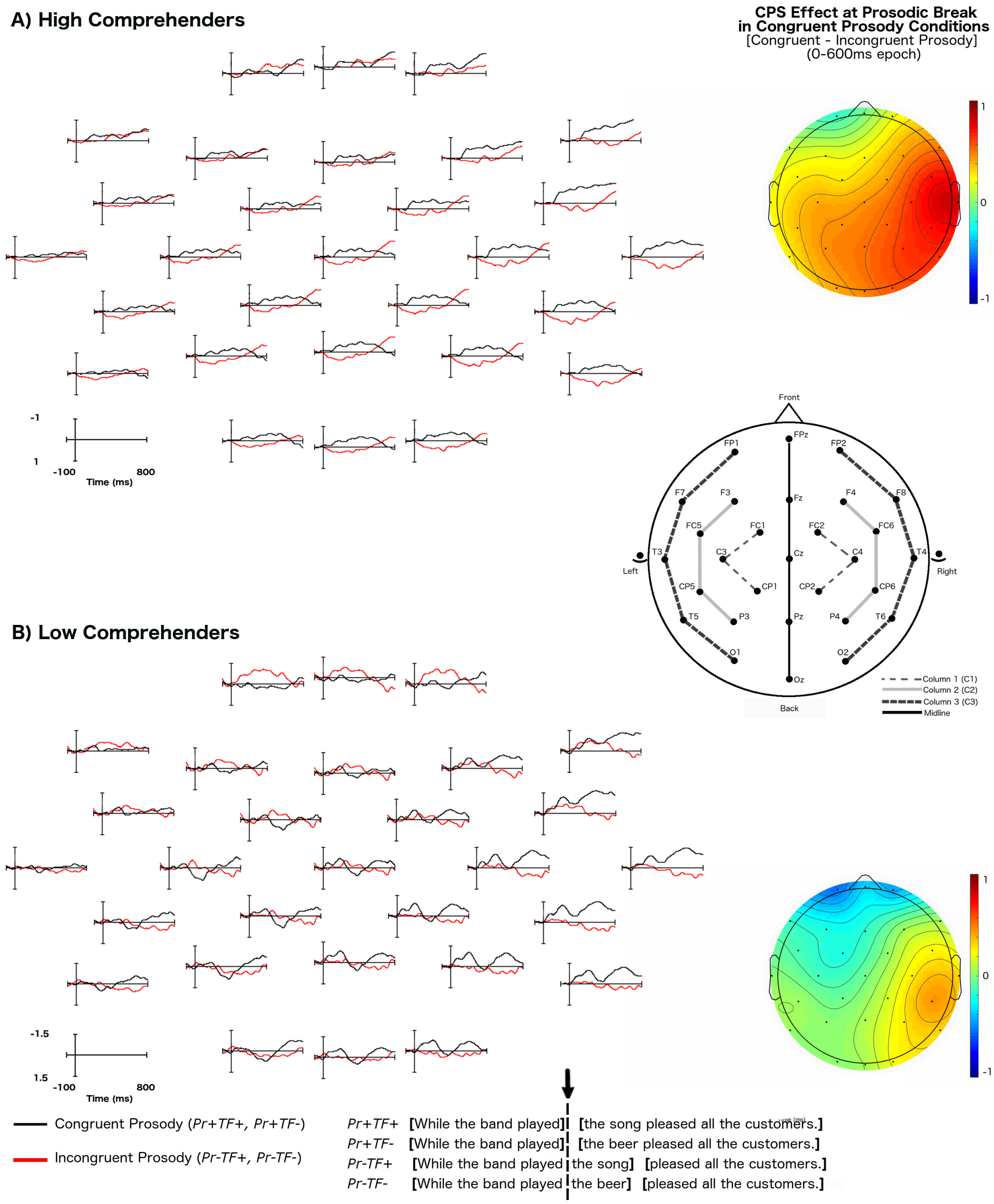


Figure 5-7. Grand average ERPs and voltage maps of the CPS effect at the onset of the prosodic break in conditions with congruent prosody relative to those with incongruent prosody in A) High Comprehenders and B) Low Comprehenders. The voltage maps show the scalp distribution of the difference waves (congruent – incongruent) in the 0-600ms epoch. The prosodic break in sentneces with congruent prosody (*Pr+TF+*, *Pr+TF-*) elicited a CPS effect in both High and Low Comprehenders, though the voltage maps demonstrate a smaller CPS effect in Low Comprehenders.

PLAUSIBILITY-DRIVEN GARDEN-PATH EFFECTS AT ONSET OF AMBIGUOUS NP (*SONG/BEER*)

Onset of Ambiguous NP (song/beer) – N400 Effects (300-600ms epoch)

High Comprehenders.

In the *High Comprehenders* group we discovered a Plausibility x Anteriority interaction in Columns 2-3 and midline, (c2: F (3, 15) = 4.97, p = .038; c3: F (4, 20) = 5.56, p = .025; midline: F (4, 20) = 6.13, p = .031). These analyses indicated a significant N400 effect at all but the most anterior sites in the implausible NP condition (*Pr-TF-*) relative to the plausible NP condition (*Pr-TF+*).

Low Comprehenders.

A Prosody x Plausibility x Laterality interaction at Columns 2-3, (c2: F (1, 8) = 7.72, p = .024; c3: F (1, 8) = 8.43, p = .020)) indicated that the comparison between implausible NP (*Pr-TF-*) vs. a plausible NP (*Pr-TF+*) elicited positive-going waveforms at left-hemisphere sites (Figure 5-8B).

Onset of Ambiguous NP (song/beer) – P600 Effects (600-1200ms epoch)

High Comprehenders.

The comparison between *Pr-TF-* (incongruent prosody and implausible NP) vs. *Pr-TF+* (incongruent prosody and plausible NP), elicited a significant P600 effect in the High Comprehenders. Significant Prosody x Anteriority interactions in Columns 1-2, (c1: $F(2, 10) = 5.64$, $p = .044$; c2: $F(3, 15) = 6.36$, $p = .027$), indicated this P600 effect was primarily distributed at centroparietal and parietal sites (Figure 5-8A).

Low Comprehenders.

A significant Plausibility x Laterality x Anteriority interaction was revealed in Column 1 ($F(2, 16) = 6.05$, $p = .025$), signifying positive-going waveforms in *Pr-TF-* vs. *Pr-TF+* in left-hemisphere central sites (Figure 5-8B).

