Title
Sentence Comprehension in Aphasia: A Test of the Intervener Hypothesis

Author
Sullivan, Natalie

Publication Date
2017

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA, SAN DIEGO

SAN DIEGO STATE UNIVERSITY

Sentence Comprehension in Aphasia: A Test of the Intervener Hypothesis

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

in

Language and Communicative Disorders

by

Natalie Jean Sullivan

Committee in charge:

University of California, San Diego

Professor Seana Coulson
Professor Jeanne Townsend

San Diego State University

Professor Tracy Love, Co-Chair
Professor Lewis Shapiro, Co-Chair
Professor Gregory Keating

2017

The Dissertation of Natalie Jean Sullivan is approved, and is acceptable in quality and form for publication on microfilm and electronically:

Co-Chair

Co-Chair

University of California, San Diego

San Diego State University

2017

TABLE CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

ACKNOWLEDGEMENTS

I would like to thank my advisors Tracy Love and Lew Shapiro for their knowledge, support, and guidance over the past seven years. It was your enthusiasm about the field that inspired me to pursue a doctoral program. A heartfelt thank you to all of my off-site clinical supervisors, Paul McRae, Andrea Newall, and Linda Schmitz. Your unsurpassable clinical skills have provided me with invaluable experiences. A special thank you to Sonja Pruitt-Lord for guiding me along my path and helping me to develop and plan SAID. I would also like to thank my committee members, Seana Coulson, Greg Keating and Jeanne Townsend for their insightful feedback and support during this process.

Mom and Dad, this is as much your accomplishment as it is mine. I am grateful for your wonderful parenting, friendship, love, and support. To my husband Sean, thank you for being my partner in life. I don't know where I would be without your love, partnership and support. To my sister Sarah, I appreciate your love and support. Many thanks for keeping my hair looking fabulous and fun. To my brother Stephen, thanks for all the laughs, love and support. To my sweet pups Captain Jack and Penelope, I am grateful for your love. Thanks for being so understanding about the lack of walks lately. To the rest of my family, thank you for always being my biggest cheerleaders.

Thank you to my best friend Steven, for always being there, and for providing me with many adventures. I can't wait to repay the favor. Sam, thank you for all of your invaluable help during this process. You and Dame are part of my chosen family, and I am grateful for your friendship and support.

Dorothy, thanks for all of our doc-student donut dates. Michelle, many thanks for the wonderful times we have shared. Shannon, thanks for all of our coffee breaks. Irina, and Phil, but the times we've had. Completing the clinical requirements would not have been the same without you both. To all of the JDP students, thanks for helping me navigate grad school. I look forward to seeing what your futures hold.

To all of the lovely and talented research assistants that have helped me over the years, thank you for all your hard work. A very special thank you to all of the participants with language impairments that have participated in these studies. Finally, thank you to my funding sources: the Chapter 33 GI Bill, the NIH Predoctoral Training Grant (NIH/NIDCD T3DC007361), and the SDSU Center for Clinical and Cognitive Neuroscience Graduate Student Dissertation Award.

Chapter 7, in full, is a reprint of material as it appears in Sullivan, N., Walenski, M., Love, T., & Shapiro, L.P. (2017). The curious case of processing unaccusative verbs in aphasia, *Aphasiology*, Advance online publication. doi: 10.1080/02687038.2016.1274873. The dissertation author was the primary investigator and author of this paper.

Chapter 8, in full, is a reprint of material as it appears in Sullivan, N., Walenski, M., Love, T., & Shapiro, L.P. (2017). The comprehension of unaccusative verbs in aphasia: a test of the intervener hypothesis, *Aphasiology*, *31*(1), 67-81. The dissertation author was the primary investigator and author of this paper. The dissertation author was the primary investigator and author of this paper.

Chapter 9 is being prepared for submission for publication of material. Sullivan, N., Shapiro, L.P., Love, T., (*in preparation*). The intervener effect during the online

processing of sentences that contain unaccusative verbs in aphasia. The dissertation author was the primary investigator and author of this paper.

VITA

EDUCATION

Ph.D.	**Language and Communicative Disorders** San Diego State University and University of California San Diego, San Diego Advisor: Tracy Love, Ph.D. Dissertation Committee: Dr. Tracy Love, Dr. Lewis P. Shapiro, Dr. Seana Coulson, Dr. Jeanne Townsend, and Dr. Gregory Keating Training required for Speech-Language Pathology Certificate of Clinical Competence	2017
B.A.	**Speech, Language, and Hearing Sciences** San Diego State University *Summa Cum Laude*	2012

MILITARY EXPERIENCE

Petty Officer Second Class (E-5) United States Navy Honorable Discharge Deployed in support of Operation Iraqi Freedom	2003 - 2008

AWARDS AND HONORS

SDSU Center for Clinical and Cognitive Neuroscience Collaborative Pilot Program Graduate Student Dissertation Research Awardee Award for “Sentence Comprehension in Aphasia: A Test of the Intervener Hypothesis”	2017
SDSU Student Success Fee Awardee Award for Speech-Language Awareness and Information Day	2016
NIDCD Student Fellowship to attend and present at the Clinical Aphasiology Conference	2014
NIH Training Grant (PI, Dr. Lewis P. Shapiro) “Neurocognitive Approaches to Communicative Disorders” NIH/NIDCD T32DC007361	2013 - 2015
Sally Casanova Pre-Doctoral Program, Honorable Mention	2012
Dean’s List	Fall 2010 - Spring 2012

RESEARCH EXPERIENCE

Doctoral Student 2012 - 2017
Language and Neuroscience Group, Aphasia Division
San Diego State University; San Diego, CA
Directors: Drs. Tracy Love and Lewis Shapiro
Projects: A multi-modal approach investigating sentence comprehension in individuals with aphasia, and age-matched neurologically unimpaired individuals. Methodologies include behavioral measures such as cross-modal priming, eye-tracking while listening, and final comprehension. Imaging approaches include arterial spin labeling and structure-function analyses.

Undergraduate Research Assistant 2010 - 2012
Cognitive Neuroscience Laboratory, Aphasia Division
San Diego State University; San Diego, CA
Director: Dr. Tracy Love, Director (619) 594-6354

CLINICAL EXPERIENCE

Adjunct Substitute Instructor (Non-Credit) 07/2017 - current
San Diego Community College District
Continuing Education
Roles:

- Provide instruction in accordance with established curriculum and course outlines
- Provide quality instruction, create and maintain an environment which emphasizes teaching and learning and encourages free discussion of ideas, interests and issues

Specialization: Adult Outpatient 01/2017 - 03/2017
Cognitive Retraining/Acquired Brain Injury Program
San Diego Community College District
Roles:

- Led classroom based intervention/instruction focusing on communication skills for adults with acquired brain injury (ABI)
- Organized and provided individual and small group speech and language intervention
- Developed individualized home programs focusing on cognitive and communication skills
- Collaborated with other instructors in regards to course content and student goals

Specialization: School-aged Pediatric 08/2016 -
Rancho San Diego Elementary; Rancho San Diego, CA 12/2016
Roles:

- Conducted speech and language evaluations using standardized and dynamic assessment measures
- Organized and led individual and group therapy focusing on articulation, fluency, pragmatics, expressive language skills, and receptive language skills
- Attended Individualized Education Plan (IEP) meetings and educated parents and faculty on students' progress toward goals
- Determined augmentative and alternative communication (AAC) candidacy and individualized both low and high tech AAC devices

Specialization: Adult Acute Care and Adult Outpatient 06/2016 -
Rehabilitation Services 08/2016
Sharp Grossmont Hospital; La Mesa, CA
Roles:

- Evaluated and treated speech, language, cognition, and swallowing deficits in adult and geriatric patients, including neurological, pulmonary, oncology and cardiology populations
- Developed appropriate client-centered goals and documented evaluation and treatment outcomes
- Collaborated with patients, family members, and other healthcare professionals regarding patients' medical stability and plan of care
- Performed clinical bedside swallow evaluations and assisted with the administration and interpretation of Fiberoptic Endoscopic Evaluation of Swallow (FEES) and Modified Barium Swallow (MBS) studies

Specialization: Pediatric and Adult Outpatient 09/2015 -
Speech and Language Clinic 05/2016
San Diego State University; San Diego, CA
Roles:

- Administered speech, language, and cognitive evaluations for adult and pediatric clients across socio-culturally diverse backgrounds
- Collected and synthesized relevant case history
- Developed and implemented individualized, functional treatment goals
- Worked with adult clients with acquired language disorders and pediatric patients with developmental language disorders, articulation disorders, and fluency disorders

Educational Technician 02/2015 -
Cognitive Retraining/Acquired Brain Injury Program 07/2015
San Diego Community College District
Roles:

- Provided individual, small group instruction and tutorial support for adults with developmental disorders and adults with acquired disorders resulting from stroke, or traumatic brain injury
- Assisted students with classroom activities focusing on speech, language, cognitive-linguistic and functional skills.
- Prepared materials for classroom activities focusing speech, language, cognitive-linguistic and functional skills
- Monitored and maintained student records

Volunteer 2010 - 2012
Developmental Services, Speech-Language Department
Rady Children's Hospital; San Diego, CA
Roles:

- Worked with pediatric clients on the autism spectrum and children with low language skills
- Assisted with the Early Intervention Program for children with communication disorders, including speech, language, and hearing impairments
- Carried out group activities, with direct guidance from staff to stimulate communication development via various preschool-type activities
- Assisted in preparation of activities/materials focused on communication development

PEER-REVIEWED JOURNAL PUBLICATIONS

Sullivan, N., Walenski, M., Love, T., & Shapiro, L. P. (2017). The curious case of processing unaccusative verbs in aphasia. *Aphasiology,* Advance online publication. doi: 10.1080/02687038.2016.1274873.

Sullivan, N., Walenski, M., Love, T., & Shapiro, L. P. (2017). The offline comprehension of sentences with unaccusative verbs in aphasia: a test of the intervener hypothesis. *Aphasiology, 31*(1), 67-81. doi: 10.1080/02687038.2016.1154499

PEER-REVIEWED PRESENTATIONS

Akhavan, N., **Sullivan, N.,** Love, T., and Blumenfeld, H. (2017). Effect of bilingualism on ambiguity resolution in object-relativeive sentences: Evidence from eye-tracking and cognitive tasks. To be presented at the 2017 American Speech-Language Hearing Association Convention.

Garcia, V., Harris-Bloom, O., **Sullivan, N.**, Love, T. (2017). Time-course of lexical activation of verbs during sentence processing. Presented at the 10th Annual San Diego State University Student Research Symposium, March 2017, San Diego, CA.

Shapiro, L. P., Love, T., MacKenzie, S., **Sullivan, N.**, Harris Wright, H. (2015). Sentence Comprehension in Aphasia: The Intervener Hypothesis. Presented at the Experimental Psycholinguistics Conference, October 2015, Madrid, Spain.

Engel, S., Love, T., **Sullivan, N**., Shapiro, L. P. (2015). Online Processing of Pronouns in Individuals with Broca's Aphasia. Presented at the 45th Annual Clinical Aphasiology Conference, May 2015, Monterey, CA.

Sullivan, N., Walenski, M., MacKenzie, S., Ferill, M., Love, T., Shapiro, L. P. (2014). The Time-course of Lexical Reactivation of Unaccusative Verbs in Broca's Aphasia. Presented at the 52nd Annual Academy of Aphasia Conference, October 2014, Miami, FL.

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

Mackenzie, S., Walenski, M., Love, T., Ferrill, M., Engel, S., **Sullivan, N.**, Harris Wright, H. and Shapiro, L. P. (2014). The Impact of Similarity-Based Interference in Processing Wh-Questions in Aphasia. Presented at the 52nd Annual Academy of Aphasia Conference, October 2014, Miami, FL.

Sullivan, N., MacKenzie, S., Walenski, M., Love, T., Shapiro, L. P. (2014). The Auditory Processing of Unaccusative Verbs in Aphasia. Presented at the 44th Annual Clinical Aphasiology Conference, May 2014, St. Simon's Island, GA.

Sullivan, N., Walenski, M., Love, T., Shapiro, L. P. (2013). Online Processing of Unaccusative Verbs in Individuals with Aphasia. Presented at the 5th Annual Neurobiology of Language Conference, November 2013, San Diego, CA.

TEACHING EXPERIENCE

Invited Guest Lecturer (Course Instructor: Melissa Hough, M.S.) Summer 2015
Continuing Education level Personal Living Skills
San Diego Community College District/Disability Support Programs and Services
Topic: Home Responsibilities and Chores

Graduate Assistant - (Course Instructor: Dr. Tracy Love) Fall 2014
Undergraduate level Neuroanatomy and Disorders of Speech and Language (SLHS 539)
San Diego State University

Invited Guest Lecturer – (Course Instructor: Dr. Lewis P. Shapiro) Spring 2013
Undergraduate level Introduction to Language Science (SLHS 300)
San Diego State University
Topic: Gap-filling in Sentence Processing

Graduate Assistant - (Course Instructor: Dr. Tracy Love) Fall 2013
Undergraduate level Anatomy, Neurology and Physiology of Speech (SLHS 321)
San Diego State University

Invited Guest Lecturer - (Course Instructor: Dr. Tracy Love) Fall 2013
Graduate level Acquired Neurogenic Language & Cognitive Disorders I (SLHS 609A)
San Diego State University
Topic: Cranial Nerves

PROFESSIONAL TRAINING

Optimized Pseudocontinuous Arterial Spin Labeling Protocol Training 2016
UCSD Center for Functional Magnetic Resonance Imaging; San Diego, CA

Magnetic Resonance Imaging Operator Training 2016
UCSD Center for Functional Magnetic Resonance Imaging; San Diego, CA

Healthcare Provider CPR and AED Training 2015
American Heart Association; San Diego, CA

E-Prime Basic Training Webinar 2015
Psychology Software Tools; Philadelphia, PA

SAS Programming I 2015
UCSD Extension; San Diego, CA

Analysis of Functional NeuroImages (AFNI) Training 2013
National Institutes of Health (NIH); Bethesda, MD

Magnetic Resonance Imaging Safety Training 2013
UCSD Center for Functional Magnetic Resonance Imaging; San Diego, CA

SERVICE

Co-Chair 2017
Speech-Language Awareness Information Day (S.A.I.D.)
San Diego State University, CA

Invited Ad-hoc Reviewer 2016
Aphasiology

Co-Chair 2016
Speech-Language Awareness Information Day (S.A.I.D.)
San Diego State University; San Diego, CA

Co-Chair 2015
San Diego Stroke Awareness and Information Day (S.A.I.D.)
San Diego State University; San Diego, CA

Volunteer 2012
2nd Annual SoCal Cognitive Neuroscience Conference
San Diego State University; San Diego, CA

ABSTRACT OF THE DISSERTATION

Sentence Comprehension in Aphasia: A Test of the Intervener Hypothesis

by

Natalie Jean Sullivan

Doctor of Philosophy in Language and Communicative Disorders

University of California, San Diego, 2017
San Diego State University, 2017

Professor Tracy Love, Co-Chair
Professor Lewis Shapiro, Co-Chair

This dissertation investigates the factors that contribute to the sentence comprehension deficits exhibited by individuals with a particular acquired language disorder, Broca's aphasia. Individuals with Broca's aphasia (IWBA) have no difficulty comprehending sentences that conform to canonical (S-V-O) word order. However, difficulty arises for non-canonical sentences that contain syntactic dependencies. There are several accounts that attempt to explain these deficits. The focus of these accounts differs, some focus on syntax, others on lexical level deficits, and others on reduced

cognitive resources. The current dissertation offers and focuses on a more recent account of the sentence processing deficits in IWBA, the Intervener Hypothesis (IH).

The IH suggests that difficulty comprehending sentences that contain syntactic dependencies arises when comprehension requires the crossing of an intervening noun phrase (NP), or intervener. The intervener causes similarity-based interference (SBI) because it is a possible element in the syntactic dependency. This dissertation tests the IH using sentences that contain a syntactic dependency inherent to unaccusative verbs.

Chapter 2 outlines pertinent linguistic concepts. Chapter 3 provides an overview of aphasia. Chapter 4 reviews psycholinguistic literature focusing on verb processing. Chapter 5 describes the sentence comprehension deficits observed in aphasia and theoretical accounts of these deficits. Chapter 6 details the account this dissertation focuses on, the IH. Chapter 7 investigates the time-course of lexical reactivation of unaccusative verbs during sentence processing. The results revealed that IWBA exhibit a time-course of lexical reactivation similar to neurologically unimpaired age-matched control (AMC) individuals indicating that IWBA are sensitive to the unaccusative property. Chapter 8 evaluates the IH by comparing final comprehension of sentences that contain unaccusative verbs in sentence constructions that contain an intervener and ones that do not. For IWBA, chance comprehension was found for sentences that contained an intervener suggesting SBI interferes with comprehension. Chapter 9 further investigates the pattern of comprehension observed in Chapter 8 using a real-time methodology, and also includes the first semantic manipulation of an intervener. The results revealed that SBI is observed during real time sentence processing of sentences that contain an unaccusative verb and an intervener, and that animacy reduced observed SBI.

CHAPTER 1:

Introduction

1.1 Introduction

Successful auditory language comprehension requires processes that activate and integrate several types of linguistic and nonlinguistic information. These processes are often only revealed when temporally sensitive online tasks are used, that is, tasks that measure comprehension during the unfolding of the sentence in real time. On the other hand, offline tasks, those that measure the endpoints of these online processes, reveal final sentence comprehension performance. Thus, a combination of on- and offline studies are necessary to reveal the moment-by-moment processing routines that give way to final comprehension.

For most individuals, auditory language comprehension appears effortless and automatic, but for some individuals this ability is compromised. This dissertation focuses on how adult individuals with a language disorder comprehend particular types of sentences, using both off- and online investigations. **The goal is to understand the underlying nature of the comprehension deficit in aphasia**, an acquired language disorder typically resulting from the brain damage following a stroke. For individuals with a specific sub-type of aphasia (agrammatic Broca's aphasia) comprehension of some sentences with non-canonical word order is difficult. In English, canonical word order is subject-verb-object (SVO). Sentences that do not conform to canonical word order include, among others, passives, sentences with object-extracted relatives, and object-extracted *Wh*-questions. Consider the following examples:

(1) The girl that kissed the boy has red hair.

(2) The girl that the boy kissed <~~the girl~~> has red hair.

In both (1) and (2), the ‘underlying’ meaning of the sentence is roughly ‘girl (with red hair) kissed boy,’ yet word order differs between the two. Example (1) conforms to SVO word order, contains a subject-relative clause where the Noun Phrase (NP) *the girl* is the subject or Agent of the action described by the verb *kiss*, and the NP *the boy* is the object or Patient of the action. Example (2), with an object-relative clause, reverses the subject and object, yielding Object-Subject-Verb (OSV) word order. On some theoretical accounts, (2) contains a syntactic dependency, where the object has been displaced (‘moved’) from its canonical position occurring after the verb to a position occurring before the verb. This displacement yields a copy of the affected NP (*the girl*) in the underlying object position. Skipping details here, to understand (2), listeners and readers must be able to link the two positions to understand “who did what to whom.” If such linking is absent or delayed during sentence processing, comprehension suffers.

Sentences (1) and (2) contain a verb (*kiss*) that is transitive, that requires two arguments in the sentence, both a subject and an affected object, and thus non-canonical word order is derived by displacement of the object. Consider now verbs that are intransitive, that only require a single argument or NP:

(3) The boy jumped.

(4) The boy disappeared <~~the boy~~>.

Sentence (3) contains an **unergative** verb, a type of verb that has one NP that serves as the semantic agent of the action and is essentially the subject. Sentence (4) contains an **unaccusative** verb, where the single argument is not the Agent of the action but is instead the Patient or Theme. On one important linguistic account – the Unaccusativity Hypothesis – the single argument of the verb in (4) has been displaced from the

underlying object position to a position at the front of the sentence, leaving behind a copy of the derivation (or "trace" in other linguistic terminology) (Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984). I reserve the details of this verb type and its implication for the syntactic representation of a sentence for later chapters. Here I note that I exploit the properties of these verb types in our investigations, which will help reveal the underlying nature of the comprehension deficit in aphasia.

Accounts of sentence comprehension difficulties in Broca's aphasia have posited a variety of underlying causes. Some accounts center on lexical level deficits (Love, Swinney, Walenski & Zurif, 2008; Thompson and Choy, 2009), others on syntax (Grodzinsky, 2000; Burkhardt, Piñango & Wong, 2003), and still others focus on memory processes that underlie similarity-based interference, termed the Intervener Hypothesis (e.g., Sheppard, Walenski, Love, & Shapiro, 2015). The latter approach is one of the primary foci of this dissertation, detailed in further chapters. Importantly, revealing the underlying nature of the sentence comprehension deficit in aphasia has the potential to aid in the development of theoretically motivated and efficacious language interventions (see, for example, Thompson & Shapiro, 2007), and has implications for understanding brain-behavior relations.

1.2 Overview of Dissertation

The primary goal of this dissertation is to understand the factors contributing to the pattern of sentence comprehension deficits evinced by individuals with Broca's aphasia. This dissertation focuses on a recent account of the sentence processing deficits in individuals with Broca's aphasia, the Intervener Hypothesis (Sheppard et al., 2015; Engel, Shapiro, & Love, submitted). The Intervener Hypothesis suggests that the

presence of intervening noun phrase (NP) between the elements linked by a syntactic dependency induces similarity-based interference. The claim here is that similarity-based interference is responsible for the sentence comprehension patterns that are a hallmark of Broca's aphasia. To evaluate the Intervener Hypothesis, a variety of methods, including offline and online tasks, are used to explore how particular sentence types that include unaccusative verbs are understood.

In Chapter 2 I provide an overview of linguistic terminology relevant to sentence processing, focusing on the properties of verbs. In Chapter 3 I offer an interlude, discussing aphasia and its symptoms. Chapter 4 describes the psycholinguistic literature regarding processing verb properties in both unimpaired and aphasic populations. Chapter 5 offers a brief review of the sentence processing deficits that result from Broca's aphasia and the theoretical accounts aimed at explaining these deficits. Chapter 6 offers a thorough explanation of the Intervener Hypothesis and a review of relevant psycholinguistic literature.

To determine if individuals with Broca's aphasia are sensitive to unaccusative verbs and process them with a similar time-course as neurologically unimpaired individuals, Chapter 7 includes studies that investigate the online processing of sentences that contain unaccusative verbs. Chapter 8 provides an offline study that uses sentences that contain unaccusative verbs as a test case for the Intervener Hypothesis.

To date, the Intervener Hypothesis has only been evaluated in terms of structural similarity, that is, using NPs that are structurally similar (e.g., those that have both a Determiner and Noun). However, other characteristics of interveners, such as semantics, may also play a role in similarity-based interference during sentence processing. Chapter

9 includes an online study that explores how and when similarity based interference manifests during sentences that contain unaccusative verbs, and investigates whether semantically manipulating an intervener via its animacy reduces its impact and thus improves comprehension performance. Finally, Chapter 10 is a general discussion of the topics of the dissertation, along with its conclusions. I now move to Chapter 2, where some basic linguistic properties of sentences are discussed.

References

Burkhardt P., Pinango M.M., & Wong K. (2003). The role of the anterior left hemisphere in real-time sentence comprehension: evidence from split intransitivity. *Brain and Language, 86*(1), 9–22

Burzio, L. (1986). *Italian syntax: A government-binding approach*. Dordrecht: Reidel.

Engel, S., Shapiro, L.P., & Love, T., (submitted). Proform-Antecedent linking in individuals with agrammatic aphasia: A test of the intervener hypothesis. Manuscript submitted for publication.

Grodzinsky, Y. (2000). The Neurology of Syntax: Language Use without Broca's Area. *Behavioral and Brain Sciences, 23*, 1–71.

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

Perlmutter, D. M. (1978). Impersonal passives and the Unaccusative Hypothesis. In *Proceedings of the Fourth Annual Meeting of the Berkeley Linguistics Society* (157–189). Berkeley: University of California, Berkeley Linguistics Society.

Perlmutter, D. M., & Postal, P. (1984). The 1-Advancement Exclusiveness Law. In Perlmutter, D. & Rosen, C. (Eds.), *Studies in Relational Grammar* (281–126). Chicago: University of Chicago Press.

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.

Thompson, C., & Choy, J. (2009). Pronominal resolution and gap filling in agrammatic aphasia: Evidence from eye movements. *Journal of Psycholinguistic Research, 38*(3), 255-283.

Thompson, C. K., & Shapiro, L. P. (2007). Complexity in treatment of syntactic deficits. *American Journal of Speech-Language* Pathology, *16*(1), 30-42.

CHAPTER 2:

Linguistic Considerations

2.1 Phrase Structure (Simplified)

Sentences are comprised of constituents that are organized in a hierarchical manner. In Figure 2-1 below, revealing the simplified structure of the sentence, **"***The boy kicked the girl*," each lexical item belongs to a lexical category, for example, Noun, Determiner, Verb.

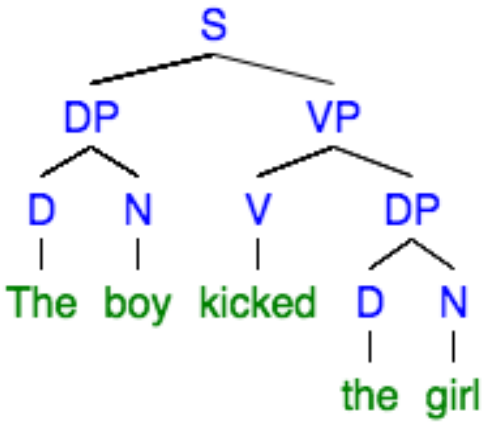


Figure 2-1. Abbreviated phrase structure for *the boy kicked the girl*.

Following Chomsky's transformational grammar framework, constituents combine via a Merge operation to form higher order phrasal categories (Chomsky, 1995). In the example above, the Determiner *the* and the Noun *boy* merge to form the Determiner Phrase (DP) *the boy*. The successive merging of phrasal categories yields a sentence. Thus in Figure 1, the DP[1] and the Verb Phrase (VP) merge to form the sentence, *The boy kicked the girl*.

Phrasal categories are constrained by a set of rules. A phrasal category must contain a lexical item belonging to the lexical category of the phrase, for example, a VP

[1] For simplicity, in the remainder of the paper NP will be used instead of DP.

must contain a Verb. Second, the lexical item from which a phrasal category projects is the head of that phrase. For example, the VP *kicked the girl* projects from the verb *kick* and therefore *kick* is the head of the VP. Third, all phrasal categories must contain a head. English is a head-first language such that anything that is formed to the right of the head is a complement of the head. For example, the NP *the girl* is a complement of the head of the VP, the verb *kick*.

2.2 Lexical Properties of Verbs

An individual's mental lexicon is comprised of all the lexical items that an individual knows. Two important classes of lexical items that comprise an individual's lexicon are nouns and verbs, both of which are required to form a sentence. The representations of nouns and verbs in the lexicon are similar in that they both include their lexical category, phonological, orthographic, and semantic information. One important property of verbs is its **argument structure**. As shown below, argument structure constrains phrasal structure to yield only grammatical (well-formed) sentences.

Predicate argument structure in its simplest form characterizes how many participants a verb requires in a sentence. Consider:

(1) The girl slept.

(2) The girl kicked the boy.

(3) The girl put the book on the shelf.

(4) *The girl bought.

In (1) the verb *slept* requires one argument (*the girl*) and so is a one place predicate, with the single argument playing the role of grammatical subject; one argument verbs are intransitive. In (2) the verb *kicked* requires two arguments, one in the grammatical subject

position (*the girl*) and one in the grammatical object position (*the boy*). Verbs such as *kicked,* that require two arguments, are transitive verbs. In (3) the verb *put* requires three arguments, one in the grammatical subject position (*the girl*), one in the grammatical direct object position (*the book*), and one in the grammatical indirect object position (*the shelf*). Verbs like *put,* that select for three arguments, are ditransitive verbs.

Violations of argument structure such as missing or extra arguments result in ungrammatical sentences, as in (4). Here, the verb *bought* requires two arguments. Because the sentence contains only one argument (the NP, *the girl*), the argument structure for the verb is not satisfied in the sentence, and the sentence therefore is ungrammatical. In this way, argument structure is a constraint on the well-formedness of sentences.

Some verbs can take more than one argument structure configuration. In (5) and (6) below, the verb *serve* selects for either a two-place argument structure (5), or a three-place argument structure (6):

(5) The waitress served the sandwich.

(6) The waitress served the customer to the customer

Verbs can also be optionally transitive as demonstrated in (7) and (8):

(7) The boy ate.

(8) The boy ate the hamburger.

In (7) the verb *ate* takes the single argument *the boy,* while in (8) the verb takes two arguments (*the boy* and *the hamburger*).

In addition to these syntactic constraints, verb argument structure also plays a role in the semantics of sentences through *thematic roles*. Thematic roles describe the

semantic relationship between a verb and its arguments. Recall that the transitive verb *kick* requires two arguments. One argument must perform the action of kicking and one must receive it. In (9) the argument initiating the action is assigned the thematic role of *Agent* and the argument receiving the action is assigned the thematic role of *Theme*.

(9) The boy kicked the girl.
Agent **Theme**

Each argument can receive one and only one thematic role and each thematic role can be assigned to only one argument. When these constraints are violated, it results in ungrammaticality, shown below in (10). In (10) there is no argument position to receive the thematic role of *Theme* and therefore the sentence is ungrammatical.

(10) *The boy kicked
Agent

There are several other thematic roles that describe the semantic relationship between a verb and its arguments. Some other common thematic roles include *Experiencer*, assigned to an argument undergoing a psychological or mental event (e.g., <u>John</u> thinks that Mary likes him), *Goal*, assigned to an argument that something moves towards (e.g., John gave the book to <u>Mary</u>), and *Locative*, assigned to the location where something happens (e.g., John hid the ball under <u>the table</u>).

Verbs assign thematic roles to their arguments via theta marking (Chomsky, 1981). Recall from the description of phrase structure that elements to the right of the head of a phrase in English are complements. On some accounts, complements or arguments within the VP (also called internal arguments) are assigned a thematic role as they merge with the verb to form the VP. When the VP merges with the external argument (i.e., the subject) it is assigned a thematic role. Verbs assign thematic roles to

grammatical positions, for example, the transitive verb *kick* has two thematic roles to assign, one to the grammatical subject position (Agent) and one to the grammatical object position (Theme).

The sentences above used to demonstrate thematic role assignment conform to canonical subject-verb-object (for English) word order. In the case of non-canonical sentences such as (11), thematic role assignment is similar.

(11) The boy that the girl kicked <~~the boy~~>.

Skipping some details, recall that non-canonical word order sentences often contain a syntactic dependency. In (11) the direct object NP (*the boy*) is displaced to an earlier position and leaves behind a covert copy or trace resulting in a syntactic link between the two constituents. In many non-canonical word order sentences, the Agent role is assigned to the subject NP (*the girl*) the same way that it is assigned for canonical word order sentences. And like canonical sentences, the thematic role Theme is assigned to the direct object position, but this position is now occupied by a copy (or trace) of the displaced NP. The displaced NP (*the boy*) receives the thematic role of Theme via the link between the copy and the displaced NP (on other similar accounts, the thematic role is assigned to the syntactic chain, in this case consisting of the displaced NP and its copy).

Moving back to intransitive verbs, there are two types of interest to this study: unergatives and unaccusatives. Both types require only one argument, yet there are semantic and syntactic properties that distinguish the two. For example, in (12) below the single argument (the NP *the boy*) of the unergative verb *jump* is initiating the action of jumping and is assigned the thematic role of *Agent*.

(12) The boy jumped.

(13) The boy disappeared <~~the boy~~>.

In (13) the single argument (the NP the boy) of the unaccusative verb *disappear* is not initiating the action of disappearing. Instead, the action is happening to the single argument and is therefore assigned the thematic role of theme, a thematic role typically assigned to the grammatical object of a sentence.

In addition to this semantic difference, unaccusatives and unergatives also differ syntactically. In both (12) and (13) the single argument occurs in the grammatical subject position. However, according to the Unaccusativity Hypothesis (Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984), the single argument for unaccusative verbs such as *disappear* (13) is claimed to be base-generated in object position and is displaced to the surface subject position, leaving behind a covert constituent called a *trace* (or *copy*) in linguistic terminology and a *gap* in psycholinguistic terminology. To successfully comprehend a sentence such as (13), the link between the gap and its antecedent must be established and processed.

Some unaccusative verbs can alternate in transitivity. For example, in (14) *melt* occurs in a transitive context and in (15) *melt* is used intransitively.

(14) The sun melted the popsicle.

(15) The popsicle melted.

Unaccusative verbs that can be used both transitively and intransitively are called alternating unaccusatives. Not all unaccusative verbs alternate in transitivity. For example, if the unaccusative verb *arrive* is used transitively it results in an ungrammatical sentence, as shown in (16).

(16) *The girl arrived the boy.

Unaccusative verbs that can only be used in an intransitive context are called non-alternating unaccusative verbs.

To briefly summarize, argument structure characterizes how many participants a verb requires. Thematic role assignment from the verb or VP to its arguments characterizes the sentence in terms of ‘who does what to whom’. Finally, there are also two types of intransitive verbs, with one type, unaccusatives, yielding a syntactic dependency. I now move to a chapter describing aphasia, with a focus on individuals with Broca’s aphasia and the comprehension deficits they evince.

References

Burzio, L. (1986). *Italian Syntax: A government-binding approach.* Dordrecht: Reidel Publishing Company.

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

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

Perlmutter, D. M. (1978). Impersonal passives and the unaccusative hypothesis. *Proceedings of the 4th Annual Meeting of the Berkeley Linguistics Society* (pp. 157-189). Berkeley: University of California: Berkeley Linguistics Society.

Perlmutter, D. M., & Postal, P. M. (1984). The 1-Advancement Exclusiveness Law. In D. Perlmutter, & C. Rosen (Eds.), *Studies in Relational Grammar 2* (pp. 81-126). Chicago: University of Chicago Press.

CHAPTER 3:

Aphasia: An Interlude

3.1 Introduction

Aphasia is an acquired language disorder that results from a cerebrovascular accident, or stroke. Most often, when a stroke occurs in the left hemisphere (for most right-handed individuals), it results in difficulties in core language areas such as comprehension, production, reading, and/or writing. The extent of language impairments can vary depending on the size and location of the resulting lesion. Aphasia is not a unitary disorder, as many subtypes of the disorder have been classified based on the constellation of behavioral symptoms and deficits that are present (Kertesz, 1982; Goodglass & Kaplan, 1972). Although this dissertation focuses on a particular sub-type of aphasia (Broca's aphasia), this group is typically compared to other sub-types of aphasia as control groups to aid in understanding brain-behavior relationships. This tactic allows investigators to isolate language processing to specific groups and ultimately to the neural networks underlying the impairment. Thus, a general overview of aphasia sub-types is provided below.

3.2 Categories of Aphasia

Historically, aphasia has been categorized based on behavior and the general areas of the brain that have been affected by neural trauma (Kertesz, 1982; Goodglass & Kaplan, 1972). There are two main categories of aphasia, fluent and non-fluent. The sub-types of aphasia that fall under the **fluent** category include Wernicke's, Conduction, Anomia and Transcortical Sensory. Individuals with fluent aphasias produce speech rather effortlessly. However, the content of their utterances can be nonsensical and often referred to as "empty" as it is riddled with errors such as jargon or inappropriate word choices, making those patients difficult to understand. While the ability to produce

speech is relatively intact for individuals with fluent aphasia, their language comprehension abilities are impaired. This pattern of receptive/expressive language is in contrast to the other general sub-types of aphasia that fall under the **non-fluent** aphasia **category** that include Broca's, Global and Transcortical Motor. Individuals with non-fluent aphasias typically have expressive impairments, producing halting, telegraphic, slow speech. Historically, they were thought to have impairments limited to the language production domain, but back in the 1970's, it became clear that comprehension was also vulnerable in some of these individuals (more details below).

What follows is a brief overview to the language profile of a specific subtype of aphasia that will be the focus of this dissertation- Broca's aphasia. This group has been shown to have particular impairments comprehending complex sentence structures and thus provides an excellent opportunity to explore the brain-behavior relationship underlying language processing.

