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More than Words:
Lexical Processing During Sentence Comprehension in Broca's Aphasia

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

in

Language and Communicative Disorders

by

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2015

The Dissertation of Michelle Lynn Ferrill is approved, and is acceptable in quality and

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University of California, San Diego

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DEDICATION

This dissertation is dedicated to the memory of my mother, Debby Gravier. She

taught me the value of hard work, patience, selflessness, empathy, and most

importantly a good sense of humor. Without her support and guiding spirit I would

not be where I am today.

EPIGRAPH

No matter what people tell you, words and ideas can change the world

– Robin Williams

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ABSTRACT OF THE DISSERTATION

More than Words:
Lexical Processing During Sentence Comprehension in Broca's Aphasia

by

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Doctor of Philosophy in Language and Communicative Disorders

University of California, San Diego, 2015
San Diego State University, 2015

Professor Tracy Love, Chair
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Though Broca's aphasia is traditionally defined as an expressive language impairment, listeners with Broca's aphasia (LWBA) typically evince sentence comprehension deficits as well. These comprehension deficits are characterized by difficulty understanding certain types of sentences that contain complex syntax. While some research proposes that the source of the comprehension disorder can be

attributed to a syntactic processing delay, other research argues that syntactic

processing impairments are secondary to primary lexical processing impairments. The

Delayed Lexical Activation Hypothesis (DLA) suggests that a slowed lexical

activation system results in lexical information "feeding" syntactic processing too

slowly, leading to a mismatch between processing rate and what is required for fast-

acting processing routines.

   A series of three studies with LWBA are presented to explore (a) if the DLA

holds in the face of simple, canonically ordered sentences (Chapter 3), and (b) if

lexical access delays can be mitigated through manipulations of speech input rate

(Chapter 4) and/or cue based prediction (Chapter 5).

   Chapter 2 reviews current research with LWBA and details prior empirical

evidence supporting the presence of a processing delay in both lexical and syntactic

processing. Chapter 3 presents evidence of real-time lexical access during processing

of syntactically simple sentences. Results showed LWBA demonstrated a pattern of

protracted lexical access as compared to unimpaired controls. Chapter 4 explores if

slowed input rate would combine with the purported slowed lexical activation to yield

'on-time' lexical access patterns. While a LWBA group effect of rate was not found,

interesting patterns emerged when considering individual patterns of brain damage. It

was found that the proportion of damage to a brain region of interest implicated in

lexical, but not syntactic processing, significantly predicted the effect of rate of speech

on the time-course of lexical access. Finally, Chapter 5 investigates if LWBA

demonstrate predictive processing by showing 'on-time' access with contextual cues that unimpaired listeners have been shown to use - biased adjectives. LWBA were able to use semantic, not structural, cues to mitigate a lexical access delay. These results taken together support the DLA hypothesis; that a lexical access delay underlies the comprehension disorder in LWBA.

CHAPTER 1:

Introduction

1.0 Introduction

Aphasia is an acquired language disorder that occurs subsequent to neural

trauma, typically stroke, and can result in deficits related to expressive language (e.g.,

naming or writing), receptive language (comprehension), or both. Although many

sub-classifications of aphasia exist based on the varying degrees to which these

domains are impaired, Broca's aphasia has historically been of particular interest to

researchers involved in sentence processing.   Individuals with Broca's aphasia

demonstrate an obvious expressive impairment, characterized by non-fluent,

agrammatic speech (Goodglass & Kaplan, 1972) but relatively preserved

comprehension of simple sentences. However,, individuals with Broca's aphasia do

have difficulty understanding certain types of sentences, particularly syntactically

complex ones that do not follow typical "canonical" word order (subject-verb-object

in English: Blumstein & Milberg, 2000; Caramazza & Zurif, 1976; Love, Swinney,

Walenski, & Zurif, 2008; Zurif, Swinney, Prather, Solomon, & Bushell, 1993).