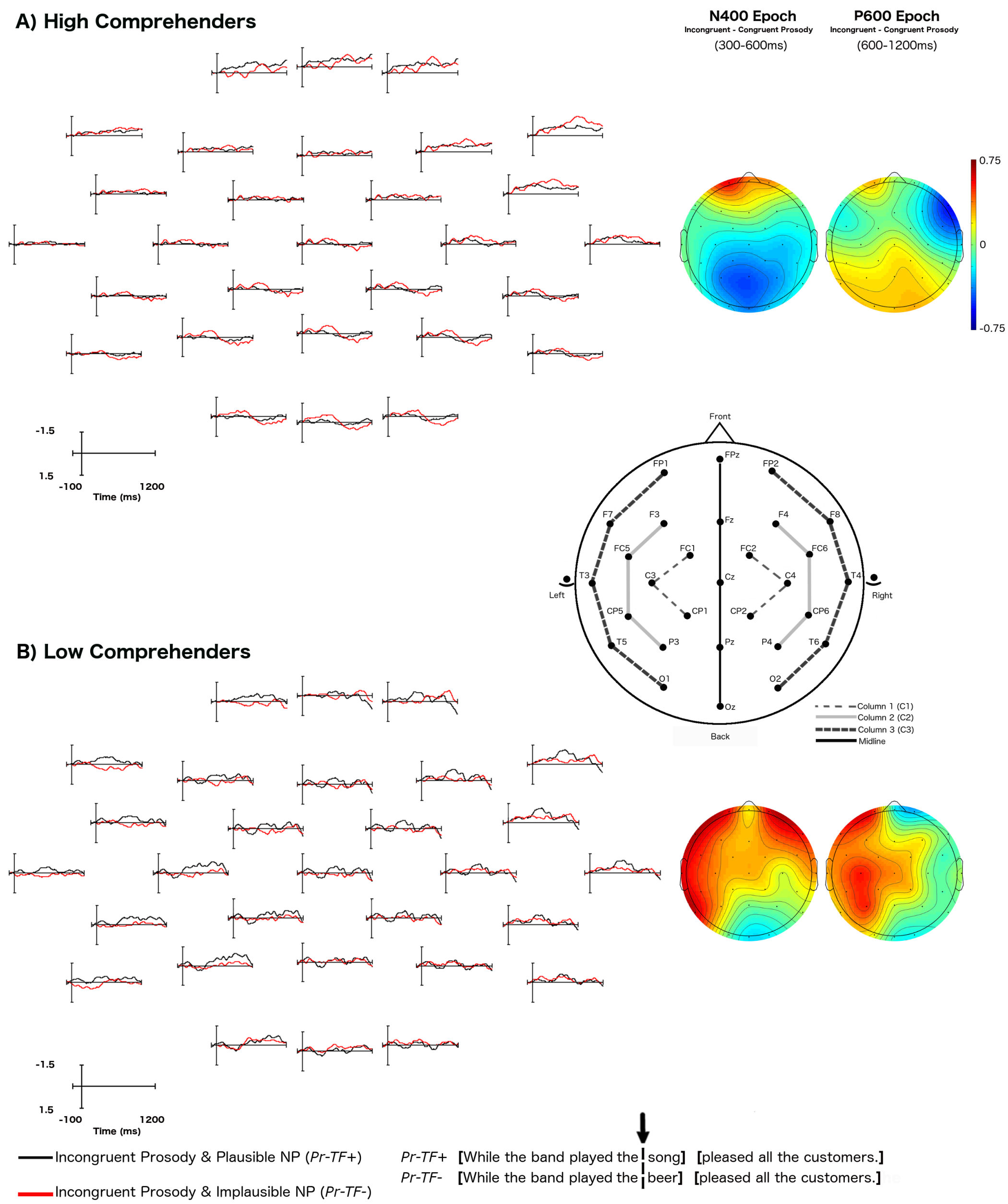


Figure 5-8. Grand average ERPs and voltage maps of the N400 epoch (300-600ms) and P600 epoch (600-1200ms) at the onset of the ambiguous NP (*song/beer*) in conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) in A) High Comprehenders, and B) Low Comprehenders. Voltage maps depict the scalp distribution of the difference waves (incongruent – congruent) in each epoch. The plausibility cue present in the implausible NP (*beer*) in *Pr-TF-* vs. *Pr-TF+* elicited a significant N400-P600 complex in High Comprehenders. However, a left-lateralized sustained positivity in both the 300-600ms and 600-1200ms epochs was revealed in the group of Low Comprehenders.

PROSODY-DRIVEN GARDEN-PATH EFFECTS AT DISAMBIGUATION POINT (CRITICAL VERB *PLEASED)*

Onset of Critical Verb (pleased) – N400 Effects (300-600ms epoch)

High Comprehenders.

In the High Comprehenders group a Plausibility x Laterality interaction at Column 2 (F (1, 5) = 6.63, p = .05), a Plausibility x Anteriority interaction at Column 2 and midline (c2: F (3, 15) = 4.97, p = .039; midline: F (4, 20) = 5.66, p = .005), and a Plausibility x Laterality x Anteriority at Column 3 (F (4, 20) = 6.50, p = .023) were revealed. These interactions portrayed negative-going effects in conditions with implausible NPs (*Pr+TF-*, *Pr-TF-*) relative to plausible NPs (*Pr+TF+,* Pr-TF+) that was largest at right-hemisphere central, centro-parietal, parietal, temporal and occipital sites (Figure 5-9A). Therefore, there was significant evidence of an N400 effect in conditions with an implausible NP. However, no evidence of prosody driven N400 effects was found.

Low Comprehenders.

There were interactions of Prosody x Laterality x Anteriority in Columns 2-3, (c2: F (3, 24) = 16.97, p < .001; c3: F (4, 32) = 12.72, p = .001), indicating positive-going waveforms at right-hemisphere anterior electrodes in conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) relative to those with congruent prosody (*Pr+TF+*, *Pr+TF-*). Interactions of Prosody x Plausibility x Laterality at Columns 2-3, (c2: F (1, 8) = 6.21, p = .037; c3: F (1, 8) = 26.95, p = .001), revealed that waveforms in the condition with incongruent prosody and a plausible NP (*Pr-TF+*) were more positive-going than the condition with incongruent prosody and an implausible NP (*Pr-TF-*) at right-hemisphere sites (Figure 5-9B). Thus, while significant positive-going waveforms were discovered no evidence of N400 effects were found.

Onset of Critical Verb (pleased) – P600 Effects (600-1200ms epoch)

High Comprehenders.

The High Comprehenders group showed a main effect of Prosody at Columns 1-2, (c1: $F\,(1, 5) = 11.06$, $p = .021$; c2: $F\,(1, 5) = 6.90$, $p = .047$), and a Prosody x Laterality interaction at Column 1 ($F\,(1, 5) = 12.55$, $p = .017$). These results demonstrate that conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) were more negative -going than those with congruent prosody (*Pr+TF+*, *Pr+TF-*) at right-hemisphere sites. A main effect of Plausibility was also discovered at Columns 2-3 and midline (c2: $F\,(1, 5) = 16.90$, $p = .009$; c3: $F\,(1, 5) = 17.85$, $p = .008$; midline: $F\,(1, 5) = 21.95$, $p = .005$). The waveforms in conditions with incongruent NPs (*Pr+TF-*, *Pr-TF-*) were significantly more negative-going relative to those with congruent NPs (*Pr+TF+,* Pr-TF+). In other words, no evidence of a P600 effect was found in these comparisons. Rather a large negativity was found, particularly in sentences with incongruent prosody and an implausible NP (*Pr-TF-*) (Figure 5-9A).

Low Comprehenders.

The results from the Low Comprehenders group show a main effect of Prosody at Column 1 and midline (c1: F (1, 8) = 5.30, p = .05; midline: F (1,8) = 5.75, p = .043) where conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) were more positive-going than those with congruent prosody (*Pr+TF+*, *Pr+TF-*) (Figure 5-9B). Interactions of Prosody x Plausibility x Laterality at Columns 2-3, (c2: F (1, 8) = 18.06, p = .003; c3: F (1, 8) = 17.50, p = .003), and Plausibility x Laterality x Anteriority at Column 3 (F (4, 32) = 4.18, p = .035) were also found.

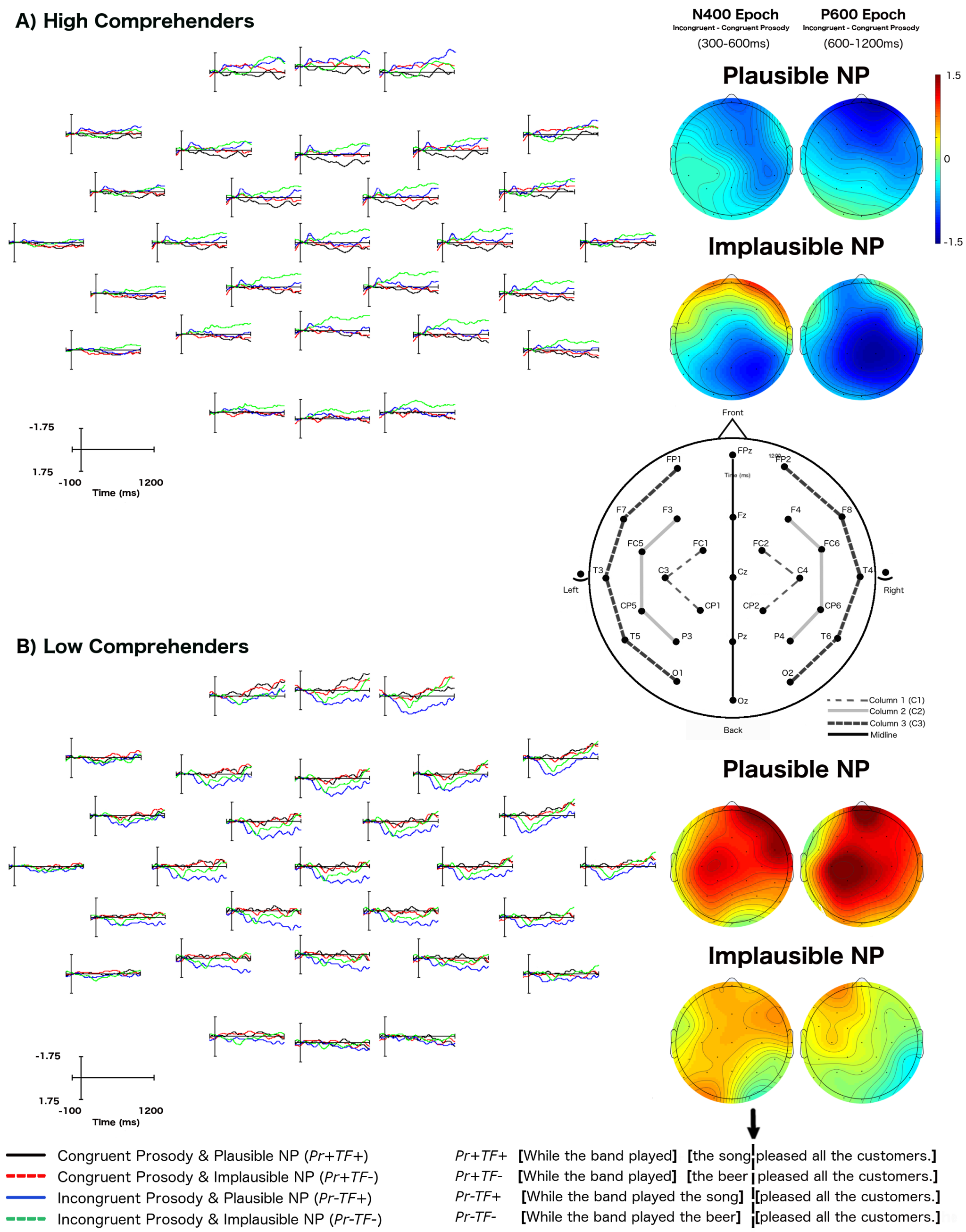


Figure 5-9. Grand average ERPs and voltage maps of the N400 epoch (300-600ms) and P600 epoch (600-1200ms) at the onset of the critical verb (*pleased*) in A) High Comprehenders, and B) Low Comprehenders. Voltage maps demonstrate the scalp distribution of the difference waves (incongruent – congruent prosody) in conditions with a plausible NP (*song* in *Pr-TF+* vs. *Pr+TF+*) and an implausible NP (*beer* in *Pr-TF-* vs. *Pr+TF-*) in each epoch. Sentences with incongruent prosody and an implausible NP (*Pr-TF-*) elicited a sustained negativity in High Comprehenders, while sentences with incongruent prosody (*Pr-TF+*, *Pr-TF-*) elicited a sustained positivity in Low Comprehenders.