3.3 Broca's Aphasia

Language production in individuals with Broca's aphasia is characterized as slow, halting and telegraphic as they often omit function words, such as "the" or "and," as well as grammatical markers for tense, agreement, number, and gender. While language production difficulties are most apparent in individuals with Broca's aphasia, research has demonstrated that they also have comprehension impairments (Caramazza & Zurif, 1976; Love, Swinney, Walenski, & Zurif, 2008; Grodzinsky, 2000, among others).

In one of the first studies to highlight comprehension deficits in individuals with Broca's aphasia, Caramazza and Zurif (1976) reported comprehension deficits for semantically reversible sentences (2) as compared to nonreversible ones (1); the former

being one in which multiple nouns in the sentence could viably perform the action of the sentence. Consider the following:

(1) The pizza was eaten by the boy.

(2) The girl was kicked by the boy.

Both of these sentences are passivized, as such the noun receiving the action of the verb precedes the verb. Sentence (2) is semantically reversible since the two nouns ("boy" and "girl") are each capable of performing the action (the act of "kicking"), as they are both animate nouns. However, in example 1, the two nouns ("pizza" and "boy") are not semantically reversible, because the boy is an animate noun, and is thus the only entity who can perform the action of eating (pizza, as an inanimate object, cannot perform this action).

When individuals with Broca's aphasia were presented with semantically reversible (e.g., example 2) and non-reversible (e.g., example 1) sentences in a sentence-picture matching task, they demonstrated above-chance performance on non-reversible constructions (1) and chance performance for reversible ones (2). Based on these results, the authors argued that these individuals used their real-world knowledge of the properties of animate and inanimate objects in order to determine who performed the action in non-reversible sentences. However, when both nouns in the sentence could possibly perform the action in reversible sentences, patients were unable to use any semantic cues to determine who performed the action of the sentence.

Based on this set of findings, Caramazza and Zurif argued for a representational deficit for these individuals, arguing that Broca's patients lack the syntactic knowledge needed to comprehend syntactically-complex sentence structures. They further argued

that these patients would rely on heuristic strategies whenever possible to aid in understanding these types of sentences. Thus, in the same way that individuals with Broca's aphasia lack grammar in their production, Caramazza and Zurif argued that they also lack the grammatical skills that are needed to properly comprehend sentences, and the authors described this collection of deficits under the new term "overarching agrammatism," which refers to the purported grammatical deficit in Broca's aphasia, across both receptive and expressive domains.

Beyond Caramazza and Zurif's original study (1976), a great deal of work has been devoted to trying to more fully understand the nature of sentence comprehension deficits in this population. It has been repeatedly demonstrated that individuals with Broca's aphasia have minimal difficulties understanding canonically ordered (S-V-O, English) sentences (3) below, but have difficultly comprehending non-canonical sentences such as (4) below (Schwartz, Linebarger, Saffran, & Pate, 1987; Love & Oster, 2002; Grodzinsky, 2000; Hickok, 1992; Zurif, Swinney, Prather, Solomon, & Bushell, 1993, Love et al., 2008, and many others).

(3) The boy kicked the girl with red hair.
subject verb object

(4) The girl that the boy kicked <~~the girl~~> had red hair.
object subject verb

In (4), a non-canonical object-extracted relative clause, the direct object NP has been displaced from a post verbal position to the beginning of the sentence. This displacement leaves behind a trace (or gap) in the direct object position from which the NP (*the girl)* has been displaced as depicted in (4). In order to successfully comprehend a

sentence that contains a filler-gap syntactic dependency, processing the link between the gap or trace and its antecedent is required.

In summary, this chapter included a brief description of the two categories of aphasia, fluent and non-fluent. I also outlined the language abilities of individuals with Broca's aphasia and detailed the sentence comprehension deficit among this population. The studies included in this dissertation focus on a verb property to further investigate the factors contributing to the sentence comprehension deficit observed for individuals with Broca's aphasia. As such, in the following chapter I provide a review of psycholinguistic studies that focus on verb properties in neurologically unimpaired individuals and individuals with aphasia.

References

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.

Goodglass, H., & Kaplan, E. (1972). The Assessment of Aphasia and Related Disorders. Philadelphia: Lea & Febiger.

Grodzinsky, Y. (2000). The Neurology of Syntax: Language Use without Broca's Area. *Behavioral and Brain Sciences, 23*, 1–71.

Hickok, G. (1992). *Agrammatic comprehension and the trace-deletion hypothesis.* Occasional paper, 45, Center for Cognitive Science, MIT.

Kertesz, A. (1982). *Western aphasia battery test manual*. Psychological Corp.

Love, T., & Oster, E. (2002). On the categorization of aphasic typologies: The SOAP (a test of syntactic complexity). *Journal of Psycholinguistic Research, 31(5),* 503-529.

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

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

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 4:

Psycholinguistics of Verb Properties

4.1 Introduction

In this chapter, the properties of verbs and sentences reviewed in Chapter 2, Linguistic Considerations, are discussed in terms of their processing implications for both unimpaired individuals as well as aphasic populations. To begin, I offer a brief primer on the various methods and tasks typically employed in psycholinguistic research.

4.2 Methods and Tasks

Recall from Chapter 1 the distinction between online and offline methods. Online sentence processing methods examine the types of information that are available on a moment-to-moment, real-time basis during sentence processing. Methods in this category include cross-modal interference (CMI) tasks, cross-modal priming (CMP) tasks, functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and eye tracking using the visual world paradigm (VWP).

Cross-modal interference (CMI) is a dual-task method that uses reaction times as a measure of cognitive load. As participants are presented with auditory sentences, they are required to make a binary decision about a visual probe (e.g., string of letters) presented momentarily (e.g., 500 ms) on a screen at a particular point in time. Participants must determine if the letter string is or is not a real word and push a response button as quickly as possible. In trials where the letter string is a real word, the word is unrelated to the sentence. Reaction times to the lexical decision are collected, with longer reaction times indicative of greater processing demands at the point where the probe was encountered, essentially revealing a snapshot of processing. One advantage of this method is that it allows for the uninterrupted presentation of the auditory stimuli; that is, the sentence plays through to its end. Furthermore, the lexical probes can be placed

anywhere during the unfolding of the sentence. Yet, CMI is a dual-task, and thus has the disadvantage of requiring a listener to make a decision during the sentence while also listening to the sentence for meaning. Also, depending on the number of probe positions required in an experiment, the designs can get cumbersome, since the method requires that only a single probe be placed during any one sentence.

Similar to cross-modal interference tasks, **CMP** also employs a dual-task. This technique has two variants that differ on the type of overt response the participant makes. During cross modal lexical priming (CMLP) or cross modal picture priming (CMPP), participants are presented with auditory sentences and required to make a binary decision about a visually presented probe (lexical item or picture). Importantly in this method, the visual probe is related to a lexical item of interest in the sentence in one condition and unrelated in another. Faster reaction times to the related versus the unrelated visual probe indicates priming, a measure of lexical activation. The other variant of CMP is cross-modal naming (CMN). Here, rather than participants making a binary decision to a visual probe (e.g., lexical decision), they overtly name what is visually presented. As in CMLP and CMPP, the visual probes are either related or unrelated to a critical item in the sentence and the participant's naming time and accuracy are recorded. All CMP variants have been shown to be effective in reflecting lexical activation.

Similar to CMI tasks this method is advantageous as it allows for continuous presentation of the auditory stimuli. However, like CMI, the binary decision that allows for measurement of lexical activation in CMP only occurs at predetermined time-points of interest during the unfolding of the sentence. Thus, one disadvantage of this task is that it can only illuminate what is occurring at the specified time points, and not over the

entire auditory stream. And like CMI, CMP also has the disadvantage of a dual task – though dual task processing is reasonably easy for neurologically-unimpaired, arguments can be made that the task itself could be difficult for those participants with brain damage.

The ability to investigate processing over the entire auditory stream is offered by the **visual world paradigm** (VWP). VWP, also called "looking-while-listening" was motivated by Cooper's (1974) observation that when listeners view a scene and are simultaneously presented with auditory language, they look at what is mentioned in the auditory input. As such, during a VWP study participants are simultaneously presented with a visual display and auditory input. Visual displays are either a scene or an array that depicts the constituents mentioned in the auditory input, as well as distractor items not mentioned in the auditory input. Eye gazes to the referents are recorded as the sentence unfolds and used as the dependent measure. A potential disadvantage of this methodology is that the visual stimuli may support, or influence, auditory processing.

Another online method comes from electroencephalography (EEG). In EEG studies, electrodes are placed on the scalp to measure the electrical activity of the brain. **Event related potentials (ERPs)** are changes in voltage that are time-locked to the presentation of a stimulus. ERPs are averaged over several trials and the succession of negative and positive changes in voltage over time collected are referred to as ERP components. ERP components are typically characterized in terms of polarity, amplitude, latency, and scalp distribution. For example, the P300 component is a positive fluctuation in voltage that occurs roughly 300 milliseconds after a visual or auditory stimulus. The distinct advantages of ERP include the fluent presentation of the input and that no dual

task is necessary, and indeed, in many cases the listener's only task is to listen to the sentences. ERP is well suited for determining the timing of neural activity, as it is sensitive to millisecond effects, but is less effective at determining where in the brain neural activity is occurring if that is one of the goals of the experiment.

In comparison to the fine-grained temporal resolution offered by EEG, **fMRI** is an online imaging method that provides very good spatial resolution. fMRI is a type of magnetic resonance imaging that measures changes in blood flow and blood oxygenation in the brain. The primary unit of measure is the blood-oxygen level dependent (BOLD) signal. The BOLD signal provides an indirect measure of neuronal activation. As neural activity in an area of the brain increases, the amount of blood flowing to that area increases. This increased blood flow is disproportionate to the amount of oxygen being metabolized. This results in higher concentrations of oxygenated blood and provides a stronger BOLD signal. As the BOLD signal is an indirect measure, one disadvantage of fMRI is that it not reflective of moment by moment activation.

Unlike the online methods discussed above, offline studies focus on the final interpretation of sentences rather than moment-to-moment language processing. **Sentence-picture matching (SPM)** tasks are a commonly used method to investigate conscious metalinguistic sentence comprehension. In a SPM task, participants are presented with an auditory sentence (e.g., "the girl is pushing the boy") and two images, one that accurately reflects the sentence meaning (e.g., a picture of a girl pushing boy) and the other, typically a foil that reverses the NPs (e.g., boy pushing girl). The participant is required to indicate which picture depicts the meaning of the presented sentence. Another variant is a **truth-value judgment task**, where a participant is

presented with a single picture while listening to a sentence, and has to decide if the picture does or does not accurately depict the sentence. **Grammaticality judgment** is another type of offline task. After being presented with a sentence, participants are asked to indicate if the sentence was or was not grammatical. These offline methods allow the listener to hear all components of the sentence and, in an untimed manner, reflect upon those sentences to make an overt decision about them.

I move now to a discussion of psycholinguistic studies that draw on a variety of the methods just described. I organize these studies with respect to the properties of verbs previously reviewed: argument structure and unaccusativity. The goal of this section is to understand the effects of these properties on sentence processing and comprehension, in both unimpaired individuals and those with aphasia.

4.3 Argument Structure: unimpaired listeners

Recall that argument structure characterizes how many participants a verb requires for a sentence to be well-formed. Shapiro and colleagues (e.g., Shapiro, Zurif, and Grimshaw, 1987; Shapiro, Brookins, Gordon, and Nagel, 1991) conducted a series of CMI studies demonstrating that verb argument structure is immediately available upon hearing a verb in a sentence. Sentences were designed that included verbs that varied in their argument structure representations. Two groups of verbs allowed for only one argument structure configuration such as (1) and (4). Transitive verbs such as *solve* in (1) require two arguments and ditransitive verbs such as *handed* in (4) require three arguments.

(1) Nancy solved the problem.

(2) Reagan lent the money.

(3) Regan lent the money to the Contras.

(4) Parish handed the teeth to Lambier.

Although these verbs differ in the number of arguments they require, they are similar in that they only allow for one argument structure configuration. A set of optionally ditransitive verbs were also included such as *lent* in (2) and (3). These types of verbs allow for two different argument structure configurations, one that requires two arguments (2) and one that requires three arguments (3). Sentences were presented aurally, and lexical decision probes were presented at the offset of the verb, while the sentence continued. Participants were required to listen to the sentence and make the lexical decision when the probe appeared. The idea here is that the more argument structure configurations, the greater the local processing load, and thus longer reaction times should be observed relative to verbs that had fewer configurations. Longer reaction times for the lexical decision task were found at the offset of the verb for sentences with optionally ditransitive verbs compared to sentences with transitive and ditransitive verbs. These results suggest that listeners activate all possible argument structure configurations for a verb upon encountering it during auditory sentence comprehension, setting up further operations of the parser.

The ‘processing reality’ of argument structure has also been demonstrated with studies measuring neural activity. The role of argument structure during sentence processing has also been evaluated using an ERP and CMI paradigm (Rubin, Newhoff, Peach, and Shapiro, 1996). Similar to Shapiro and colleagues, Rubin et al. (1996) presented sentences that contained transitive verbs, ditransitive verbs, or optionally ditranstive verbs. Again, transitive verbs and ditransitive verbs allow for only one

argument structure possibility (two and three arguments respectively). In contrast, optionally ditransitive verbs allow for two different argument structure possibilities (either two or three arguments) and as such are argued to be more complex. Within ERP studies, the degree to which the resources required for a primary task and a secondary task overlap are understood to impact the amplitude of the P300 signal such that as the complexity of the primary task increases the P300 amplitude increases (Wickens, Kramer, Vanasse, and Donchin, 1983). In the current case, where the primary task was listening to sentences and the secondary task was a lexical decision, the cognitive resources overlap. The results of the study found greater P300 amplitudes for the high complexity condition (optionally ditransitive verbs) compared to the low complexity condition (transitive and ditransitive verbs). These results provide electrophysiological evidence that verbs that allow for multiple argument structure configurations require greater processing, indicating that listeners immediately activate all of a verb's possible argument structure possibilities during sentence comprehension.

Together the findings from the above studies demonstrate that all the possible argument structures of a given verb are immediately activated by listeners upon hearing a verb in a sentence. In contrast, Ahrens and Swinney (1995) conducted a CMI task and found that the number of arguments a verb requires resulted in an increase in processing demands during auditory sentence comprehension. Faster reaction times at the offset of the verb were found for verbs that required fewer arguments (two arguments) than for verbs that required a greater number of arguments (three arguments). Unlike the Shapiro et al. studies, these results suggest that the number of arguments a verb requires is also made immediately available to a listener upon encountering a verb in a sentence. One

possibility for the differences observed in these studies is that verb categorization differed across the studies. For example, Ahrens and Swinney (1995) accepted dialectical and idiolectical usage of verbs (e.g. I donated the library some books) while Shapiro and colleagues employed stricter criteria.

Evidence for an increase in neural activity in specific regions of the brain have also been found when sentences contain more arguments relative to fewer arguments. Ben-Shachar, Hendler, Kahn, Ben-Bashat, and Grodzinsky (2003) found increased activation in the left superior temporal sulcus (STS), Brodmann areas (BA) 22/39 as the number of arguments a verb required in sentences increased during an fMRI study. The left STS has also been associated with auditory language processing (e.g. Ahmad, Balsamo, Sachs, Xu, and, Gaillard, 2003). Similar patterns of graded activation for the number of arguments a verb requires has also been found in areas of the brain not associated with language processing. Shetreet, Palti, Friedmann, and Hadar (2007) found graded activation as the number of verb arguments increased in the right anterior cingulate and precuneus during sentence processing.

Another line of research has investigated the semantic relationship between verb meaning and argument structure during sentence processing. In a classic VWP study, Altmann and Kamide (1999) compared eye gazes to objects while hearing sentences such as (5) and (6) with a group of college-aged adults.

(5) The boy will eat the cake.

(6) The boy will move the cake.

The visual display consisted of a scene which depicted five items (e.g. a boy, a cake, a ball, a toy car, and a toy train set). All of the items in the display were moveable, but only

one of the items was edible (cake). Subjects exhibited significantly greater gazes to the cake than to the other objects in the scene while hearing *The boy will eat the cake*. The time course of gazes revealed that the increase in gazes to the cake were anticipatory: they were observed at verb-offset, prior to hearing the word *cake*. In the *move* condition, no significant difference in gazes to objects was found. These results demonstrate that the meaning of verbs is used to anticipate potential noun phrases during sentence processing, at least as measured by a visual world task, and provide an example of how semantic verb properties impact online sentence processing.

Finally here, though some verbs require multiple argument structure possibilities as discussed above, there is evidence that some of these possibilities are preferred over others during sentence processing, and these preferences predict upcoming material in the sentence (e.g., for a seminal study, see Fodor, Garret, & Bever, 1968; see also Shapiro, Nagel, & Levine, 1993; Trueswell, Tanenhaus, & Kello, 1993). It is clear then that verbs and their properties play a privileged role during sentence processing.

4.4 Argument Structure: Broca's Aphasia

In a study that is likely the first to examine the role of argument structure during sentence processing in aphasia, Shapiro and Levine (1990) investigated argument structure processing in individuals with either Broca's or Wernicke's aphasia using a cross-modal interference task. Canonical word order sentences containing verbs that allowed for one argument structure (transitive with two arguments, ditransitive with three arguments) or multiple argument structure possibilities (optionally ditransitive, two or three arguments) were presented aurally. Participants were required to make a lexical decision at the offset of the verb, while the sentence continued unimpeded. Participants

with Wernicke's aphasia exhibited no difference in reaction times across conditions. However, similar to neurologically unimpaired listeners, the participants with Broca's aphasia exhibited longer reaction times during sentences that contained verbs with more than one possible argument structure than for those that allow for only one argument structure.

These findings suggest that listeners with Broca's aphasia are normally sensitive to the argument-taking properties of verbs, while those with Wernicke's aphasia are not. Note that the sentence structures used in this study conformed to canonical word order, which do not pose difficulty for individuals with Broca's aphasia. A follow-up study by Shapiro, Gordon, Hack and Killackey (1993) investigated sensitivity to verb argument structure in individuals with Broca's and Wernicke's aphasia in sentences with non-canonical word order. Again, similar to neurologically unimpaired listeners, the participants with Broca's aphasia evinced longer reaction times at the offset of verbs that allowed for more than one argument structure than for verbs that only allowed one argument structure. Again, individuals with Wernicke's aphasia did not show such sensitivity to argument structure. These findings suggest that verb argument structure is immediately accessed by listeners with Broca's aphasia, even for sentence constructions where comprehension is impaired. The results from both of the above studies also suggest that areas of the brain typically impacted with a Wernicke's type aphasia may play a role in the processing of verb argument structure during auditory sentence comprehension.

Although behaviorally listeners with Broca's aphasia demonstrate sensitivity to verb argument structure similar to neurologically unimpaired listeners, differences in neural activity have been observed (Kielar, Meltzer-Assher, & Thomspon, 2012). The

role of argument structure during sentence processing was investigated with an ERP study with individuals with Broca's aphasia and two groups of neurologically unimpaired individuals (young college-aged and age-matched). Participants were aurally presented with sentences that contained an argument structure violation such as (7).

(7) Anne sneezed the doctor and the nurse.

The verb *sneeze* is an intransitive verb and only accepts one argument. Sentences that contained transitive verbs that require two arguments were included as a control condition (e.g. *Anne visited the doctor and the nurse*). Participants were required to make grammaticality judgments about the sentences after hearing them. During sentences that violated verb argument structure negative shifts in polarity were present for both groups of neurologically unimpaired individuals. The negative shift occurred during the determiner (*the*) for the younger neurologically unimpaired group and during the noun (*nurse*) for the older neurologically unimpaired group. The pattern of neural activity observed for the participants with Broca's aphasia differed from both neurologically unimpaired groups. Positive shifts were present during the determiner of the argument structure violation. In addition to the electrophysiological differences, the participants with Broca's aphasia exhibited poorer accuracy than the neurologically unimpaired participants for the grammaticality judgment task.

These findings demonstrate that listeners with Broca's aphasia are processing verb argument structure differently than neurologically unimpaired individuals as different polarities were observed for ERP components during sentences that violated verb argument structure. Due to the differences in neural activity and poorer accuracy, the authors argue that listeners with Broca's aphasia are not sensitive to verb argument

structure. However, given that listeners with Broca's aphasia have experienced neural trauma it is not surprising that their neural activity may differ from neurologically unimpaired listeners. Moreover, while accuracy at detecting grammatically may have been poorer compared to neurologically unimpaired participants in this study, other grammaticality judgment studies have demonstrated that listeners with Broca's aphasia are sensitive to verb argument structure. Kim and Thompson (2000; 2004) evaluated the ability of listeners with Broca's to detect ungrammaticalities in sentences that contained verbs with varying argument structures. Verbs that obligatorily selected for one, two, or three arguments were included. Ungrammaticalities were created with either the addition of an argument, the omission of one or more arguments. They found greater than 90% mean accuracy in both studies.

The semantic constraint of verb argument structure has also been the focus of an investigation in listeners with Broca's aphasia. Mack, Ji, and, Thompson (2013) investigated the relationship between verb meaning and argument structure in a group of individuals with Broca's aphasia and group of neurologically unimpaired age-matched adults using a VWP. Participants heard sentences such as (8) and (9) while viewing a four picture grid (e.g. jar, plate, pencil, stick).

(8) Tomorrow Susan will open the jar.

(9) Tomorrow Susan will break the jar.

Note that only one of the items can be opened (the jar), but all of the items can be broken. Participants with Broca's aphasia exhibited a gaze pattern similar to the age-matched controls. Within 500ms of the offset of the verb significantly more gazes to the jar were observed in the *open* condition than in the *break* condition.

Recall that in a similar study Altmann and Kamide (1999) demonstrated that younger listeners are able to make use of verb meaning earlier as they exhibited anticipatory gazes in the *open* condition. Here, gazes to the argument of the verb in the *open* condition are not observed until after the verb has been heard. These results demonstrate that with age the ability to make use of verb meaning to anticipate an upcoming argument may be delayed compared to younger listeners. Of importance, listeners with Broca's aphasia exhibit a similar time-course of verb meaning activation as older neurologically unimpaired listeners.

Together these findings suggest that listeners with Broca's aphasia are sensitive to both syntactic and semantic properties of verb argument structure. Differences in electrophysiological data have been observed compared to neurologically unimpaired individuals. However, offline and online behavioral measures have demonstrated that individuals with Broca's aphasia evince similar verb argument structure processing during auditory sentence comprehension to neurologically unimpaired individuals.

Unaccusativity: unimpaired listeners

Recall that according to the Unaccusativity Hypothesis (Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984) unaccusative verbs differ from other intransitive verbs syntactically and semantically. The single argument of unaccusative verbs is base-generated in the direct object position and displaced to the grammatical subject position leaving behind a copy or trace (linguistic terminology), or gap (psycholinguistic terminology). The single argument of unaccusative verbs is also assigned the thematic role of Theme or Patient, thematic roles typically associated with arguments in the grammatical direct object position. As a result, some studies have taken the unique

properties of unaccusatives as their focus. Friedmann, Taranto, Shapiro, and Swinney (2008) conducted a cross-modal priming study to determine if there were online processing differences between sentences containing unergative and unaccusative verbs. Sentences that contained unergative verbs such as (10) and sentences that contained unaccusative verbs such as (11) were aurally presented to young college-aged adults.

> (10) The surgeon[1] with a brown felt fedora hat and matching coat eagerly smiled[2] when the beautiful[3] actress walked down the corridor to exam room three.
>
> (11) The tailor[1] from East Orange, New Jersey, mysteriously disappeared <the tailor>[2] when it was[3] time to adjust the tuxedos and dresses for the participants in the wedding party.

Probes were presented at the offset of the single argument, at the offset of the intransitive verb, and 750ms post offset of the verb (indicated by superscript numerals above). For both sentences types, activation of the single argument was found at the offset of the single argument. However, only in the sentences that contained unaccusative verbs was reactivation of the argument found at a post verb position, 750ms after verb offset. These results support the Unaccusativity Hypothesis, as only in sentences that contained unaccusative verbs was lexical reactivation of the single argument evinced near the ‘gap’ position.

Further support for the Unaccusativity Hypothesis has been provided by fMRI evidence. Shetreet, Friedmann, and Hadar (2010) found activation in areas of the brain unique to sentences that contained unaccusative verbs compared to sentences that contained unergative verbs and sentences that contained transitive verbs. Activation in

the left IFG (BA45/46/47), left posterior medial temporal gyrus (BA21), left STG, and cerebellum was found during sentences that contained unaccusative verbs compared to sentences that contain unergative verbs. Two of these areas also distinguished sentences containing unaccusative verbs from those with transitive verbs or unergative verbs, the left IFG (BA45/46) and the left posterior medial temporal gyrus (MTG) (BA21). BA45/46 has been associated with syntactic processing (Kang, Constable, Gore, & Avrutin, 1999; Caplan, Alpert, & Waters, 1999) and lexical-semantic processing (Suzuki & Sakai, 2003; Homae, Hashimoto, Nakajima, Miyashita, & Sakai, 2002). The left MTG has been associated with semantic processing (e.g. McDermott, Petersen, Watson, & Ojemann, 2003).

Unaccusativity: Broca's Aphasia

The online processing of unaccusative verbs in sentences in individuals with Broca's aphasia has been another line of research explored. One study, Burkhardt, Piñango, and Wong (2003) used CMP to investigate the lexical reactivation of the single argument of sentences that contained unaccusative verbs with individuals with aphasia and neurologically unimpaired adults. Lexical reactivation was probed during sentences that contained either an unaccusative verb or unergative verb using cross-modal priming. The neurologically unimpaired adults evinced priming 650ms post verb-offset for the sentences that contained unaccusative verbs. The participants with Broca's aphasia exhibited a later time-course and exhibited priming 800ms post verb-offset. These results provide evidence that listener with Broca's aphasia are sensitive to the unaccusative property, and exhibit a similar time-course of lexical reactivation as neurologically unimpaired listeners. Recall that Friedmann et al. (2008) found a 750ms delay in lexical

reactivation of the single argument of non-alternating unaccusative verbs. The unaccusative verbs used in the current study included the alternating type. Friedmann et al. (2008) also included sentences that contain alternating unaccusative verbs, and found variable results with this alternation of unaccusative verbs. Moreover, the difference between the two time points is 150 ms, approximately a syllable in the auditory stream therefore these results suggest that individuals with Broca's aphasia are processing unaccusative verbs similar to neurologically unimpaired individuals.

Another CMP study also investigated the lexical reactivation of the single argument of unaccusative verbs in sentences (Peristeri, Tsimpli, and Tsapkini, 2013). Lexical reactivation of the single argument was found at the gap. Unfortunately, there are some issues with the employment of the cross-modal priming methodology in this study. The auditory sentence was interrupted while the lexical decision was made and the visually presented probes remained on the screen indefinitely. As the participants were able to focus on the lexical decision these results are not reflective of real-time language processing. Given the methodological issues it is difficult to argue that the results support the immediate reactivation of the single argument of unaccusative verbs during sentence processing in individuals with Broca's aphasia.

The offline comprehension of unaccusative verbs in sentences has also been the focus of studies exploring the sentence comprehension abilities of listeners with Broca's aphasia. Lee and Thompson (2004) conducted a truth value-judgment study to investigate the comprehension of sentences that contain alternating and non-alternating unaccusative verbs in individuals with Broca's aphasia and found 95% accuracy. McAlister, Bachrach, Waters, Michaud and Caplan (2009) used a sentence-picture matching task and used

alternating unaccusative verbs in transitive (e.g., “The dog is rolling the ball”) and intransitive (e.g., “The dog is rolling”) constructions. The image of the opposite alternation of the verb served as the foil (e.g. transitive alternation served as foil for the intransitive alternation). They found 86% correct for the intransitive constructions and 99% correct for the transitive constructions.

A study by Piñango (2000) tested two individuals with Broca’s aphasia on a sentence-picture matching task using alternating and non-alternating unaccusatives (e.g., The girl fell because of the boy). Both participants exhibited 93% correct comprehension of sentences containing non-alternating unaccusatives and above chance (100% correct and 80% correct) comprehension of sentences containing alternating unaccusatives. Most of the studies of the comprehension of sentences that contain unaccusative verbs in Broca’s have focused on the alternating type of unaccusative verbs. Across these studies, the patterns of comprehension suggest that individuals with Broca’s aphasia have do not difficulty processing sentences containing unaccusative verbs online or offline.

In summary, psycholinguistic studies have provided evidence that the lexical properties of verbs are acknowledged by listeners when verbs are first encountered during sentence processing, and play a central role in comprehension. fMRI studies following this line of inquiry have demonstrated that regions of the brain found to be involved in language processing are also involved with verb processing during sentence comprehension (argument structure, left STS; subcategorization, left STG and left IFG; unaccusativity, left IFG). Finally here, individuals with Broca’s aphasia appear to be normally sensitive to unaccusativity, setting the stage for using unaccusative verbs as a

test case for the Intervener Hypothesis. I now move to Chapter 5, where I describe some of the extant theoretical accounts of sentence processing in aphasia.

References

Ahmad, Z., Balsamo, L. M., Sachs, B. C., Xu, B., & Gaillard, W. D. (2003). Auditory comprehension of language in young children: Neural networks identified with fMRI. *Neurology*, *60*(10), 1598-1605.

Ahrens, K., & Swinney, D. (1995). Participant roles and the processing of verbs during sentence comprehension. *Journal of psycholinguistic research*,*24*(6), 533-547.

Altmann, G. T. M., & Kamide, Y. (1999). Incremental interpretation at verbs: restricting the domain of subsequent reference. *Cognition, 73*(3), 247–64.

Ben-Shachar, M., Hendler, T., Kahn, I. , Ben-Bashat, D., & Grodzinsky, Y. (2003). The neural reality of syntactic transformations: Evidence from functional magnetic resonance imaging. *Psychological Science*, *14*(5), 433.

Burkhardt P., Pinango M.M., & Wong K. (2003). The role of the anterior left hemisphere in real-time sentence comprehension: evidence from split intransitivity. *Brain and Language, 86*(1), 9–22.

Burzio, L. (1986). *Italian Syntax: A government-binding approach.* Dordrecht: Reidel Publishing Company.

Caplan, D., Alpert, N., & Waters, G. (1999). PET studies of syntactic processing with auditory sentence presentation. Neuroimage, 9, 343–351.

Cooper, R. M. (1974). The control of eye fixation by the meaning of spoken language: A new methodology for the real-time investigation of speech perception, memory, and language processing. *Cognitive Psychology, 6*, 84-107.

Fodor, J. A., Garrett, M., & Bever, T. G. (1968). Some syntactic determinants of sentential complexity, II: Verb structure. *Attention, Perception, & Psychophysics*, *3*(6), 453-461.

Friedmann, N., Taranto, G., Shapiro, L. P., & Swinney, D. (2008). The leaf fell (the leaf): The online processing of unaccusatives. *Linguistic Inquiry, 39* (3), 355-377.

Homae, F., Hashimoto, R., Nakajima, K., Miyashita, Y., & Sakai, K. L. (2002). From perception to sentence comprehension: The convergence of auditory and visual information of language in the left inferior frontal cortex. *Neuroimage, 16*, 883–900.

Kang, A., Constable, R., Gore, J., & Avrutin, S. (1999). An event-related fMRI study of implicit phrase level syntactic and semantic processing. *Neuroimage, 10*, 555–561.

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*, 3320–3337.

Kim, M., & Thompson, C.K. (2000). Patterns of Comprehension and Production of Nouns and Verbs in Agrammatism: Implications for Lexical Organization, Brain and Language, (74) 1, August 2000, Pages 1-25.

Kim, M., & Thompson, C.K. (2004). Verb deficits in Alzheimer's disease and agrammatism: Implications for lexical organization, *Brain and Language, 88* (1), 1-20.

Lee, M., & Thompson, C. (2004). Agrammatic aphasic production and comprehension of unaccusative verbs in sentence contexts. *Journal of Neurolinguistics, 17(4),* 315-330.

Mack, J. E., Ji, W., & Thompson, C. K. (2013). Effects of verb meaning on lexical integration in agrammatic aphasia: Evidence from eyetracking. *Journal of Neurolinguistics*, *26*(6), 619–636.

McAlister, T., Bachrach, A., Waters, G., Michaud, J., & Caplan, D. (2009). Production and comprehension of unaccusatives in aphasia. *Aphasiology, 23(7-8),* 989-1004.

McDermott, K. B., Petersen, S. E., Watson, J. M., & Ojemann, J. G. (2003). A procedure for identifying regions preferentially activated by attention to semantic and phonological relations using functional magnetic resonance imaging. *Neuropsychologia*, *41*(3), 293-303.

Peristeri, E., Tsimpli, I., & Tsapkini, K. (2006). The online processing of unaccusativity in greek agrammatism. *Applied Psycholinguistics,34*(2), 1-44.

Perlmutter, D. M. (1978). Impersonal passives and the unaccusative hypothesis. *Proceedings of the 4th Annual Meeting of the Berkeley Linguistics Society* (pp. 157-189). Berkeley: University of California: Berkeley Linguistics Society.

Perlmutter, D. M., & Postal, P. M. (1984). The 1-Advancement Exclusiveness Law. In D. Perlmutter, & C. Rosen (Eds.), *Studies in Relational Grammar 2* (pp. 81-126). Chicago: University of Chicago Press.

Piñango, M. M. (2000). Canonicity in Broca's sentence comprehension: The case of psychological verbs. In Y. Grodzinsky, L. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing* (pp. 327–350). San Diego/London: Academic Press.

Rubin, S., Newhoff, M., Peach, R., & Shapiro, L.P. (1996). Electrophysiological indices of lexical processing: The effects of verb complexity and age. *Journal of Speech and Hearing Research, 39*(5), 1071.

Shapiro, L.P., Brookins, B., Gordon, B., & Nagel, N. (1991). Verb effects during sentence processing. Journal of Experimental Psychology: Learning, Memory, and Cognition, 17, 983–996.

Shapiro, L. P., Gordon, B., Hack, N., & Killackey, J. (1993). Verb-argument structure processing in complex sentences in Broca's and Wernicke's aphasia. Brain and Language, 45, 423–447.

Shapiro, L.P., & Levine, B. (1990). Verb processing during sentence comprehension in aphasia. *Brain and Language*, *38*(1), 21-47.

Shapiro, L. P., Nagel, H. N., & Levine, B. A. (1993). Preferences for a verb's complements and their use in sentence processing. *Journal of Memory and Language*, *32*(1), 96.

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

Shetreet, E., Friedmann, N., & Hadar, U. (2010). The neural correlates of linguistic distinctions: unaccusative and unergative verbs. *Journal of Cognitive Neuroscience*, *22*, 2306–2315.

Shetreet E, Palti D, Friedmann N, Hadar U. (2007). Cortical representation of verb processing in sentence comprehension: Number of complements, subcategorization, and thematic frames. *Cerebral Cortex*, *17*, 1958–1969.

Suzuki, K., & Sakai, K. L. (2003). An event-related fMRI study of explicit syntactic processing of normal/anomalous sentences in contrast to implicit syntactic processing. *Cerebral Cortex*, *13*, 517–526.

Trueswell, J. C., Tanenhaus, M. K., & Kello, C. (1993). Verb-specific constraints in sentence processing: separating effects of lexical preference from garden-paths. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*(3), 528.

Wickens, C., Kramer, A., Vanasse, L., & Donchin, E. (1983). Performance of concurrent tasks: a psychophysiological analysis of the reciprocity of information-processing resources. *Science*, *221*(4615), 1080-1082.

CHAPTER 5:

Accounts of Sentence Processing in Aphasia

5.1 Introduction

As a reminder, individuals with Broca's aphasia do not have difficulty comprehending sentences that follow canonical word order (1), however difficulty arises for some non-canonical sentences (2).

(1) The man hugged the woman with red hair.
subject verb object

(2) The woman that the man hugged <~~the woman~~> had red hair.
object subject verb

Also recall that in (2), a non-canonical object-extracted relative clause, the direct object NP has been displaced from a post verb position to the beginning of the sentence. This displacement leaves behind a trace (or gap) in the direct object position from which the NP (*the woman)* has been displaced as depicted in (2). In order to successfully comprehend a sentence that contains a filler-gap syntactic dependency, processing the link between the gap or trace and its antecedent is required.

There are several accounts that attempt to explain the sentence processing deficits that are a hallmark of Broca's aphasia. The focus of these accounts differs, with some focusing at the grammatical level, others at the lexical level, and others still on the role of cognitive resources. Grammar-oriented accounts posit that grammatical representations or processing are responsible for patterns of comprehension observed in Broca's aphasia. Lexical accounts argue that lexical processing difficulties underlie the comprehension deficits. Cognitive resource based accounts posit that reduced resources for cognitive processes involved in language processing underlie the sentence comprehension deficits.

5.2 Grammar Oriented Accounts

The Trace Deletion Hypothesis (TDH; Grodzinsky, 1986, 1995, 2000) claims that listeners with Broca's aphasia are unable to represent traces and therefore cannot successfully comprehend non-canonical sentences. For example, according to the TDH, when a listener with Broca's aphasia encounters a sentence such as (3) they are unable to link the displaced object NP, *the girl* to the trace or gap that its displacement left behind in the object position.

(3) The girl that the boy kissed <~~the girl~~> has red hair.

As they are unable to link the trace or gap to the displaced NP, they are unable to assign a thematic role to the displaced argument. It is proposed that listeners with Broca's aphasia employ an agent first strategy and assign the first encountered NP (*the girl*) the thematic role of agent. Consequently, two arguments are assigned the thematic role of agent and the listener with aphasia must then guess who is doing what to whom.

The Slow Syntax Hypothesis (Burkhardt, Avrutin, Piñango & Ruigendijk, 2008; Burkhardt, Piñango & Wong, 2003; Piñango, 2000) proposes that syntax is fully intact in individuals with Broca's aphasia, but there is delay in syntactic operations, more specifically the Merge operation. Recall that Merge is how constituents are combined to form the hierarchical structure of phrases. As syntactic processes are delayed, thematic role assignment relies on semantics. In instances of sentences that contain syntactic dependencies, this results in a conflict between thematic role assignment derived from semantics and syntax, once it is realized. According to this account, it is this mismatch between thematic role assignments that results in the comprehension deficits observed in Broca's aphasia.

5.3 Lexical Accounts

The Delayed Lexical Activation (DLA) hypothesis suggests that the comprehension deficits exhibited in individuals with Broca's aphasia are due to a delay in lexical activation during sentence processing. The delay in lexical activation results in a desynchronization of lexical access and syntactic processing routines, resulting in comprehension deficits. Results supporting this account stem from findings that demonstrate delayed lexical activation and reactivation of lexical items. For example, in a cross-modal priming study, Love, Swinney, Walenski, & Zurif (2008) investigated the time course of lexical activation and reactivation in object-relative sentence constructions such as (4).

> (4) The audience liked the wrestler[1] that the[2] parish priest condemned <~~the wrestler~~>[3] for [4]foul [5]language.

Recall that object-relatives contain a filler-gap syntactic dependency. The neurologically unimpaired group immediately activated the displaced argument NP *the wrestler*, and immediate re-activation upon encountering the gap (PP3). Unlike the immediate reactivation found with the unimpaired group, individuals with Broca's aphasia did not evince lexical activation of *the wrestler* until 300ms (PP2) downstream from the lexical item of interest in the unfolding sentence, and re-activation was not observed until 500ms downstream from the gap. This delay in lexical activation is not the result of sentence complexity as delayed lexical activation has also been demonstrated in canonical word order sentences (Ferrill, Love, Walenski & Shapiro, 2012). These results suggest that a delay in lexical activation disrupts the synchronization of lexical activation and syntax

such that lexical items are fed too slowly into syntactic operations resulting in comprehension difficulties.

Also focusing on lexical activation, Thompson and colleagues (Thompson & Choy, 2009; Choy, 2011; Mack, Ji and Thompson, 2013) suggest that non-canonical sentence comprehension deficits arise due to difficulty with the integration of lexical items during sentence processing. This idea is supported by visual world paradigm studies which have demonstrated delayed lexical activation, but immediate reactivation of displaced arguments at the gap in sentences that contain syntactic dependencies (Choy, 2011; Dickey, Choy and Thompson, 2007; Dickey and Thompson, 2009).

5.4 Cognitive Resource Accounts

Caplan and colleagues argue that components of working memory specific to syntactic processing are reduced resulting in sentence comprehension deficits (Caplan, Waters, DeDe, Michaud, & Reddy, 2007). Another cognitive resource account claims that a reduction in more general working memory resources are reduced and this reduction underlies sentence comprehension deficits (Haarmann, Just, & Carpenter, 1997).

I have thus briefly reviewed the deficit in comprehension following Broca's aphasia. Not surprisingly perhaps, given the well-known heterogeneity of aphasia, no single account has been embraced by investigators. For example, the TDH has been criticized for its limited scope and its syntactico-centric focus. The slow-syntax approach is too powerful (e.g., if the basic Merge operation is compromised, how then do participants with Broca's aphasia understand canonical word-order sentences?). Cognitive resource accounts have been criticized for their reliance on vague notions of

“resources.” The DLA account has some difficulty explaining why some sentence constructions are more easily understood than others, and the Lexical Integration account, in its details, is not distinct from the DLA.

Now that I have briefly described some of the important accounts of the sentence comprehension deficit observed in Broca’s aphasia, I offer an alternative that is the focus of this dissertation, the Intervener Hypothesis.

References

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

Burkhardt P., Pinango M.M., & Wong K. (2003). The role of the anterior left hemisphere in real-time sentence comprehension: evidence from split intransitivity. *Brain and Language, 86*(1), 9–22.

Ferrill, M., Love, T., Walenski, M., & Shapiro, L. P. (2012). The time-course of lexical activation during sentence comprehension in aphasia. *American Journal of Speech-Language Pathology, 21*, 179-189.

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.

Choy, J.J. (2011). Effects of lexical processing deficits on sentence comprehension in agrammatic Broca's aphasia. Evanston, IL: Northwestern University. (Unpublished doctoral dissertation).

Dickey M.W., Choy J.J., & Thompson, C.K. (2007). Real-time comprehension of wh-movement in aphasia: evidence from eyetracking while listening. *Brain and Language*, 1001–22.

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

Grodzinsky, Y. (1986). Language Deficits and the Theory of Syntax. *Brain and Language, 27*, 135–159.

Grodzinsky, Y. (1995). Trace Deletion, Theta-Roles, and Cognitive Strategies. *Brain and Language, 51*, 469–497.

Grodzinsky, Y. (2000). The Neurology of Syntax: Language Use without Broca's Area. *Behavioral and Brain Sciences, 23*, 1–71.

Haarmann, H., Just, M., & Carpenter, P. (1997). Aphasic sentence comprehension as a resource deficit: A computational approach. *Brain and Language, 59(1),* 76-120.

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

Mack, J. E., Ji, W., & Thompson, C. K. (2013). Effects of verb meaning on lexical integration in agrammatic aphasia: Evidence from eyetracking. *Journal of Neurolinguistics, 26*(6), 619–636.

Piñango, M. M. (2000). Canonicity in Broca's sentence comprehension: The case of psychological verbs. In Y. Grodzinsky, L. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing* (pp. 327–350). San Diego/London: Academic Press.

Thompson, C., & Choy, J. (2009). Pronominal resolution and gap filling in agrammatic aphasia: Evidence from eye movements. *Journal of Psycholinguistic Research, 38*(3), 255-283.

CHAPTER 6:

The Intervener Hypothesis

6.1 Introduction

Revealing the underlying comprehension deficit requires examining the processing of different sentence types, those that meet a particular structural description relevant to specific hypotheses. As I have discussed, in the simplest case constructions have been characterized as having canonical word order in the language of interest (in English, Subject-Verb-Object; SVO). Examples include the subject-extracted *Wh*-question, "Which fireman pushed the mailman?" and the subject-extracted relative clause, "The mouse who scratched the rabbit ran under the house." In the more complex case, sentences have been characterized as having non-canonical word order, as in, for example, Object-Subject-Verb (OSV) word order in English. Relevant examples include the object-extracted *Which*-question, "Which mailman did the fireman push," and the object-extracted relative, "The rabbit who the mouse scratched ran under the house." Evidence from aphasia has long claimed that this canonicity property of sentences is revealed in final comprehension performance; individuals with Broca's aphasia who have a comprehension disorder perform poorly on non-canonical relative to canonical structures (Caramazza & Zurif, 1976; Schwartz, Linebarger, Saffran, & Pate, 1987; Grodzinsky, 1990; Love & Oster, 2002). Thus, it appears that subject-extracted sentences that conform to canonical word order are easier to understand than object-extracted versions (the so-called Subject-Object asymmetry). I will show below that this simple explanation is not supported by recent data on aphasia.

The Intervener Hypothesis (IH) suggests that difficulty during sentence processing in aphasia occurs when the displacement of an argument yields a syntactic dependency. The difficulty with this sentence structure occurs when an NP is positioned

between the displaced NP and its base-generated position (i.e., filler-gap dependency). The intervening NP interrupts the formation of the dependency chain, causing confusion as to the elements (and their thematic roles) that contribute to the dependency. Furthermore, and critical to the IH, difficulty arises when the displaced NP crosses over another NP that is **similarly structured**. For example, in (1) the argument NP *the girl* is displaced from the direct object position leaving behind a gap.

(1) The girl that **the boy** kicked <~~the girl~~> had red hair.

The NP (*the girl*), when displaced, crosses an intervening argument NP *the boy* (in bold above) in the grammatical subject position. Both the displaced argument and the intervening argument, or intervener, are fully realized lexical NPs. The structural similarity (Determiner, Noun) causes similarity-based interference resulting in a processing disadvantage for sentences that contain an intervener. This hypothesis has also been suggested in previous investigations of the comprehension deficits in agrammatic Broca's aphasia (Friedmann, 2008; Friedmann & Gvion, 2012; Friedmann & Shapiro, 2003). The possibility of interference effects in language processing has been examined in neurologically unimpaired individuals and relevant findings are reviewed below. While much of this work has been conducted in an attempt to better understand working memory and its role in language processing, it has the potential to refine the processing deficit accounts of aphasia.

6.2 Similarity-based Interference During Unimpaired Sentence Processing

To determine if language processing is susceptible to similarity-based interference, Gordon, Hendrick, and Levine (2002) had participants remember a set of

three words (a memory load) while performing a self-paced reading task. The sentences were subject clefts (2) and object-clefts (3; gap added).

(2) It was the dancer that liked the fireman before the argument began.

(3) It was Tony that Joey liked ___ before the argument began.

The NPs in the sentences were either descriptions as in (2) or proper names as in (3). The memory load was either descriptions as in (4) or proper names as in (5).

(4) poet- cartoonist- voter

(5) Joel-Greg-Andy

In one condition the memory load matched the NPs in the sentence (e.g., 2 and 4) and in another condition the memory load and the sentence NPs mismatched (e.g., 2 and 5). The results revealed that when the memory load matched the NP type in the sentence it resulted in lower comprehension; the comprehension of object-clefts was poorer than the comprehension of subject clefts and the difference in the matched and non-matched condition was greater for object-clefts. These findings provide evidence that sentence processing is susceptible to similarity-based interference, at least when a self-paced reading task is used.

In other studies, Gordon, Hendrick & Johnson (2001; 2004) manipulated the features of NPs to determine if semantically distinguishing the NPs would impact similarity-based interference during sentence processing. During reading tasks, object-extracted sentences typically result in longer reading times than subject-extracted sentences - this is referred to as subject-object asymmetry. Gordon et al. (2001;2004) used an eye tracking-while-reading task using subject-extracted (6) and object-extracted sentences (7). In some conditions, the NPs included in the sentences were semantically

similar (e.g. the banker, the barber) and in other conditions the NPs were semantically different (e.g. the banker, everyone).

(6) The banker that praised [the barber / a barber / Joe / you / everyone] climbed the mountain.

(7) The banker that [the barber / a barber / Joe / you / everyone] praised climbed the mountain.

A reduction in subject-object asymmetry was found when the NPs were different relative to when they were semantically (and syntactically) similar. This work provides evidence that the semantics of the NPs plays a role in similarity-based interference during sentence processing. However, I note that the syntax of the NPs was different as well. For example, the fully realized NPs could be determinate (*the*) or indeterminate (*a*); proper names with a bare NP (*Joe*), or pronouns (*everyone*).

Other studies following this line of investigation have explored the phase of working memory that is susceptible to similarity-based interference: encoding, storage or retrieval (Van Dyke and Lewis, 2003; Van Dyke and McElree, 2006). Van Dyke and McElree (2006) conducted a self-paced reading task with object-cleft sentence constructions and a memory load. In one condition the memory load contained nouns that were plausible objects of the verb (8) and in the other condition the memory load contained nouns that were implausible objects of the verb (9).

(8) It was <u>the boat</u> that the guy who lived by the sea fixed ___ in two sunny days.

Plausible Memory load: table, sink, truck

(9) It was the boat that the guy who lived by the sea sailed ___ in two sunny days.

Implausible Memory load: table, sink, truck

No difference in reading times in the plausible load condition compared to the implausible load condition were found except in the region of the verb, where reading times were greater for the plausible condition compared to the implausible condition. Furthermore, comprehension accuracy was poorer for the plausible memory load conditions compared to the implausible conditions. These results indicate that the retrieval phase of working memory is susceptible as increased reading times were observed in the region of the verb, the point at which the displaced NP is reactivated or retrieved (at the gap).

Though there have been several other attempts to investigate similarity-based interference in neurologically intact participants, the studies briefly reviewed above are good examples from the psycholinguistic literature. To briefly summarize here, there is evidence that sentence processing is susceptible to similarity-based interference for neurologically unimpaired individuals. Reducing the semantic (and syntactic) overlap of NPs included in sentences reduces observed similarity-based interference. Finally, the retrieval phase of working memory appears to be impacted by similarity-based interference as differences are observed at retrieval sites (gaps) during sentence processing. I now move to a review of the aphasia literature that has investigated the impact of similarity-based interference on sentence processing in IWBA in an effort to determine the explanatory power of the Intervener Hypothesis.

6.3 Support for the Intervener Hypothesis in Aphasia

In one of the first investigations of its kind, Sheppard, Walenski, Love, & Shapiro (2015) used a visual world eye tracking-while-listening method to examine how interveners affect sentence processing in Broca's aphasia. Four types of *Wh*-questions were tested and presented aurally: subject-extracted *who*- (10), object-extracted *who*- (11), subject-extracted *which*- (12), and object-extracted *which*-questions(13):

(10) Who pushed the fireman yesterday afternoon?

(11) Who did **the fireman** push <~~who~~> yesterday afternoon?

(12) Which mailman pushed the fireman yesterday afternoon?

(13) Which mailman did **the fireman** push <~~which mailman~~> yesterday afternoon?

Both (11) and (13) contain a displaced object NP and thus form a filler-gap syntactic dependency. In both (11) and (13) the linking of the filler and its gap require the crossing of an intervening argument (or *intervener*; indicated in bold). However, only in (13), the object-extracted *which*-question, are the filler and intervener structurally similar (Determiner, Noun). In the object-extracted *who*-question, the arguments are not structurally similar, as one of the arguments is a bare *Wh*-word (*who*) and the other is Determiner-Noun. Results revealed that for the object-extracted *which*-questions, chance accuracy and significantly more gazes to the incorrect versus the correct referent was found. For all other question types, including the object-extracted *who*-questions, comprehension was above chance and there were significantly more gazes to the correct referent. These findings suggest that canonicity of the sentences is not the issue for these participants. Instead, individuals with Broca's aphasia are more susceptible to similarity-

based interference as structurally similar noun phrases negatively impact the comprehension of sentences in which an argument is displaced over another argument.

More recently, support for the Intervener Hypothesis has also been demonstrated with an overt syntactic dependency found in anaphora (Engel, Shapiro, & Love, submitted). Anaphora refers to a referential dependency where a link between a reflexive pronoun such as *herself* or a personal pronoun such as *her* and another sentence element (the antecedent) must be made in order for the sentence to be successfully comprehended.

In an eye tracking-while-listening study, Engel et al. (submitted) embedded reflexives and pronouns in complement phrase (CP) sentences ((14) and (15)) and in subject-relative sentences ((16) and (17)):

(14) The grandma said that **the baker** cleaned her.

(15) The grandma said that the baker cleaned herself.

(16) The baker that helped the grandma cleaned her.

(17) The baker that helped **the grandma** cleaned herself.

Under the typical Binding constraints (Chomsky, 1981), reflexives must refer to a sentence element in the same, or local, clause, and pronouns must not refer to a sentence element within a local clause. In (14), the personal pronoun gets its reference from the long-distance NP (both underlined). In (15), the reflexive pronoun gets its reference from the local NP. However, using subject-relatives turns this constraint on its head. In (16), the personal pronoun gets its reference from the close NP, while in (17) the reflexive gets its reference from the long-distance NP.

This manipulation allowed for refining the criteria of an intervener as it compared temporal (linear) distance to structural distance. Consider the following structures:

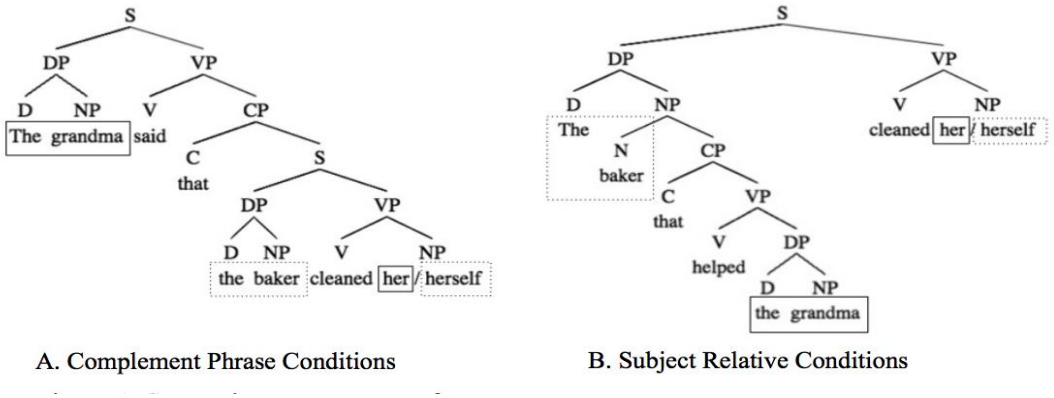


Figure 6-1. Diagram of syntactic structure of sentences included in Engel et al., submitted

As shown in Figure 6-1 (a diagram from Engel et al., submitted), in the **complement phrase condition** (6-1A), the reflexive (*herself*) and its antecedent (*the baker*) are both in the same clause and as such do not differ in structural distance. They are also close linearly. However, the pronoun (*her*) and its antecedent (*the grandma*) are in different clauses and are therefore structurally distant from one another. They are also linearly distant. In the **subject relative condition** (6-1B), the reflexive (*herself*) and its antecedent (*the baker*) are linearly distant, but do not differ in level of embeddedness and therefore are not structurally distant from one another. The pronoun (*her*) and its antecedent (*the grandma*) are linearly close, but are structurally distant as the antecedent is more deeply embedded than the pronoun. Of importance, both the pronouns and reflexives have a condition that contains a linear intervener. However, only the pronouns contain a structural intervener in both conditions.

Results indicated that more gazes to the correct referent and better comprehension accuracy was found for the reflexive conditions compared to the pronoun conditions, regardless of the linear distance between the pronouns and antecedents. Given that personal pronouns are always structurally distant from their antecedents, the results provide support for the Intervener Hypothesis, and refines the hypothesis such that an Intervener is defined structurally and not linearly.

To date, support for the Intervener Hypothesis has been demonstrated with two different types of syntactic relationships, covert filler-gap syntactic dependencies found in *Wh*-questions, and overt anaphor-antecedent dependencies (see also Friedmann, 2008, for evidence from relative clauses in Hebrew). As discussed previously, this dissertation focuses on testing the Intervener Hypothesis with another type of syntactic dependency, one inherent to unaccusative verbs. As a first step, I explore the time course of lexical reactivation of sentences that contain unaccusative verbs in the following chapter.

References

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.

Engel, S., Shapiro, L.P., & Love, T., (submitted). Proform-Antecedent linking in individuals with agrammatic aphasia: A test of the intervener hypothesis. Manuscript submitted for publication.

Friedmann, N. (2008). Traceless relatives: Agrammatic comprehension of relative clauses with resumptive pronouns. *Journal of Neurolinguistics, 21*(2), 138-149.

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

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.

Gordon, P., Hendrick, R., & Johnson, M. (2001). Memory interference during language processing. Journal of Experimental Psychology: Learning, Memory, and Cognition, 27(6), 1411- 1423.

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., & Levine, W.H. (2002). Memory-load interference in syntactic processing. Psychological Science, 13, 425-430.

Grodzinsky, Y. (1990). *Theoretical Perspectives on Language Deficits*. MIT Press.

Love, T., & Oster, E. (2002). On the categorization of aphasic typologies: The SOAP (a test of syntactic complexity). *Journal of Psycholinguistic Research, 31(5),* 503-529.

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

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.

Van Dyke, J. A., & Lewis, R. L. (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.

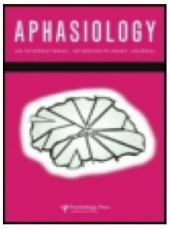
Van Dyke, J. A., & McElree, B. (2006). Retrieval interference in sentence comprehension. *Journal of Memory and Language*, *55*(2), 157-166.

CHAPTER 7:

The Curious Case of Processing Unaccusative Verbs in Aphasia

Preface

As established in Chapter 5, individuals with Broca's aphasia exhibit a delayed time course of lexical activation and reactivation during online sentence processing compared to neurologically unimpaired individuals (Love, Swinney, Walenski, & Zurif, 2008; Ferrill, Love, Walenski & Shapiro, 2012). Recall from Chapter 4, that neurologically unimpaired individuals exhibit delayed lexical reactivation of displaced NPs in sentences that contain unaccusative verbs (Friedmann, Taranto, Shapiro, and Swinney, 2008). The delay inherent to unaccusative verbs provide a unique opportunity to further investigate delayed lexical reactivation in individuals with Broca's aphasia. Previous studies have focused on the online processing of unaccusative verbs in aphasia, but have included alternating unaccusative verbs which allow for a transitive alternation. Friedmann et al. (2008) found patterns similar to unergatives for the alternating type. Thus, the following study is limited to non-alternating verbs, and tested for reactivation at four time points, verb offset, 500 ms post verb offset, 750 ms post verb offset, and 1250 ms post verb offset. The verb offset and 750 ms post verb offset time points were selected as they are the same time points used in Friedmann et al., 2008. Prior reports of delayed lexical reactivation in individuals with Broca's aphasia motivated the inclusion of the 500 ms and 1250 ms post verb offset time points. The 500 ms time point is included as this is the time point where lexical reactivation has been found with other sentences that contain syntactic dependencies. The 1250 ms time point serves to test for the possibility that individuals with Brocas's aphasia will demonstrate a delay beyond what was found with neurologically unimpaired individuals.



Aphasiology

Routledge
Taylor & Francis Group

ISSN: 0268-7038 (Print) 1464-5041 (Online) Journal homepage: http://www.tandfonline.com/loi/paph20

The curious case of processing unaccusative verbs in aphasia

Natalie Sullivan, Matthew Walenski, Tracy Love & Lewis P. Shapiro

To cite this article: Natalie Sullivan, Matthew Walenski, Tracy Love & Lewis P. Shapiro (2017): The curious case of processing unaccusative verbs in aphasia, Aphasiology, DOI: 10.1080/02687038.2016.1274873

To link to this article: http://dx.doi.org/10.1080/02687038.2016.1274873

Published online: 03 Jan 2017.

APHASIOLOGY, 2017
http://dx.doi.org/10.1080/02687038.2016.1274873

Routledge
Taylor & Francis Group

The curious case of processing unaccusative verbs in aphasia

Natalie Sullivan[a], Matthew Walenski[b], Tracy Love[a,b] and Lewis P. Shapiro[a,b]

[a]SDSU/UCSD Joint Doctoral Program in Language and Communicative Disorders, School of Speech, Language, and Hearing Sciences, San Diego, CA, USA; [b]School of Speech, Language, and Hearing Sciences, San Diego State University, San Diego, CA, USA

ABSTRACT

Background: Individuals with agrammatic Broca's aphasia (IWBA) exhibit a delay in lexical activation in S-V-O word order sentences and delayed lexical reactivation in sentences that contain syntactic dependencies. This pattern is in contrast to neurologically unimpaired individuals who immediately evince lexical reactivation at the gap in sentences that contain syntactic dependencies. However, in the case of sentences that contain unaccusative verbs, neurologically unimpaired individuals also exhibit a delay in lexical reactivation. This delay provides a unique opportunity to further examine lexical delays in IWBA.

Aim: The purpose of the current studies is to investigate the online comprehension of sentences that contain unaccusative verbs in IWBA and in a group of age-matched control (AMC) individuals.

Methods and Procedures: Cross-modal picture priming was used to test for priming of a displaced lexical item (direct object noun) immediately after the unaccusative verb (at the gap) during the ongoing auditory stream and at three additional time points downstream from the verb (500 ms, 750 ms, and 1,250 ms).

Outcomes and Results: Delayed reactivation of the displaced lexical item downstream from the gap (similar to prior reports of delayed reactivation with younger unimpaired listeners) for both the AMCs and the IWBA was found.

Conclusion: These results provide support that IWBA do not evince a delayed time course of lexical reactivation for unaccusative verbs compared to neurologically unimpaired individuals.

ARTICLE HISTORY
Received 12 August 2016
Accepted 16 December 2016

KEYWORDS
Aphasia; sentence processing; syntax; neurolinguistics

A common pattern exhibited by individuals with agrammatic Broca's aphasia (IWBA) is that sentences containing syntactic dependencies are often difficult to understand. Consider:

(1) The woman saw <u>the girl</u> who the boy kicked <~~the girl~~> yesterday.

Under a transformational grammar framework, in the object-extracted relative clause in (1), the noun phrase (NP) *the girl* has been displaced from its underlying direct object position occurring after the verb *kicked* to an earlier position in the sentence. In linguistic terminology, the NP that is displaced (*the girl*) is the "antecedent" and is copied at the

CONTACT Natalie Sullivan njsullivan@ucsd.edu

underlying position and then deleted from the representation (Chomsky, 1981, 1995). In psycholinguistic terminology, the displaced NP is the "filler" and the position from where it was displaced is the "gap". To normally understand this sentence, a listener must compute the relation between these non-adjacent positions. As described in more detail later, neurologically unimpaired individuals compute this filler-gap relation immediately upon encountering the gap (see Love & Swinney, 1996; Love, Swinney, Walenski, & Zurif, 2008; Shapiro, Oster, Garcia, Massey, & Thompson, 1999; Tanenhaus, Boland, Garnsey, & Carlson, 1989; and many others). However, some IWBA demonstrate a delay in filling a gap (Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008; Love et al., 2008; and references therein), and that delay has been claimed to yield offline disruptions.

Much of the evidence for this processing delay in IWBA comes from the comprehension of sentences that contain transitive verbs, those that allow both a subject and an affected object. However, there is a case where single-argument (intransitive) verbs enter into this discussion. Consider:

(2) The boy sneezed.
(3) The girl disappeared <~~the girl~~>.

Both (2) and (3) contain one-argument verbs. In (2) the single-argument (the NP *the boy*) serves as the subject of the unergative verb *sneezed*. In (3), however, there is evidence that the single argument has been base generated in object position and then displaced to the subject position occurring before the verb (i.e., the Unaccusativity Hypothesis; see Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984). Furthermore, while (2) and (3) each contains a single argument, the thematic roles assigned to the arguments differ. In (2), the unergative verb (*sneezed*) has a single argument (*the boy*) that performs the action of "sneezing" and is thus assigned an Agent role. In the unaccusative example (3), the single argument (*the girl*) is not responsible for the action but is the recipient of the action, hence assigned the role of Theme or Patient.

Evidence supporting the distinction between unaccusative and unergative verbs has also been demonstrated in the psycholinguistic literature. Friedmann, Taranto, Shapiro, and Swinney (2008) determined the time course of lexical reactivation in sentences containing unaccusative verbs such as (4) and sentences containing unergative verbs such as (5) in a group of neurologically unimpaired college-aged adults:

(4) The tailor[1] from East Orange, New Jersey, mysteriously disappeared <~~the tailor~~> [2] when it was[3] time to adjust the tuxedos and dresses for the participants in the wedding party.
(5) The surgeon[1] with a brown felt fedora hat and matching coat eagerly smiled[2] when the beautiful[3] actress walked down the corridor to exam room three.

In (4), *the tailor* is the single argument of the unaccusative verb *disappear* and has been displaced, leaving behind a gap. In (5) *the surgeon* is the single argument of the unergative verb *smile* and no displacement has occurred. Friedmann et al. (2008) used cross-modal priming (CMP), a method in which individuals are presented with sentences aurally and at a strategic point during the temporal unfolding of each sentence, a visual probe that is either related (e.g., "suit") or unrelated (e.g., "shoe") to the lexical item of

interest (*tailor*) is momentarily presented. The participant is required to listen to the uninterrupted sentence for meaning and to make a binary (yes/no) decision about the visual probe when it occurs. Faster reaction times (RTs) to the related, compared with the unrelated, probes are indicative of priming, suggesting that the target lexical item has been activated at that point in time. CMP was used to determine the time course of lexical activation and reactivation by taking "snapshots" of activation at three distinct time points in the sentence indicated by superscript numerals in the examples earlier.

Similar to what has been demonstrated in other published reports, participants evinced immediate activation (priming) for the NP at noun offset (position 1) for sentences containing either unaccusative verbs (4) or unergative verbs (5). However, only for the sentences containing unaccusative verbs was lexical reactivation of the single argument observed at a post-verb position. These results support the Unaccusativity Hypothesis, and suggest that the single argument of unaccusative verbs is base generated in a post-verb position and displaced to the subject position and leaves behind a gap (see also Bever & Sanz, 1997; Lee & Thompson, 2011; Shetreet, Friedmann, & Hadar, 2010).

Of particular interest in this report is the fact that, for unimpaired individuals, computing the filler-gap relation in sentences containing unaccusative verbs is temporally delayed, unlike that observed for the object relative case. Consider (from Love et al., 2008):

(6) The audience liked the wrestler[1] that the[2] parish priest condemned ~~<the wrestler>~~[3] for [4]foul [5]language.

In the object relative (6), *the wrestler*, an argument of the verb *condemn*, has been displaced from a post-verb position to a position occurring before the verb, leaving behind a gap. Love et al. (2008) used CMP and presented visual probes at five probe points (superscripted numbers) indicated in (6). Unimpaired individuals revealed lexical activation of the direct object NP *the wrestler* at two critical points during the sentence: at the offset of the lexical item of interest (position 1) and at the syntactically licensed gap (position 3). Thus, as has been demonstrated in numerous prior studies, lexical access of the target word and subsequent reaccess at the gap is immediate.

Consider again the unaccusative example from Friedmann et al. (2008):

(7) The tailor[1] from East Orange, New Jersey, mysteriously disappeared ~~<the tailor>~~[2] when it was[3] time to adjust the tuxedos and dresses for the participants in the wedding party.

Unlike the patterns found at the gap in object relatives (6), immediate reactivation of the displaced argument was not observed at the gap (position 2), but instead was shown to occur 750 ms after verb offset (position 3). A similar delay in reactivation while processing sentences containing unaccusative verbs was reported by Burkhardt, Piñango, and Wong (2003) for both groups of participants, neurologically intact controls, and three participants with Broca's aphasia. Unfortunately, the description of their study suggests that their unaccusative verbs were the "alternating" kind. That is, the verbs allowed both a transitive (as in, "the microwave melted the butter") and intransitive

possibility (as in "The butter in the small white dish melted after the boy turned on the microwave"); Friedmann et al. (2008) found variable results for these types of verbs.[1]

Both Friedmann et al. (2008) and Burkhardt et al. (2003) have suggested that the gap-filling delay with unaccusatives could be caused by the lack of an observable surface cue that could signal a gap is forthcoming (see also Fodor, 1993). Unlike object relatives that typically contain an overt complementiser (e.g., *that* in (6)), sentences containing unaccusatives lack such a cue. Listeners cannot know that a gap will occur in sentences containing unaccusative verbs until the verb has been encountered and its relevant (unaccusative) properties are activated. This possibility implies that listeners have immediate access to a verb's properties. Some relevant work in this regard is the finding, for both neurologically healthy participants and those with Broca's aphasia, that once a verb is encountered in a sentence, its argument structure properties (core participants for the verb) are immediately made available, subsequently allowing the arguments in the sentence to receive their proper thematic role assignments (Agent, Patient, Theme, etc.) (see, e.g., Shapiro, Gordon, Hack, & Killackey, 1993; Shapiro, Zurif, & Grimshaw, 1987, 1989; see also Biran & Friedmann, 2012; Shetreet, Palti, Friedmann, & Hadar, 2007). We revisit this possibility in the General Discussion to follow our experiments. For now, the normal delay observed with unaccusatives provides an opportunity to further examine the nature of the sentence comprehension deficit found in individuals with Broca's aphasia. Before we detail these experiments, we discuss some relevant accounts of the comprehension deficit in aphasia, and then further discuss the motivation for the present study.

Dependency Processing in Broca's Aphasia

Unlike unimpaired listeners, IWBA have been reported to have difficulty processing (in real time) and understanding (via final comprehension) sentences containing syntactic dependencies. There have been numerous accounts posited to explain why individuals with Broca's aphasia evince these deficits; we briefly canvas some here. Burkhardt et al. (2008) suggest that syntactic computation is slowed under the conditions that yield a Broca's aphasia (see also Avrutin, 2006), yet they also claim that the syntactic structure, once finally formed, is identical to the normal syntactic system. Thompson and colleagues (Choy & Thompson, 2010; Thompson & Choy, 2009) suggest that syntactic processing routines are intact, but the process that integrates a lexical item into the sentence is disrupted. Grodzinsky's trace deletion hypothesis, likely the most well-known and studied account, suggests that IWBA cannot represent the traces or copies of the displaced arguments in sentences containing syntactic dependencies, leading to impaired thematic role assignment to the displaced NP (e.g., Drai & Grodzinsky, 2006; Grodzinsky, 2006; among many others). Caplan and colleagues suggest an account whereby reduced processing resources combined with pathological variability results in the inability to comprehend sentences that require multiple syntactic operations (Caplan, Waters, DeDe, Michaud, & Reddy, 2007; see also Haarmann, Just, & Carpenter, 1997).

A more recent account, the Intervener Hypothesis, suggests that when an NP intervenes between two elements of a syntactic dependency, comprehension deficits that are a hallmark of Broca's aphasia occur, perhaps as a result of similarity-based interference (see Friedmann & Shapiro, 2003; Sheppard, Walenski, Love, & Shapiro, 2015; Sullivan, Walenski, Love, & Shapiro, 2016). We revisit this hypothesis in the General

Discussion to follow our experiments. Another account, the Delayed Lexical Activation (DLA) Hypothesis, posits that lexical access is delayed in Broca's aphasia, and thus the syntactic system that requires lexical items to be inserted into the syntactic configuration of the sentence is also affected. In essence, the claim is that the lexical and syntactic systems are desynchronised, leading to what appears to be a syntactic comprehension disorder in Broca's aphasia (Ferrill, Love, Walenski, & Shapiro, 2012; Love et al., 2008). Consider again the example from Love et al. (2008):

(8) The audience liked the wrestler[1] that the[2] parish priest condemned <~~the wrestler~~>[3] for [4]foul [5]language.

Unlike the neurologically unimpaired group's immediate activation of the displaced argument *the wrestler* (position 1) or immediate reactivation upon encountering the gap (position 3), IWBA did not evince lexical activation of *the wrestler* until 300 ms downstream from the lexical item of interest in the unfolding sentence (position 2), and reactivation was not observed until 500 ms downstream from the gap (position 5). The initial delayed activation of the noun is not a by-product of some version of sentence complexity, as it has also been demonstrated in canonical word order (S-V-O) sentences that do not contain syntactic dependencies (Ferrill et al., 2012). Furthermore, with such object-extracted sentences, there was a direct association between delayed gap-filling and poor offline comprehension (Love et al., 2008; see also similar patterns for *Wh*-questions in Sheppard et al., 2015).