FINAL WORD ANALYSES (*CUSTOMERS)*

Onset of Final word (customers) – N400 Effects (300-600ms epoch)

High Comprehenders.

A significant Prosody x Plausibility interaction at Column 1, (F (1, 5) = 8.34, p = .034), indicated more negative-going waveforms in *Pr-TF-,* with incongruent prosody and an implausible NP, relative to the other conditions. This reveals an N400 effect in the implausible NP comparison [(*Pr-TF-*) vs. (*Pr+TF-*)], but not the plausible NP comparison [(Pr-TF+) vs. (Pr+TF+)] (see Figure 5-10A).

Low Comprehenders.

No evidence of N400-like effects was discovered in this epoch (see Figure 5-10B).

Onset of Final word (customers) – Sustained N400 Effects (600-900ms epoch)

High Comprehenders.

No evidence of sustained N400 effects was found.

Low Comprehenders.

We found evidence of an N400 effect elicited by incongruent prosody, as evidenced by a significant main effect of Prosody in Column 1 (F (1, 8) = 6.04, p = .039), and a significant Prosody x Laterality x Anteriority interaction in Column

3 (*F* (4, 32) = 4.58, *p* = .018). Also, a significant Prosody x Plausibility x Laterality interaction in Column 2 (*F* (1, 8) = 7.44, *p* = .026), demonstrated the N400 effect in the implausible NP comparison (*Pr-TF-* vs. *Pr+TF-*) was larger at right-hemisphere sites than the plausible NP comparison (*Pr-TF+* vs. *Pr+TF+*) (see Figure 5-10B).

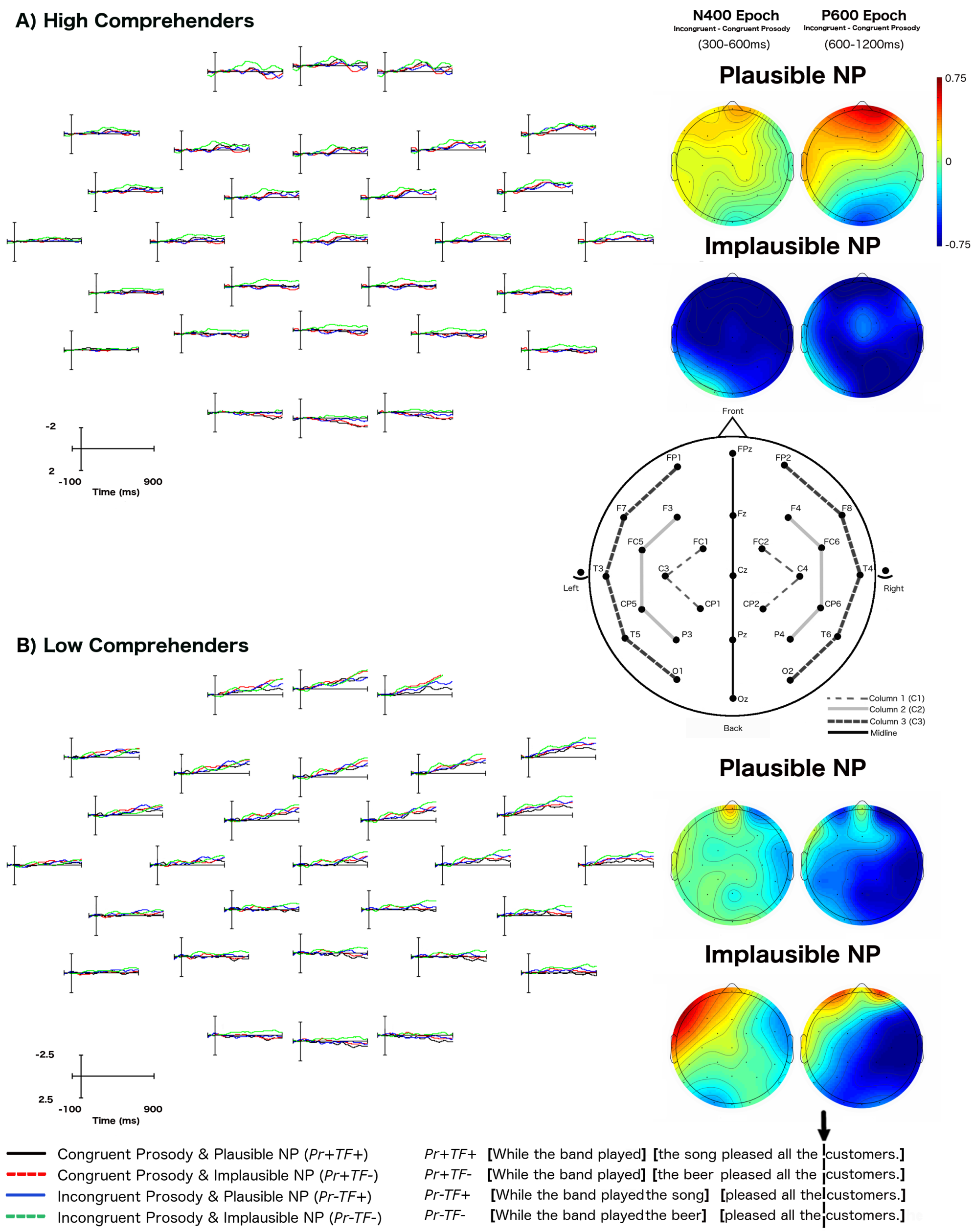


Figure 5-10. Grand average ERPs and voltage maps time locked to the onset of the final word across all four conditions. A 300-600ms and 600-900ms epoch are shown in A) High Comprehenders, and B) Low Comprehenders. The voltage maps show the scalp distribution of the difference waves (incongruent – congruent prosody) in conditions with a plausible NP [*song* in (*Pr-TF+*) – (*Pr+TF+*)] and an implausible NP [*beer* in (*Pr-TF-*) – (*Pr+TF-*)] in each epoch. Only sentences with incongruent prosody and an implausible NP (*Pr-TF-*) elicited a significant N400 effect in the 300-600ms epoch in High Comprehenders. Sentences with incongruent prosody (*Pr-TF+*, *Pr-TF-*) elicited an N400 effect in the 600-900ms epoch in the Low Comprehenders.

5.3.1.2 Behavioral Results

Table 5-3. Mean (standard deviation) accuracy (%) for age-matched control participants.

	Congruent Prosody		Incongruent Prosody	
	Plausible NP (*Pr+TF+*)	Implausible NP (*Pr+TF-*)	Plausible NP (*Pr-TF+*)	Implausible NP (*Pr-TF-*)
Age-matched Controls	83.8% (11.7%)	83.1% (14.0%)	86.4% (10.5%)	91.3% (7.9%)
Individuals with aphasia	70.8% (13.9%)	63.0% (13.2%)	44.3% (28.8%)	37.7% (31.3%).
High Comprehenders	71.5% (10.9%)	65.3% (10.0%)	40.2% (36.9%)	32.5% (38.7%)
Low Comprehenders	70.3% (16.3%)	61.4% (15.4%)	47.0% (24.0%)	41.2% (27.4%)

The age-matched controls were significantly more accurate than the individuals with aphasia at judging the acceptability of sentences (F (1, 33) = 80.83, $p < .001$) (see Table 5-3). Significant interactions of Group x Prosody (F (1, 33) = 12.24, $p = .001$) and Group x Plausibility were found (F (1, 33) = 15.65, $p < .001$), indicating the control group was significantly more accurate at judging the acceptability in all conditions.

Age-Matched Controls.

Analyses revealed a main effect of Plausibility (F (1, 19) = 5.41, p = .031) indicating that participants were most accurate at judging sentences with an implausible NP. A significant Prosody x Plausibility interaction showed that participants were most accurate at judging sentences with both incongruent prosody and an implausible NP (*Pr-TF-*).

Individuals with Aphasia.

A significant main effect of Prosody was found (F (3, 56) = 18.47, p < .001) indicating that individuals with aphasia were significantly more accurate at judging the acceptability of sentences with congruent relative to incongruent prosody.

High Comprehenders.

Analyses of the acceptability responses revealed a significant main effect of Prosody (F (3, 20) = 8.02, p = .010). The High Comprehenders were significantly more accurate at judging the acceptability of conditions with congruent relative to incongruent prosody.

Low Comprehenders.