While few studies have employed real-time methods to investigate how individuals with Broca's aphasia process unaccusative verbs during sentence processing, offline studies have demonstrated that IWBA do not have difficulty with the final comprehension of such sentences (Lee & Thompson, 2004; McAlister, Bachrach, Waters, Michaud, & Caplan, 2009; Piñango & Grodzinsky, 2000). In a recent offline study examining the comprehension of sentences containing unaccusative verbs, we (Sullivan et al., 2016) used a sentence-picture matching task with the same participants with Broca's aphasia included in our current study. Non-alternating unaccusative verbs were embedded in two different sentence constructions, complement phrase constructions (9) and subject-extracted relative clauses (10):

(9) The girl observed that the boy disappeared <~~the boy~~> into the trees.
(10) The girl that observed **the boy** disappeared <~~the girl~~> into the trees.

In both (9) and (10) the single argument of the unaccusative verb has been underlined. In (9)—the complement phrase construction—no NP occurs between the single argument of the unaccusative verb, *the boy* and the position from which it has been displaced. However, in (10)—the subject-extracted relative clause construction—an NP (***the boy***) occurs between the two elements of the dependency chain. Results revealed above chance comprehension of the complement phrase construction (9) but comprehension suffered for the subject-extracted relative clauses (10).

We discuss these results further in our General Discussion to follow our experiments, but for now we are left with the following puzzle: In object-extracted sentences and some *Wh*-questions, a delay in lexical activation is associated with poor offline

comprehension by participants with aphasia, but with unaccusatives, a delay in lexical activation does not necessarily give way to poor offline comprehension, as evinced by neurologically unimpaired who reveal a delay yet have no observable offline deficits (Friedmann et al., 2008). Thus, to understand the relation between online and offline comprehension, we need to also carefully examine the online processing of sentences containing unaccusative verbs in individuals with aphasia, and comparatively, to neurologically unimpaired control participants. We now turn to our first experiment.

Experiment 1: The time course of lexical reactivation of unaccusatives in neurologically unimpaired adults

We examined the time course of lexical reactivation in sentences containing non-alternating unaccusative verbs in older neurologically unimpaired individuals. This study sought to replicate the Friedmann et al. (2008) findings of delayed reactivation and to establish an age-match comparison for our subsequent study using participants with Broca's aphasia (Experiment 2). Here, we predicted that AMCs would perform similarly to those in Friedmann et al. (2008); that is, we predicted significant priming would not be observed at verb offset, but instead would be observed downstream from the gap.

Method

Participants

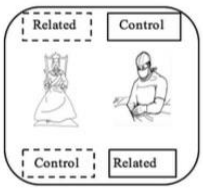
Eleven AMC participants were included in this study (mean age at time of testing: 60 years; range: 42–74 years). All of the AMC participants were monolingual native English speakers with normal or corrected-to-normal visual and auditory acuity, with no reported history of active or significant alcohol and/or drug abuse, active psychiatric illness or intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). All of the participants were tested at the Language and Neuroscience Group Laboratory at San Diego State University and were paid $15 per session.

Task

We used a cross-modal picture priming task (e.g., Swinney & Prather, 1989). Participants listened to uninterrupted auditory sentences and made binary, alive (YES)/not alive (NO), decisions about visually presented black and white line drawings (visual probes) during sentence comprehension. Each experimental sentence (see (14)) had two visual probes (each requiring a YES response): A related probe that was a representation of the displaced NP, and a control probe that was unrelated to any word in the sentence yet served as a related item in another stimulus set (see Figure 1).

In this task, the visual probes are presented at key times during the ongoing sentence. Response choice (yes/no) and RTs to the visual probes are measured with millisecond accuracy. Faster RTs to related relative to unrelated probes yields a priming effect, indicating that the NP of interest has been activated. Importantly, priming effects in cross-modal tasks reflect activation of the lexical item of interest at that point in the

(a) The queen with the bad temper *vanished* ~~<the queen>~~ *1during *2the *3spectacu*4lar fireworks show.



(b) The surgeon with the coin collection *vanished* ~~<the surgeon>~~ *1in the *2midd*3le of the comm*4unity crime watch meeting.

Figure 1. (a) A sample sentence and corresponding probe pictures from the online cross-modal picture priming task for Experiments 1 and 2. The sentence was presented auditorily at a normal speech rate. Probe pictures were presented at the offset of the verb, at the gap, in each sentence (italics) and at three subsequent test points. Approximate probe positions in each sentence are indicated by *. Probe pictures for the related and control conditions are depicted, though only one probe picture was presented on each individual trial. (b) The paired sentence that had the same probe pictures to depict counterbalancing of related and control probes. In this matched sentence design, the pictures related to the displaced argument for one sentence were used as the unrelated control pictures for the displaced argument of another sentence (e.g., as indicated by the dashed box around queen), so that over all items, the related and control sets of pictures were identical, avoiding response time confounds due to differences between pictures.

ongoing auditory sentence, not the integration of the visual probe into the sentence (Nicol, Swinney, Love, & Hald, 2006).

Materials

Sixteen non-alternating unaccusative verbs were selected based on their behaviour with respect to three linguistic diagnostics: occurrence in *there*-constructions, ungrammaticality with a direct object, and inability to undergo passivisation (see also Friedmann et al., 2008):

(11) There disappeared three students after class.
(12) *The teacher disappeared three students after class.
(13) *Three students were disappeared after class (by the teacher).

Thirty-two experimental sentences with the following structure were created (See Appendix A for a full list):

(14) The queen with the bad temper vanished ~~<the queen>~~ *1 during *2 the *3 spectacu*4lar fireworks show.

As shown in Figure 1, the experiment employed a switched target design in which the related probe for one experimental sentence appeared as a control probe for a different experimental sentence, and vice versa. Thus, over all of the sentences, the set of related probes was identical to the set of control probes, minimising the possibility that any observed priming effects are due to aspects of the pictures that might influence participants' RT (e.g., visual complexity differences).

To establish the time course of activation of the single argument, the related and control visual probes were presented at four positions during the ongoing auditory sentence (indicated approximately by the superscript numerals in (14). Unlike the Friedmann et al. (2008) study, we only tested at post-verb positions. Probe position (PP) 1 and 3 were at the same time points found in Friedmann et al. (2008); PP1 (verb offset) and PP3 (750 ms downstream). However, because of prior reports of delayed gap filling in IWBA, two additional PPs were tested; PP2 (500 ms from verb offset, the time point of lexical reactivation found in Love et al., 2008) and PP4 (1,250 ms downstream from verb offset). This last PP serves to test for the possibility that IWBA will demonstrate a delay beyond what was found with unimpaired controls.

In addition to the 32 experimental sentences, 28 filler sentences were created and were paired with an inanimate picture probe (requiring a "No" response). As is standard practice in CMP tasks, the position of the visual probe varied for the filler sentences, with probes appearing equally often near the beginning, middle, and end of the sentences so that appearance of the probe could not be anticipated. Finally, eight practice sentences (also balanced for the type of response) were added to the beginning of each script to familiarise the participant with the task as well as to allow the experimenter the opportunity to monitor the participants' responses thus ensuring that they understood the task. After the 8 practice items, the remaining 60 sentences (32 experimental; 28 filler) were presented in a pseudorandom order such that no more than 3 sentences in a given condition or with a particular response occurred sequentially. The sentences were recorded by a female native English speaker at a normal rate of speech (5.32 syllables per second). Recording and editing were performed using Adobe Audition 3.0 software.

Design

We used a 4 × 2 within-subjects design. The four PPs, combined with the related/control variable, yielded eight conditions. In this design each participant heard every sentence and saw every picture in every condition, and these were counterbalanced across sessions so that no one sentence or picture was repeated in any given session. This design resulted in 8 separate testing sessions where the order of presentation was counterbalanced across participants. Sessions were separated by at least 1 week.

Procedure

To ensure that our participants were performing reliably on the binary picture decision task and that they understood this dual task, a training session was given before the experimental script at each of the eight visits. Participants were told that a picture would

appear in the middle of the screen and that they were to identify whether the picture was of an object that was alive or not by pressing a button labelled "yes" for animate or "no" for not animate, as quickly as possible. The list consisted of 20 items: 10 animate and 10 inanimate. None of the pictures used in the training task were repeated in the experimental scripts.

Once the experimenter felt that the participant understood the binary decision task, participants were then given the instructions for the experimental task. Participants were instructed that they would be listening to sentences for comprehension and responding to a picture probe that would appear centrally on a screen at a given point during the unfolding of a sentence. When they saw the picture, they were to make a YES/NO (alive/not alive) decision as quickly and accurately as possible by using a two-button response box. To encourage attention to the sentences and keep participants on task, participants were told that it was important for them to listen carefully to each of the sentences, as they would be asked comprehension questions at various points during the session. These questions bore only on the setting or general topic of the sentence and were intended only to reinforce the need for the participants to attend to the sentences. Tempo (Version 2.1.5) software was used to control the timed presentation of auditory and visual stimuli and the collection of participant responses. Each visual probe was presented for 1,000 ms, or until a response was made. Responses were recorded for up to 2,000 ms following the appearance of the picture probe, for a total possible time of 3,000 ms. An interstimulus interval of 2,000 ms followed each sentence.

Analysis

The AMC participants responded to the button press decision with >99% accuracy (M = 99.4%; SD = 0.63%; range 98–100%). Before analysis, incorrect responses (wrong button press or no response) were removed (0.61% of data). A < 300 ms and >2,000 ms RT screening was also performed (0.04% of data). A two standard deviation screening per participant by condition of the remaining data was then performed to reduce item variance (4.5% of data).

One item was eliminated from further analyses, as >10% of data were removed after screenings, and because a switched target design was used, the item that it served as a switched target match was also eliminated.

Analysis of the RTs of the remaining 30 items was conducted using restricted maximum likelihood in a mixed-effects model. Included in this model were the crossed-random effects on the intercept of participant and sentence and fixed effects of PP (1 vs. 2 vs. 3 vs. 4), relatedness versus control, and their interaction.[2] The models were fit with an unstructured covariance matrix for each random effect. Follow-up models examined the interaction of PP and relatedness separately for each pair of PPs and are presented in the Results section accordingly. Type III F-tests are reported for main effects and interactions. All analyses were conducted using SAS Version 9.4 software. While the fixed and random effect terms were entered into the model per our design and hypotheses, we also examined the justification of the crossed-random effect structure using the Bayesian information criterion (BIC; Schwarz, 1978) to evaluate model fit (a relative measure in which smaller values indicate better fit). With no random effects, the overall

Table 1. Experiment 1: Mean reaction times (and standard error) in milliseconds to control and related probes at each probe position for AMC participants (n = 11).

	PP1 Verb offset	PP2 500 ms post gap	PP3 750 ms post gap	PP4 1,250 ms post gap
Control	657(7)	649(8)	654(7)	639(8)
Related	652(7)	647(8)	635(6)	628(8)
(Control-Related)	5 ms	2 ms	19 ms*	11 ms

*p < .05.

model (i.e., including both levels of PP) had BIC = −888.2, which improved to BIC = −2,139.3 when the random effect of participant was added, and improved again to BIC = −2,169.8 when the additional random effect of sentence was added, thus justifying the inclusion of both random effects. The follow-up models on pairs of PPs showed similar improvements to model fit. Note that differences in BIC values >10 (such as those found when adding in both random effects of participant and item) constitute very strong evidence of a better fit for the model with the smaller (more negative) score (Kass & Raftery, 1995). For planned comparisons of related and control probes at each PP, we computed t-tests of the differences of the least square means from the full model. All p-values are reported two-tailed. Degrees of freedom (reported in the t-tests below) 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).

Results

Mean RTs and standard errors for each condition are shown in Table 1.

There was a main effect of relatedness, $F(1, 2460) = 5.62$, $p = 0.02$ and a main effect of probe point, $F(3, 2459) = 7.8$, $p < 0.0001$. However there was no overall interaction between PP and relatedness $F(3, 2459) = 0.45$, $p = 0.72$. Planned comparisons of the RTs for related and control probes for each PP are of primary importance to address the question of when (at which PP) any priming effects reach significance. These planned comparisons revealed significant priming (control minus related) at only **PP3**; 19 ms; $t(2,459) = 2.13$, $p = 0.03$; 95% CI: [0.002, 0.05]. No significant priming effect was found at **PP1**; 5 ms; $t(2,459) = 0.7$, $p = 0.48$; 95% CI: [−0.02, 0.03], **PP2;** 2 ms; $t(2,459) = 0.74$, $p = 0.46$; 95% CI: [−0.01, 0.03] or **PP4**; 11 ms; $t(2,459) = 1.16$, $p = 0.25$; 95% CI: [−0.01, 0.04].

Discussion

The purpose of this experiment was twofold: to chart the time course of lexical reactivation of the displaced argument in sentences containing unaccusative verbs, with older neurologically unimpaired individuals, and to offer a comparison to our age-matched participants with Broca's aphasia (Experiment 2, to follow). Recall that Friedmann et al. (2008) found that gap filling was delayed with sentences containing unaccusative verbs in college-aged neurologically unimpaired participants, unlike what is observed with, for example, object-extracted relatives (Love et al.,

2008, and references therein). In the present experiment, no significant priming effects were observed at the gap, but were observed 750 ms downstream. Thus gap filling was delayed for our older neurologically unimpaired participants, similar to the delayed gap filling evinced with college-aged individuals found in Friedmann et al. (2008). We agree with the suggestion made by Friedmann et al. (2008) that the lack of an overt cue signalling an upcoming gap could be responsible for the delay in lexical reactivation with unaccusative verbs. We now move to Experiment 2, which investigates the impact of Broca's aphasia on the lexical reactivation of displaced NPs in sentences that contain unaccusative verbs.

Experiment 2: The time course of lexical activation of unaccusatives in individuals with Broca's aphasia

There are a few possibilities for our IWBA regarding activation patterns in sentences containing unaccusative verbs. The first is that they could exhibit lexical reactivation with a time course similar to what has been demonstrated with IWBA with other types of syntactic dependencies; that is, 500 ms downstream from the gap. Consider again an object-extracted clause from Love et al. (2008):

(15) The audience liked the wrestler[1] that the[2] parish priest condemned <~~the wrestler~~>[3] for [4]foul [5]language.

Recall that neurologically unimpaired individuals exhibited immediate lexical reactivation of the displaced argument at the gap (PP3). Individuals with Broca's aphasia did not immediately exhibit lexical reactivation at the gap but instead, reactivation of the displaced argument was observed at PP5, 500 ms downstream from the gap.

A second possibility is that our participants with Broca's aphasia would exhibit the same delay in lexical reactivation with unaccusatives as observed with college-aged neurologically unimpaired individuals in Friedmann et al. (2008) and with the AMCs in our current Experiment 1; 750 ms downstream from the gap. Both of these possibilities would indicate that individuals with Broca's aphasia are able to take advantage of the inherent delay of unaccusative verbs and would also indicate that IWBA exhibit a time course of lexical reactivation that is similar to neurologically unimpaired individuals. The final possibility we entertained is that IWBA may evince lexical reactivation with a time course that is delayed compared to neurologically unimpaired individuals, and thus observed at the1,250 ms post-gap position.

Method

Participants

Seven individuals with Broca's aphasia met criteria for inclusion in this study (mean age at time of testing: 58 years; range: 39–75 years). Demographic information for these participants is presented in Table 2.

All participants with Broca's aphasia experienced a single, unilateral left-hemisphere (LH) stroke, were native English speakers with normal or corrected-to-normal visual and

Table 2. Demographic information for individuals with agrammatic Broca's aphasia.

Participant	Gender	Years post stroke	Lesion location^	Age at testing	Education in years	BDAE* severity level	SOAP # Canonical	SOAP ~ non-canonical
LHD009	M	13	LH lesion involving inferior frontal gyrus (BA44, 45)	53	17	3	75%	55%
LHD101	M	7	LH lesion involving posterior inferior frontal gyrus (BA44) with posterior extension	64	20	2	95%	35%
LHD130	M	5	L IPL with posterior extension sparing STG	61	16	4	95%	65%
LHD132	M	9	LH lesion involving inferior frontal regions with extension to the anterior two thirds of STG and MTG	50	16	4	85%	55%
LHD140	F	13	L MCA infarct secondary to occlusion of L proximal CA	39	16	2	80%	30%
LHD142	M	3	L MCA infarct	75	8	4	100%	65%
LHD159	F	3	L MCA infarct	61	14	3	100%	70%
		Mean = 8 *SD* = 4		*M* = 58 *SD* = 11	*M* = 15 *SD* = 4	*M* = 3 *SD* = 1	*M* = 90% *SD* = 10	*M* = 54% *SD* = 15

^ L = left; LH = left hemisphere; BA = Brodmann area; IPL = inferior parietal lobule; STG = superior temporal gyrus; MTG = middle temporal gyrus; MCA = middle cerebral artery; CA = cerebral artery.

* BDAE = Boston Diagnostic Aphasia Examination (0 = no usable speech or auditory comprehension, 5 = minimal discernable speech handicap).

SOAP Canonical = Average percent correct of active and subject relative items on SOAP Test of Auditory Sentence Comprehension.

~ SOAP Non-Canonical = Average percent correct of passive and object relative items on SOAP Test of Auditory Sentence Comprehension.

auditory acuity, and were right-handed before their stroke. The clinical diagnosis of Broca's aphasia was made based on the administration of standardised language testing to determine the extent and severity of each participant's language impairment; specifically in the areas of fluency and auditory comprehension ability. Testing included the Boston Diagnostic Aphasia Examination—Third Edition (BDAE—3; Goodglass, Kaplan, & Barresi, 2000), and Subject-relative Object-relative Active and Passive (SOAP) Test of Auditory Sentence Comprehension (Love & Oster, 2002). Participants with Broca's aphasia were included in this study if they met clinical consensus and demonstrated comprehension deficits, which we defined as at- or below-chance performance on comprehension of sentences with non-canonical word order (object relatives and passives) as assessed by the SOAP. All participants were neurologically and physically stable (i.e., at least 6 months post onset), with no reported history of active or significant alcohol and/or drug abuse, active psychiatric illness or intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). All of the participants were tested at the Language and Neuroscience Group Laboratory at San Diego State University and were paid $15 per session. A review of treatment history reveals that six of our seven participants had treatment for sentence-level deficits, though the extent of treatment (number of sessions, type of treatment, treatment response) were not available.

Task, Materials, Design, and Procedure

The same Task, Materials, Design, and Procedure as those used in Experiment 1 were used. See Sections 2.1.2–2.1.5 for details.

Analysis

The IWBA responded to the button press decision with >99% accuracy (M = 99.6%; SD = .24%; range 99.2–100%). Before analysis, incorrect responses (wrong button press or no response) were removed (.42% of data). A < 300 ms and >2,000 ms RT screening was performed, but no data were removed as no RTs were outside this range. A two standard deviation screening per participant by condition of the remaining data was then performed to reduce item variance (4.72% of data).

The same item eliminated from analyses for the AMCs was also removed here as 20% of the data were eliminated for the IWBA. As a switched target design was used, the item that it served as a switch target match was also eliminated.

Similar to the analyses performed in Experiment 1, analysis of the RTs of the remaining 30 items was conducted using restricted maximum likelihood in a mixed-effects model (see Section 2.2). Included in this model were the crossed-random effects on the intercept of participant and sentence and fixed effects of PP (1 vs. 2 vs. 3 vs. 4), relatedness versus control, and their interaction. With no random effects, the overall model (i.e., including both levels of PP) had BIC = −1,049, which improved to BIC = −2,156.2 when the random effect of participant was added, and improved again to BIC = −2,188.3 when the additional random effect of sentence was added, thus justifying the inclusion of both random effects. Refer to Experiment 1 for the details of this analysis.

Results

Mean RTs and standard errors for each condition for IWBA are shown in Table 3.

There was a main effect of PP, $F(3,1552) = 12$, $p < 0.0001$, but no main effect of relatedness, $F(1,1552) = 0.05$, $p = 0.82$. A significant overall interaction between PP and relatedness was observed, $F(3,1552) = 2.98$, $p = 0.03$. Planned comparisons of the RTs for related and control probes for each PP are of primary importance to address the question of when (at which PP) any priming effects reach significance.

As shown in Figure 2, these planned comparisons between the RTs for related compared to control picture probes revealed significant priming, 17 ms, at only **PP2**, $t(1,552) = 2.2$, $p = 0.03$; 95% CI: [0.003, 0.05]. No significant priming was found at **PP1**, $t(1,553) = 0.82$,

Table 3. Experiment 2: Mean reaction times (and standard error) in milliseconds to control and related probes at each probe position for participants with Broca's aphasia (n = 7).

	PP1 Verb offset	PP2 500 ms post gap	PP3 750 ms post gap	PP4 1,250 ms post gap
Control	727(10)	698(8)	711(9)	693(8)
Related	720(10)	681(7)	726(10)	700(8)
(Control-related)	7 ms	17 ms*	−15 ms	−7 ms

*p < .05.

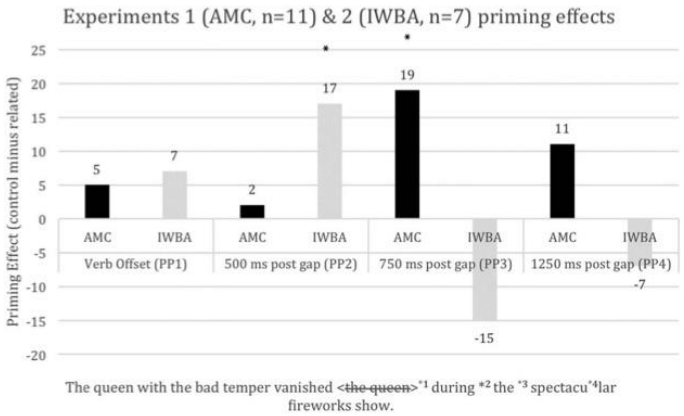


Figure 2. Priming effects for AMC group (Experiment 1) and IWBA group (Experiment 2) across four probe positions.

$p = 0.41$; 95% CI: [−0.01, 0.03], **PP3**, $t(1,552) = -1.59$, $p = 0.11$; 95% CI: [−0.04, 0.004] or **PP4**, $t(1,552) = -0.98$, $p = 0.33$; 95% CI: [−0.03, 0.01].

Discussion

The purpose of this experiment was to chart the time course of lexical reactivation of the displaced argument in sentences containing unaccusative verbs, with individuals who have a Broca's aphasia and a comprehension deficit. Both groups revealed delayed reactivation with unaccusative verbs at points downstream from the gap. Specifically, in Experiment 1, our neurologically unimpaired participants evinced priming 750 ms post gap, replicating the effect shown with neurologically unimpaired college-aged participants in Friedmann et al. (2008). Recall also that in prior studies investigating gap filling with participants with Broca's aphasia (e.g., Love et al., 2008), there is evidence for both delayed lexical access and delayed reaccess (i.e., delayed gap filling), both of which have been revealed through CMP experiments like the present one, with some further evidence from eye tracking-while-listening tasks (Thompson & Choy, 2009).

We offered the following predictions: The normally inherent delay observed with unaccusatives would match the inherent lexical access delay, culminating in similarly delayed patterns between our participants with Broca's aphasia and the neurologically unimpaired participants from Friedmann et al. (2008) and Experiment 1. Alternatively, we surmised that our participants might reveal an even longer delay with unaccusatives, suggesting that the normal delay and the aphasia lexical (re)access delay would be compounded. We observed strong evidence for the former prediction: Significant priming was observed downstream from the gap but not at the farthest downstream point.

Interpretation of these results relative to the extant literature is not straightforward. For example, both the DLA and the slowed syntax accounts can explain these patterns. The DLA suggests delayed access when a noun is encountered and delayed reaccess of that NP at gap positions (Love et al., 2008). In the present study we observed activation

of the displaced NP temporally downstream from the gap. The slow syntax approach, likewise, predicts late activation of the single argument of unaccusatives, given that gap filling may be a syntactically driven process (Burkhardt et al., 2003). One interpretation that is clear from these results is that IWBA who have sentence comprehension deficits are sensitive to the argument structure properties of verbs (see Shapiro et al., 1993; Shapiro & Levine, 1990); otherwise they would be insensitive to the unaccusativity property. We discuss this further in the General Discussion.

General discussion

We examined the comprehension of sentences containing non-alternating unaccusative verbs in a group of AMCs and in participants with agrammatic Broca's aphasia who also have a comprehension deficit. We took our initial cue from Friedmann et al. (2008), who found that college-aged neurologically healthy adults delay reaccess of the single argument of unaccusatives, unlike what is observed with, for example, transitive verbs inserted into object-extracted relatives (Love et al., 2008, and references therein). We observed a replication of the Friedmann et al. (2008) results with our AMC participants—activation of the displaced object of unaccusative verbs was observed at a 750 ms post-gap position. For our IWBA, we also found delayed reactivation of the displaced object of the unaccusative verb, but at 500 ms post gap and not at 750 ms. It is possible that if Friedmann et al. (2008) had tested at a PP that was 500 ms post gap instead of just 750 ms, they may have demonstrated effects beginning at 500 ms post gap. Of course we cannot be sure of this. Even so, this difference in timing (between 500 and 750 ms) occurs over a very small segment, perhaps 1–2 syllables at most, and thus does not alter our overall conclusion—both unimpaired and agrammatic Broca's participants are not showing immediate reactivation of the antecedent at the gap; reactivation is occurring downstream. Our participants with agrammatic Broca's aphasia do not exhibit a delayed time course of lexical reactivation with sentences containing unaccusative verbs compared to neurologically unimpaired indviduals.

These patterns, then, beg the question: Why do syntactic dependencies such as object relatives and *Wh*-questions yield immediate reactivation of the displaced argument in neurologically unimpaired participants, while unaccusatives yield late gap filling in both neurologically unimpaired and impaired participants? One possibility, as discussed in our Introduction, based on Friedmann et al. (2008), is that *Wh*-questions and relative clauses contain an explicit surface cue early in the sentence that signals that a gap position will be forthcoming. The cue for *Wh*-questions is the *Wh*-word (e.g., *Which* boy did the girl kiss <~~which boy~~> yesterday?) and the cue for relative clauses is the complementiser *that* or *who* (e.g., The audience liked the wrestler *that* the priest condemned <~~the wrestler~~> for foul language). There are no surface cues that a gap will be forthcoming for unaccusatives and thus a listener cannot predict that a gap will occur until the unaccusative verb itself is encountered. At that point the parser—having access to the verb's properties—would "know" to posit a gap, and then form the dependency chain between the gap and the displaced argument, which would take longer with unaccusative sentences than structures that contain early and explicit cues.

Of considerable interest is that individuals with Broca's aphasia who show late gap filling with *Wh*-questions and object relatives also do poorly on offline comprehension of

those structures, as discussed in our Introduction. Yet, though late gap filling is observed for unaccusatives (similar to that found with unimpaired listeners), offline comprehension remains unimpaired.[3] One possibility is that there is no direct relation between online behaviour and offline final comprehension in aphasia. We believe this conclusion is too strong. Another possibility that we have recently investigated is the Intervener Hypothesis. An intervener is an NP that interrupts the dependency chain between the displaced NP and its gap; if the two NPs are structured similarly (e.g., DET *N*), similarity-based interference occurs, decreasing comprehension performance.

Recent findings from our lab support the intervener account (Friedmann & Shapiro, 2003; Sheppard et al., 2015; Sullivan et al., 2016). As discussed in our Introduction and repeated and extended here, Sullivan et al. (2016) used a sentence-picture matching task with the seven participants with Broca's aphasia included in the current Experiment 2. Non-alternating unaccusative verbs were embedded in two different sentence constructions, complement phrase constructions (16) and subject-extracted relative clauses (17):

(16) The girl observed that the boy disappeared ~~<the boy>~~ into the trees.
(17) The girl that observed **the boy** disappeared ~~<the girl>~~ into the trees.

In both (16) and (17) the single argument of the unaccusative verb has been underlined. In (16)—the complement phrase construction—no NP occurs between the single argument of the unaccusative verb, *the boy* and the position from which it has been displaced. However, in (17)—the subject-extracted relative clause construction—an NP (***the boy***) occurs between the two elements of the dependency chain. Results revealed above chance comprehension of the complement phrase construction (16) but comprehension suffered for the subject-extracted relative clauses (17). These results provide support for the Intervener Hypothesis, which claims that the sentence comprehension deficits observed in individuals with Broca's aphasia occur as a result of interference among structurally similar NPs. For example, in (17) above, the NP *the girl*, once displaced, crosses over the intervening NP *the boy*, and both are NPs that result from the merging of a Determiner and a Noun. The similar structure causes similarity-based interference and negatively impacts comprehension. Thus, we suggest that the reason why unaccusative verbs are relatively easy to understand even for participants with Broca's aphasia who have sentence comprehension impairments and exhibit a delay in lexical activation is that there is no possibility of an intervener interfering with interpretation in most sentence types; unaccusatives are single-argument verbs. Delayed lexical activation only results in comprehension difficulties for IWBA when a structurally similar NP intervenes between a gap and its filler.

One issue we have ignored thus far is whether the effects we have observed are specific to participants with a Broca's aphasia who evince a sentence comprehension deficit, or is a general pattern characteristic of LH damage. That is, do participants with agrammatic Broca's aphasia who do not have a comprehension disorder, or participants without Broca's aphasia, reveal similar or different patterns? We cannot be sure because we did not test a group of participants with brain damage who have non-agrammatic aphasia, and so ultimately this question remains unresolved. There is some reasonable evidence that people with a fluent, Wernicke's like aphasia do not show late gap filling that is observed in agrammatic Broca's aphasia (e.g., Love et al., 2008; Zurif, Swinney, Prather, Solomon, &

Bushell, 1993), and do not show sensitivity to argument structure (necessary to understand unaccusative verbs; see Russo, Peach, & Shapiro, 1998; Shapiro et al., 1993). Yet, we recognise that participants with a Wernicke-like aphasia are dissimilar behaviourally (and neurologically) to participants with damage to other cortical and subcortical areas, including damage to LH regions more closely associated with agrammatic aphasia. Thus, further work is required to examine the generalisability of our approach.

To conclude, we conducted an experiment examining the online comprehension of sentences containing unaccusative verbs in a group of IWBA with a demonstrated comprehension deficit, and in a group of neurologically unimpaired age-matched individuals. We found reactivation of the displaced NP at a position downstream from the gap in both groups, though at slightly different temporal points. We have suggested that the source of the delay is the lack of a surface cue to the gap (based on Friedmann et al., 2008). While studies examining other types of syntactic dependencies in individuals with Broca's aphasia reveal that late gap filling gives way to poor offline performance, for unaccusative verbs late gap filling does not result in impaired offline comprehension, except when sentences contain an intervener between a filler and its gap. The delay in lexical activation observed in IWBA only has repercussions to sentence comprehension for constructions that include a structurally similar NP that intervenes between two elements of a filler-gap syntactic dependency.

Notes

1. A recent cross-modal priming study by Peristeri, Tsimpli, and Tsapkini (2013) found that their participants with aphasia revealed on time gap filling with unaccusatives. However, concerns about their method (e.g., allowing the visual probes to stay on the screen indefinitely, and stopping the auditory sentence while the lexical decision was made) compromise their findings. That is, because the participants could focus on the lexical decision while the sentence was no longer unfolding, reflection likely occurred (see Nicol et al., 2006). And indeed, lexical decision times were very slow (an average of 2,879 ms for control participants and 3,834 ms for the participants with aphasia; note that the average RTs for the neurologically healthy participants in Friedmann et al. was 640 ms).
2. This model combines traditionally separate F1 and F2 analyses into a single statistical test.
3. We have observed a similar finding in aphasia with sentences containing verb phrase ellipsis (e.g., The fireman defended the policeman, and the lawyer did too, according to someone who was there). Here, the verb phrase from the initial clause—*defended the policeman*—is reconstructed at the elided position (after *did*), yet is either not found reactivated in some participants (Poirier, Shapiro, Love, & Grodzinsky, 2009) or found reactivated at 750 ms after the elided position (Walenski et al., submitted). However, offline performance was very good.

Acknowledgements

We thank our research assistants, our participants, and their families for their time.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The work reported in this report was supported by NIH Grants (NIDCD) R01DC03681, R01DC009272, and T32DC007361.

References

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

Baayen, R. H. (2004). Statistics in psycholinguistics: A critique of some current gold standards. *Mental Lexicon Working Papers in Psycholinguistics*, *1*, 1–45.

Baayen, R. H. (2008). *Analyzing linguistic data. A practical introduction to statistics using R*. Cambridge, UK: CambridgeUniversity Press.

Bever, T. G., & Sanz, M. (1997). Empty categories access their antecedents during comprehension: Unaccusatives in Spanish. *Linguistic Inquiry*, *28*, 69–91.

Biran, M., & Friedmann, N. (2012). The representation of lexical-syntactic information: Evidence from syntactic and lexical retrieval impairments in aphasia. *Cortex*, *48*, 1103–1127. doi:10.1016/j.cortex.2011.05.024

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. doi:10.1016/j.jneuroling.2006.10.004

Burkhardt, P., Piñango, M. M., & Wong, K. (2003). The role of the anterior left hemisphere in real-time sentence comprehension: Evidence from split intransitivity. *Brain and Language*, *86*, 9–22. doi:10.1016/S0093-934X(02)00526-6

Burzio, L. (1986). *Italian syntax: A government-binding approach*. Dordrecht: Reidel.

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*, 103–150. doi:10.1016/j.bandl.2006.06.225

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

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

Choy, J., & Thompson, C. K. (2010). Binding in agrammatic aphasia: Processing to comprehension. *Aphasiology*, *24*, 551–579. doi:10.1080/02687030802634025

Drai, D., & Grodzinsky, Y. (2006). The variability debate: More statistics, more linguistics. *Brain and Language*, *96*, 157–170. doi:10.1016/j.bandl.2005.05.004

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*, 179–189. doi:10.1044/1058-0360(2012/11-0109)

Fodor, J. D. (1993). Processing empty categories: A question of visibility. In G. Altamnn & R. Shillcock (Eds.), *Cognitive models of speech processing: The second Sperlonga meeting* (pp. 351–400). Mahwah, NJ: Lawrence Earlbaum Associates.

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. doi:10.1044/1092-4388(2003/023)

Friedmann, N., Taranto, G., Shapiro, L. P., & Swinney, D. (2008). The leaf fell (the leaf): The online processing of unaccusatives. *Linguistic Inquiry*, *39*, 355–377. doi:10.1162/ling.2008.39.3.355

Goodglass, H., Kaplan, E., & Barresi, B. (2000). *Boston diagnostic aphasia examination* (3rd ed.). Philadelphia: Taylor & Francis.

Grodzinsky, Y. (2006). A blueprint for a brain map of syntax. In K. Amunts & Y. Grodzinsky (Eds.), *Broca's Region* (pp. 83–108). New York: Oxford University Press.

Haarmann, H., Just, M., & Carpenter, P. (1997). Aphasic sentence comprehension as a resource deficit: A computational approach. *Brain and Language*, *59*, 76–120. doi:10.1006/brln.1997.1814

Kass, R., & Raftery, A. (1995). Bayes factors. *Journal of the American Statistical Association*, *90*, 773–795. doi:10.1080/01621459.1995.10476572

Lee, J., & Thompson, C. K. (2011). Real-time production of unergative and unaccusative sentences in normal and agrammatic speakers: An eyetracking study. *Aphasiology*, *25*, 813–825. doi:10.1080/02687038.2010.542563

Lee, M., & Thompson, C. K. (2004). Agrammatic aphasic production and comprehension of unaccusative verbs in sentence contexts. *Journal of Neurolinguistics*, *17*, 315–330. doi:10.1016/S0911-6044(03)00062-9

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberger, R. D. (2006). *SAS system for 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. doi:10.1023/A:1021208903394

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*, 5–24. doi:10.1007/BF01708418

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. doi:10.1016/j.bandl.2007.11.004

McAlister, T., Bachrach, A., Waters, G., Michaud, J., & Caplan, D. (2009). Production and comprehension of unaccusatives in aphasia. *Aphasiology*, *23*, 989–1004. doi:10.1080/02687030802669518

Nicol, J., Swinney, D., Love, T., & Hald, L. (2006). The on-line study of sentence comprehension: An examination of dual task paradigms. *Journal of Psycholinguistic Research*, *35*, 215–231. doi:10.1007/s10936-006-9012-0

Peristeri, E., Tsimpli, I., & Tsapkini, K. (2013). The on-line processing of unaccusativity in greek agrammatism. *Applied Psycholinguistics*, *34*, 233–276. doi: 10.1017/S0142716411000683.

Perlmutter, D. M. (1978). Impersonal passives and the Unaccusative Hypothesis. In *Proceedings of the Fourth Annual Meeting of the Berkeley Linguistics Society* (157–189). Berkeley: University of California, Berkeley Linguistics Society.

Perlmutter, D. M., & Postal, P. (1984). The 1-advancement exclusiveness law. In D. Perlmutter & C. Rosen (Eds.), *Studies in relational grammar* (pp. 195–229). Chicago, IL: University of Chicago Press.

Piñango, M. M. (2000). Canonicity in Broca's sentence comprehension: The case of psychological verbs. In Grodzinsky, Y. Shapiro, L. P., & Swinney, D. (Eds.), *Language and the brain: Representation and processing* 327–350. San Diego, CA: Academic Press.

Poirier, J., Shapiro, L. P., Love, T., & Grodzinsky, Y. (2009). The on-line processing of verb-phrase ellipsis in aphasia. *Journal of Psycholinguistic Research*, *38*, 237–253. doi:10.1007/s10936-009-9108-4

Russo, K. D., Peach, R. K., & Shapiro, L. P. (1998). Verb preference effects in the sentence comprehension of fluent aphasic individuals. *Aphasiology*, *12*, 537–545. doi:10.1080/02687039808249556

Schwarz, G. (1978). Estimating the dimension of a model. *The Annals of Statistics*, *6*, 461–464. doi:10.1214/aos/1176344136

Shapiro, L. P., Gordon, B., Hack, N., & Killackey, J. (1993). Verb-argument structure processing in complex sentences in Broca's and Wernicke's Aphasia. *Brain and Language*, *45*, 423–447. doi:10.1006/brln.1993.1053

Shapiro, L. P., & Levine, B. (1990). Verb processing during sentence comprehension in aphasia. *Brain and Language*, *38*, 21–47. doi:10.1016/0093-934X(90)90100-U

Shapiro, L. P., Oster, E., Garcia, R., Massey, A., & Thompson, C. K. (1999). *On-line comprehension of wh- questions in discourse*. Poster presented at the CUNY Conference on Human Sentence Processing, CUNY, New York.

Shapiro, L. P., Zurif, E., & Grimshaw, J. (1987). Sentence processing and the mental representation of verbs. *Cognition*, *27*, 219–246. doi:10.1016/S0010-0277(87)80010-0

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

Sheppard, S. M., Walenski, M., Love, T., & Shapiro, L. P. (2015). The auditory comprehension of *Wh*-questions in aphasia: Supportfor the intervener hypothesis. *Journal of Speech, Language, and Hearing Research*, *58*, 781–797. doi:10.1044/2015_JSLHR-L-14-0099

Shetreet, E., Friedmann, N., & Hadar, U. (2010). The neural correlates of linguistic distinctions: Unaccusative and unergative verbs. *Journal of Cognitive Neuroscience*, *22*, 2306–2315. doi:10.1162/jocn.2009.21371

Shetreet, E., Palti, D., Friedmann, N., & Hadar, U. (2007). Cortical representation of verb processing in sentence comprehension: Number of complements, subcategorization, and thematic frames. *Cerebral Cortex*, *17*, 1958–1969. doi:10.1093/cercor/bhl105

Sullivan, N., Walenski, M., Love, T., & Shapiro, L. P. (2016). The offline comprehension of sentences with unaccusative verbs in aphasia. *Aphasiology*. Advance online publication. doi:10.1080/02687038.2016.1154499

Swinney, D., & Prather, P. (1989). On the comprehension of lexical ambiguity by young children: Investigations into the development of mental modularity. In D. Gorfein (Ed.), *Resolving semantic ambiguity* (pp. 225–238). New York, NY: Springer-Verlag.

Tanenhaus, M., Boland, J., Garnsey, S., & Carlson, G. (1989). Lexical structure in parsing long-distance dependencies. *Journal of Psycholinguistic Research (Special Issue on Sentence Processing)*, *18*, 37–50.

Thompson, C. K., & Choy, J. (2009). Pronominal resolution and gap filling in agrammatic aphasia: Evidence from eye movements. *Journal of Psycholinguistic Research*, *38*, 255–283. doi:10.1007/s10936-009-9105-7

Walenski, M., Ferrill, M., Deschamps, I., Pieperhoff, P., Amunts, K., Grodzinsky, Y., … Shapiro, L. P. (in press). *Correspondences between brain structure and function in aphasia*. Manuscript submitted for publication.

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. doi:10.1006/brln.1993.1054

Appendix A. Stimuli used in Experiment 1 and 2

Sentence	Unaccusative verb
The runner with the funny accent thrived until the last semester of the undergraduate programme.	Thrived
The fireman from the next county fell during an obnoxiously noisy motorcycle race.	Fell
The electrician with bushy eyebrows survived during the devastating Category 3 storm.	Survived
The director from the tiny province remained after the extravagant charity function.	Remained
The tailor from East Orange, New Jersey disappeared after the ridiculously uninspiring self-help seminar.	Disappeared
The queen with the bad temper vanished during the spectacular fireworks show.	Vanished
The tourist on the unshaded side of the street languished after the paddleboarding tour of the cove.	Languished
The umpire from the neighbouring city arrived after the horrifying automobile accident.	Arrived
The musician with the expensive jewellery emerged with a large and boisterous entourage.	Emerged
The captain with the worst attendance flourished after the vitally important discovery.	Flourished
The chef from the wealthy family arose after the obnoxious shrill of the alarm clock.	Arose
The goalie from the suburbs of Charlotte departed before dawn for a long overdue vacation.	Departed
The skateboarder with the navy blue socks soared through the fluffy clouds for several minutes.	Soared
The dentist from the suburbs of Detroit awoke before the high intensity kick boxing class.	Awoke
The actor with a collection of stamps lived during the undeniably life altering internet boom.	Lived
The janitor from the private high school appeared after the grand opening of the department store.	Appeared
The gymnast with a green and white Dodge Caravan thrived during the wheelbarrow racing competition.	Thrived
The golfer with thirteen pet guinea pigs fell in the middle of the surprise birthday party.	Fell
The plumber with a grey scraggly beard survived during the incredibly hectic final exam week.	Survived
The teacher with the wire framed glasses remained after the extremely emotional performance.	Remained
The lawyer with an appetite for sweets disappeared before the first act of the Broadway show.	Disappeared
The surgeon with the coin collection vanished in the middle of the community crime watch meeting.	Vanished
The librarian from West Virginia languished after the first day of the semester.	Languished
The roofer from Sacramento arrived during the third period of the basketball game.	Arrived
The farmer with the curly hair emerged after the televised singing competition.	Emerged
The girl from the small town in Maine flourished after the dance academy graduation.	Flourished
The jockey from Minnesota arose after the tremendously inconsiderate telephone call.	Arose
The barber with three small children departed before the seventh inning of the baseball game.	Departed
The reporter with the purple jumpsuit soared past the cliffs above the populated beach.	Soared
The bartender with reflective shoelaces awoke after several hours of restful sleep.	Awoke
The illustrator from Madison, Wisconsin lived after the notably influential French Renaissance.	Lived
The cowgirl with the large emerald necklace appeared after the heroic rescue of the kitten.	Appeared

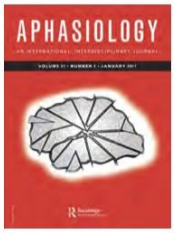
Chapter 7, in full, is a reprint of material as it appears in Sullivan, N., Walenski, M., Love, T., & Shapiro, L.P. (2017). The curious case of processing unaccusative verbs in aphasia, *Aphasiology*, Advance online publication. doi: 10.1080/02687038.2016.1274873. The dissertation author was the primary investigator and author of this paper.

CHAPTER 8:

The Comprehension of Sentences with Unaccusative Verbs in Aphasia: A Test of the Intervener Hypothesis

Preface

As established in previous chapters, individuals with Broca's aphasia have difficulty comprehending sentences that do not follow canonical word order and contain a syntactic dependency. The Intervener Hypothesis suggests that the presence of an intervening structurally similar noun phrase between two elements of a syntactic dependency causes similarity-based interference and negatively impacts sentence comprehension. Support for the Intervener Hypothesis has been established with the covert syntactic dependency in Wh- questions (Sheppard, Walenski, Love, & Shapiro, 2015), as well as the overt syntactic dependency found with anaphors (Engel, Shapiro, & Love, submitted). Chapter 7 established that individuals with Broca's aphasia are sensitive to the unaccusative property during online sentence processing in a fashion similar to neurologically unimpaired individuals. That is, they exhibit reactivation of a displaced NP in sentences that contain unaccusative verbs at post verb position. This finding demonstrates that the syntactic dependency afforded by unaccusative verbs provide an ideal test case for the Intervener Hypothesis. In the following chapter, the Intervener Hypothesis is evaluated with the syntactic dependency afforded by unaccusative verbs by comparing final comprehension of sentences that contain an unaccusative verb and an intervener and sentences that contain an unaccusative verb and no intervener.



Aphasiology

Routledge
Taylor & Francis Group

ISSN: 0268-7038 (Print) 1464-5041 (Online) Journal homepage: http://www.tandfonline.com/loi/paph20

The comprehension of sentences with unaccusative verbs in aphasia: a test of the intervener hypothesis

Natalie Sullivan, Matthew Walenski, Tracy Love & Lewis P. Shapiro

To cite this article: Natalie Sullivan, Matthew Walenski, Tracy Love & Lewis P. Shapiro (2017) The comprehension of sentences with unaccusative verbs in aphasia: a test of the intervener hypothesis, Aphasiology, 31:1, 67-81, DOI: 10.1080/02687038.2016.1154499

To link to this article: http://dx.doi.org/10.1080/02687038.2016.1154499

Published online: 09 Mar 2016.

APHASIOLOGY, 2017
VOL. 31, NO. 1, 67–81
http://dx.doi.org/10.1080/02687038.2016.1154499

Routledge
Taylor & Francis Group

The comprehension of sentences with unaccusative verbs in aphasia: a test of the intervener hypothesis

Natalie Sullivan[a], Matthew Walenski[b], Tracy Love[a,b] and Lewis P. Shapiro[a,b]

[a]SDSU/UCSD Joint Doctoral Program in Language and Communicative Disorders, San Diego, CA, USA; [b]School of Speech Language and Hearing Sciences, San Diego State University, San Diego, CA, USA

ABSTRACT

Background: It is well accepted that individuals with agrammatic Broca's aphasia have difficulty comprehending some sentences with filler-gap dependencies. While investigations of these difficulties have been conducted with several different sentence types (e.g., object relatives, *Wh*-questions), we explore sentences containing unaccusative verbs, which arguably have a single noun phrase (NP) that is base-generated in object position but then is displaced to surface subject position. Unaccusative verbs provide an ideal test case for a particular hypothesis about the comprehension disorder—the Intervener Hypothesis—that posits that the difficulty individuals with agrammatic Broca's aphasia have comprehending sentences containing filler-gap dependencies results from similarity-based interference caused by the presence of an intervening NP between the two elements of a syntactic chain.

Aim: To assess a particular account of the comprehension deficit in agrammatic Broca's aphasia—the Intervener Hypothesis.

Methods & Procedures: We used a sentence–picture matching task to determine if listeners with agrammatic Broca's aphasia (LWBA) and age-matched neurologically unimpaired controls (AMC) have difficulty comprehending unaccusative verbs when placed in subject relative and complement phrase (CP) constructions.

Outcomes & Results: We found above-chance comprehension of both sentence constructions with the AMC participants. In contrast, we found above-chance comprehension of CP sentences containing unaccusative verbs but poor comprehension of subject relative sentences containing unaccusative verbs for the LWBA.

Conclusions: These results provide support for the Intervener Hypothesis, wherein the presence of an intervening NP between two elements of a filler-gap dependency adversely affects sentence comprehension.

ARTICLE HISTORY
Received 5 August 2015
Accepted 5 February 2016

KEYWORDS
Aphasia; sentence processing; syntax; neurolinguistics

This article describes an investigation of an account of the sentence comprehension impairment in agrammatic Broca's aphasia—the Intervener Hypothesis. Briefly here and elaborated in a subsequent section, an intervener is a noun phrase (NP) that is placed between two elements of a filler-gap dependency (a type of a syntactic dependency), which can result in processing interference if the NPs in the sentence are structured similarly. Before we detail our hypothesis, we first describe the linguistic background to

CONTACT Natalie Sullivan njsullivan@ucsd.edu

our study, and then describe some investigations of sentence comprehension in aphasia that form the theoretical background to our work.

Linguistic background

Research has demonstrated that some individuals with agrammatic Broca's aphasia have difficulty understanding sentences containing filler-gap dependencies; that is, sentences where one element in a structure co-refers with another element. Investigations of this difficulty have included a variety of sentences types including, for example, object-extracted relative clauses, *Wh*-questions and passives (e.g., Caramazza & Zurif, 1976; Drai & Grodzinsky, 2006; Grodzinsky, 1990; and many others). One type of filler-gap dependency that has not been the focus of prior investigations involves sentences containing non-alternating unaccusative verbs. Unaccusatives are one-argument (intransitive) verbs; consider:

(1) The boy disappeared <~~the boy~~>.
(2) The boy slept.

According to the Unaccusativity Hypothesis, in (1)—the unaccusative case—the single argument NP (*the boy*) has been base-generated in object position after the verb and then displaced (i.e., "moved") to the subject position occurring before the verb (Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984). In linguistic terms, the NP that is displaced (*the boy*) is the "antecedent" and is copied at the underlying position and then deleted from the surface representation (Chomsky, 1981, 1995). In psycholinguistic terms, the displaced NP is the "filler" and the position from where it was displaced is the "gap", forming a filler-gap dependency between the two positions. Unaccusatives can be compared to intransitive unergative verbs. In the unergative case (2), the single argument is base-generated in subject position and thus no displacement is involved.

Unaccusatives and unergatives are also distinguished by the thematic roles they assign to their single argument. In the unergative case (2), the single argument (*the boy*) performs the action of "sneezing" and is thus assigned an Agent role. In the unaccusative example (1), the single argument is not responsible for the action but is in fact the recipient of the action, hence assigned the role of Theme. In English, there are two types of unaccusative verbs, alternating and non-alternating. Alternating unaccusative verbs can be used both transitively and intransitively. For example, the verb *broke* can be used transitively as in (3) and intransitively as in (4).

(3) The boy broke the bowl.
(4) The bowl broke <~~the bowl~~>.

In (3) the verb *broke* occurs in a transitive context with two arguments, a subject NP (*the boy*) that is assigned the thematic role of Agent and an object NP (*the bowl*) that is assigned the thematic role of Theme. In (4) the verb *broke* occurs in an intransitive context and thus requires only one argument, which, again, is base-generated in object position and is displaced to surface subject position. The single argument (*the bowl*) is assigned the thematic role of Theme.

Non-alternating unaccusative verbs do not allow for this alternation in transitivity. For example, the verb *disappear* can only be used intransitively as shown in (5) and (6) below (*note the * represents an ungrammatical construction*).

(5) *The boy disappeared the bowl.
(6) The boy disappeared.

In (5) the verb *disappear* occurs in a transitive context with two arguments, but the verb *disappear* is a non-alternating unaccusative verb. Non-alternating unaccusative verbs only take a single argument and thus (5) is ungrammatical. In (6) the verb *disappear* occurs in an intransitive context with only a single argument and thus results in a grammatical sentence.

The Unaccusativity Hypothesis—that unaccusatives have base-generated objects that move to subject position—has its detractors; there has been considerable effort suggesting that the distinction between unaccusatives and unergatives is best described in semantic and not syntactic terms (see Dowty, 1991; Rappaport Hovav & Levin, 2001; Van Valin, 1990). Even so, there is considerable processing evidence that sentences containing unaccusatives show reactivation of the displaced NP at the post-verb direct object position but unergatives do not. For example, Friedmann, Taranto, Shapiro, and Swinney (2008) investigated the real-time processing of sentences containing unaccusative and unergative verbs. They found reactivation of the displaced single argument of non-alternating unaccusative verbs at a post-verb position, but no reactivation of the single argument of unergative verbs. If unaccusative verbs do not involve a filler-gap dependency, reactivation of the displaced argument would not have been observed, similar to what was found for the unergative verbs (see also Koring, Mak, & Reuland, 2012).

Investigations of the sentence comprehension impairment in agrammatic Broca's aphasia

The few studies have examined the comprehension of sentences containing unaccusative verbs in listeners with agrammatic Broca's aphasia (LWBA) have found comprehension to be intact. For example, Lee and Thompson (2004) tested LWBA in an off-line truth-value judgement task with sentences containing alternating unaccusative verbs in intransitive constructions (e.g., The snowman is melting) and revealed 95% accuracy. Another study by McAlister, Bachrach, Waters, Michaud, and Caplan (2009) tested LWBA in a sentence–picture matching task and used alternating unaccusative verbs in transitive (e.g., "The dog is rolling the ball") and intransitive (e.g., "The dog is rolling") constructions. The image of the opposite alternation of the verb served as the foil (e.g. transitive alternation served as foil for the intransitive alternation). They found 86% correct for the intransitive constructions and 99% correct for the transitive constructions. A study by Piñango (2000) tested two LWBA on a sentence–picture matching task using alternating and non-alternating unaccusatives (e.g., The girl fell because of the boy). Both participants exhibited 93% correct comprehension of sentences containing non-alternating unaccusatives and above chance (100% correct and 80% correct) comprehension of sentences containing alternating unaccusatives. Given the pattern of results across these studies, it does not appear that individuals with agrammatic Broca's aphasia have difficulty comprehending sentences containing unaccusative verbs.

The intervener hypothesis

The patterns of comprehension in the studies described above are in contrast to the patterns of comprehension impairments in LWBA with sentences containing other types of filler-gap dependencies. There have been several accounts posited to explain why individuals with agrammatic Broca's aphasia evince these deficits. For example, the *trace deletion hypothesis* claims that LWBA cannot represent traces and are therefore unable to assign thematic roles to displaced NPs (e.g., Drai & Grodzinsky, 2006). The *delayed lexical activation* hypothesis claims that a delay in lexical activation results in de-synchronisation of lexical access and syntactic systems (Ferrill, Love, Walenski, & Shapiro, 2012; Love, Swinney, Walenski, & Zurif, 2008). The *slow syntax hypothesis* claims that syntactic operations are slow, but unimpaired (Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008). Thompson and colleagues also suggest that syntactic operations are unimpaired, but that the *integration of lexical items* is impaired (Choy & Thompson, 2010). Caplan and colleagues suggest that these deficits arise due to a *reduction in processing resources and variability* (Caplan, Waters, DeDe, Michaud, & Reddy, 2007). In our investigation, we examine a relatively new account of the comprehension disorder—*the Intervener Hypothesis*—which proposes that when the displacement of an NP crosses over another argument, comprehension deficits that are a hallmark of agrammatic Broca's aphasia occur (see Friedmann & Gvion, 2012; Friedmann & Shapiro, 2003; Sheppard, Walenski, Love, & Shapiro, 2015). Consider:

(7) The man saw the boy that **the girl** kissed <~~the boy~~> behind the bleachers.

The NP—*the boy*—has been displaced from its underlying direct object argument position to a position occurring earlier in the sentence, leaving behind a copy that is deleted from the representation or a gap (in psycholinguistic terminology). Note that the displaced NP crosses over an intervening argument position occupied by the subject NP *the girl* (boldfaced above). Both the intervener and the filler are fully realised lexical NPs that result from the merging of a Determiner and Noun. The intuition here is that the intervening NP interferes with computing the dependency relation between the displaced NP and its gap, rendering a processing disadvantage of such structures over those that do not contain an intervener. Some adults with a language disorder may be particularly vulnerable to interveners during sentence processing, perhaps because they are susceptible to interference among similarly structured NPs. This hypothesis, grounded in the linguistic (e.g., Rizzi, 2004) and psycholinguistic literatures (Gordon, Hendrick, & Johnson, 2004; Gordon, Hendrick, Johnson, & Lee, 2006), has also been suggested in previous investigations of the comprehension deficits in agrammatic Broca's aphasia (Friedmann, 2008; Friedmann & Gvion, 2012; Friedmann & Shapiro, 2003; Grillo, 2005, 2009).

Recent findings support the Intervener account. Sheppard et al. (2015), in an eye tracking-while-listening study, presented the following *Wh*-questions to LWBA—the same participants tested in the present study—while they viewed a three-figure picture (e.g., a mailman pushing a fireman pushing another mailman; see Figure 1):

Two mailmen and a fireman got into a fight yesterday afternoon.

Figure 1. Example of three-figure image used in Sheppard et al's. (2015) eye tracking-while-listening study.

(8) Who pushed the fireman yesterday afternoon?
(9) Who did the fireman push ≤~~who~~≥ yesterday afternoon?
(10) Which mailman pushed the fireman yesterday afternoon?
(11) Which mailman did **the fireman** push <~~which mailman~~> yesterday afternoon?

Sentence (8) is a subject-extracted *Who*-question while (9) is object-extracted. Likewise for the *Which*-questions, (10) is subject-extracted and (11), object-extracted. Results revealed chance accuracy and significantly more gazes to the incorrect referent compared to the correct referent for object-extracted *Which*-questions only (sentence (11)). More gazes to the correct referent and above-chance final comprehension was observed for each of the other three question types. Crucially, only the object-extracted *Which*-questions contained a fully realised NP (*the fireman*, bolded in 11 above) that intervenes between the displaced NP (*Which mailman*) and its gap. These patterns suggest, again, a "similarity interference" account of sentence processing deficits in agrammatic Broca's aphasia; when one NP is displaced over another and both are structured similarly, the participant with aphasia has considerable difficulty determining "who did what to whom."[1]

The current study

Our experiment further investigates the intervener account in individuals with agrammatic Broca's aphasia using a sentence–picture matching task. To this end, we embedded unaccusative verbs into two different sentence structures; consider:

(12) The girl observed that the boy disappeared <~~the boy~~> into the trees.

(13) The girl that observed **the boy** disappeared <~~the girl~~> into the trees.

[1]Though there is also an intervening NP (*the fireman*) in the object-extracted *Who*-question (3), the displaced constituent is simply a Wh-word (*who*) and thus is structurally dissimilar to the intervening NP. Hence, no interference occurs.

Sentence (12) contains a complement phrase (CP; *the boy disappeared into the trees*), headed by the complementiser *that*. The embedded CP contains an unaccusative verb (*disappeared*), and thus its single argument (*the boy*) is base-generated in direct object position and is displaced to the surface subject position of the embedded clause. Sentence (13) contains a subject-extracted relative (SR) clause, which intervenes between the displaced argument (*the girl*) of the unaccusative verb and its gap; that is, the NP *the boy* intervenes between the two elements of the filler-gap dependency chain.

The predictions that emerge from the Intervener Hypothesis are twofold. First, from the literature we predicted that, generally, individuals with agrammatic Broca's aphasia should not have difficulty comprehending sentences that contain unaccusative verbs even though they contain a filler-gap dependency. Specifically, they should exhibit above-chance comprehension of the CP constructions as in (12) because there is not an NP that intervenes between the two elements of the syntactic chain. Second and specific to the Intervener Hypothesis, we predicted that the presence of an intervening NP as in (13) should result in a comprehension deficit for LWBA who have a sentence comprehension deficit. We also included a group of age-matched control (AMC) participants to use as a comparison to our participants with aphasia, and to examine if interveners also affect final sentence comprehension in these neurologically healthy participants.

Method

Participants

Age-matched control participants

Eleven (eight females and three males) AMC participants were included in this study (mean age at time of testing: 60 years; range: 42–74 years; mean education in years: 16 years; range 12–18 years). All of the AMC participants were native English speakers with normal or corrected-to-normal visual and auditory acuity, and no reported history of active or significant alcohol and/or drug abuse, active psychiatric illness, intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's).

Participants with agrammatic Broca's aphasia

Seven participants with agrammatic Broca's aphasia participated in this study (mean age at time of testing: 58 years; range: 39–64 years). Participants were included if they demonstrated auditory comprehension deficits, which we defined as at- or below-chance performance on comprehension of sentences with non-canonical word order (object relatives and passives) and above-chance comprehension on canonical sentences (actives and subject relatives) as assessed by the Subject-relative, Object-relative, Active, and Passive Test of Auditory Sentence Comprehension (SOAP; Love & Oster, 2002).[2] All participants with agrammatic Broca's aphasia experienced a single, unilateral left-hemisphere stroke, were native English speakers with

[2]Example stimuli from the SOAP: *Active*: The girl chases the small boy in the green shirt. *Subject Relative*: The boy that chases the girl is wearing a green shirt. *Passive*: The boy is chased by the girl in the green shirt. *Object Relative*: The boy that the girl chases is wearing a green shirt.

Table 1. Demographic information for individuals with agrammatic Broca's aphasia.

Participant	Gender	Years post-stroke	Lesion location*	Age at testing	Education in years	BDAE† severity level	SOAP‡ canonical (%)	SOAP§ non-canonical (%)
LHD009	M	13	LH lesion involving inferior frontal gyrus (BA44, 45)	53	17	3	75	55
LHD101	M	7	LH lesion involving posterior inferior frontal gyrus (BA44) with posterior extension	64	20	2	95	35
LHD130	M	5	L IPL with posterior extension sparing STG	61	16	4	95	65
LHD132	M	9	LH lesion involving inferior frontal regions with extension to the anterior two thirds of STG & MTG	50	16	4	85	55
LHD140	F	13	L MCA infarct secondary to occlusion of L proximal CA	39	16	2	80	30
LHD142	M	3	L MCA infarct	75	8	4	100	65
LHD159	F	3	L MCA infarct	61	14	3	100	70
		M = 8 SD = 4		*M* = 58 *SD* = 11	*M* = 15 *SD* = 4	*M* = 3 *SD* = 1	*M* = 90% *SD* = 10	*M* = 54% *SD* = 15

*L = left; LH = left hemisphere; BA = Brodmann area; IPL = inferior parietal lobule; STG = superior temporal gyrus; MTG = middle temporal gyrus; MCA = middle cerebral artery; CA = cerebral artery.

†BDAE = Boston Diagnostic Aphasia Examination (0 = no usable speech or auditory comprehension, 5 = minimal discernable speech handicap).

‡SOAP Canonical = Average percent correct of active and subject relative items on Subject-relative, Object-relative, Active, and Passive Test of Auditory Sentence Comprehension (SOAP) Test of Auditory Sentence Comprehension.

§SOAP Non-Canonical = Average percent correct of passive and object relative items on SOAP Test of Auditory Sentence Comprehension.

normal or corrected-to-normal visual and auditory acuity, and were right-handed before their stroke. The clinical diagnosis of agrammatic Broca's aphasia was made based on the administration of standardised language testing to determine the extent and severity of each participant's language impairment; specifically, in the areas of fluency and auditory comprehension ability. Testing included the Boston Diagnostic Aphasia Examination—Third Edition (Goodglass, Kaplan, & Barresi, 2000), Western Aphasia Battery-Revised (Kertesz, 2006), and SOAP (Love & Oster, 2002). All participants were neurologically and physically stable (i.e., at least 6 months post onset), with no history of active or significant alcohol and/or drug abuse, active psychiatric illness, intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). Demographic information for these participants is presented in Table 1.

All of the participants were tested at the Language and Neuroscience Group Laboratory at San Diego State University and were paid $15 per session.

Materials and design

Ten non-alternating unaccusative verbs were selected based on their behaviour with respect to three linguistic diagnostics: occurrence in *there*-constructions,

ungrammaticality with a direct object, and inability to undergo passivisation (see also Friedmann et al., 2008):

(14) There disappeared three students after class.
(15) *The teacher disappeared three students after class.
(16) *Three students were disappeared after class (by the teacher).

The unaccusative verbs were then used to create our experimental sentence items where full NPs (i.e., DET N) were used as the subject and object, and always referred to animate entities. Each set contained an introductory sentence followed by either a sentence containing an embedded complement or a SR clause, as in 17 and 18 below (see the Appendix for full set of materials used):

Introductory discourse sentence: A boy and a girl were playing in the park.

(17) The girl observed that the boy disappeared into the trees. [CP]
(18) The girl that observed the boy disappeared into the trees. [SR]

Ten sentences of each type were constructed, yielding 20 experimental sentences. Colour line drawings were created to depict all 20 experimental sentences. The reversible coloured line drawings for the CP and the SR clause constructions from each experimental set were combined so that two pictures were presented for each discourse/experimental item (see Figure 2 as an example). The 20 stimuli were randomised with the constraint that the same NP/Verb of the CP or SR constructions did not repeat within 5 items of another. Testing was completed in one session.

Procedure

The participants were presented with a discourse-sentence set as described above along with a visual stimulus (see Figure 2), one depicting the correct interpretation of the sentence, and the other a foil, reversing the two referents. The order of the pictures varied so that the position could not be used as a cue. The participants were instructed to listen carefully to each sentence and to point to the picture that best matched the sentence that they just heard. All sentences were read aloud to each participant. The participants were first familiarised with the task with practice items prior to the presentation of the experimental stimuli. Once the participant correctly responded to both practice items, testing began.

At the beginning of each item, the two referents in each picture were identified by the experimenter. Then the participant listened to the introductory sentence followed by the experimental sentence. Each experimental sentence was read twice and could be repeated a third time upon the participant's request. All responses were marked incorrect or correct by the experimenter on a score sheet.

Analysis

Accuracy data were subjected to unequal variance *t*-tests to determine if comprehension of each sentence type differed from chance (50%) for each group. For each group, a

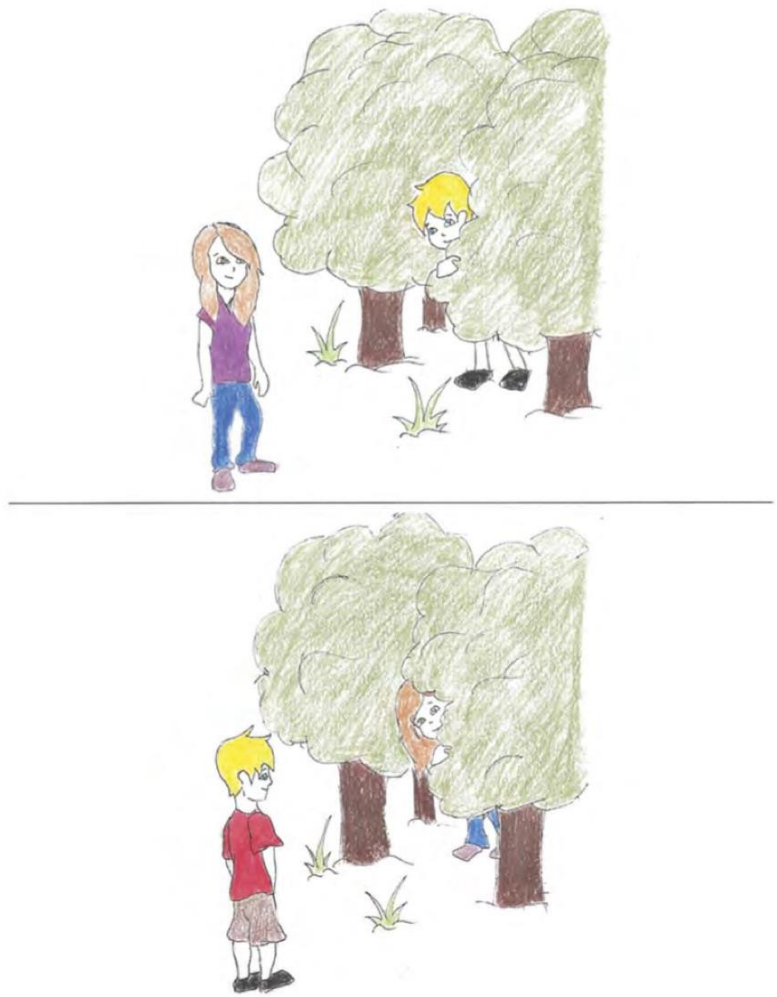


Figure 2. Example used in sentence–picture matching task for the verb "disappeared".
Discourse: A boy and a girl were playing in the park. COMPLEMENT PHRASE: The girl observed that the boy disappeared into the trees. SUBJECT RELATIVE: The girl that observed the boy disappeared into the trees.

paired *t*-test was performed to determine if there was a statistical difference in comprehension accuracy between the two sentence types. Probability values are presented as two-tailed.

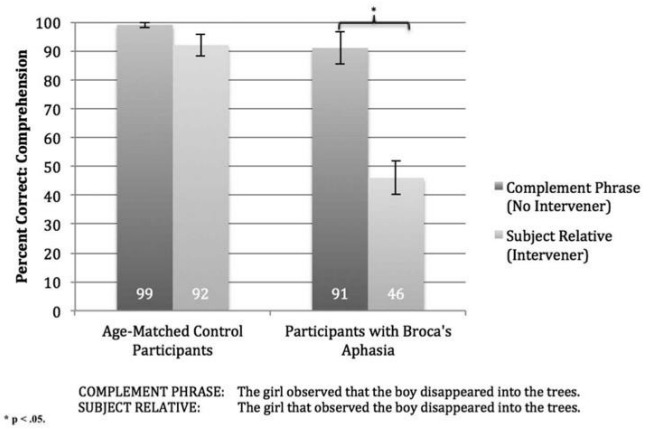


Figure 3. Percentage correct for comprehension of each sentence type for age-matched control participants (n = 11) and participants with agrammatic Broca's aphasia (n = 7).

Results

Comprehension accuracy data for both subject groups are shown in Figure 3.

For the AMC participants, comprehension of the *CP sentences* (M = 99%; SD = 3%, t(10) = 54, p = < .0001) was above-chance. Comprehension of the *SR clause sentences* (M = 92%; SD = 13%, t(10) = 11.09, p = < .0001) was also above-chance. For these control participants, no significant difference was found between the two sentence types, t(10) = 1.9, p = 0.09; though we note a trend in our statistical analysis, both sentences were clearly comprehended above-chance suggesting that the trend is not meaningful.

For our participants with agrammatic Broca's aphasia, mean performance on the *CP sentences* was excellent (91%; SD = 15%, t(6) = 7.49, p = .0003) and was above-chance. Comprehension of the *SR sentences* (46%; SD = 15%, t(6) = −0.75, p = .48) was not different from chance. Furthermore, for these participants with agrammatic Broca's aphasia, a significant difference was observed between the two sentence types, t(6) = 7.47, p = .0003, with performance significantly worse of the subject-extracted sentences, unlike what was observed for our control participants.

Discussion

The purpose of our study was to investigate the sentence comprehension impairment in agrammatic Broca's aphasia through the lens of the Intervener Hypothesis. We presented non-alternating unaccusative verbs in two different sentence structures—sentences with a CP and SRs. Based on the Intervener Hypothesis, we predicted that the SR condition would result in poorer comprehension than the CP condition for the participants with agrammatic Broca's aphasia. The results from the CP sentences clearly show that our participants with agrammatic Broca's aphasia do quite well (91% correct), similar to the AMC participants. Yet unlike the AMC group who performed at 92% accuracy on the SR sentences, our

participants with agrammatic Broca's aphasia demonstrated poorer, and at-chance, performance (46% accuracy). This pattern of results supports our predictions: Individuals with agrammatic Broca's aphasia only have difficulty understanding sentences containing unaccusative verbs when they are inserted into sentence constructions that contain an intervener, in the present case, inserted into subject relative constructions.

The significantly poorer performance found with the SRs cannot be attributed to the construction itself. We point out here that LWBA have been shown in the literature and here in our screening tasks to exhibit above-chance performance on SR clauses on the SOAP (see Table 1). Furthermore, there is a reasonably long history suggesting that subject-extracted, but not object-extracted sentences, are easier to understand for participants with agrammatic Broca's aphasia compared to other sentences containing filler-gap dependencies (e.g., Caramazza & Zurif, 1976; Grodzinsky, 1990; Love & Oster, 2002; among many others). Thus we propose that the Intervener Hypothesis explains this pattern and argue that when an unaccusative verb is embedded in a subject relative construction, the conditions specified by the Intervener Hypothesis are met and result in the predicted comprehension deficit.