No significant differences were found between conditions.

5.4 Discussion

In this study we investigated ERPs in a group of individuals with aphasia and an age-matched control group in sentences containing temporary syntactic ambiguities in order to compare the effects of prosody and thematic fit/plausibility on sentence processing. Our main goal was to investigate whether and how individuals with aphasia exploit prosodic and thematic fit information and to determine how this process differs from sentence processing in neurologically unimpaired participants.

Consider again the sentences we compared in this study:

14a. [While the band played] [the song pleased all the customers.] (*Pr+TF+*)

14b. [While the band played] [the beer pleased all the customers.] (*Pr+TF-*)

14c. [While the band played the song] [pleased all the customers.] (*Pr-TF+*)

14d. [While the band played the beer] [pleased all the customers.] (*Pr-TF-*)

Recall that we examined waveforms for possible CPS effects, which are elicited at intonational phrase boundaries, time-locked to the onset of the prosodic break in conditions with congruent prosody [(14a) and (14b)], to the same point in the counterpart sentences [(14c) and (14d)], where there was not a prosodic break. We predicted we would find a significant CPS effect in the age-matched controls, and we also expected to find one in the participants with aphasia however we expected to find latency, distribution or amplitude differences between the two participant groups.

Our predictions were confirmed as the prosodic break in (14a) and (14b) elicited a significant CPS effect in the age-matched controls and the individuals with aphasia. However, while the CPS effect in the age-matched controls was distributed across both hemispheres, in the aphasia group the CPS effect was significantly smaller and distributed in the right-hemisphere. The CPS effect in both the High and Low Comprehenders was also distributed in the right-hemisphere. However, the CPS in the High Comprehenders was larger than the CPS in the Low Comprehenders. Thus, even though differences in amplitude and scalp distribution were found, our results confirm that individuals with aphasia do process prosodic information on time. While the CPS effect was small in the Low Comprehenders, even this group showed sensitivity to prosody.

Moving to our analyses at the temporarily ambiguous NP (*the song/the beer*), in the age-matched control group we predicted finding a significant biphasic N400-P600 effect in the comparison between the implausible NP (*the beer*) and the plausible NP (*the song*) in sentences with incongruent prosody:

15a. [While the band played the song] [pleased all the customers.]

15b. [While the band played the beer] [pleased all the customers.]

Recall that in (15b) *the beer* is a poor thematic fit as the direct object of *played.* Thus, (15b) may provide plausibility information to the parser that *the beer* is actually the subject of the upcoming main clause, which is the correct interpretation. However, in (15a) *the song* is a good thematic fit with the subordinate verb *played*, thus in (15a) no plausibility cue is present to signal the correct syntactic structure. In this comparison we anticipated the plausibility cue at the ambiguous NP in (15b) vs. (15a) would result in an N400-P600 effect in the control group. We found a significant N400-P600 complex in the healthy controls, suggesting that the poor thematic fit between *played* and *the beer* resulted in semantic integration difficulty (indexed by the N400) that triggered the parser to engage in syntactic reanalysis (indexed by the P600) to build or choose the correct syntactic structure. It is likely this P600 effect was similar to the thematic P600 described by Kuperberg et al. (2003), which was elicited by thematic role violations.

However, we found a P600 but no N400 effect in the individuals with aphasia. Yet, analyses in the High and Low Comprehender groups revealed that the High Comprehenders showed both an N400 and P600 effect distributed across both hemispheres, and the Low Comprehenders only showed a sustained positivity in the left-hemisphere.

These results suggest that both the age-matched controls and the High Comprehenders were sensitive to thematic fit information and were able to use plausibility cues in (15b) to engage in syntactic reanalysis before reaching the critical verb. However, the Low Comprehenders do not show this same sensitivity. Kielar and colleagues (2012) found a similar pattern in response to verb argument structure violations elicited a biphasic N400-P600 in healthy controls but only a P600 effect in individuals with aphasia. Also, Friederici et al. (1998) found that word category violations (e.g., * The friend was in the visited) elicited a negativity followed by a positivity in healthy controls but only a positivity in the patient with Broca's aphasia. The authors suggested that the early negativity reflected fast automatic semantic processing and the P600 reflected secondary syntactic processing. They proposed that the patient with Broca's aphasia had lost the resources required for initial fast processing but maintained secondary syntactic processing ability. It is possible that something similar could account for the pattern of ERPs at the ambiguous NP in the Low Comprehenders where only a positivity was discovered.

Our next set of analysis compared all four sentence types at the critical verb, *pleased:*

16a. [While the band played] [the song pleased all the customers.] (*Pr*+*TF*+)

16b. [While the band played] [the beer pleased all the customers.] (*Pr*+*TF*-)

16c. [While the band played the song] [pleased all the customers.] (*Pr*-*TF*+)

16d. [While the band played the beer] [pleased all the customers.] (*Pr*-*TF*-)

In all four conditions, the temporary syntactic ambiguity is resolved at the critical verb *pleased*, where the syntactic structure is disambiguated and it becomes clear that the NP (*the song/the beer*) is the subject of the verb *pleased*. In the healthy controls we predicted we would find an N400-P600 effect in the (16c) vs. (16a) comparison, where both prosodic and plausibility cues would bias the listener toward the incorrect parse. We did not expect to find an N400-P600 effect in (16d) vs. (16b) where plausibility cues at *the beer* in (16d) would bias the listener toward the correct parse before reaching the critical verb. In other words, because we anticipated finding a biphasic N400-P600 at *the beer* in (16d) we did not expect to find another N400-P600 complex at *pleased* in (16d).

Our predictions for the healthy controls were confirmed. We found an N400-P600 complex in the (16c) vs. (16a) (plausible NP, *Pr-TF+* vs. *Pr+TF+*) comparison, but only an N400 in the (16d) vs. (16b) (implausible NP, *Pr-TF-* vs. *Pr+TF-*) comparison. Thus, when both prosodic and plausibility cues biased the listener toward the incorrect parse [as in (16c) vs. (16a)], listeners were garden-pathed and engaged in syntactic reanalysis at the critical verb. When examining the results of the entire group of patients with aphasia, it appeared that they had a similar pattern of results. We found evidence of a prosody-driven N400 effect in sentences with incongruent prosody, but only a P600 effect in (15c, *Pr-TF+*). However, when we examined the High and Low Comprehender groups separately we found different patterns within each group.

First we will discuss the findings in the High Comprehenders group. We did not find evidence of an N400 or P600 effect in (16c) vs. (16a) at the critical verb (*pleased*) where we found an N400-P600 complex in the healthy controls.

However, we did find an N400 effect in (16d) relative to the other conditions. We also found an N400 effect in this comparison in the healthy controls in the 300-600ms epoch, however the negativity was sustained throughout both the 300-600ms and 600-1200ms epochs in the aphasia group. Thus, the High Comprehenders were not sensitive to the prosody-driven garden-path effect in (16c) vs. (16a) at the critical verb (*pleased*). They did not display evidence of semantic integration difficulty (N400 effect) or syntactic reanalysis (P600 effect) in this comparison. Recall that in a self-paced listening study, DeDe (2012) found evidence of longer listening times in individuals with aphasia at the critical verb in a prosody-driven garden-path condition. This was considered to be evidence of syntactic reanalysis at the verb. However, we did not find evidence of either an N400 or P600, required for syntactic reanalysis, at the critical verb in High Comprehenders.

Rather than the N400-P600 complex we found in (16c) vs. (16a) at the critical verb in the healthy controls, in the Low Comprehenders we found a sustained positivity in (16c, *Pr-TF+)* in both the 300-600 and 600-1200ms epochs. We did not find evidence of an N400 effect in either condition with incongruent prosody. This sustained positivity likely does not reflect a true P600 effect because it begins in the 300-600ms epoch before you would anticipate finding P600 effects. Thus, while the sustained positivity shows that Low Comprehenders are sensitive to the prosody-driven garden-path effect in conditions with a plausible NP [(16c) vs. (16d)], their ERPs are fundamentally different from the healthy controls. Thus, we did not find evidence in support of Dede's (2012) conclusion that individuals with aphasia engage in syntactic reanalysis at the critical verb. While we found a sensitivity to the manipulation, indexed by a sustained positivity, the Low Comprehenders do not show evidence of an N400-P600 complex that would indicate they resolved the garden-path violation. Again, this pattern is similar to the findings of Friederici et al. (1998) and Kielar et al. (2012), where Broca's patients only showed a positivity and no negativity in response to argument-structure and word-category violations. This was attributed to a loss of access to automatic semantic integration abilities but maintenance of secondary syntactic processing resources. It is possible that a similar explanation is relevant in the current study.

For our analyses at the sentence-final word (*customers*) we anticipated we would find evidence of an N400 effect in the healthy controls for both conditions with incongruent prosody [(16c) and (16d)]. In the individuals with aphasia we also anticipated we would evidence of an N400 effect at sentence-final words in sentences with incongruent prosody, though we expected it may be slightly delayed and attenuated relative to the N400 effect in the healthy controls. As we predicted, incongruent prosody elicited an N400 effect at the sentence-final word in healthy controls. The N400 was present in both the 300-600ms and 600-900ms epochs, and it was largest in (16d, *Pr-TF-*), the condition with incongruent prosody and an implausible NP. These findings are similar to past studies, where a sustained N400 effect was elicited at sentence-final words in garden-path sentences (Osterhout & Holcomb, 1992, 1993).