To explain further, we repeat the relevant structure below:

(19) The girl that observed **the boy** disappeared <~~the girl~~> into the trees.

Recall that the NP (*the girl*) occupies the underlying object position for the unaccusative verb *disappeared* and is displaced to the beginning of the sentence, while crossing over the direct object NP (*the boy*) of the intervening relative clause. In line with the predictions of the Intervener Hypothesis, we suggest that the presence of the intervening NP disrupts processing the dependency chain formed when the object of the unaccusative verb was displaced to surface subject position. The result of this disruption is that the participant with agrammatic Broca's aphasia becomes confused as to "who did what to whom" due to similarity interference and thus performance suffers. As discussed in our Introduction, an intervener is a referential NP that interrupts the dependency chain composed of the displaced NP filler and its gap; if the two NPs are structured similarly (e.g., DET N), similarity interference occurs, decreasing comprehension performance. Though the details of the interference effect await further study, there is considerable evidence in the psycholinguistic literature that the effect compromises the memory system that subserves language comprehension (e.g., Gordon et al., 2006; Lewis, Vasishth, & Van Dyke, 2006; Van Dyke & McElree, 2006).

Importantly, the Intervener Hypothesis can be extended to other sentence constructions, increasing its theoretical range. As discussed in our "Introduction" section, *Wh*-questions are another test case; only object-extracted *Which*-questions yielded performance indicative of an intervener effect (see Sheppard et al., 2015). Similarly, Friedmann and Shapiro (2003) found that comprehension of topicalisation structures in Hebrew (O-S-V and O-V-S word order), those that involve displacement of an argument to the front of the sentence while also crossing over an intervening NP, are impaired in agrammatic Broca's aphasia relative to S-V-O word order sentences.

Furthermore, the following constructions ((b) versions only) also meet the structural description for interveners:

(20a) Show me the mouse that scratched the rabbit.

(20b) Show me the mouse that **the rabbit** scratched <~~the mouse~~>.
(21a) The dog saw that the cat licked himself.
(21b) The dog saw that **the cat** licked him.

Only the object-extracted relative clause (20b), and not the subject-extracted version (20a), contains an intervening NP; as discussed in the "Introduction" section, only object-extracted relatives yield poor comprehension performance in agrammatic Broca's aphasia (see also Friedmann & Shapiro, 2003; Garraffa & Grillo, 2008; see Friedmann & Costa, 2010; for evidence from acquisition). The sentences in (21) contain overt anaphors; personal pronouns (21b) are more difficult to understand for participants with agrammatic Broca's aphasia relative to intact comprehension for sentences containing reflexive pronouns (21a) (Grodzinsky, Wexler, Chien, Marakovitz, & Solomon, 1993). Note that sentences with personal pronouns contain an intervening NP (boldfaced above) between the anaphor and its antecedent. We are currently conducting studies to examine the above constructions and others to determine the further generalisability of the Intervener Hypothesis. If this work uncovers a similar disruption, then the Intervener Hypothesis will extend to the processing of syntactic dependencies that are not only characterised by filler-gaps.

To conclude, we conducted an off-line experiment to investigate the comprehension of sentences containing unaccusative verbs in participants with agrammatic Broca's aphasia who have a comprehension deficit. Our study was designed to evaluate the Intervener Hypothesis. We found above-chance comprehension of sentences containing an embedded clause with non-alternating unaccusative verbs, but comprehension suffered in subject-relative constructions that contained an intervener. We suggest, then, that one source of the comprehension deficit in agrammatic Broca's aphasia is the presence of an intervener that is located between the two elements of a syntactic dependency chain, leading to similarity-based interference.

Acknowledgement

We thank our research assistants, our participants and their families for their time.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The work reported in this paper was supported by NIH Grants (NIDCD) R01DC009272, R01DC03681 and R01DC000494 and T32DC007361.

References

Burkhardt, P., Avrutin, S., Piñango, M., & Ruigendijk, E. (2008). Slower-than-normal syntactic processing in agrammatic Broca's aphasia: Evidence from Dutch. *Journal of Neurolinguistics*, *21*, 120–137. doi:10.1016/j.jneuroling.2006.10.004

Burzio, L. (1986). *Italian syntax: A government-binding approach*. Dordrecht: Reidel.

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*, 103–150. doi:10.1016/j.bandl.2006.06.225

Caramazza, A., & Zurif, E. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language*, *3*, 572–582. doi:10.1016/0093-934X(76)90048-1

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

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

Choy, J., & Thompson, C. K. (2010). Binding in agrammatic aphasia: Processing to comprehension. *Aphasiology*, *24*, 551–579. doi:10.1080/02687030802634025

Dowty, D. (1991). Thematic proto-roles and argument selection. *Language*, *67*(3), 547–619. doi:10.2307/415037

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. doi:10.1016/j.bandl.2004.10.016

Ferrill, M., Love, T., Walenski, M., & Shapiro, L. P. (2012). The time-course of lexical activation during sentence comprehension in aphasia. *American Journal of Speech-Language Pathology*, *21*, 179–189. doi:10.1044/1058-0360(2012/11-0109)

Friedmann, N. (2008). Agrammatic aphasia and the psychological reality of the syntactic tree. In G. Hatav (Ed.), *Theoretical Hebrew linguistics* (pp. 339–368). Jerusalem, Israel: Magnes.

Friedmann, N., & Costa, J. (2010). The child heard a coordinated sentence and wondered: On children's difficulty in understanding coordination and relative clauses with crossing dependencies. *Lingua*, *120*, 1502–1515. doi:10.1016/j.lingua.2009.10.006

Friedmann, N., & Gvion, A. (2012). Intervention and Locality in agrammatic aphasia. In V. Bianchi & C. Chesi (Eds.), *Enjoy Linguistics! Papers offered to Luigi Rizzi on the occasion of his 60th birthday*. Siena, Italy: CISCL Press.

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. doi:10.1044/1092-4388(2003/023)

Friedmann, N., Taranto, G., Shapiro, L., & Swinney, D. (2008). The leaf fell (the leaf): The online processing of unaccusatives. *Linguistic Inquiry*, *39*, 355–377. doi:10.1162/ling.2008.39.3.355

Garraffa, M., & Grillo, N. (2008). Canonicity effects as a grammatical phenomenon. *Journal of Neurolinguistics*, *21*, 177–197. doi:10.1016/j.jneuroling.2007.09.001

Goodglass, H., Kaplan, E., & Barresi, B. (2000). *Boston diagnostic aphasia examination* (3rd ed.). Philadelphia: 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. doi:10.1016/j.jml.2004.02.003

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.

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. doi:10.1016/j.lingua.2008.04.003

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

Grodzinsky, Y., Wexler, K., Chien, Y.-C., Marakovitz, S., & Solomon, J. (1993). The breakdown of binding relations. *Brain and Language*, *45*, 396–422. doi:10.1006/brln.1993.1052

Hovav, M. R., & Levin, B. (2001). An event structure account of English resultatives. *Language*, *77*, 766–797. Retrieved from http://www.jstor.org/stable/3086847

Kertesz, A. (2006). *Western aphasia battery*. San Antonio: PsychCorp.

Koring, L., Mak, P., & Reuland, E. (2012). The time course of argument re-activation revealed: Using the visual world paradigm. *Cognition*, *123*, 361–379. doi:10.1016/j.cognition.2012.02.011

Lee, M., & Thompson, C. (2004). Agrammatic aphasic production and comprehension of unaccusative verbs in sentence contexts. *Journal of Neurolinguistics*, *17*, 315–330. doi:10.1016/S0911-6044(03)00062-9

Lewis, R. L., Vasishth, S., & Van Dyke, J. A. (2006). Computational principles of working memory in sentence comprehension. *Trends in Cognitive Science*, *10*, 447–454. doi:10.1016/j.tics.2006.08.007

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. doi:10.1023/A:1021208903394

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. doi:10.1016/j.bandl.2007.11.004

McAlister, T., Bachrach, A., Waters, G., Michaud, J., & Caplan, D. (2009). Production and comprehension of unaccusatives in aphasia. *Aphasiology*, *23*, 989–1004. doi:10.1080/02687030802669518

Perlmutter, D. M. (1978). *Impersonal passives and the Unaccusative Hypothesis*. Proceedings of the 4th Annual Meeting of the Berkeley Linguistics Society, (pp. 157–189). Berkeley: University of California, Berkeley Linguistics Society.

Perlmutter, D. M., & Postal, P. M. (1984). The 1-Advancement Exclusiveness Law. In D. M. Perlmutter & C. Rosen (Eds.), *Studies in Relational Grammar 2* (pp. 81–126). Chicago: University of Chicago Press.

Piñango, M. M. (2000). Canonicity in Broca's sentence comprehension: The case of psychological verbs. In Y. Grodzinsky, L. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing* (pp. 327–350). San Diego/London: Academic Press.

Rizzi, L. (2004). Locality and left periphery. In A. Belletti (Ed.), *Structures and Beyond: The cartography of syntactic structures* (Vol. *3*). New York, NY: Oxford University Press.

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. doi:10.1044/2015_JSLHR-L-14-0099

Van Dyke, J. A., & McElree, B. (2006). Retrieval interference in sentence comprehension. *Journal of Memory and Language*, *55*, 157–166. doi:10.1016/j.jml.2006.03.007

van Valin, R. D. (1990). Semantic parameters of split intransitivity. *Language*, *66*, 221–260. doi:10.2307/414886

Appendix: Stimuli used in experiment

Sentence	Type
A doctor and a nurse were attending a party.	Discourse
The doctor detected that the nurse arrived through the backdoor.	CP
The doctor that detected the nurse arrived through the backdoor.	SR
A farmer and a cowgirl were competing in a race.	Discourse
The farmer recognised that the cowgirl vanished around the corner.	CP
The farmer that recognised the cowgirl vanished around the corner.	SR
A mother and daughter were on a camping trip.	Discourse
The daughter detected that the mother arose in the middle of the night.	CP
The daughter that detected the mother arose in the middle of the night.	SR
A father and son were fishing at a lake.	Discourse
The son noticed that the father appeared from behind the bush.	CP
The son that noticed the father appeared from behind the bush.	SR
A man and a woman were vacationing at a hotel.	Discourse
The woman noticed that the man emerged from the pool.	CP
The woman that noticed the man emerged from the pool.	SR
A boy and a girl were playing in the park.	Discourse
The girl observed that the boy disappeared into the trees.	CP
The girl that observed the boy disappeared into the trees.	SR
A rollerblader and a skateboarder were practising for a competition.	Discourse
The rollerblader recognised that the skateboarder soared over the ramp.	CP
The rollerblader that recognised the skateboarder soared over the ramp.	SR
A mailman and a tourist were walking down the street.	Discourse
The tourist saw that the mailman fell in the crosswalk.	CP
The tourist that saw the mailman fell in the crosswalk.	SR
A teacher and a student were riding the bus.	Discourse
The teacher saw that the student remained on the bus.	CP
The teacher that saw the student remained on the bus.	SR
A firefighter and a policeman were attending a conference.	Discourse
The firefighter observed that the policeman departed through the lobby door.	CP
The firefighter that observed the policeman departed through the lobby door.	SR

Notes: CP = Complement phrase, SR = Subject relative.

Chapter 8, in full, is a reprint of material as it appears in Sullivan, N., Walenski, M., Love, T., Shapiro, L.P. (2017). The comprehension of unaccusative verbs in aphasia: a test of the intervener hypothesis, *Aphasiology*, *31*(1), 67-81. The dissertation author was the primary investigator and author of this paper.

CHAPTER 9:

The Intervener Effect During the Online Processing of Sentences that Contain Unaccusative Verbs in Aphasia

The Intervener Effect During the Online Processing of Sentences that Contain Unaccusative Verbs in Aphasia

Natalie Sullivan[1], Lewis P. Shapiro[1,2], and Tracy Love[1,2]

1 SDSU/UCSD Joint Doctoral Program in Language and Communicative Disorders
2 School of Speech, Language, and Hearing Sciences, San Diego State University

Abstract

Individuals with agrammatic Broca's aphasia (IWBA) typically exhibit difficulty comprehending sentences that do not conform to canonical (S-V-O for English) word order and contain a syntactic dependency. The Intervener Hypothesis (IH) offers a single explanation for the mechanism underlying these aberrant sentence comprehension patterns. The IH posits that the presence of an intervening noun phrase between two syntactically linked sentential elements causes similarity-based interference (SBI), resulting in comprehension difficulties. Support for the IH has been demonstrated with different sentence structures (e.g., Wh-questions, overt anaphora) but has only been investigated in terms of structural similarity. However, it is reasonable to predict that manipulating other factors, such as semantic properties, may allow for a reduction of similarity-based interference.

The purpose of this paper is two-fold. First, using eye-tracking while listening, we seek to determine the impact of a structurally similar intervener on real-time auditory sentence processing in sentences containing unaccusative verbs (compared to those containing unergatives). The second goal is to determine if manipulating the animacy of an intervener can reduce SBI. Results indicate that while aurally processing sentences that contain unaccusative verbs and an intervener of similar animacy, IWBA show a SBI effect, unlike age-matched control participants. This effect is reduced when the intervener differs in animacy. These results provide support for the IH, and suggest that semantics impacts SBI during sentence processing for IWBA. Reactivation was also found in sentences that contained unergatives, and we suggest reactivation in this case is motivated by a different process, thematic role assignment.

Introduction

Individuals with agrammatic Broca's aphasia (IWBA) are classically characterized as exhibiting difficulty with expressive language. However, in addition to difficulty with language expression, IWBA often exhibit sentence comprehension deficits. While IWBA do not generally demonstrate difficulty comprehending sentences that are in canonical word order (Subject-Verb-Object for English) such as the subject-extracted relative construction (1) below. Complications arise for those sentences that are non-canonically formed, such as the object-extracted relative construction (2).

(1) *The dog* that chased the cat last night was angry.
AGENT VERB THEME

(2) The cat that *the dog* chased <~~the cat~~> last night was angry.
THEME AGENT VERB

According to linguistic theory, non-canonically ordered sentences as in (2) are derived from their canonical counterparts (Chomsky, 1981, 1995). To illustrate this derivation, consider how the verb *chase* assigns its thematic roles. In both (1) and (2) the verb *chase* requires two arguments, one to perform the action, assigned the thematic role of Agent, and one to receive the action, assigned the thematic role of Theme. In (1) the Agent role is assigned to the argument occupying the grammatical subject position, the *dog*. The Theme role is assigned to the argument occupying the grammatical object position, the cat. In (2), while the thematic roles of Agent and Theme are assigned to the same arguments, *the dog* and the cat respectively, the arguments occupy different grammatical (surface) positions. The cat has been displaced from an underlying post verb position, leaving behind a phonologically null syntactic marker (a "trace" in linguistic terminology or "gap" in psycholinguistic terminology). This displacement results in a syntactic

dependency between the displaced element, the cat (a.k.a. “filler”), and its post verb position (a.k.a. “gap”). The thematic role of Theme is first assigned to the gap and the argument, the cat, receives this thematic role via the ‘filler-gap’ syntactic dependency. Thus, in order to successfully comprehend non-canonical sentences such as (2), the listener must immediately realize the relationship between the filler and its gap.

Several accounts have attempted to explain the pattern of sentence comprehension deficits observed in IWBA and are briefly reviewed here. The Trace Deletion Hypothesis (Drai & Grodzinsky, 2006; Grodzinsky, 2006) argues that difficulties in sentence comprehension arise due to an inability to represent traces, which results in incorrect thematic role assignment. The Delayed Lexical Activation Hypothesis (Love, Swinney, Walenski, & Zurif, 2008; Ferrill, Love, Walenski, & Shapiro, 2012) posits that delayed lexical activation results in the desynchronization of lexical activation and syntactic processes which negatively impacts comprehension. Thompson and colleagues (Choy & Thompson, 2010; Thomson & Choy, 2009) offer that difficulty in lexical integration underlie sentence comprehension deficits. It has also been argued that slowed syntactic processing is responsible for the observed comprehension patterns (Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008). Other accounts suggest that diminished processing resources in the domain of working memory are responsible for sentence comprehension difficulties (Caplan, Waters, Dede, Michaud, & Reddy, 2007; Haarman, Just, & Carpenter, 1997).

The focus of this paper is a more recent account, the Intervener Hypothesis. The Intervener Hypothesis (IH) posits that sentence comprehension difficulties are due to

similarity-based interference induced when a noun phrase (NP) intervenes between two elements of a syntactic dependency. Consider (2) from above again, renumbered as (3).

(3) The cat that *the dog* chased <~~the cat~~> last night was angry.

Recall that (3) contains a syntactic dependency; a link between the 'filler', *the cat*, and its post verb 'gap' must be made for successful comprehension of the sentence to occur. In order for this link between the gap and the displaced NP, the cat, to be established, the listener must cross over an intervening noun phrase (*the dog*), which has a similar structure.

(3) The cat that *the dog* chased <~~the cat~~> last night was angry.

Both noun phrases (NPs)- the filler (the cat) and the intervener (*the dog*) - are structured as DET N. The IH argues that in (3), the intervener causes similarity-based interference because it easily "fits" as a possible element in the syntactic dependency chain. Evidence supporting the Intervener Hypothesis has been demonstrated with *Wh*-Questions (Sheppard, Walenski, Love, & Shapiro, 2105), and more recently anaphor resolution (Engel, Shapiro, & Love, submitted). Support for the IH has also been illustrated with a syntactic dependency inherent to a specific type of intransitive verb - one that requires a single argument (Sullivan, Walenski, Love, & Shapiro, 2017a).

Both (4) and (5) below contain intransitive verbs. In (4), the single argument of the unergative verb, *jump*, acts as the subject. The single argument initiates the action and is assigned the thematic role of Agent.

(4) The boy jumped.
AGENT **VERB**

According to the Unaccusativity Hypothesis (Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984), in (5), the single argument of the unaccusative verb *disappear*, is base-generated in the object position and is displaced to the grammatical subject position.

(5) The boy disappeared <~~the boy~~>.
THEME **VERB**

The single argument of the unaccusative verb, *disappear*, is receiving the action, and is assigned the thematic role of Theme or Patient.

Psycholinguistic evidence further supports the distinction among intransitive verbs (Friedmann, Taranto, Shapiro, & Swinney, 2008; Sullivan, Walenski, Love & Shapiro, 2017b). Friedmann et al. (2008) investigated the real-time processing of intransitive verbs using a cross-modal priming paradigm with a group of college-aged neurologically unimpaired participants. Cross-modal priming allows for determining the time course of lexical activation and reactivation. Probes related and unrelated to lexical items of interest are visually presented at distinct points of interest during the un-interrupted aural presentation of sentences. The presentation of visual probes requires a binary (yes/no) response. Faster reaction times to the related compared to unrelated probes is indicative of priming, and activation of lexical items of interest. Friedmann et al. probed lexical activation at three time points (indicated by the superscript numerals below) in sentences that contain unaccusative verbs, such as (6) and unergative verbs (7).

(6) <u>The tailor</u>[1] from East Orange, New Jersey, mysteriously disappeared <~~the tailor~~>[2] when it was[3] time to adjust the tuxedos and dresses for the participants in the wedding party.

(7) The surgeon[1] with a brown felt fedora hat and matching coat eagerly smiled[2] when the beautiful[3] actress walked down the corridor to exam room three.

A priming effect was found at the offset of the single argument (probe position 1) for sentences that contained both unaccusative and unergative verbs. However, reactivation for the single argument at a post verb position was only found for the sentences that contain unaccusative verbs (6). These findings support the linguistic notion that the single argument of unaccusative verbs is base-generated in a post verb position and is displaced to the grammatical subject position. Of note, reactivation was not found at offset of the verb (gap position) as has been found with other types of syntactic dependencies see (Love & Swinney, 1996; Love et al., 2008; Shapiro, Oster, Garcia, Massey, & Thompson 1999; Tanenhaus, Boland, Garnsey, & Carlson, 1989; and many others). Reactivation was found 750 ms downstream from the gap. The authors argue that the lack of an overt cue signaling an upcoming gap contributes to this delay in reactivation. It is not until a listener encounters the unaccusative verb and activate its properties that they are aware of the upcoming gap. This delayed time-course for unaccusative verbs motivated the investigation of sentences containing unaccusative verbs during real-time processing for IWBA as the results could help differentiate theories of sentence comprehension deficits, which were described earlier.

Sullivan et al. (2017b) conducted a cross-modal priming study to investigate real-time processing of sentences with unaccusative verbs in participants with agrammatic Broca's aphasia and a group of age-matched neurologically unimpaired participants (AMC). Sentences such as (8) were presented and lexical reactivation was probed at four post verb positions (indicated by superscript numerals).

(8) The queen with the bad temper vanished ^{1} during ^{2} the ^{3} spectacu^{4}lar fireworks show.

Reactivation of the single argument (*the queen*) was found at a post verb position for both IWBA and AMC participants. I note here that there was a slight difference in the time course of lexical reactivation among the groups, with the IWBA evincing reactivation at probe position 2 while the AMC participants did so at probe position 3—a 250 ms difference which spans 1-2 syllables at most. More importantly, these results demonstrate that IWBA are sensitive to the unaccusative property of unaccusative verbs and do not evince a delayed time-course of lexical reactivation compared to neurologically unimpaired adults. As unaccusative verbs contain a syntactic dependency and IWBA are sensitive to the unaccusative property, they provide a test case for the Intervener Hypothesis, the focus of this paper.

Sullivan et al. (2017a) investigated the offline processing, or final comprehension, of sentences containing unaccusative verbs in an effort to evaluate the IH with the same IWBA and AMCs included in Sullivan et al. (2017b). A sentence-picture matching task was used and unaccusative verbs were embedded in two different sentence constructions, complement phrase (CP) constructions (9) and subject-extracted relative (SR) constructions (10).

(9) The girl observed that *the boy* disappeared <~~the boy~~> into the trees.

(10) *The girl* that observed **the boy** disappeared <~~the girl~~> into the trees.

In the CP (9), there is no intervener as the linking of the single argument, *the boy* of the unaccusative verb *disappea*r does not requiring the crossing of another NP of similar structure. However, in the SR (10), linking of the single argument, *the girl* and the gap position does require the crossing of an intervener (*the boy*), an NP of similar structure. Participants were presented with an image that contained two scenes; one scene depicted

the CP version of the sentence and the other scene depicted the SR version of the sentence. Upon hearing an experimental sentence, participants were required to choose the scene that matched the sentence they heard. The AMCs revealed above chance comprehension for both sentence types. The IWBA exhibited above chance comprehension for the CP sentences, however, for the SR constructions, comprehension was at chance level. For IWBA, there was a significant difference between the CP and SR conditions. These results support the IH as comprehension difficulty was only observed for the SR sentences that contained an intervener. Recall that IWBA typically do not have difficulty comprehending SR sentences as they conform to canonical word order. It is only when unaccusative verbs are embedded in SR constructions that difficulty arises. In the current study, we further examine the comprehension of SR sentences that contain unaccusative verbs to determine if an intervener effect is observed during real-time, or online processing.

Current investigation

We utilized an eye-tracking while listening paradigm to investigate our questions of interest with a group of IWBA and a group of age-matched neurologically unimpaired individuals (AMC). Eye-tracking offers an advantageous way to explore online processing as behavior over the entire auditory presentation of a sentence is possible. This differs from other online methodologies, such as cross-modal priming which only allow for understanding what is occurring at specific, pre-determined time point during the auditory presentation of sentences.

Question 1: Does the presence of an intervener cause similarity-based interference during the real-time auditory sentence processing of sentences containing an unaccusative verb and a structurally similar intervener?

To this end, we embedded unaccusative verbs in subject-relative sentences (11) similar to those used in Sullivan et al. (2017a) to determine if reactivation of the displaced NP occurs at a post verb position.

(11) Last night at the Halloween party, the pirate that observed the wizard suddenly emerged <~~the pirate~~> before the costume contest.

As IWBA have difficulty comprehending these sentences, we predict that reactivation of the single argument will not be found as evidenced by no difference between gazes to the displaced NP (the pirate) and the intervener (the wizard) after the verb for the IWBA. We also included an age-matched control group (AMC), as a comparison, and we predict that they will exhibit reactivation of the displaced NP at a post verb position; i.e. that there will be greater gazes to the displaced NP after the verb.

Question 2: Does manipulating the animacy of an intervener impact real-time sentence processing of sentences that contain an unaccusative verb and an intervener?

To date, interveners have only been evaluated in terms of structural similarity; here we offer a semantic manipulation of the intervener. It is reasonable to predict that semantics may reduce the intervener effect for IWBA as prior work has demonstrated better comprehension of semantically irreversible sentences such as (12) than semantically reversible sentences such as (13; Caramazza and Zurif, 1976).

(12) The apple that the boy is eating is red.

(13) The man that the woman is hugging is happy.

In (12) the verb *eat* semantically constrains the sentence, as only *the boy* eating *the apple* is plausible. In (13) it is equally plausible that *the man* or *the woman* would perform or receive the action of hugging, making it semantically reversible. IWBA showed greater accuracy in (12) as compared to (13), suggesting that IWBA take advantage of semantic constraints (when available) to ease comprehension. If performance with sentences containing semantically distinguished NPs reduces the intervener effect for IWBA, we will be able to offer a mechanism – similarity-based interference – for why reversibility matters in aphasia. This finding will also provide a method to reduce or eliminate the comprehension deficit observed for IWBA. In the current study, we manipulate the animacy of the intervener to determine if it mitigates the intervener effect for SR sentences that contain unaccusative verbs. To this end, we embed unaccusative verbs in subject-relatives sentences that contain an inanimate intervener (14).

(14) Last night at the Halloween party, the pirate that observed the pumpkin suddenly emerged <~~the pirate~~> before the costume contest.

In (14) the intervener (*the pumpkin*) and the displaced NP (*the pirate*) are the same structure, however the animacy of the intervener and the filler does not overlap. For the AMCs, we again predict reactivation of the displaced NP, or greater gazes to the displaced NP compared to the intervener at a post verb position. For the IWBA, we predict that similarity-based interference will be reduced when the intervener differs in animacy and will reactivate the displaced NP at post verb position, or greater gazes to the displaced NP compared to the intervener will be found after the verb.

METHOD

Participants

Age-Matched Control Participants (AMC) - Eleven AMC participants were included in this study (mean age at time of testing: 62 years old; range: 57-66 years old). All of the AMC participants were monolingual native English speakers with normal or corrected-to-normal visual and auditory acuity, with no reported history of active or significant alcohol and/or drug abuse, active psychiatric illness or intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's).

Individuals with Agrammatic Broca's Aphasia (IWBA) - Eight individuals diagnosed with agrammatic (Broca's) aphasia met criteria for inclusion in this study (mean age at time of testing: 64 years old; range: 56-77 years old). Demographic information for these participants is presented in Table 9-1. All IWBA experienced a single, unilateral left- hemisphere unilateral left-hemisphere stroke, were native English speakers with normal or corrected-to-normal visual and auditory acuity, and were right-handed before their stroke. The clinical diagnosis of Broca's aphasia was made based on the administration of standardized language testing to determine the extent and severity of each participant's language impairment, specifically, in the areas of fluency and auditory comprehension ability. Testing included the Boston Diagnostic Aphasia Examination—Third Edition (BDAE– 3; Goodglass, Kaplan, & Barresi, 2000), and SOAP (Subject-relative Object-relative Active and Passive) Test of Auditory Sentence Comprehension (Love & Oster, 2002). IWBA were included in this study if they met clinical consensus and demonstrated comprehension deficits, which were defined as

poorer performance on comprehension of non-canonical object-relative sentences compared to canonical subject-relative sentences as assessed by the SOAP. All participants were neurologically and physically stable (i.e., at least 6 months post onset), with no reported history of active or significant alcohol and/or drug abuse, active psychiatric illness or intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). All of the participants were tested at the Language and Neuroscience Group Laboratory at San Diego State University and were paid $15 per session.

Table 9-1. Demographics information for IWBA.

Participant	Gender	Years Post Stroke	Lesion location^	Age at Testing	Education level	BDAE* Severity Level	SOAP SR#	SOAP OR~
LHD009	M	15	LH lesion involving inferior frontal gyrus (BA44, 45)	56	1 year of grad school	3	70%	20%
LHD101	M	9	LH lesion involving posterior inferior frontal gyrus (BA44) with posterior extension	67	Ph.D.	2	80%	60%
LHD130	M	8	L IPL with posterior extension sparing STG	64	4 years of college	4	90%	60%
LHD159	F	6	L MCA infarct	64	college	3	90%	40%
LHD165	F	5	LH lesion	66	High School	3	80%	60%
LHD169	M	4	L MCA infarct with small areas of acute infarction at margins of encephalomalacia	60	High School	1	90%	20%
LHD190	F	4	LH lesion	77	High School	3	90%	40%
LHD191	M	2	L MCA infarct	57	Master's Degree	4.5	100%	60%

^ L = left; LH=left hemisphere; BA = Brodmann area; IPL = inferior parietal lobule; STG = superior temporal gyrus; MCA = middle cerebral artery
* BDAE = Boston Diagnostic Aphasia Examination (0 = no usable speech or auditory comprehension, 5 = minimal discernable speech handicap)
# SOAP SR = Average percent correct on subject relative items from the SOAP Test of Auditory Sentence Comprehension
~ SOAP OR = Average percent correct of object relative items from the SOAP Test of Auditory Sentence Comprehension

Materials and Design

Fifteen non-alternating unaccusative verbs were selected to be embedded in experimental sentences. Similar to Sullivan et al. (2017a), only non-alternating unaccusative verbs were included, as they do not have a transitive alternation. The verbs were selected based on their behavior with respect to linguistic diagnostics (see also Friedmann et al., 2008). For the unaccusatives, occurrence in *there*-constructions (15), ungrammaticality with a direct object (16), and inability to undergo passivization (17).

(15) There disappeared three girls after class.

(16) *The principal disappeared three girls after class.

(17) *Three girls were disappeared after class (by the principal).

We also selected a set of 15 unergative verbs to embed in subject-relatives to serve as control conditions. The unergatives were also selected based on their performance with respect to linguistic diagnostics, ungrammaticality in the *there*-construction (18), ungrammaticality in the resultative construction (19), and inability to occur with a reflexive pronoun (20) unless followed by a resultative (21).

(18) *There jumped a smart little boy.

(19) *The smart little boy jumped silly.

(20) *The smart little boy jumped himself.

(21) The smart little boy jumped himself silly.

All of the verbs selected were used twice resulting in thirty experimental sets. The experimental sets consisted of four SR sentences as seen in Table 9-2 resulting in 120 experimental sentences.

Table 9-2 Example experimental sentences by condition.

	Unaccusative	Unergative
Animate	Last night at the Halloween party, the pirate that observed **the wizard** suddenly emerged <~~the pirate~~> before the costume contest.	Last night at the Halloween party, the pirate that observed the wizard suddenly joked before the costume contest.
Inanimate	Last night at the Halloween party, the pirate that observed **the pumpkin** suddenly emerged <~~the pirate~~> before the costume contest.	Last night at the Halloween party, the pirate that observed the pumpkin suddenly joked before the costume contest.

One hundred and twenty non-experimental sentences that differed in sentence structure were also included as filler items. For each experimental set, line drawings depicting each of the NPs of interest were constructed (see Figures 9-1 and 9-2).

Figure 9-1. Example animate condition trial.

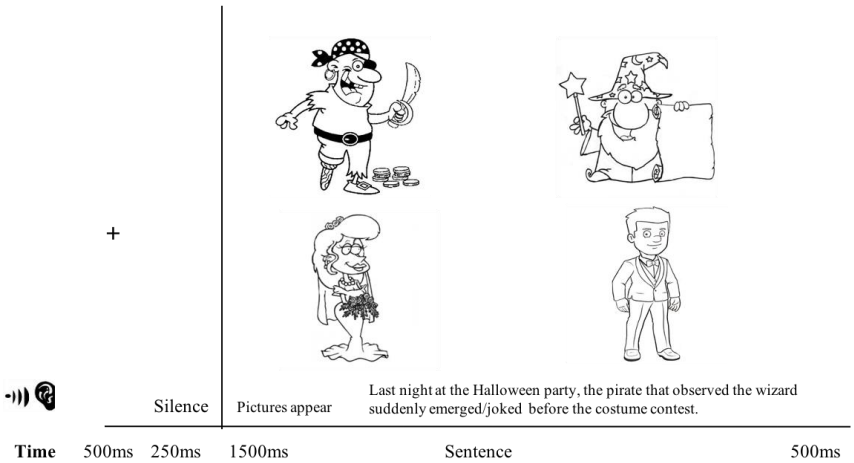
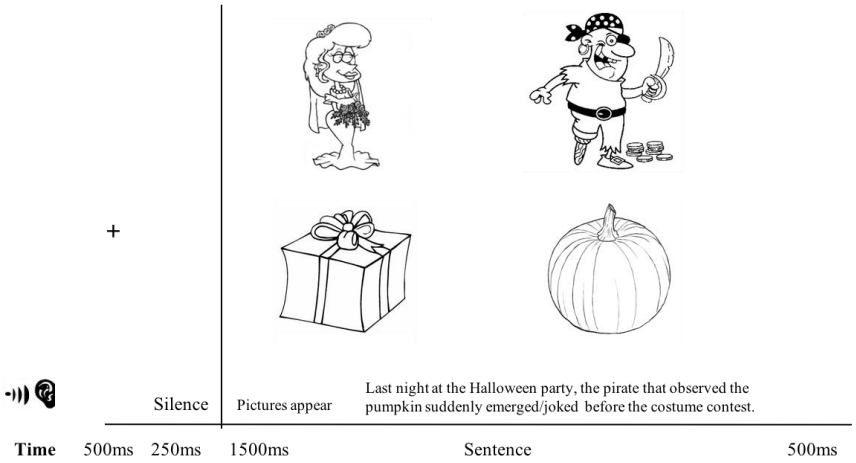


Figure 9-2. Example inanimate condition trial.



Two pre-tests were conducted to ensure the stimuli were appropriate for use. In *pre-test I*, images of the noun phrases were presented to college-age unimpaired participants (n=20) to ensure that they clearly depicted the NP of interest (i.e. that the image of *the pirate* was easily and readily identified as a pirate). In this picture identification task, all pictures included in the study had a minimum of 75% agreement (exact naming and semantically related naming matches). In *pre-test II*, in order to reduce plausibility effects, all of the NPs were pretested with another group of college-age students (n=27) to confirm that they were all equally likely to be at the place mentioned in the initial PP of each sentence ("Last night at the Halloween party", "the pirate" and "the wizard"). Participants were presented with two words (PERSON : PLACE) and asked to rate on a 1-5 likert scale how likely (1-not very likely, 5-extremely likely) it was that the person (e.g. PIRATE) would be at the place (e.g., HALLOWEEN PARTY). All items included in the study received ratings of 4s and 5s regarding the likelihood of being at the place tested (NP1 mean=4.8, NP2 mean = 4.7).

In the current experiment, a switch target design was employed such that the NPs of interest from one experimental set serves as distractor items for another experimental set and vice versa. For example, for the animate condition, the display contained the two animate NPs mentioned in the sentence (e.g. pirate and wizard), and the two animate referents from another experimental sentence (e.g. bride and groom). This design ensures that gazes to NPs were indicative of lexical activation and reactivation, and not due to a preference for a particular image. The experimental sets were counterbalanced across four presentation lists and the location of the images presented were counterbalanced across items. The order of presentation across participants was also balanced with an

average of 5 days between sessions. All sentences were recorded by a native English-speaking female at an average rate of 4.47 syllables per second.

Procedure

Participants listened to uninterrupted auditory sentences over headphones while viewing a four-picture display of black-and-white line drawings. All images were sized to match one another at 450 x 450 pixels.