Overall in the aphasia group we found that incongruent prosody elicited a sustained negativity at the sentence-final word in the 300-600ms and 600-900ms epochs. In the 600-900ms epoch the N400 effect was largest in (16d, *Pr-TF-*) with an implausible NP. However, when we examined the High and Low Comprehender groups separately we found differences between groups. Only sentences with incongruent prosody and an implausible NP (16d, *Pr-TF-*) elicited an N400 effect in the High Comprehenders, in the first epoch (300-600ms), but not the second epoch (600-900ms). In contrast, both conditions with incongruent prosody (*Pr-TF+*, *Pr-TF-*) elicited an N400 at the sentence-final word in the Low Comprehenders, although it was larger in (16d) *Pr-TF-.* Also, in the Low Comprehenders this N400 was only significant in the second epoch (600-900ms). Thus, the High Comprehenders appeared to only be sensitive to sentences with both incongruent prosody and an implausible NP (16d, *Pr-TF-*), while incongruent prosody paired with a plausible NP (16c, *Pr-TF+*) did not elicit an N400. The Low Comprehenders did show delayed sensitivity to incongruent prosody, regardless of the presence of a thematic fit violation.

Finally, moving to the behavioral results. The age-matched controls showed high accuracy in all conditions, though they were most accurate at judging sentences with incongruent prosody and an implausible NP (16d, *Pr-TF-*) sentences as unacceptable. However, the individuals with aphasia were most accurate at judging the acceptability of sentences with congruent prosody (16c, 16d). This pattern remained true in the High Comprehenders, yet there were no significant differences found between conditions in the Low Comprehenders.

These patterns, taken together, suggest that our healthy controls were sensitive to intonational phrase boundaries, as indicated by the CPS effect at the prosodic break. Also, even when faced with incongruent prosody they were able to repair the syntactic structure before the critical verb when thematic fit/plausibility cues were available at the ambiguous NP [*the beer* in (16d)]. This was indicated by the N400-P600 complex at *the beer* in (16d). Furthermore, they showed evidence of engaging in syntactic reanalysis, indicated by the N400-P600 complex at the critical verb in classic garden-path sentences where thematic fit/plausibility information wasn't available to help predict upcoming syntactic structure [(16c) vs. (16a)]. Finally, the presence of a sustained N400 effect to the final-word in sentences with incongruent prosody (16c, 16d), provides more evidence that they were sensitive to the prosody violation.

In contrast, the individuals with aphasia revealed a different pattern of results. Similar to the age-matched controls, the prosodic break elicited a CPS effect (indicating sensitivity to intonational phrase boundaries) the High Comprehenders, and they were able to detect a lexical-semantic violation and engage in syntactic reanalysis (N400-P600 complex) when encountering a thematic fit violation at *the beer* in (16d). However, the classic garden-path comparison between (16c) and (16a) did not elicit an N400-P600 complex in the High Comprehenders as it did in the controls. Hence, we assume that the High

Comprehenders possess the resources necessary to immediately identify a thematic fit violation and engage in syntactic reanalysis, but syntactic reanalysis does not occur when no plausibility cue is available to help predict upcoming syntactic structure. Even in the analyses of sentence-final words, only the condition with incongruent prosody and an implausible NP (15d, *Pr-TF-*) elicited an N400 effect, suggesting they did not detect the prosody-driven garden-path violation (15c vs. 15a) even at the end of the sentence. Thus, High Comprehenders are able to use plausibility cues to predict upcoming syntactic structure. Yet they are not able to detect or resolve syntactic ambiguities resulting from incongruent prosody alone, suggesting that they exhibit an impairment in integrating prosodic cues with syntactic structure when lexical-semantic information is not available to help them predict syntactic structure.

The Low Comprehenders also showed a CPS effect at the prosodic break, although it was smaller than the CPS in the healthy controls. Yet, they did not show evidence of an N400-P600 resulting from the thematic fit violation at *the beer* in (16d) or from the garden path violation at the critical verb *pleased* in (16c) vs. (16a). Instead, at both of these points a sustained positivity was revealed in the N400 epoch and P600 epoch. It is unlikely this reflects a true P600-like syntactic reanalysis as it had an earlier onset than a traditional P600 effect. Because both types of violations elicited a similar sustained positivity, it is more likely that the positivity reflects error perception, but not repair processes. Recall that both Kielar and colleagues (2012) and Friederici and colleagues (1998) found that verb argument structure violations and word-category violations, respectively, elicited a P600 but no N400 effect in patients with Broca's aphasia. This was attributed to a loss of early semantic processing and a retention of later syntactic processing. It is possible that the Low Comprehenders in the current study have lost fast automatic semantic processing resources, but still have access to later syntactic processes. Perhaps the sustained positivity reflects difficulty integrating the information into syntactic structure, rather than syntactic reanalysis and repair. The presence of a delayed N400 effect at the sentence-final word in both conditions with incongruent prosody provides evidence of lexical-semantic processing, but it is delayed relative to healthy controls.

Also, here we will briefly compare the results from the college-age adults discussed in Chapter 4 and the older adults in the present study. Overall we found smaller amplitudes and more variability in the older adults compared to the college-age adults across all comparisons. This corresponds with prior studies comparing ERPs in young versus older adults in language processing studies (Faustmann, Murdoch, Finnigan, & Copland, 2007; Steinhauer et al., 2010).

Both groups showed a CPS effect elicited at the prosodic break, though differences in scalp distribution were present. Specifically, the CPS effect was primarily distributed in the right-hemisphere in the college-age adults while it was distributed across both hemispheres in the older adults. This was particularly surprising since a study by Steinhauer et al. (2010) found that CPS effects were more broadly distributed across the scalp in a group of younger vs. older adults.

Perhaps these differential findings reflect larger variability in the older adults group in the present study, where participants ranged in age from 41-82 years. In contrast the participants in the Steinhauer et al. study were all elderly adults ranging in age from 65-80 years.

Moving to the effects at the temporarily ambiguous NP, an N400 and P600 effect was found in both groups in the comparison between sentences with an implausible NP (*the beer*) and a plausible NP (*the song*). Thus, when faced with incongruent prosody, both groups were able to use plausibility cues (in *the beer*) to engage in syntactic reanalysis. Once again, differences in scalp distribution were present where the P600 effect was distributed primarily at anterior electrodes in the college-age adults and at posterior electrodes in the older adults. Perhaps this reflects that aging results in the use of slightly different processes to detect plausibility cues and subsequently engage in syntactic reanalysis. It may also suggest that aging causes less efficient use of syntactic reanalysis resources. Future analyses and studies can potentially tease apart these scalp distribution differences.

Finally, recall that sentences with incongruent prosody and no plausibility cue (*Pr-TF+*) elicited an N400-P600 complex at the critical verb (*pleased*) in both groups of participants. The scalp distribution of the N400 effect differed by group, where the college-age students showed a broad N400 across the central column at anterior and posterior sites. However, the N400 effect was confined to posterior electrodes in the older adults. This may reflect that resources used in semantic integration evolve to be less efficient with age. In the future it will be important to examine differences due to age in greater detail. Analyses examining specific differences in amplitude, latency, and scalp distribution could serve to identify how aging impacts prosodic, semantic and syntactic processing abilities.

5.4.1 Conclusions

In conclusion, we manipulated both prosodic and plausibility cues in sentences containing temporary syntactic ambiguities, and examined the ERPs in a group of healthy age-matched controls and a group of individuals with aphasia. Also, in the individuals with aphasia we examined how the severity of the comprehension deficit would impact their sensitivity to these manipulations by examining ERPs in the High and Low Comprehender groups separately. The results showed that all participant groups were sensitive to intonational phrase boundaries, as evidenced by the CPS effect at the prosodic break. However, the CPS was distributed across both hemispheres in the control group, but was attenuated and only present in right-hemisphere sites in both the High and Low Comprehenders. Thus, individuals with aphasia demonstrated processing of intonational phrase boundaries in the same time course as the healthy controls, although the effect was smaller.

Individuals with aphasia were also sensitive to both thematic fit and prosody manipulations. However, the High and Low Comprehender groups showed a different pattern of results. While the High Comprehenders showed evidence of on-time semantic integration difficulty (N400) and subsequent syntactic reanalysis (P600) in the condition with conflicting cues (incongruent prosody and a plausibility cue) (16d, *Pr-TF-*) at the ambiguous NP (*the beer*), they did not show similar sensitivity to the condition with a prosodic violation but no plausibility cue at the critical verb (16c, *Pr-TF+*). In contrast, both of these manipulations elicited a sustained positivity in the Low Comprehenders, with no evidence of semantic integration difficulty (N400) in either comparison. Although, both of these manipulations did produce a delayed N400 effect at the sentence-final word in the Low Comprehenders. Thus, the Low Comprehenders do show a delayed sensitivity to prosodic and thematic fit/plausibility violations, yet they lacked the ability to engage in immediate semantic integration and subsequent syntactic repair to resolve these violations in the same way as the healthy controls.

Overall the results suggest that individuals with aphasia who have a less severe comprehension deficit are able to capitalize on thematic fit/plausibility cues to predict and repair syntactic structure. They also can immediately process intonational phrase boundaries. However, they cannot repair syntactic structure resulting from incongruent prosody when a plausibility cue is not present. The implication is that even though they immediately process prosodic breaks, they have difficulty integrating prosodic cues with underlying syntactic structure when lexical-semantic information is not available to aid their parse. In contrast, individuals who have a more severe comprehension deficit show a delayed sensitivity to prosodic and thematic fit violations, and cannot capitalize on lexical-semantic information to aid comprehension and syntactic repair. Thus, individuals with a severe comprehension impairment appear to have difficulty integrating both prosodic and lexical-semantic cues with syntactic structure.

Finally here, the delayed sensitivity to lexical-semantic and prosodic information as revealed in the present work is similar to the delayed lexical access observed during online sentence comprehension in participants with agrammatic Broca's aphasia (i.e, the DLA; Love, Swinney, Walenski, & Zurif, 2008). Thus, one admittedly premature but exciting possibility is that some individuals with aphasia might have a pervasive processing delay that generalizes across different types of information.

References

Altmann, G. (1999). Thematic role assignment in context. *Journal of Memory and Language, 41*, 124-145.

Altmann, G. T., & Kamide, Y. (1999). Incremental interpretation at verbs: Restricting the domain of subsequent reference. *Cognition, 73*(3), 247-264.

Arai, M., & Keller, F. (2013). The use of verb-specific information for prediction in sentence processing. *Language and Cognitive Processes, 28*(4), 525-560.

Baum, S. R., & Dwivedi, V. D. (2003). Sensitivity to prosodic structure in left- and right-hemisphere-damaged individuals. *Brain and Language, 87*(2), 278-289.

Blodgett, A. R. (2004). *The interaction of prosodic phrasing, verb bias, and plausibility during spoken sentence comprehension.* The Ohio State University.

Bögels, S., Schriefers, H., Vonk, W., Chwilla, D. J., & Kerkhofs, R. (2010). The interplay between prosody and syntax in sentence processing: The case of subject-and object-control verbs. *Journal of Cognitive Neuroscience, 22*(5), 1036-1053.

Bögels, S., Schriefers, H., Vonk, W., Chwilla, D. J., & Kerkhofs, R. (2013). Processing consequences of superfluous and missing prosodic breaks in auditory sentence comprehension. *Neuropsychologia, 51*(13), 2715-2728.

Brown, C., & Hagoort, P. (1993). The processing nature of the N400: Evidence from masked priming. *Journal of Cognitive Neuroscience, 5*(1), 34-44.

Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language, 3*(4), 572-582.

Carlson, K., Frazier, L., & Clifton, J., Charles. (2009). How prosody constrains comprehension: A limited effect of prosodic packaging. *Lingua, 119*(7), 1066-1082.

Cooper, W. E., & Paccia-Cooper, J. (1980). *Syntax and speech*: Harvard University Press.

DeDe, G. (2010). Utilization of prosodic information in syntactic ambiguity resolution. *Journal of Psycholinguistic Research, 39*(4), 345-374.

DeDe, G. (2012). Lexical and prosodic effects on syntactic ambiguity resolution in aphasia. *Journal of Psycholinguistic Research, 41*(5), 387-408.

Faustmann, A., Murdoch, B. E., Finnigan, S. P., & Copland, D. A. (2007). Effects of advancing age on the processing of semantic anomalies in adults: Evidence from event-related brain potentials. *Experimental Aging Research, 33*(4), 439-460.

Friederici, A. D. (2011). The brain basis of language processing: from structure to function. *Physiological Reviews, 91*(4), 1357-1392.

Friederici, A. D., Hahne, A., & Von Cramon, D. Y. (1998). First-pass versus second-pass parsing processes in a Wernicke's and a Broca's aphasic: electrophysiological evidence for a double dissociation. *Brain and Language, 62*(3), 311-341.

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

Friederici, A. D., & Weissenborn, J. (2007). Mapping sentence form onto meaning: The syntax–semantic interface. *Brain Research, 1146*, 50-58.

Gahl, S., Menn, L., Ramsberger, G., Jurafsky, D. S., Elder, E., Rewega, M., & Audrey, L. H. (2003). Syntactic frame and verb bias in aphasia: Plausibility judgments of undergoer-subject sentences. *Brain and Cognition, 53*(2), 223-228.

Geisser, S., & Greenhouse, S. W. (1959). On methods in the analysis of profile data. *Psychometrika, 24*(2), 95-112.

Geyer, A., Holcomb, P., Kuperberg, G., & Perlmutter, N. (2006). Plausibility and sentence comprehension. An ERP study. *Cogn. Neurosci. Suppl., Abstract*, 1-1.

Gibson, E., Sandberg, C., Fedorenko, E., Bergen, L., & Kiran, S. (2015). A rational inference approach to aphasic language comprehension. *Aphasiology*, 1-20.

Hagoort, P., Baggio, G., & Willems, R. M. (2009). Semantic unification *The Cognitive Neurosciences* (4th ed., pp. 819-836): MIT press.

Hagoort, P., Brown, C. M., & Swaab, T. Y. (1996). Lexical—semantic event–related potential effects in patients with left hemisphere lesions and aphasia, and patients with right hemisphere lesions without aphasia. *Brain, 119*(2), 627-649.

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language and Cognitive Processes, 5*(4), 281-312.

Holcomb, P. J., Reder, L., Misra, M., & Grainger, J. (2005). The effects of prime visibility on ERP measures of masked priming. *Cognitive brain research, 24*(1), 155-172.

Jung, T.-P., Makeig, S., Humphries, C., Lee, T.-W., Mckeown, M. J., Iragui, V., & Sejnowski, T. J. (2000). Removing electroencephalographic artifacts by blind source separation. *Psychophysiology, 37*(02), 163-178.

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

Kawohl, W., Bunse, S., Willmes, K., Hoffrogge, A., Buchner, H., & Huber, W. (2009). Semantic event-related potential components reflect severity of comprehension deficits in aphasia. *Neurorehabilitation and neural repair*.

Kielar, A., Meltzer-Asscher, A., & Thompson, C. K. (2012). Electrophysiological responses to argument structure violations in healthy adults and individuals with agrammatic aphasia. *Neuropsychologia, 50*(14), 3320-3337.

Kjelgaard, M., & Speer, S. (1999). Prosodic facilitation and interference in the resolution of temporary syntactic closure ambiguity. *Journal of Memory and Language, 40*(2), 153-194.

Kuperberg, G. R. (2007). Neural mechanisms of language comprehension: Challenges to syntax. *Brain Research, 1146*, 23-49.

Kuperberg, G. R., Kreher, D. A., Sitnikova, T., Caplan, D. N., & Holcomb, P. J. (2007). The role of animacy and thematic relationships in processing active English sentences: Evidence from event-related potentials. *Brain and Language, 100*(3), 223-237.

Kuperberg, G. R., Sitnikova, T., Caplan, D., & Holcomb, P. J. (2003). Electrophysiological distinctions in processing conceptual relationships within simple sentences. *Cognitive brain research, 17*, 117-129.

Kutas, M. (1993). In the company of other words: Electrophysiological evidence for single-word and sentence context effects. *Language and Cognitive Processes, 8*(4), 533-572.

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*(12), 463-470.

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event related brain potential (ERP). *Annual Review of Psychology, 62*, 621.

Kutas, M., & Hillyard, S. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203-205.

Love, T., Swinney, D., Walenski, M., & Zurif, E. (2008). How left inferior frontal cortex participates in syntactic processing: Evidence from aphasia. *Brain and Language, 107*(3), 203-219.

Marslen-Wilson, W. D., Tyler, L. K., Warren, P., Grenier, P., & Lee, C. S. (1992). Prosodic effects in minimal attachment. *The quarterly Journal of Experimental Psychology, 45*(1), 73-87.

Midgley, K. J., Holcomb, P. J., & Grainger, J. (2011). Effects of cognate status on word comprehension in second language learners: An ERP investigation. *Journal of Cognitive Neuroscience, 23*(7), 1634-1647.

Nagel, H. N., Shapiro, L. P., & Nawy, R. (1994). Prosody and the processing of filler-gap sentences. *Journal of Psycholinguistic Research, 23*(6), 473-485.

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*(6), 785-806.

Osterhout, L., & Holcomb, P. J. (1993). Event-related potentials and syntactic anomaly: Evidence of anomaly detection during the perception of continuous speech. *Language and Cognitive Processes, 8*(4), 413-437.

Pauker, E., Itzhak, I., Baum, S., & Steinhauer, K. (2011). Effects of cooperating and conflicting prosody in spoken English garden path sentences: ERP evidence for the boundary deletion hypothesis. *Journal of Cognitive Neuroscience, 23*(10), 2731-2751.

Pell, M. D., & Baum, S. R. (1997). Unilateral brain damage, prosodic comprehension deficits, and the acoustic cues to prosody. *Brain and Language, 57*(2), 195-214.