Participants were seated in front of a computer screen and a Tobii X-120 eye-tracker with their eyes a distance of 60 cm from the eye-tracker. The eye-tracker was calibrated at the beginning of each experimental session. Stimuli were presented with E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Each trial began with a 500 ms fixation cross, followed by a 250 ms blank screen. The four-picture display was presented for 1500 ms before the experimental sentence began, and remained on the screen for 500 ms after the experimental sentence ended (see Figures 9-1 and 9-2). For all trials, gaze location was sampled at a rate of 60 Hz resulting in gaze location being recorded every 17 ms across each trial. To keep participants on task, participants were instructed that they would be asked yes-no questions after each sentence. These questions were intended only to reinforce the need for the participants to attend to the sentences. Participants responded to the questions using a button box using one hand. In order to familiarize each participant with the task, 10 practice trials were conducted prior to each experimental session. This allowed the experimenter to provide feedback or redirection prior to beginning experimental trials when necessary.

ANALYSIS

Four rectangular areas of interest (AOIs) of the same size were defined around each of the pictures in the display. When data were available from both eyes, gaze location was computed as their average. When gaze location was available from only one eye, gaze location was computed from that eye alone. When gaze location was not available from either eye, or was not within of any of the AOIs, the sample was excluded from further analyses. A gaze was defined as six consecutive samples within the same AOI (a total of 102ms; see Manor and Gordon, 2003). Gazes that did not meet this criterion were also excluded from analysis.

The total percent trackloss was calculated for each participant across all trials. Two of the eleven AMCs had fifty percent or greater trackloss and were excluded from further analysis, leaving 9 AMC participants. All 8 IWBA had less than 50 percent trackloss and were therefore included in the analyses presented below. For each group, all analyzable data was used to calculate the mean proportion of gazes to each of the four AOIs for each subject and each item. To account for gaze delay, the analysis window was shifted 200 ms forward (Allopena, Magnuson & Tanenhaus, 1998). Empirical logit transformed proportions were analyzed to avoid issues that can occur with analyzing raw proportions in linear models (see Jaeger, 2008). Raw proportions are reported in the text for interpretation purposes. Analyses were conducted using R version 3.3.1 (R Core Team, 2016), the lme4 package (Bates, Maechler, Bolker & Walker, 2015), and the eyetrackingR package (Dink & Ferguson, 2016).

Below we present the time course of gazes to each of the four AOIs throughout the time-course of each sentence as detailed below.

[Last night at the Halloween party],	[the pirate]	[that observed]	[**the wizard]**	[suddenly]	[emerged]	[before the costume contest].
INITIAL PP	**NP1**	**REL**	**NP2**	**ADV**	**VERB**	**FINAL PP**

To begin, we established sensitivity to the task by confirming that participants gazed to a NP upon hearing it in the auditory stream. The mean proportion of gazes to NP1 and NP2 were averaged across the NP1 (*the pirate*), and the relativizer (*that observed*) sentence elements across conditions to determine if gazes to NP1 increased upon hearing it. The mean proportion of gazes to NP1 and NP2 were also averaged across the NP2 (*the wizard*), adverb (*suddenly*) and verb (*emerged*) sentence elements across conditions to determine if gazes to NP2 increased upon hearing it. For each participant group, the mean proportions were subjected to linear mixed effects modeling. Random effects of subjects and items, and a fixed effect of AOI were included in the model.

As shown in Table 9-3, both groups exhibited significantly greater gazes to the AOI containing NP1 compared to the AOI containing NP2 after encountering **NP1** in the auditory stream (NP1 region), **AMCs**: t(3805) = 27.4, p = <0.001, estimate = 2.56(.10); **IWBA**: t(3469) = 12.67, p = <0.001, estimate = 1.24(.10). Greater gazes to the AOI containing NP2 were found compared to the AOI containing NP1 after encountering **NP2** in the auditory stream (NP2 region), **AMCs**: t(5729) = -12.52, p = <.001, estimate = -1.03(.08); **IWBA**: t(5307) = - 3.70, p = 0.00021, estimate = -0.31(.08).

Table 9-3. Average Proportion of gazes (standard error) across all conditions to NP1 and NP2 during the region of NP1 and NP2 during the auditory stream for AMCs and IWBA.

	NP1 REGION	NP2 REGION
AMCs		
PROPORTION OF GAZES TO NP1	0.53(.009)*	0.31(.007)
PROPORTION OF GAZES TO NP2	0.20(.008)	0.45(.008)*
IWBA		
PROPORTION OF GAZES TO NP1	0.39(.01)*	0.30(.008)
PROPORTION OF GAZES TO NP2	0.23(.009)	0.35(.008)*

* = significantly greater gazes

These results indicate that both groups are sensitive to the task as they both exhibited gazes toward a named referent upon hearing it. Though not the focus of this investigation, we do point out that the time course of activation of the NPs appear temporally delayed for IWBA (see graphs 9-3 and 9-4) as compared to the AMCs.

As we have established that both groups are sensitive to the task and can switch gazes appropriately, we now move to discussion of the analyses targeted at answering our questions of interest. Because the main area in the sentence that is of interest occurs at post verb positions, and since behavioral studies indicated delayed reactivation for the displaced NP post verb, we broke down the final PP in to 250 millisecond time bins so as to better capture the time course of reactivation (detailed below).

Final PP analysis window

In addition to the sentence components shown above, an analysis window beginning at the onset of the final preposition and continuing for 2000 ms was created.

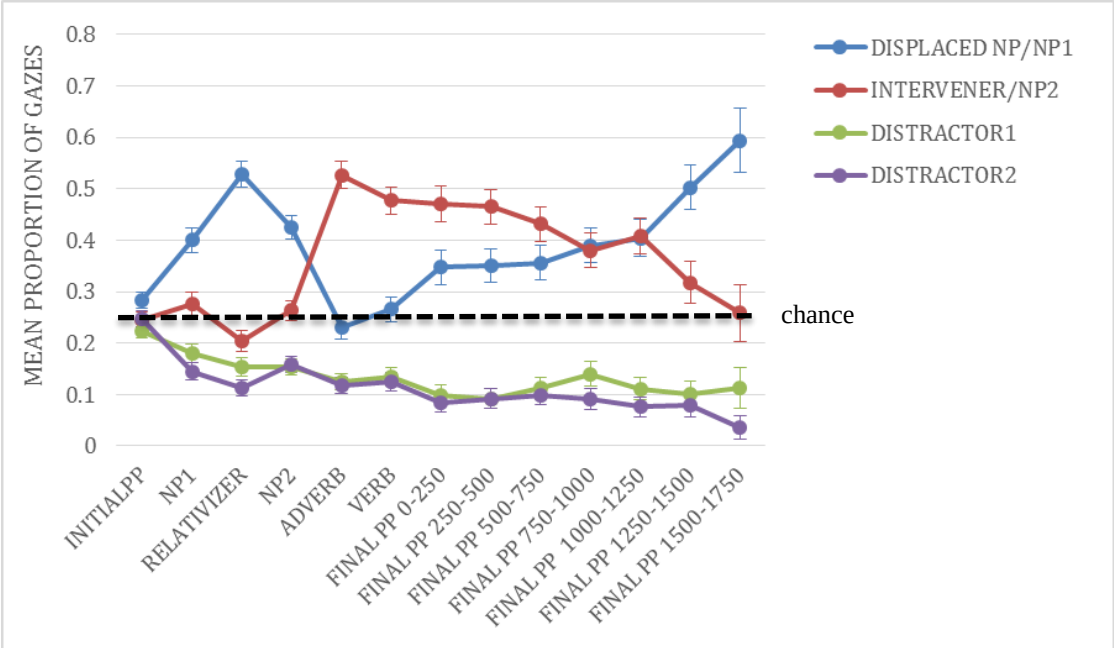
The 2000 ms time window was broken down into eight 250 ms time bins. The final time bin had fewer than twenty data points in each condition and was excluded from further analysis. The mean proportion of gazes to each of the four AOIs was calculated for each of the remaining time bins. For each participant group, the proportion of gazes to the displaced NP/NP1 and the proportion of gazes to the intervener/NP2 in each of the Final PP time bins were subjected to linear mixed effects modeling. Random effects of subjects and items, and a fixed effect of AOI were included in the model.

RESULTS: SENTENCES CONTAINING UNACCUSATIVE VERBS

AMC Participants

Graph 9-1 display the mean proportion of gazes to all four AOIs for each sentence element and Final PP time bins for the **animate unaccusative condition**.

Graph 9-1. Mean proportion of gazes (with standard errors) to all AOIs over the duration of the sentence for the animate unaccusative condition for the AMCs.



It is clear from that, participants did not show significant gazes to the two distractor items. Again, because we are primarily interested in what occurs beyond the verb, we focus here comparing the 2 NPs of interest- the displaced NP (NP1) and the intervening NP (NP2). Table 9-4 shows the mean proportions of gazes to NP1 and NP2 for the final analysis window.

Table 9-4. Mean proportion of gazes (standard error) to the displaced NP/NP1 and the Intervener/NP2 during the Final PP time bins for the animate unaccusative condition for the AMCs.

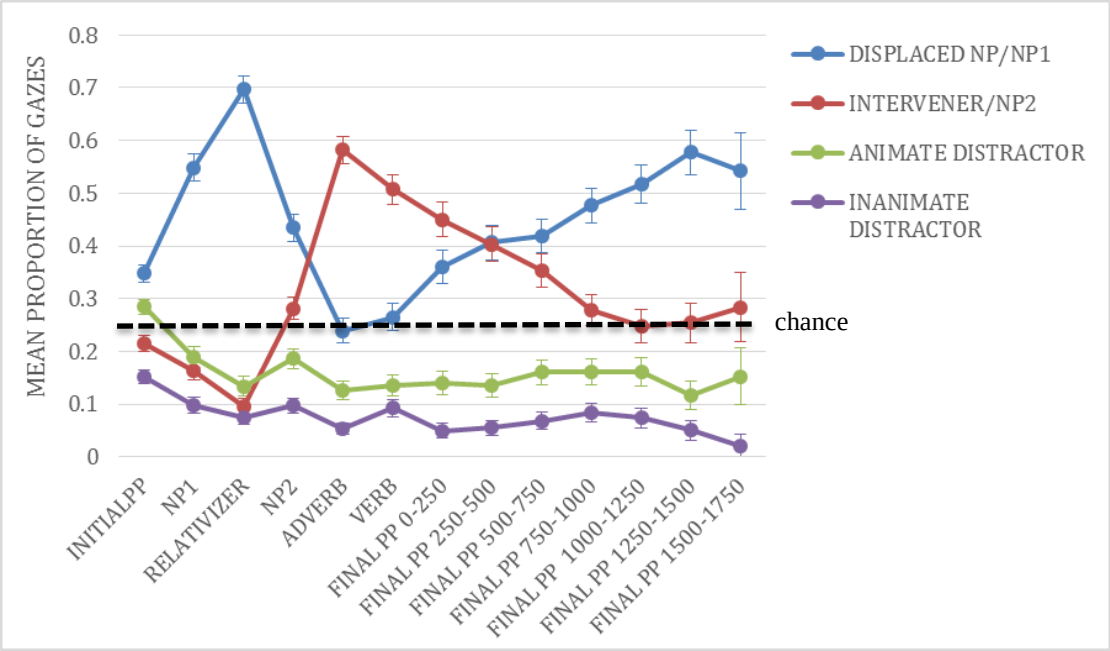
	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
Displaced NP (NP1)	0.35 (.03)	0.35 (.03)	0.36 (.03)	0.39 (.03)	0.40 (.04)	0.50 (.04)*	0.59 (.06)*
Intervener (NP2)	0.47 (.03)*	0.46 (.03)*	0.43 (.03)	0.38 (.03)	0.41 (.04)	0.32 (.04)	0.26 (.06)

* = significantly greater gazes

As NP2 was the most recent NP listeners heard prior to the Final PP, we see greater gazes to NP2. While still greater than gazes to NP1, the proportion of gazes to NP2 quickly shifts downward. Gazes are moving away from NP2 and towards NP1, an indicator of reactivation. This pattern is shown though significantly greater gazes to the intervener (NP2) at two post verb time bins: **offset to 250 ms**; t(397) = -2.55, p = 0.01, estimate = -0.12(0.05) and **250 to 500 ms**; t(401) = -2.33, p = 0.02, estimate = -0.68(0.29). With significantly greater gazes to the displaced NP (NP1) in the **1250 to 1500 ms**; t(265) = 3.00, p = 0.003, estimate = 1.01(0.34), and **1500 to 1750 ms**; t(123) = 4.07, p =.00001, estimate = 1.73(0.43) time bins. No significant differences were found in the **500 to 750 ms**; t(415)= -1.54, p = 0.12, estimate = -0.45(0.29), **750 to 1000 ms**; t(411) = -0.10, p = 0.92, estimate = -0.029(0.29), and **1000 to 1250 ms**; t(373) = 0.04, p = 0.97, estimate = 0.01(0.30) time bins.

Graph 9-2 displays the mean proportion of gazes to all four AOIs for each sentence element and Final PP time bins for the **inanimate unaccusative condition**.

Graph 9-2. Mean proportion of gazes to all AOIs (with standard errors) over the duration of the sentence for the inanimate unaccusative condition for the AMCs.



Similar to the patterns above, participants did not show significant gazes to the two distractor items. The mean proportion of gazes to the displaced NP (NP1) and the intervener (NP2) for each of the Final PP time bins in the **inanimate unaccusative condition** are presented in Table 9-5.

Table 9-5. Mean proportion of gazes (standard error) to the displaced NP/NP1 and the Intervener/NP2 during the Final PP time bins for the inanimate unaccusative condition for the AMCs.

	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
Displaced NP (NP1)	0.36 (.03)	0.41 (.03)	0.42 (.03)	0.48 (.03)*	0.52 (.04)*	0.58 (.04)*	0.54 (.07)*
Intervener (NP2)	0.45 (.03)*	0.40 (.03)	0.35 (.03)	0.28 (.03)	0.25 (.03)	0.25 (.04)	0.28 (.07)

* = significantly greater gazes

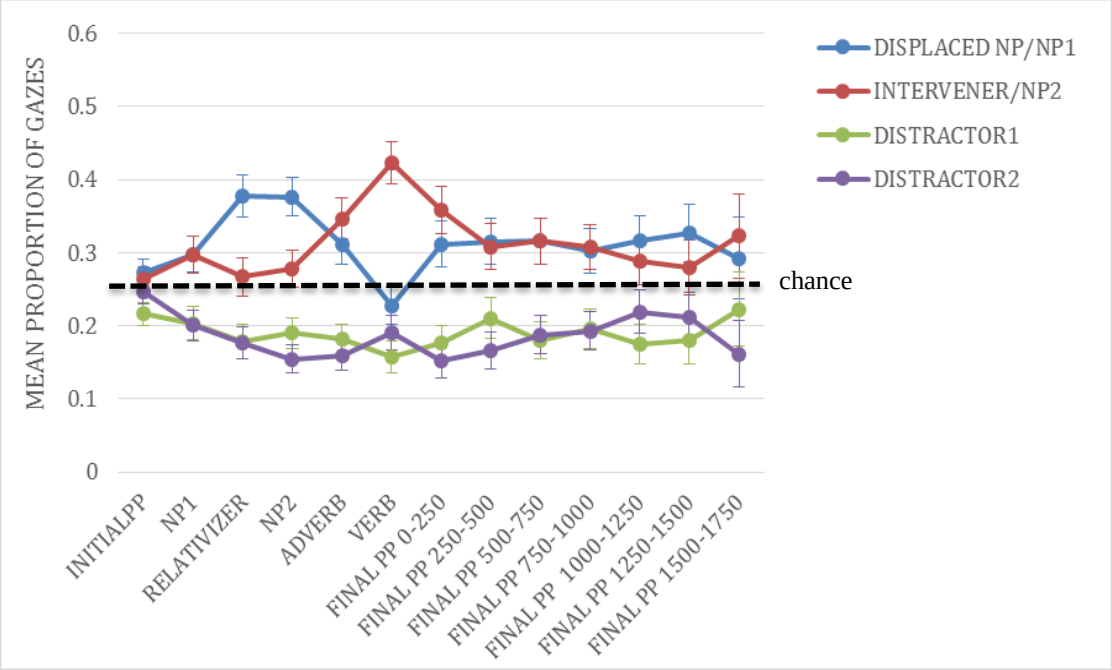
Similar to the patterns described above, we see significantly greater gazes to the intervener (NP2) in the **offset to 250 ms**; t(437) = -1.96, p = 0.05, estimate = -0.09(0.05)

time bin. Interestingly, the point at which significantly greater gazes to the displaced NP (NP1) are starting is earlier than in the animate condition: **750 to 1000 ms**; t(445) = 4.31, p = < .001, estimate = 1.19 (0.28)), **1000 to 1250 ms**; t(377) = 5.40, p = <.001, estimate = 1.55 (0.29), **1250 to 1500 ms**; t(275) = 5.66, p = <.001, estimate = 1.86(0.33), and **1500 to 1750 ms**; t(91) = 3.00, p = 0.03, estimate = 1.62(0.54) time bins. No significant differences were found in the **250 to 500 ms**; t(441) =0.09, p = 0.93, estimate = 0.03(0.29), and **500 to 750 ms**; t(449) = 1.61, p = 0.11, estimate = 0.46(0.28) time bins.

Individuals With Broca's Aphasia (IWBA)

Graph 9-3 displays the mean proportion of gazes to all four AOIs for each sentence element and Final PP time bins for the **animate unaccusative condition**.

Graph 9-3. Average Proportion of gazes to all AOIs over the duration of the sentence for the animate unaccusative condition for the IWBA.



As was the case for the AMCs, IWBA do not appear to be gazing towards the two distractor items during sentence processing. The mean proportion of gazes to the displaced NP (NP1) and the intervener (NP2) for each of the Final PP time bins in the **animate unaccusative condition** are presented in Table 9-6.

Table 9-6. Mean proportion of gazes (standard error) to the displaced NP/NP1 and the Intervener/NP2 during the Final PP time bins for the animate unaccusative condition for the IWBA.

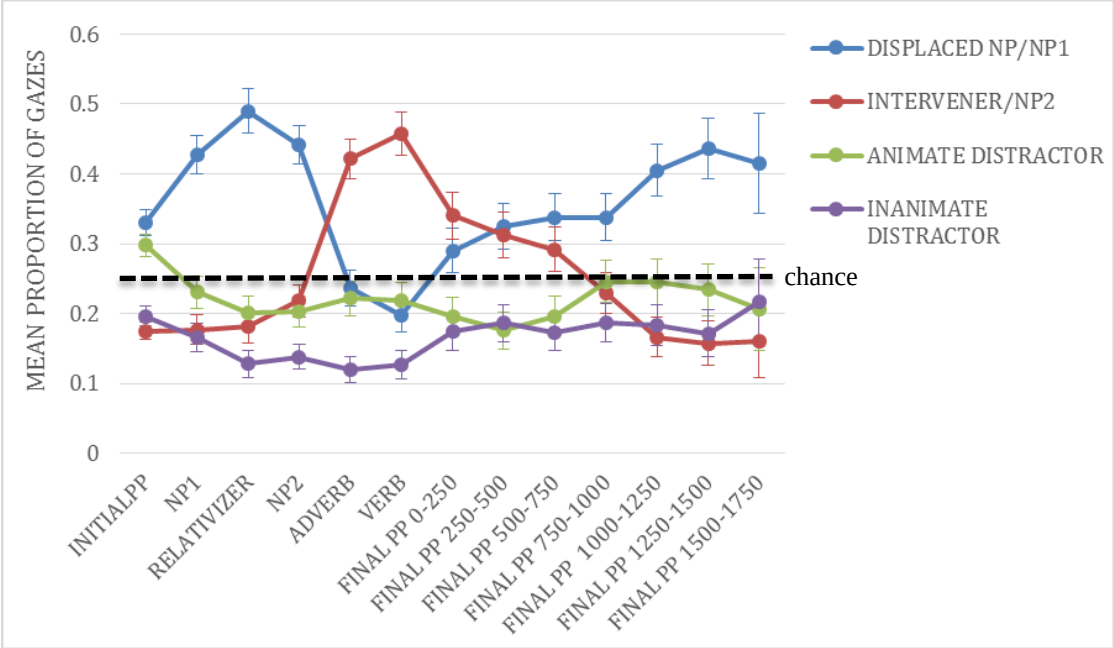
	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
Displaced NP (NP1)	0.31 (.03)	0.32 (.03)	0.32 (.03)	0.30 (.03)	0.32 (.03)	0.33 (.04)	0.29 (.06)
Intervener (NP2)	0.36 (.03)	0.31 (.03)	0.32 (.03)	0.31 (.03)	0.29 (.03)	0.28 (.04)	0.32 (.06)

* = significantly greater gazes

Unlike the AMCs who showed a clear shift in gaze patterns post verb from the most recently heard NP (NP2) towards the displaced NP (NP1), no significant difference in gazes to the displaced NP (NP1) and the intervener (NP2) was found in any of the post verb time bins for the IWBA: **offset – 250 ms**; t(415) = -0.27, p = 0.79, estimate = -.08(0.28), **250 – 500 ms**; t(413) = 0.08, p = 0.94, estimate = 0.02(0.28), **500 – 750 ms**; t(423) = .15, p = 0.88, estimate = 0.04(0.28), **750 – 1000 ms**; t(421) = -0.01, p = 0.99, estimate = -0.002 (0.27), **1000-1250 ms**; t(369) = 1.25, p = 0.21, estimate = 0.35(0.28), **1250 – 1500 ms**; t(277) = 0.87, p = 0.38, estimate = 0.05(0.05), and **1500 – 1750 ms**; t(129) = -0.41, p = 0.68, estimate = -0.15(0.37) time bins.

Interestingly though, differences were found for the **inanimate unaccusative condition.** Graph 9-4 displays the mean proportion of gazes to all four AOIs for each sentence element and Final PP time bins.

Graph 9-4. Average Proportion of gazes to all AOIs over the duration of the sentence for the inanimate unaccusative condition for the IWBA.



The mean proportion of gazes to the displaced NP (NP1) and the intervener (NP2) for each of the Final PP time bins in the **inanimate unaccusative condition** are presented in Table 9-7.

Table 9-7. Mean proportion of gazes (standard error) to the displaced NP/NP1 and the Intervener/NP2 during the Final PP time bins for the inanimate unaccusative condition for the IWBA.

	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
Displaced NP (NP1)	0.29 (.03)	0.33 (.03)	0.34 (.03)	0.34 (.03)*	0.41 (.04)*	0.44 (.04)*	0.42 (.07)*
Intervener (NP2)	0.34 (.03)	0.31 (.03)	0.29 (.03)	0.23 (.03)	0.17 (.03)	0.16 (.03)	0.16 (.05)

* = significantly greater gazes

Visually, there is a clear shift in gazes post verb away from the most recently heard NP2 towards the displaced NP (NP1). This pattern is also shown with significantly greater gazes to the displaced NP (NP1) being found in four post verb time bins: **750 to 1000 ms;** t(387) = 2.3, p = 0.02, estimate = 0.62(0.27), **1000 to 1250 ms**; t(332) = 4.92, p = <.001, estimate = 1.35(0.27), **1250 to 1500 ms**; t(257) = 5.27, p = <.001, estimate = 0.28

(0.05), and **1500 to 1750 ms**; t(91) = 2.77, p = 0.006 , estimate = 1.28 (0.46). No significant differences were found in the **offset to 250 ms**; t(389) = -1.03, p = 0.30, estimate = -0.30 (0.29), **250 to 500 ms**; t(389) = 0.06, p = 0.95, estimate = 0.02(0.29), and **500 to 750 ms**; t(387) = 0.91, p = 0.36, estimate = 0.26 (0.29) time bins.

INTERIM DISCUSSION

The purpose of this study was to test the Intervener Hypothesis and determine if similarity-based interference manifests during the real-time processing of sentences that contain an unaccusative verb and an intervener of similar structure for IWBA. We also included a group of AMC participants for comparison. Recall that sentences with unaccusative verbs contain a filler-gap syntactic dependency that requires the linking of a displaced NP and a post verb "gap" for successful comprehension. Here, unaccusative verbs were embedded in subject-relative sentences (22), requiring the crossing of a NP of similar structure (DET N; **the wizard**) to process the syntactic dependency.

(22) Last night at the Halloween party, the pirate that observed **the wizard** suddenly <u>emerged</u> <~~the pirate~~> before the costume contest.

We note here that our prior work has demonstrated that IWBA show impaired final comprehension of these sentences (Sullivan et al., 2017a) and argued that similarity-based interference (SBI) could be the reason for the comprehension impairment. In this experiment, we manipulated the animacy of the intervener (23; **the pumpkin**) to determine whether semantic information reduces SBI.

(23) Last night at the Halloween party, the pirate that observed **the pumpkin** suddenly <u>emerged</u> <~~the pirate~~> before the costume contest.

For the AMC participants, we predicted that the group would exhibit reactivation of the displaced NP in sentences that contain unaccusative verbs in both the animate (matched NP1 and NP2), and inanimate (mismatched NP1 and NP2) conditions. The results support our predictions. The AMCs exhibited greater gazes to the displaced NP (NP1) compared to the intervener (NP2) at a post verb position in both animate and inanimate conditions. The results from AMC participants also demonstrate a processing advantage for a semantically mismatched intervener. In the inanimate condition, gazes to the displaced NP occur at an earlier time point (750-1000 ms time bin) than when the intervener is semantically matched (animate) (1250-1500 ms time bin). Gazes also begin to shift to the displaced NP (NP1) at an earlier time point in the inanimate (semantic mismatch) condition. Gazes to NP2 are significantly greater in the PP **offset to 250 ms** time bin, while gazes to NPs do not differ beginning in the **250 to 500 ms** time windows. In the animate (semantic match) condition, gazes to NP2 are significantly greater across the first two time bins, **PP offset to 250 ms and 250 to 500 ms**, with no difference in gazes beginning in the **500 to 750** ms time windows.

Given the pattern of final comprehension observed for the IWBA in Sullivan et al. (2017a) for sentences that contain an unaccusative verb and an intervener, we predicted that the IWBA would not exhibit reactivation of the displaced NP at a post verb position. The results support the Intervener Hypothesis as no statistical difference between gazes to the displaced NP and the intervener were found in any of the post verb, Final PP time bins. These findings indicate that the presence of an intervening NP between the elements of the syntactic dependency induces SBI for IWBA. These results also align with the chance comprehension observed in Sullivan et al. (2017a): taken together, the findings

suggest that SBI manifests during real-time sentence processing and negatively impacts final sentence comprehension.

We also sought to determine if manipulating the animacy of an intervener would reduce SBI during real-time sentence processing of sentences that contain unaccusative verbs and an intervener for IWBA. If it is the case that an intervening NP that is of a similar structure (DET N) and other properties (e.g., animacy) causes “confusion” in thematic role assignment in IWBA, then it is reasonable to predict that altering one of those lexical features, in this case, animacy, would reduce the interference effect. We predicted that IWBA would reactivate the displaced NP at a post verb position when the displaced NP and the intervener were semantically mismatched. The results support our prediction as the IWBA exhibited significantly greater gazes to the displaced NP (NP1) compared to the intervener (NP2) at a post verb position. This pattern provides evidence for a processing advantage when the intervener and the displaced NP differ semantically. In the inanimate unaccusative condition, AMC and IWBA participants demonstrate a similar time-course of reactivation of the displaced NP, providing further support for a processing advantage when an intervener is semantically distinguished. For both groups, significantly greater gazes to the displaced NP begin at the 750-1000 ms time bin. While results from the animate unaccusative and inanimate unaccusative conditions are relatively clear-cut, recall that we also included sentences that contain unergative verbs and interpreting performance in these conditions poses a greater challenge. We turn now to the results from the unergative conditions.

RESULTS: SENTENCES CONTAINING UNERGATIVE VERBS

ANALYSIS

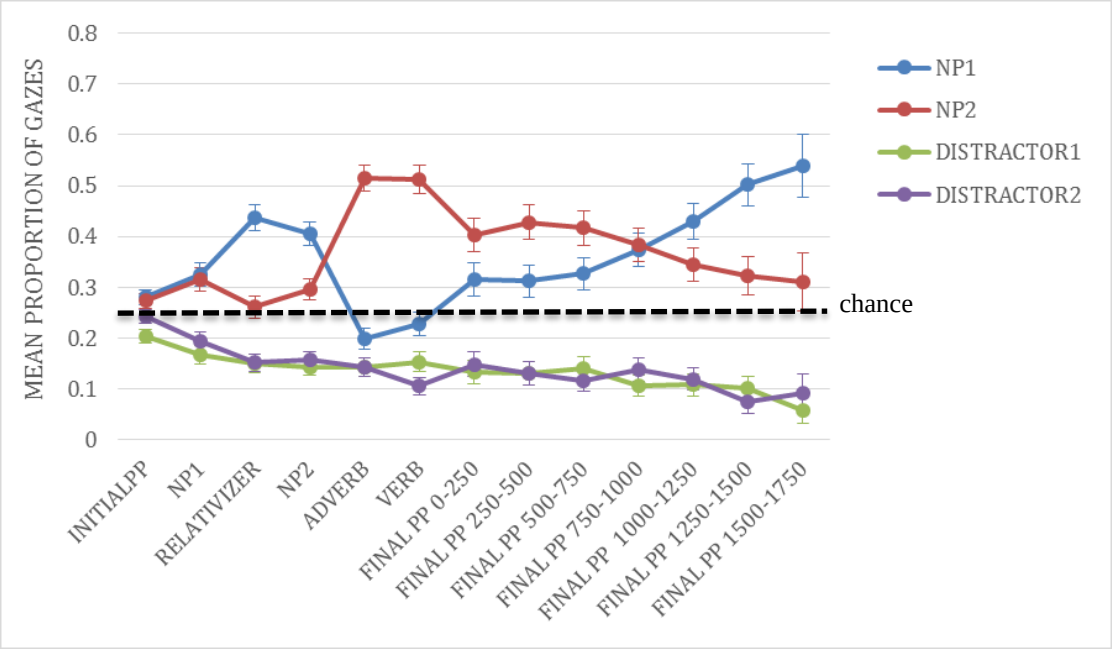
The same analysis approach used to analyze the sentences that contain unaccusative verbs was used to evaluate the sentences that contain unergative verbs.

RESULTS

AMC Participants

Graph 9-5 displays the mean proportion of gazes to all four AOIs for each sentence element and Final PP time bins for the **animate unergative condition**. As was the case above, AMCs do not appear to be gazing towards the two distractor items during sentence processing.

Graph 9-5. Mean proportion of gazes to all AOIs over the duration of the sentence for the animate unergative condition for the AMCs.



Similar to what was done for the unaccusative condition, the mean proportion of gazes to NP1 and NP2 for each of the Final PP time bins in the **animate unergative condition** are presented in Table 9-8.

Table 9-8. Mean proportion of gazes (standard error) to NP1 and NP2 during the Final PP time bins for the animate unergative condition for the AMCs.

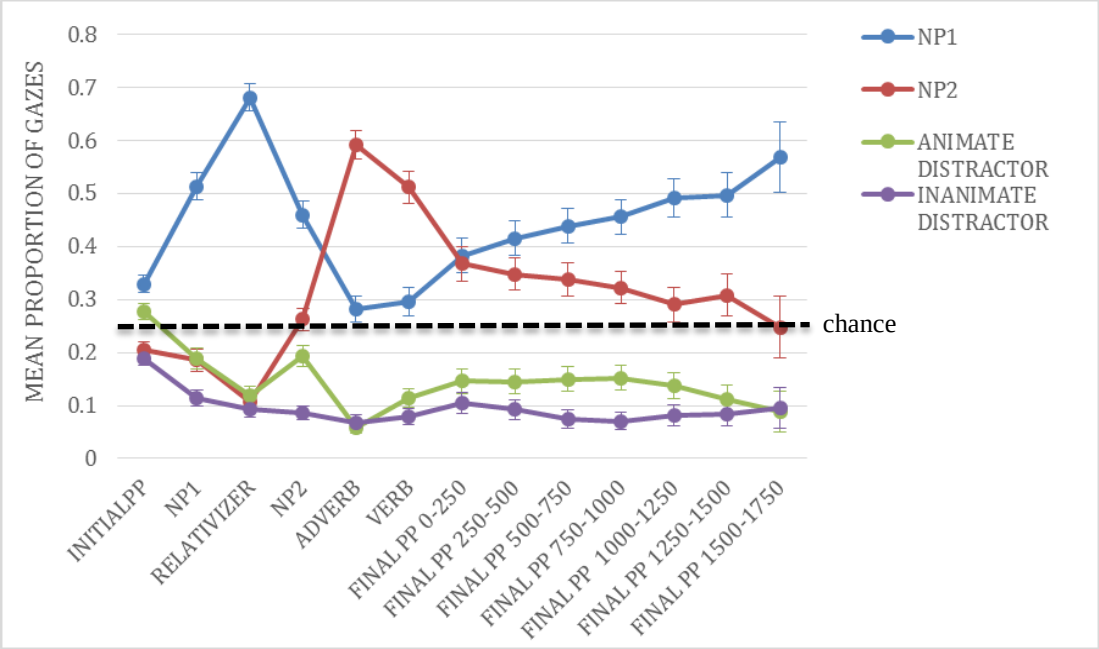
	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
NP1	0.32 (.03)	0.31 (.03)	0.33 (.03)	0.37 (.03)	0.43 (.03)*	0.50 (.04)*	0.54 (.06)*
NP2	0.40 (.03)	0.43 (.03)*	0.42 (.03)	0.38 (.03)	0.34 (.03)	0.32 (.04)	0.31 (.06)

* = significantly greater gazes

As was found in the unaccusative condition, as the AMCs heard an NP, they showed clear gaze patterns towards that item. Post verb, there were significantly greater gazes to NP2 in the **250 to 500 ms**; t(403) = -2.44, p = 0.02, estimate = -0.71(0.29) time bin. An unexpected finding, however, was that there were significantly greater gazes to NP1 in three subsequent time bins: the **1000 to 1250 ms**; t(403) = 1.97, p = 0.05, estimate = 0.54 (0.27), **1250 to 1500 ms**; t(291) = 3.79, p = 0.00015, estimate = 1.20 (0.32), and **1500 to 1750 ms**; t(129) = 2.24, p = 0.03, estimate = 0.97 (0.43). No significant differences were found in the **offset to 250 ms**; t(403) = -1.91, p = 0.06, estimate = -0.09 (0.05), **500 to 750 ms**; t(413) = -1.92, p = 0.06, estimate = -0.54(0.28), and the **750 to 1000 ms**; t(417) = -0.46, p = 0.64, estimate = -0.13(0.29) time bins.

Graph 9-6 displays the mean proportion of gazes to all four AOIs for each sentence element and Final PP time bins for the **inanimate unergative condition**. Again, AMCs appear to be ignoring the two distractor items.

Graph 9-6. Mean proportion of gazes to all AOIs over the duration of the sentence for the inanimate unergative condition for the AMCs.



The mean proportion of gazes to NP1 and NP2 for each of the Final PP time bins in the **inanimate unergative condition** are presented in Table 9-9.

Table 9-9. Mean proportion of gazes (standard error) to NP1 and NP2 during the Final PP time bins for the inanimate unergative condition for the AMCs.

	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
NP1	0.38 (.03)	0.42 (.03)	0.44 (.03)*	0.46 (.03)*	0.49 (.04)*	0.50 (.04)*	0.57 (.07)*
NP2	0.37 (.03)	0.35 (.03)	0.34 (.03)	0.32 (.03)	0.29 (.03)	0.31 (.04)	0.25 (.06)

* = significantly greater gazes

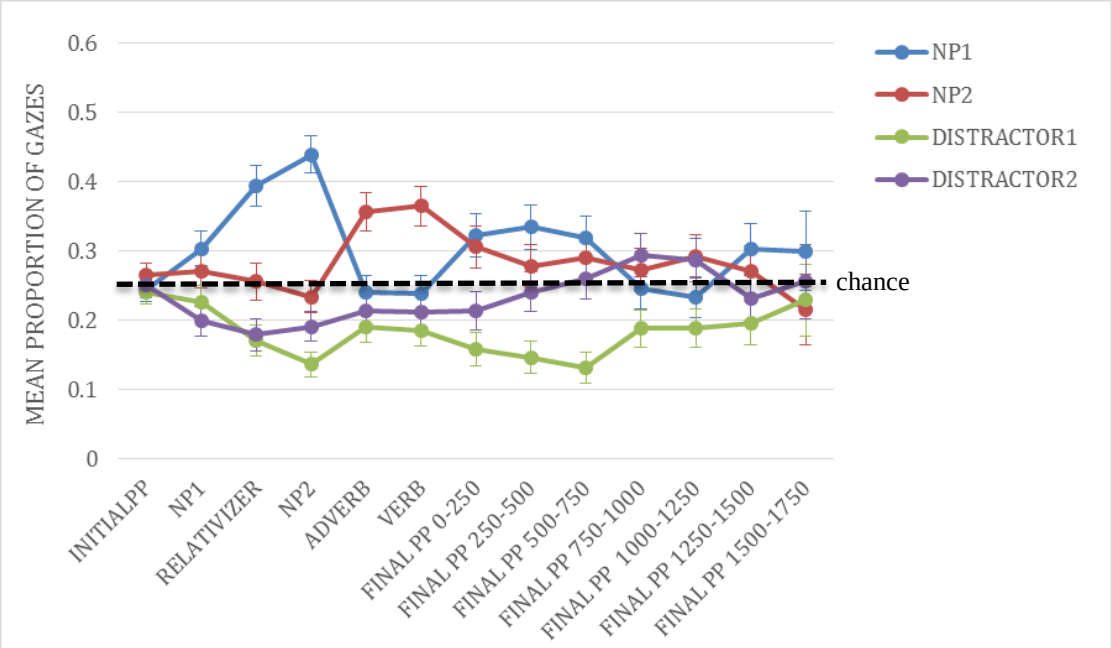
Gazes to the most recently encountered NP (NP2) begin to decrease after the verb and similar to the **animate unergative condition**, gazes to NP1 begin to increase in the post verb region. This pattern is further shown as significantly greater gazes to NP1 were found in the **500 to 750 ms**; t(439) = 2.23, p = 0.03, estimate = 0.64(0.29), **750 to 1000 ms**; t(451) = 3.44, p = 0.0006, estimate = 0.95(0.28), **1000 to 1250 ms**; t(373) = 4.3, p =

<0.001, estimate = 1.26 (0.29), **1250 to 1500 ms**; t(269) = 3.47, p = 0.0005, estimate = 1.12 (0.32), and **1500 to 1750 ms**; t(111) = 3.66, p = 0.0003, estimate = 1.73(0.47) time bins. No significant differences were found in the **offset to 250 ms**; t(437) = 0.34, p = 0.73, estimate = 0.02 (0.04) and, **250 to 500 ms**; t(453) = 1.54, p = 0.12, estimate = 0.43(0.28) time bins.

IWBA

Graph 9-7 displays the mean proportion of gazes to all four AOIs for each sentence element and Final PP time bins for the **animate unergative condition**. It appears that over most of the sentence the IWBA ignore the two distractor items. Interestingly, in this case, visually, gazes to the distractors begin to increase during the post verb region.

Graph 9-7. Mean proportion of gazes to all AOIs over the duration of the sentence for the animate unergative condition for the IWBA.



The mean proportion of gazes to NP1 and NP2 for each of the Final PP time bins in the **animate unergative condition** are presented in Table 9-10.

Table 9-10. Mean proportion of gazes (standard error) to NP1 and NP2 during the Final PP time bins for the animate unergative condition for the IWBA.

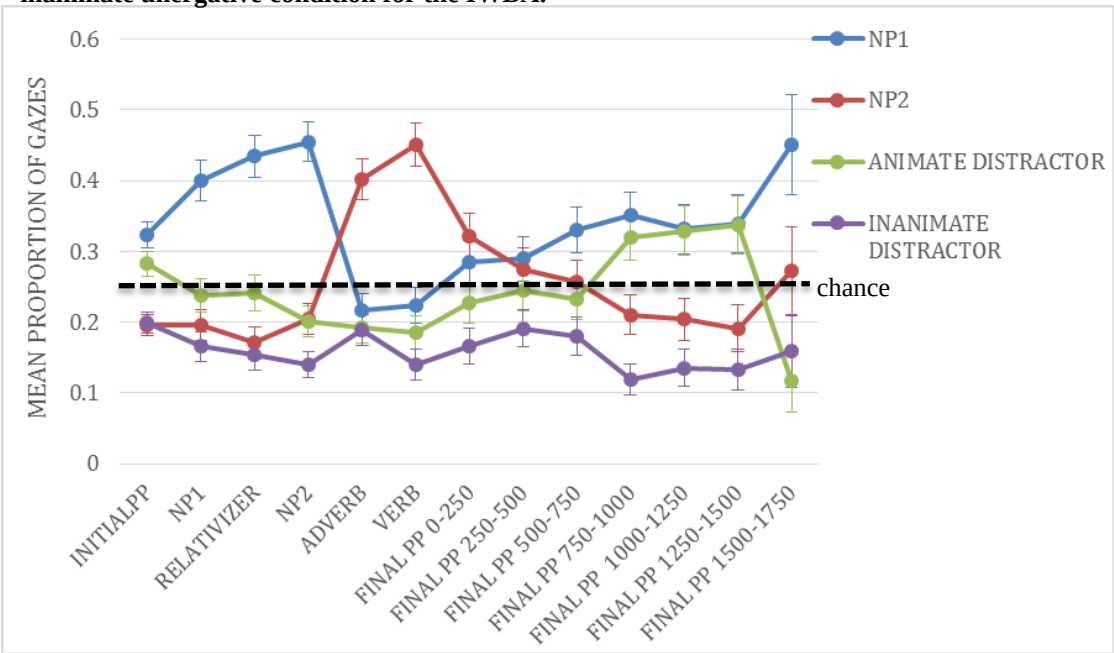
	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
NP1	0.32 (.03)	0.33 (.03)	0.32 (.03)	0.25 (.03)	0.23 (.03)	0.30 (.04)	0.30 (.06)
NP2	0.31 (.03)	0.28 (.03)	0.29 (.03)	0.27 (.03)	0.29 (.03)	0.27 (.04)	0.22 (.05)

* = significantly greater gazes

As expected, gazes to NP1 and NP2 do not differ in the post verb region, unlike what was found for the AMCs. This pattern is further shown as no significant difference in gazes to NP1 or NP2 was found in any of the time bins, **offset – 250 ms**; t(419) = 0.45, p = 0.65, estimate = -0.12(0.28), **250 – 500 ms**; t(429) = 1.15, p = 0.25, estimate = 0.31(0.27), **500 – 750 ms;** t(411) = 0.53, p = 0.60, estimate = 0.15(0.28), **750 – 1000 ms**; t(419) = -0.97, p = 0.33 , estimate = -0.26(0.26), **1000-1250 ms**; t(399) = -1.2, p = 0.23, estimate = -0.32(0.27), **1250 – 1500 ms**; t(299) = 0.62, p = 0.54, estimate = 0.03(0.05), **1500 – 1750 ms**; t(131) = 1.08, p = 0.28, estimate = 0.43(0.4).

Graph 9-8 displays the mean proportion of gazes to all four AOIs for each sentence element and Final PP time bins for the **inanimate unergative condition**. Again, over most of the duration of the sentences the IWBA ignore the distractors. Visually, unlike what was seen in the **animate unergative condition** where gazes to both of the distractors increased during the post verb region, here only gazes to the animate distractor appear to increase.

Graph 9-8. Mean proportion of gazes to all AOIs over the duration of the sentence for the inanimate unergative condition for the IWBA.



The mean proportion of gazes to NP1 and NP2 for each of the Final PP time bins in the **unergative inanimate condition** are presented in Table 9-11.

Table 9-11. Mean proportion of gazes (standard error) to NP1 and NP2 during the Final PP time bins for the inanimate unergative condition for the IWBA.

	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
NP1	0.29 (.03)	0.29 (.03)	0.33 (.03)	0.35 (.03)*	0.33 (.04)*	0.34 (.04)*	0.45 (.07)*
NP2	0.32 (.03)	0.27 (.03)	0.26 (.03)	0.21 (.03)	0.20 (.03)	0.19 (.03)	0.27 (.06)

* = significantly greater gazes

Unlike what was found for the IWBA in the **animate unergative** condition, gazes to NP1 increase during the post verb region. This pattern is further demonstrated as significantly greater gazes to NP1 were found in the **750 to 1000 ms**; t(411) = 3.39, p = 0.0008, estimate = 0.89(0.26), **1000 to 1250 ms**; t(351) = 3.35, p = 0.0009, estimate = 0.93 (0.28), **1250 to 1500 ms**; t(259) = 2.83, p = 0.005, estimate = 0.15(0.05), and **1500 to 1750 ms**; t(101) = 1.97, p = 0.05, estimate = 0.97(0.49) time bins. No significant

differences were found in the **offset to 250 ms**; t(409) =- 0.57, p = 0.57, estimate =- 0.16 (0.27), **250 to 500 ms**; t(405) = 0.69, p = 0.49, estimate = 0.19(0.27), and **500 to 750 ms**; t(395) = 1.79, p = 0.07, estimate = 0.51(0.29) time bins.

INTERIM DISCUSSION

We included subject-relative sentences that contain an unergative verb and NPs that matched in animacy (24) or mismatched in animacy (25) as control conditions.

(24) Last night at the Halloween party, the pirate that observed the wizard suddenly joked before the costume contest.

(25) Last night at the Halloween party, the pirate that observed the pumpkin suddenly joked before the costume contest.

For both groups, we predicted no difference in gazes to NP1 compared to NP2 at a post verb position, as sentences that contain unergative verbs do not contain a filler-gap syntactic dependency that motivates reactivation. Surprisingly, the AMC participants demonstrated significantly greater gazes to NP1 at a post verb position for both the semantically matched (animate) and mismatched (inanimate) conditions. Also of note is the finding of increased gazes to NP1 compared to NP2 occurs earlier in the time-course for sentences that contain unergative verbs compared to those with unaccusative verbs. Significantly greater gazes to NP1 begin in the 1000-1250 ms time bin for the animate unergative condition but do not begin until the 1250-1500 ms time bin in the animate unaccusative condition (see red boxes in Table 9-12, below). An earlier time-course is also observed when comparing gazes to NP1 and NP2 after the verb in the inanimate unergative condition and the inanimate unaccusative condition. Greater gazes to NP1 begin in the 500-750 ms time bin for the inanimate unergative condition and do not begin

until the 750-1000 ms time bin for the inanimate unaccusative condition (see blue boxes in Table 9-12, below). Similar to the processing advantage found for semantically mismatched NPs within the unaccusative conditions for the AMC participants, a processing advantage for semantically mismatched NPs was also found within the unergative conditions. Reactivation of NP1 occurs at a later time-point (1000-1250 ms time bin) when the NPs match in animacy compared to when they mismatch (500-750 ms time bin). We discuss one possible reason for this unexpected pattern below.

For the animate unergative condition, IWBA, unlike the AMC participants, demonstrated no difference between gazes to NP1 and NP2 at a post verb position. This pattern was expected as sentences that contain an unergative verb do not contain a filler-gap syntactic dependency and therefore "re-activation" is not expected in the post verb position(s); thus no difference in gaze patterns post verb for NP1 compared to NP2.

However, in the inanimate unergative condition, similar to the AMC participants, the IWBA exhibit greater gazes to NP1 compared to NP2 at post verb positions. Significantly greater looks to NP1 are found beginning in the 750-1000 ms time bin. While performance within the unergative conditions make the results within our unaccusative conditions a little more difficult to interpret, we argue that increased gazes to NP1 in the unergative conditions may be motivated by a different process than in the unaccusative conditions. We further discuss this suggestion in our general discussion.

GENERAL DISCUSSION

We conducted an eye-tracking while listening study to further test the Intervener Hypothesis. We sought to determine if similarity-based interference manifests during the real-time sentence processing of subject-relative sentences that contain unaccusative

verbs and an intervener. Sullivan et al. (2017a) demonstrated that IWBA have poor final comprehension of these sentences and argued that similarity-based interference caused by an intervening NP, or intervener between the elements of the syntactic dependency inherent to unaccusative verbs was the source of the comprehension patterns observed. We also sought to determine if semantically distinguishing the intervener by manipulating animacy mitigates similarity-based interference during real-time sentence processing. To accomplish this, we embedded unaccusative verbs in subject-relative sentences with semantically matched NPs (26), and semantically mismatched NPs (28). We included sentences that contain unergative verbs as a control condition as they are intransitive verbs but unlike unaccusatives do not contain a filler-gap syntactic dependency. The animacy of the NPs contained in these sentences was also manipulated, for one condition both NPs were animate (27), and in another one NP was animate and the other was inanimate (29).

(26) Last night at the Halloween party, the pirate that observed **the wizard** suddenly emerged <~~the pirate~~> before the costume contest.

(27) Last night at the Halloween party, the pirate that observed the wizard suddenly joked before the costume contest.

(28) Last night at the Halloween party, the pirate that observed **the pumpkin** suddenly emerged <~~the pirate~~> before the costume contest.

(29) Last night at the Halloween party, the pirate that observed the pumpkin suddenly joked before the costume contest.

We included a group of neurologically unimpaired AMC participants to establish baseline performance. For AMC participants, as expected, we found reactivation of the displaced NP at a post verb position for both the unaccusative conditions (see Table 9-12 below).

Table 9-12. Summary of gaze patterns for each post-verb time window across the 4 conditions for both the AMCs and IWBA.

	0-250 ms	250-500 ms	500-750 ms	750-1000 ms	1000-1250 ms	1250-1500 ms	1500-1750 ms
AMCs							
Unaccusative Animate	NP2	NP2	-	-	-	NP1	NP1
Unaccusative Inanimate	NP2	-	-	NP1	NP1	NP1	NP1
Unergative Animate	-	NP2	-	-	NP1	NP1	NP1
Unergative Inanimate	-	-	NP1	NP1	NP1	NP1	NP1
IWBA							
Unaccusative Animate	-	-	-	-	-	-	-
Unaccusative Inanimate	-	-	-	NP1	NP1	NP1	NP1
Unergative Animate	-	-	-	-	-	-	-
Unergative Inanimate	-	-	-	NP1	NP1	NP1	NP1

For the IWBA, we did not find reactivation of the displaced NP in the animate unaccusative condition, but did find reactivation of the displaced NP in the inanimate unaccusative condition. We interpret this as support for the Intervener Hypothesis where the presence of a structurally similar NP between the elements of a syntactic dependency causes similarity-based interference and negatively impacts final comprehension. Our animacy manipulation revealed that animacy reduces similarity-based interference caused by an intervener. Only when the intervener matched structurally and semantically did it induce similarity-based interference that negatively impacted real-time sentence processing.

At first blush, this interpretation appears to be complicated by the reactivation of NP1 in the unergative conditions in the AMCs and the IWBA (inanimate condition only).

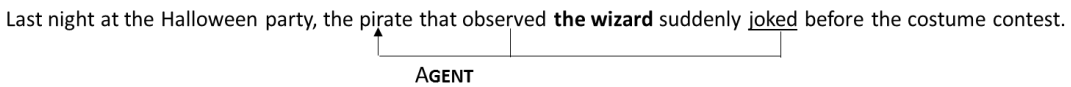
However, as we explain in greater detail below, we believe the data patterns in the unergative and unaccusative conditions in fact represent two separate processes; thematic role assignment for the unergative sentences and syntactic dependency linking for the unaccusative sentences.

While it is not possible to conclusively distinguish the processes motivating reactivation in the unergative versus the unaccusative condition in the current study, we point to key patterns in the current data and link it to prior published results below.

In the current data, for the AMC participants, reactivation occurs at an earlier time-point for the unergatives compared to the unaccusatives (see Table 9-12). We argue that the earlier onset suggests that a different process from that in the unaccusative sentences may be underlying reactivation. Consider the subject-relative that contains an unergative verb again below (30).

(30) Last night at the Halloween party, the pirate that observed the wizard/the pumpkin suddenly joked before the costume contest.

The single argument of the unergative verb, *the pirate* is assigned a thematic role by two verbs, it is assigned the Agent role by the verb *observed* in the relative clause, and an Agent role by the unergative verb, *joke*. It is therefore reasonable to assume that in order to be assigned a second thematic role, the single argument of the unergative verb would be reactivated upon hearing it.



Further support for the suggestion that reactivation is motivated by two different processes comes from Friedmann et al. (2008). They compared lexical activation patterns

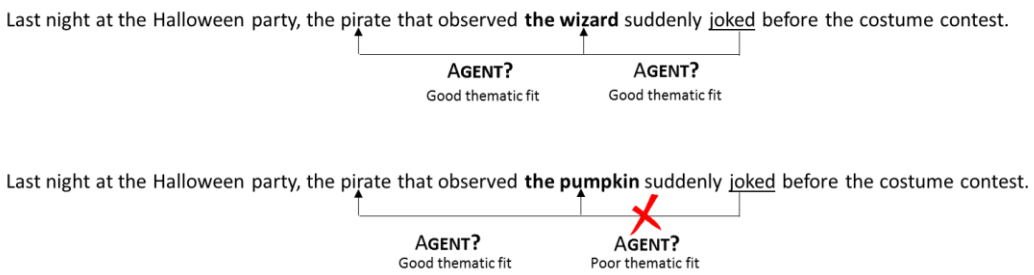
in sentences that contain unergative and unaccusative verbs in non-relative constructions that do not contain an intervener. Unlike the reactivation observed in the current study for the unergative verbs, reactivation of the single argument of the unergative verb was not found at a post verb position. Under this assumption/interpretation, it is not necessary to reactivate the displaced NP in the region of the verb as it is only assigned one thematic role by the unergative verb. The patterns observed for the IWBA in the current study within the unergative conditions align with the suggestion that reactivation is motivated by thematic role assignment.

For the IWBA reactivation is only found in the inanimate unergative condition. Compare the unergative animate sentence and unergative inanimate sentence below.

(31) Last night at the Halloween party, the pirate that observed the wizard suddenly <u>joked</u> before the costume contest.

(32) Last night at the Halloween party, the pirate that observed the pumpkin suddenly <u>joked</u> before the costume contest.

Recall that the unergative verb requires an argument to assign the thematic role of Agent. In the animate condition, NP2, *the wizard* and the single argument of the unergative verb, *the pirate* would both make a “good” Agent. That is, they are both equally likely to perform the action of the unergative verb, *joke*. However, in the inanimate condition, the inanimate NP2, *the pumpkin* is less likely to perform the action of the unergative verb, *joke*. Poor thematic fit of the Agent role for the inanimate NP2 in the inanimate condition eases thematic role assignment of the single argument.



Additionally, noteworthy is our finding that in the **inanimate unergative condition**, gazes to the animate distractor also increase at a post verb position. The animate distractor would also make a "good" Agent of the unergative verb. What remains uncertain is if IWBA have difficulty comprehending subject-relative sentences that contain an unergative verb and two animate NPs. A direct comparison may help to clarify if an intervener impacts sentence processing due to interfering with processing a syntactic dependency, or with thematic role assignment. Future work can help to answer these remaining questions.

In closing, we tested the Intervener Hypothesis using subject-relative sentences that contain unaccusative verbs and unergative verbs with NPs that matched in animacy, and NPs that mismatched in animacy. We found support for the Intervener Hypothesis as reactivation of the displaced NP was not found for the IWBA when the NPs matched in animacy within the unaccusative conditions. We did however find reactivation of the displaced NP when the NPs differed in animacy for the IWBA indicating that when NPs differ in animacy it reduces similarity-based interference caused by an intervener. Surprisingly, we found reactivation of a previously encountered NP in the unergative conditions. An earlier time-course of reactivation was found during the unergative sentences compared to the syntactically motivated reactivation found for the

unaccusatives, and therefore we suggest that reactivation within the unergatives results from a different process, perhaps thematic role assignment.

Chapter 9 is being prepared for submission for publication of material. Sullivan, N., Shapiro, L.P., Love, T., (*in preparation*). The intervener effect during the online processing of sentences that contain unaccusative verbs in aphasia. The dissertation author was the primary investigator and author of this paper.

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.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, 67(1), 1-48.

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.

Burzio, L. (1986). *Italian Syntax: A government-binding approach.* Dordrecht: Reidel Publishing Company.

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.

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.

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

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

Choy, J., & Thompson, C. K. (2010). Binding in agrammatic aphasia: Processing to comprehension. *Aphasiology*, *24*(5), 551-579.

Dink, J., Ferguson, B. (2016). _eyetrackingR. R package version 0.1.6, URL: http://www.eyetracking-R.com.

Drai, D., & Grodzinsky, Y. (2006). The variability debate: More statistics, more linguistics. *Brain and Language*, *96*(2), 157-170.

Engel, S., Shapiro, L.P., & Love, T., (submitted). Proform-Antecedent linking in individuals with agrammatic aphasia: A test of the intervener hypothesis. Manuscript submitted for publication.

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*(2), 179-189.

Friedmann, N., Taranto, G., Shapiro, L. P., & Swinney, D. (2008). The leaf fell (the leaf): The online processing of unaccusatives. *Linguistic Inquiry, 39* (3), 355-377.

Goodglass, H., Kaplan, E., & Barresi, B. (2000). *Boston diagnostic aphasia examination* (3rd Ed.). Philadelphia: Taylor & Francis.

Grodzinsky, Y. (2006). A blueprint for a brain map of syntax. In Amunts, K., Grodzinsky, Y. (Eds.), *Broca's Region* (83–108). New York: Oxford University Press.

Haarmann, H., Just, M., & Carpenter, P. (1997). Aphasic sentence comprehension as a resource deficit: A computational approach. *Brain and Language, 59(1),* 76-120.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of memory and language, 59*(4), 434-446.

Love, T., & Oster, E. (2002). On the categorization of aphasic typologies: The SOAP (a test of syntactic complexity). *Journal of Psycholinguistic Research, 31(5),* 503-529.

Love, T., & Swinney, D. (1996). Coreference processing and levels of analysis in object-relative constructions: Demonstration of antecedent re-activation with the cross-modal priming paradigm. *Journal of Psycholinguistic Research, 25*, 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.

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.

Perlmutter, D. M. (1978). Impersonal passives and the Unaccusative Hypothesis. In *Proceedings of the Fourth Annual Meeting of the Berkeley Linguistics Society* (157–189). Berkeley: University of California, Berkeley Linguistics Society.

Perlmutter, D. M., & Postal, P. (1984). The 1-Advancement Exclusiveness Law. In Perlmutter, D. & Rosen, C. (Eds.), *Studies in Relational Grammar* (281–126). Chicago: University of Chicago Press.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Shapiro, L. P., Oster, E., Garcia, R., Massey, A., & Thompson, C. K. (1999). Online comprehension of wh- questions in discourse. In Poster presented at the CUNY Conference on Human Sentence Processing.

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.

Sullivan, N., Walenski, M., Love, T., & Shapiro, L.P. (2017a). The comprehension of unaccusative verbs in aphasia: a test of the intervener hypothesis, *Aphasiology, 31*(1), 67-81.

Sullivan, N., Walenski, M., Love, T., & Shapiro, L.P. (2017b). The curious case of processing unaccusative verbs in aphasia, *Aphasiology*, Advance online publication. doi: 10.1080/02687038.2016.1274873.

Tanenhaus, M., Boland, J., Garnsey, S., & Carlson, G. (1989). Lexical structure in parsing long-distance dependencies. *Journal of Psycholinguistic Research (special issue on sentence processing), 18*, 37–50.

Thompson, C. K., & Choy, J. (2009). Pronominal resolution and gap filling in agrammatic aphasia: Evidence from eye movements. *Journal of Psycholinguistic Research, 38*(3), 255-283.

CHAPTER 10:

General Discussion and Conclusion

The primary goal of this dissertation was to investigate factors that contribute to the sentence comprehension deficits observed in Broca's aphasia. Individuals with Broca's aphasia (IWBA) show good comprehension of sentences in canonical S-V-O word order and difficulty with the comprehension of many non-canonical sentences (Caramazza & Zurif, 1976; Schwartz, Linebarger, Saffran, & Pate, 1987; Grodzinsky, 1990; Love & Oster, 2002). Several accounts have been proposed to account for these patterns, but almost all have conceptual shortcomings, or fall short in explaining the range of sentence types affected by the deficit. This dissertation focused on a new account of the sentence comprehension deficits in Broca's aphasia, the Intervener Hypothesis.

The Intervener Hypothesis (Sheppard, Walenski, Love & Shapiro, 2015; Sullivan, Walenski, Love & Shapiro, 2017; Engel, Shapiro & Love, submitted) posits that similarity-based interference is caused when the linking of two elements in a syntactic dependency crosses a noun phrase of similar structure, and thus confuses the listener as to "who did what to whom?" This hypothesis is grounded in the linguistic (e.g., Rizzi, 2004), psycholinguistic (e.g. Gordon, Hendrick, Johnson, & Lee, 2006), and aphasia literatures (Friedmann, 2008; Friedmann & Givon, 2012; Friedmann & Shapiro, 2003; Sheppard et al., 2015). The power of the hypothesis stems from its ability to generalize to several different sentence types and to predict which types should be comprehended well and which should not, while offering a single explanation for the response patterns.

Support for the Intervener Hypothesis also comes from two recent studies using two distinct sentential configurations that meet the requirements of an intervener: *Wh*-questions (Sheppard et al., 2015), and anaphors (Engel et al., submitted). This dissertation

used a multi-modal approach to further evaluate the Intervener Hypothesis in the context of a syntactic dependency inherent to a specific type of verb. As a reminder, unaccusative verbs are intransitive verbs, a verb type that requires only one argument. According to linguistic theory (Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984), the single argument of unaccusative verbs is base-generated in the object position and displaced to the grammatical subject position, leaving behind a gap. As sentences that contain unaccusative verbs contain a syntactic dependency, they can be embedded in specific sentence types to meet the requirements of containing an intervener. Unaccusative verbs have been the focus of previous investigations of online and offline sentence processing with IWBA, however, a specific class of unaccusative verbs called alternating unaccusatives were included in these studies. Alternating unaccusative verbs allow for two alternations: transitive and intransitive. Prior investigations have demonstrated that alternating unaccusatives pattern more like unergative verbs during real-time sentence processing (Friedmann, Taranto, Shapiro, and Swinney, 2008). Given these results, this dissertation limits its focus within unaccusative verbs to include only non-alternating unaccusative verbs.

Chapter 7 presented a cross-modal priming study that explored the time-course of lexical reactivation in sentences that contain unaccusative verbs with individuals who had a Broca's aphasia with a sentence comprehension disorder and age-matched control (AMC) participants. Results from previous studies establish that for neurologically unimpaired individuals, immediate reactivation of a displaced element is found at the gap (verb offset) for sentences that contain syntactic dependencies (Love & Swinney, 1996; Love, Swinney, Walenski, & Zurif, 2008; Shapiro, Oster, Garcia, Massey, & Thompson

1999; Tanenhaus, Boland, Garnsey, & Carlson, 1989). Critically, for unaccusative verbs the reactivation of a displaced element is not found until 750 ms downstream from the gap in unimpaired individuals (Friedmann et al., 2008). Compared to neurologically unimpaired subjects, individuals with Broca's aphasia exhibit a delayed time course of lexical activation, and reactivation (500 ms post verb offset; Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008; Love et al., 2008; Ferrill, Love, Walenski, & Shapiro, 2012).

In the original research study presented in chapter 7, reactivation of the displaced noun phrase was probed at four time points (indicated in superscript below), verb offset, 500 ms post verb offset, 750 ms post verb offset and, 1250 ms post verb offset during sentences such as (1).

(1) The tailor from East Orange, New Jersey disappeared <~~the tailor~~>[1] after[2] the[3] ridiculously[4] uninspiring self-help seminar.

The verb offset and 750 ms post verb time points are the same time points included in Friedmann et al., 2008. Inclusion of the 500 ms post verb position was included because reactivation of a displaced element was found at this time point for IWBA with other sentences that contain a filler-gap syntactic dependency. The 1250 ms point was included to test whether IWBA exhibit an even further delay compared to AMC participants. Reactivation of the displaced argument was found at the 750 ms post verb position for the AMC participants. These results provide a replication of Friedmann et al. (2008). IWBA exhibited reactivation of the displaced argument at the 500 ms post verb position, a time-course similar to that found in other sentences that contain syntactic dependencies. While the time-course of the two participant groups differ, results provide evidence that IWBA do not exhibit a delay in lexical reactivation compared to AMC participants with

unaccusative verbs. Of particular importance to the goals of this dissertation, these results indicate that IWBA are sensitive to the unaccusative property during auditory sentence processing.

Having established that IWBA are sensitive to the unaccusative property, Chapter 8 compared the final comprehension of two sentence constructions that contain unaccusative verbs to test the Intervener Hypothesis. Unaccusative verbs were embedded in subject-relatives (2) that require the crossing of an intervening noun phrase of similar structure to process the syntactic dependency. They were also embedded in complement phrase constructions (3) that did not contain interveners.

(2) The girl that observed **the boy** disappeared <~~the girl~~> into the trees.

(3) The girl observed that the boy disappeared <~~the boy~~> into the trees.

AMC participants demonstrated above chance comprehension of both sentences types. Similar to the AMCs, IWBA demonstrated above chance comprehension for the complement phrase constructions. However, results for the subject-relatives differed from the AMCs, where IWBA demonstrated chance comprehension. Performance in the complement phrase constructions further support that IWBA are sensitive to the unaccusative property and have intact comprehension of sentences that contain unaccusatives. Compromised performance in the subject-relative constructions provide strong support for the Intervener Hypothesis and suggest that the presence of a structurally similar noun phrase between the elements of the syntactic dependency leads to similarity-based interference that detrimentally impacts comprehension. The novelty of this finding is underscored by noting that IWBA typically do not have difficulty comprehending subject-relative sentences because they follow canonical word order. The

work presented in Chapter 8 reflects that it is only when an unaccusative verb is embedded in these constructions that difficulty arises.

Chapter 9 extends the evaluation of the Intervener Hypothesis to determine if similarity-based interference is responsible for poor comprehension of subject-relative sentences that contain an unaccusative in IWBA. Chapter 9 also builds on the methods of previous chapters by employing a method sensitive to capturing moment-to-moment changes in sentence processing. An eye tracking-while-listening task was used as it allows for determining if, when, and how interference occurs among the NPs in the sentence through the analysis of gazes to pictured referents. Subject-relative sentences that contain an unaccusative verb (4) were used to compare gaze patterns with IWBA and AMC participants.

(4) Last night at the Halloween party, the pirate that observed **the wizard** suddenly <u>emerged</u> <~~the pirate~~> before the costume contest.

Results from AMC participants aligned with our predictions: a greater proportion of gazes to the displaced NP was found at a post verb position indicating that sentence processing is not negatively impacted by an intervener. Results from IWBA also aligned with the predictions of the Intervener Hypothesis where no difference in the proportion of gazes to the displaced NP and the intervener were found. These results demonstrate that similarity-based interference caused by an intervener negatively impacts comprehension of subject-relative sentences that contain an unaccusative verb for IWBA.

Chapter 9 also included the first semantic manipulation of an intervener to determine if semantically distinguishing an intervener from a displaced NP reduces

similarity-based interference during online sentence processing. The animacy of the intervener was manipulated so that it differed from that of the displaced NP (5).

(5) Last night at the Halloween party, the pirate that observed **the pumpkin** suddenly emerged <~~the pirate~~> before the costume contest.

With a semantically distinguished intervener, a greater proportion of gazes to the displaced NP compared to the intervener were found for both AMC and IWBA participant groups. These results suggest a processing advantage for semantically distinguishing NPs as it reduces observed similarity-based interference.

An unexpected finding was revealed in Chapter 9, reactivation of a previously encountered NP after the verb for sentences that contain unergative verbs (6;7).

(6) Last night at the Halloween party, the pirate that observed the wizard suddenly joked before the costume contest.

(7) Last night at the Halloween party, the pirate that observed the pumpkin suddenly joked before the costume contest.

This was unexpected as sentences that contain unergative verbs do not contain a syntactic dependency. For the AMC participants, an earlier time-course of reactivation was found in the unergative conditions compared to the unaccusative conditions. For the IWBA, reactivation was only found for the inanimate unergative condition, and in that condition, descriptively, gazes to the animate distractor also increased after the verb. Therefore, I suggested that another process may be driving reactivation during the sentences that contain unergative verbs, thematic role assignment.

In closing, every 40 seconds someone in the United States has a stroke and roughly 1/3 of those strokes result in aphasia (National Aphasia Association, 2016). A

study that investigated the impact of 60 diseases and 15 conditions on quality of life reported that aphasia had the largest negative effect on quality of life (Lam & Wodchis, 2010). Determining the factors that contribute to the communication difficulties in individuals with aphasia are critical steps in assessment and treatment of aphasia. The findings presented in this dissertation have strong theoretical implications for the sentence processing deficits observed in Broca's aphasia. They provide support for the Intervener Hypothesis which suggests that similarity-based interference caused by structural and semantic similarity is responsible for the patterns of sentence comprehension found with IWBA. This hypothesis is quite powerful as it generalizes to several different sentence types and suggests which ones should be comprehended well and which should not, and offers a single explanation for the response patterns. Thus, the account proposes a relatively small deficit with wide-ranging implications. If the deficits across many sentence types can be linked to similarity-based interference caused by structurally and semantically similar NPs it will serve to motivate the development of assessment and treatment for investigation.

References

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.

Burzio, L. (1986). *Italian Syntax: A government-binding approach.* Dordrecht: Reidel Publishing Company.

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.

Engel, S., Shapiro, L.P., & Love, T., (submitted). Proform-Antecedent linking in individuals with agrammatic aphasia: A test of the intervener hypothesis. Manuscript submitted for publication.

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*(2), 179-189.

Friedmann, N. (2008). Traceless relatives: Agrammatic comprehension of relative clauses with resumptive pronouns. *Journal of Neurolinguistics, 21*(2), 138-149.

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

Friedmann, N., & Shapiro, L. (2003). Agrammatic comprehension of simple active sentences with moved constituents: Hebrew osv and ovs structures. *Journal of Speech, Language, and Hearing Research, 46*(2), 288-297.

Friedmann, N., Taranto, G., Shapiro, L. P., & Swinney, D. (2008). The leaf fell (the leaf): The online processing of unaccusatives. *Linguistic Inquiry, 39(3),* 355-377.

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*(6), 1304-1321.

Grodzinsky, Y. (1990). Theoretical Perspectives on Language Deficits. MIT Press.

Lam, J.M.C. & Wodchis, W. P. (2010) The relationship of 60 disease diagnoses and 15 conditions to preference-based health-related quality of life in Ontario hospital-based long-term care residents. Medical Care, 48, 380-387.

Love, T., & Oster, E. (2002). On the categorization of aphasic typologies: The SOAP (a test of syntactic complexity). *Journal of Psycholinguistic Research, 31(5),* 503-529.

Love, T., & Swinney, D. (1996). Coreference processing and levels of analysis in object-relative constructions: Demonstration of antecedent re-activation with the cross-modal priming paradigm. *Journal of Psycholinguistic Research, 25*, 5–24.

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

National Aphasia Association (2016), Aphasia Fact Sheet. Retrieved from https://www.aphasia.org/aphasia-resources/aphasia-factsheet/

Perlmutter, D. M. (1978). Impersonal passives and the unaccusative hypothesis. *Proceedings of the 4th Annual Meeting of the Berkeley Linguistics Society* (pp. 157-189). Berkeley: University of California: Berkeley Linguistics Society.

Perlmutter, D. M., & Postal, P. M. (1984). The 1-Advancement Exclusiveness Law. In D. Perlmutter, & C. Rosen (Eds.), *Studies in Relational Grammar 2* (pp. 81-126). Chicago: University of Chicago Press.

Rizzi, L. (2004). Locality and left periphery. In A. Belletti (Ed.), *Structures and Beyond: The cartography of syntactic structures* (Vol. 3). New York, NY: Oxford University Press.

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

Shapiro, L. P., Oster, E., Garcia, R., Massey, A., & Thompson, C. K. (1999). Online comprehension of wh- questions in discourse. In Poster presented at the CUNY Conference on Human Sentence Processing.

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.

Sullivan, N., Walenski, M., Love, T., & Shapiro, L.P. (2017). The comprehension of unaccusative verbs in aphasia: a test of the intervener hypothesis, *Aphasiology, 31*(1), 67-81.

Tanenhaus, M., Boland, J., Garnsey, S., & Carlson, G. (1989). Lexical structure in parsing long-distance dependencies. *Journal of Psycholinguistic Research (special issue on sentence processing), 18*, 37–50.