Price, P. J., Ostendorf, M., Shattuck‐Hufnagel, S., & Fong, C. (1991). The use of prosody in syntactic disambiguation. *the Journal of the Acoustical Society of America, 90*(6), 2956-2970.

Pynte, J., & Prieur, B. (1996). Prosodic Breaks and Attachment Decisions in Sentence Parsing. *Language and Cognitive Processes, 11*(1-2), 165-192.

Schafer, A. J., Speer, S. R., Warren, P., & White, S. D. (2000). Intonational disambiguation in sentence production and comprehension. *Journal of Psycholinguistic Research, 29*(2), 169-182.

Snedeker, J., & Yuan, S. (2008). Effects of prosodic and lexical constraints on parsing in young children (and adults). *Journal of Memory and Language, 58*(2), 574-608.

Steinhauer, K. (2003). Electrophysiological correlates of prosody and punctuation. *Brain and Language, 86*(1), 142-164.

Steinhauer, K., Abada, S. H., Pauker, E., Itzhak, I., & Baum, S. R. (2010). Prosody–syntax interactions in aging: Event-related potentials reveal dissociations between on-line and off-line measures. *Neuroscience Letters, 472*(2), 133-138.

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

Swaab, T., Brown, C., & Hagoort, P. (1997). Spoken sentence comprehension in aphasia: Event-related potential evidence for a lexical integration deficit. *Journal of Cognitive Neuroscience, 9*(1), 39-66.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: Use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language, 33*(3), 285-318.

Van Berkum, J. J., Brown, C. M., & Hagoort, P. (1999). Early referential context effects in sentence processing: Evidence from event-related brain potentials. *Journal of Memory and Language, 41*(2), 147-182.

Walker, J. P., Fongemie, K., & Daigle, T. (2001). Prosodic facilitation in the resolution of syntactic ambiguities in subjects with left and right hemisphere damage. *Brain and Language, 78*(2), 169-196.

Wassenaar, M., Brown, C. M., & Hagoort, P. (2004). ERP Effects of Subject—Verb Agreement Violations in Patients with Broca's Aphasia. *Journal of Cognitive Neuroscience, 16*(4), 553-576.

Chapter 5 is being prepared for submission for publication of the material. Sheppard, S.M., Love, T., Midgley, K.J., Holcomb, P.J., Shapiro, L.P. (*in preparation*). Influence of Prosody and Thematic Fit on Syntactic Ambiguity Resolution in Broca's Aphasia: Evidence from ERPs. The dissertation author was the primary investigator and the primary author of this paper. Preparation of this manuscript was supported, in part, by National Institute on Deafness and Other Communication Disorders Grants (NIDCD) R01 DC009272, R01 DC000494, and T32 DC007361, and by HD25889. We are very grateful to our participants and their families for participation in this investigation. We also thank members of the Language and Neuroscience Group (San Diego State University) and the NeuroCognition (San Diego State University) laboratories for their help with stimuli development and preparation, and data collection.

CHAPTER 6:

General Discussion and Conclusions

The primary aim of this dissertation was to investigate how syntax, prosody, and thematic fit impact the time course of on-line sentence processing in neurologically unimpaired populations and in individuals with Broca's aphasia. To review, while individuals with Broca's aphasia are typically able to comprehend sentences in canonical word order, they have substantial difficulty understanding sentences in non-canonical order (Caramazza & Zurif, 1976; Grodzinsky, 1990; Love, Swinney, Walenski, & Zurif, 2008; Zurif, Swinney, Prather, Solomon, & Bushell, 1993). This dissertation presented three studies examining three specific elements in sentence processing to shed more light on this comprehension deficit.

Chapter 3 presented a study exploring the influence of syntax and similarity-based interference that may result from certain syntactic constructions. The auditory processing of four types of *wh*-questions (subject- and object-extracted *who*- and *which*-questions) was examined in both college-age adults and in adults with Broca's aphasia using an eye-tracking while listening paradigm. Three competing hypotheses were compared, each of which would predict a different pattern of processing difficulty across the four question types. The *Word Order* Hypothesis predicted processing difficulty in sentences with non-canonical word order (object-extracted *who-* and *which*-questions). The *Discourse Hypothesis* predicted that *which*-questions would be more difficult to process than *who*-questions because *which*-questions are required to specifically mention referents from previous discourse, whereas *who*-questions do not have this requirement. Finally, the *Intervener Hypothesis,* states that interference will occur when a listener is holding a displaced NP (the filler) in working memory and they subsequently encounter an intervening lexical NP prior to reaching the gap where the filler is integrated. Because only the object-extracted Which-*questions* contained an intervener, it was predicted that interference would only occur in this condition if similarity-based interference could explain some of the processing deficits seen in Broca's aphasia.

In the group of neurologically unimpaired adults no unambiguous support was found for either of the three hypotheses. However, clear support of the *Intervener Hypothesis* was discovered in the individuals with Broca's aphasia. Significantly lower accuracy, slower reaction times, and increased interference in the gaze data were found in the object-extracted *which*-questions, which were the only sentence type containing an intervener that could result in interference. Thus, it appears that the comprehension deficit in Broca's aphasia cannot simply be explained by a deficit in comprehending non-canonical word order. This study demonstrates that patients with Broca's aphasia are able to comprehend some non-canonically ordered sentences (e.g.*,* object-extracted *who*-questions) with accuracy that is significantly above chance. Processing difficulty was only apparent when an intervening NP was present in between the filler and its gap-site. Future work will need to examine more sentence constructions containing interveners to determine whether the *Intervener Hypothesis* can explain sentence comprehension deficits across a wide variety of constructions. Furthermore, it will be important to examine what specific properties of the intervener result in interference effects. Future treatment studies could focus on improving comprehension by training individuals with Broca's aphasia to manage similarity-based interference effects.

While the primary goal of the study presented in Chapter 3 was to examine the impact of syntax and similarity-based interference, Chapters 4 and 5 focused on two different elements important in sentence processing: prosody and thematic fit. The studies presented in Chapters 4 and 5 examined the influence of prosody and thematic fit, and the interaction of these two sentence elements, in a group of college-age adults (Chapter 4) and a group of individuals with aphasia and age-matched controls (Chapter 5). Using event-related potentials (ERPs) allowed for the examination of language specific ERP components that are each elicited by different language processing components. Recall that the Closure Positive Shift (CPS) is elicited when participants are sensitive to the presence of intonational phrase boundaries, the N400 is sensitive to semantic integration effort, and the P600 to syntactic reanalysis/repair.

The processing of four types of sentences (e.g., [While the band played] [the song/the beer pleased all the customers.] / *[While the band played the song/the beer] [pleased all the customers.]) was investigated. The sentences, all with an early closure syntactic structure, contained temporary syntactic early (correct interpretation) late closure (incorrect interpretation) ambiguities, and were presented either with congruent or incongruent prosody. Thematic fit was also manipulated so that the temporarily ambiguous NP was either a good thematic fit (*the song*) for the direct object position of the subordinate verb (*played*) or a poor thematic fit (*the beer*). Within the two conditions with incongruent prosody, only the condition with an implausible NP could potentially provide the parser with a cue that the syntactic structure was incorrect. This was because when the parser hears "While the song played the beer" the poor thematic fit between *played* and *the beer* may provide a plausibility cue that *the beer* must be the subject of the upcoming clause – which is the correct interpretation.

There are several conflicting accounts of how prosodic and lexical-semantic cues are used in sentence processing. One account suggests that prosodic cues take precedence over other types of cues (Kjelgaard & Speer, 1999), another suggests that lexical cues take precedence over prosodic cues (Pynte & Prieur, 1996), and the last claims that prosodic and lexical cues interact (Snedeker & Yuan, 2008; Dede, 2010). However, none of these studies used ERPs to investigate what specific language processes are involved in processing these different types of information. The studies presented in Chapters 4 and 5 had two aims. First, to determine which of these three opposing accounts is supported by the data in neurologically unimpaired healthy participants (college-age in Chapter 4 and older adults in Chapter 5). Second, to determine whether individuals with aphasia process prosodic and lexical-semantic cues in the same way as neurologically healthy controls.

Research examining the processing of lexical-semantic information in aphasia have found that they are sensitive to plausibility cues, and rely on them particularly in sentences with non-canonical sentence structure (Caramazza & Zurif, 1976; Gibson, Sandberg, Fedorenko, Bergen, & Kiran, 2015). However, the research examining how individuals with Broca's aphasia use prosodic cues is not as clear. Some studies have found that they have difficulty identifying prosodic contours (Pell & Baum, 1997), others have found that they are sensitive to prosody but do not use it in the same way as healthy controls (Baum & Dwivedi, 2003), yet some researchers have found that congruent prosody facilitates processing in participants with aphasia just as it does in healthy controls (Walker, Fongemie, & Daigle, 2001).

Only one study to date has examined the interaction of prosodic and lexical-semantic cues in individuals with aphasia. Using a self-paced listening task DeDe (2012) found that people with aphasia were sensitive to both prosodic and lexical-semantic cues but they were processed in a delayed fashion relative to controls. Since this study used a self-paced listening task, which by its nature disrupts prosody during processing, a true picture of the on-line processing of these cues was not obtained. Thus, the study presented in Chapter 5 where ERPs were used offers a significant advantage over previous studies examining this question in individuals with aphasia.

The results from neurologically unimpaired college-age adults (Chapter 4) and older adults (Chapter 5) revealed that prosodic and lexical-semantic plausibility cues interacted immediately. When comparing the two conditions with incongruent prosody, one with a plausibility cue (*the beer*) and one without a plausibility cue (*the song*) at the ambiguous NP, evidence of immediate semantic integration difficulty and subsequent syntactic reanalysis (N400-P600) was discovered at the ambiguous NP. However evidence of an N400-P600 effect was only discovered at the critical verb (*pleased*) in the condition without a plausibility cue. These results suggest that the parser immediately capitalizes on plausibility cues to predict upcoming syntactic structure. Moreover, the data also revealed that congruent prosody disambiguated the temporary ambiguity.

When examining the results from the same experimental manipulations in individuals with aphasia (Chapter 5), the participants were divided into a group of High and Low Comprehenders, based on their results on a sentence comprehension task. Each group showed a different pattern of results. Recall that in the comparison between the two conditions with incongruent prosody, the ambiguous NP either contained a plausibility cue (*the beer*) or did not (*the song*). In this comparison evidence of immediate semantic integration difficulty and subsequent syntactic reanalysis (N400-P600) was discovered at the ambiguous NP in the High Comprehenders but not in the Low Comprehenders. This comparison only elicited a sustained positivity in the Low Comprehenders, suggesting the presence of an impairment in semantic integration processes. In the condition with incongruent prosody and a plausible NP, which did not contain a plausibility cue, the High Comprehenders did not show any differences between conditions, but another sustained positivity was found in the Low Comprehenders.

Again this sustained positivity likely demonstrated that Low Comprehenders noticed the incongruent prosody, but could not engage in syntactic reanalysis like the healthy controls. Overall these results suggest that the severity of the comprehension deficit in aphasia impacts both prosodic and lexical-semantic processing. The High Comprehenders were sensitive to incongruent prosody only when a plausibility cue available to help them detect the prosodic violation. Yet, in this case the parser immediately engaged in syntactic reanalysis. The Low Comprehenders however were not able to engage in syntactic reanalysis with or without a plausibility cue to aid their comprehension. Although, incongruent prosody did elicit a delayed N400 effect at the sentence-final word in the Low Comprehenders regardless of the presence of a plausibility cue, showing they displayed delayed sensitivity to prosody. Overall the results suggest that High Comprehenders can capitalize on lexical-semantic and prosodic information to aid comprehension. However, this group exhibited an impairment in the integration of prosodic cues with syntactic structure when lexical-semantic information was not available to help predict syntactic structure. Low Comprehenders, showed a delay in processing the interaction between lexical-semantic and prosodic cues.

While Chapter 3 focused on the impact of syntax and the resulting similarity-based interference that may result in certain syntactic constructions, Chapters 4 and 5 focus on two different elements in sentence processing: prosody and thematic fit. As discussed in Chapter 2, both prosody and thematic fit are essential components of sentence processing, yet many studies investigating these two components have used off-line methods. Here we examine how prosody and thematic fit influence sentence processing, and in particular how they impact the resolution of temporary syntactic ambiguities. Event-related potentials (ERPs) were used as they allowed for the investigation of specific ERP components, the Closure Positive Shift, the N400, and the P600, which are each elicited by different aspects of language processing. Specifically, the CPS indexes the processing of intonational phrase boundaries, the N400 measures semantic integration, and the P600 syntactic repair/reanalysis. Measuring each of these components at key points in experimental sentences allowed for the examination of how and when prosody and thematic fit interacted during processing, and what specific aspect of language processing was influenced by this interaction. Chapter 4 details the investigation of these processing elements in a group of college-age adults, and Chapter 5 discusses the same study conducted in a group of participants with aphasia and their age-matched controls.

The results of all of the studies described in this dissertation have several broad implications. First, when considering how neurologically unimpaired listeners comprehend language, Chapter 3 demonstrated that the parser can successfully overcome similarity-based interference effects when comprehending sentences containing an intervener. Chapters 4 and 5 demonstrated that prosodic and lexical-semantic cues interact to immediately impact sentence processing. They also demonstrated that when faced with syntactic ambiguities, the parser immediately capitalizes on plausibility cues to predict upcoming syntactic structure in both college-age and older adults. Thus, multiple components are essential in sentence processing. Future research will need to examine how and when all of these components interact with one another throughout processing. For example, future research could examine what specific properties the parser is most sensitive to when using plausibility information to predict syntactic structure.

There are also numerous implications of the findings of these studies for the study of sentence processing in individuals with aphasia. First, Chapter 3 revealed persons with aphasia are susceptible to similarity-based interference. Future studies will need to examine what specific features of NPs contribute to similarity-based interference. Chapters 4 and 5 revealed however that similarity-based interference cannot explain the entire sentence comprehension deficit in Broca's aphasia. Even High Comprehenders showed reduced ability to integrate prosodic and syntactic information when plausibility cues were not available to help them predict syntactic structure. Low Comprehenders showed sensitivity to the interaction of prosodic and lexical-semantic information, but with a delayed time course relative to the healthy controls.

One important implication of the research presented in this dissertation is the presence of language processing deficits even in those Broca's patients with high comprehension scores. While the participants in the High Comprehenders group were diagnosed with Broca's aphasia, they did not display the classic split between canonical and non-canonical sentence comprehension that often characterizes these patients. These results reveal that even patients with relatively high comprehension scores display clear deficits in their ability to integrate prosodic and syntactic information. In the rank-and-file clinical world it is often the case that patients are diagnosed as having either expressive or receptive language deficits. However, we have shown empirically that even patients with mild receptive impairments, as measured in a behavioral task, display breakdowns in on-line sentence processing that can lead to subtle but important comprehension deficits.

Moreover, the clearly distinct processing patterns found between individuals with Broca's aphasia who have high versus low comprehension have implications for treatment. For example, the results of the study presented in Chapter 5 suggests that the severity of the comprehension deficit impacts different areas of auditory language processing, thus distinct treatment programs may be more effective for patients with high versus low comprehension scores. Also, future research in this area should examine whether treatment programs can enhance sensitivity to plausibility information in patients with a more severe comprehension deficit. Future research could also examine ways to enhance the processing of prosodic information, and it's interaction with syntax. A treatment program targeting the integration of prosodic and syntactic information would likely benefit even patients with high comprehension.

In sum, this dissertation consisted of three novel experiments in both neurologically unimpaired college-age populations, as well as neurologically unimpaired older adults, and individuals with Broca's aphasia. The impact of three essential components in sentence processing, syntax, prosody, and lexical-semantic processing, were investigated. Together these studies demonstrate that the sentence comprehension deficit in Broca's aphasia can be partially explained by susceptibility to similarity-based interference, an impairment in integrating prosodic and syntactic information, and particularly in Low Comprehenders a delay of lexical-semantic integration. It remains for future work to understand if there is a relation between similarity-based interference impairments and impairments in the use of prosodic and plausibility information, all examined in this dissertation. For now, plausibility (in the form of thematic fit when examining structural ambiguities) could also be manipulated in structures containing interveners to see if the intervener effect can be overcome in aphasia. Nevertheless, the studies described here knowledge to our current models of language processing and to our understanding of the processing impairments seen in individuals with Broca's aphasia. It is my hope that these findings will also serve to inform future clinical treatment approaches.

References

Baum, S. R., & Dwivedi, V. D. (2003). Sensitivity to prosodic structure in left- and right-hemisphere-damaged individuals. *Brain and Language, 87*(2), 278-289.

Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language, 3*(4), 572-582.

DeDe, G. (2012). Lexical and prosodic effects on syntactic ambiguity resolution in aphasia. *Journal of Psycholinguistic Research, 41*(5), 387-408.

Gibson, E., Sandberg, C., Fedorenko, E., Bergen, L., & Kiran, S. (2015). A rational inference approach to aphasic language comprehension. *Aphasiology*, 1-20.

Grodzinsky, Y. (1990). *Theoretical perspectives on language deficits*: MIT press.

Kjelgaard, M., & Speer, S. (1999). Prosodic facilitation and interference in the resolution of temporary syntactic closure ambiguity. *Journal of Memory and Language, 40*(2), 153-194.

Love, T., Swinney, D., Walenski, M., & Zurif, E. (2008). How left inferior frontal cortex participates in syntactic processing: Evidence from aphasia. *Brain and Language, 107*(3), 203-219.

Pell, M. D., & Baum, S. R. (1997). Unilateral brain damage, prosodic comprehension deficits, and the acoustic cues to prosody. *Brain and Language, 57*(2), 195-214.

Walker, J. P., Fongemie, K., & Daigle, T. (2001). Prosodic facilitation in the resolution of syntactic ambiguities in subjects with left and right hemisphere damage. *Brain and Language, 78*(2), 169-196.

Zurif, E., Swinney, D., Prather, P., Solomon, J., & Bushell, C. (1993). An on-line analysis of syntactic processing in Broca′ s and Wernicke′ s aphasia. *Brain and Language, 45*(3), 448-464.