Furthermore, these deficits are revealed by minimal experimental probing, diagnosed

for example by performance on a sentence-to-picture matching task. The presence of

this unique pattern of deficits not only allows for opportunities to inform models of

how unimpaired listeners process language by demonstrating how distinct aspects of

language can be discretely impaired (or not), but also how those processes are

impacted by damage to the specific areas of the brain that typically result in Broca's

aphasia, specifically the inferior frontal cortex, known as Broca's area. I will return to

a discussion of this ability to inform neurolinguistic models of language processing by relating impaired function to affected brain structures a bit later.

Because of the seemingly relative intactness of word and simple sentence-level comprehension in Broca's aphasia as revealed via methods that measure the culmination of the use of all sources of information that can be brought to bear in making a conscious decision (so-called offline methods), most studies have focused on syntactic processing, largely ignoring lexical processing. More recently, technological advancements have enabled researchers to examine processing as it occurs via on-line methods such as cross-modal priming and eye tracking. On-line, real-time methods have been able to reveal new patterns of processing in aphasia that offline methods are unable to observe. For example, using these methods, several recent studies have identified lexical processing deficits in this population (Love et al., 2008; Thompson & Choy, 2009). These studies support hypotheses that the purported syntactic impairments in Broca's aphasia are secondary consequences to the primary lexical processing impairments.

For example, Love et al. (2008) presented sentences such as (1) below to listeners with Broca's aphasia (LWBA) and neurologically unimpaired control participants:

1) The audience liked the wrestler$_i$ $_{object}$ that the parish priest $_{subject}$ condemned $_{verb}$ ~~the wrestler$_i$~~ for foul language.

In this sentence, the object noun phrase (NP) *the wrestler* has been displaced from its underlying location following the verb *condemned* to a preverb position, leaving behind a phonologically null marker, a "gap," which then co-refers with the NP. In contrast to the unimpaired listeners in the study, who demonstrated immediate lexical access at the offset of the noun and again at the structurally-licensed location at the offset of the verb, the LWBA showed delayed lexical access at both time-points. As lexical access is delayed in Broca's aphasics for the object at *both* positions, Love et al (2008) suggested the "Delayed Lexical Activation" hypothesis of comprehension deficits in Broca's aphasia, claiming that lexical access is protracted in the disorder. Although the various lexical accounts differ in their specifics, the basic claim is that, as lexical processing serves as the interface between the sensory input and the construction of a structural and interpretative representation of an utterance, a breakdown at this more basic level can have cascading effects, disrupting later processing operations.

Although the finding of delayed activation for an NP when it was initially encountered by LWBA suggests that this delay would generalize to syntactically simple sentences, that hypothesis has not been tested until this point. The existing studies have either used syntactically complex sentences (such as (1) from Love et al., 2008) or single words lists (Hagoort, 1993; Milberg, Blumstein, & Dworetzky, 1987; Prather, Zurif, Love, & Brownell, 1997). Furthermore, the majority of the studies employing single word lists have an additional confound, as they were primarily interested in the investigation of some sort of overt lexical ambiguity, that is, processing of words that can have potentially more than one salient meaning.

As suggested above, the DLA posits that the underlying nature of the language deficits in some LWBA results from a slowed lexical activation system. This slow rise of lexical activation may result in lexical information "feeding" syntactic processing too slowly, leading to breakdowns of automatic structure-building and resulting ultimately in the apparent syntactic deficits seen in Broca's aphasia. In contrast, the "slow syntax" hypothesis (Avrutin, 2006; Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008; Piñango, 2000) posits that it is the syntactic system itself, or rather syntactic structure formation, which is slowed or weakened. As evidence for this claim, Burkhardt et al. (2008) used a cross-modal interference task to measure when syntactic dependencies (similar to, for example, the relation between the NP and the gap in (1)), were processed for LWBA. In contrast to control participants who showed evidence of interference immediately at the point at which the dependency was expected to be formed, the listeners with Broca's aphasia did not show such interference effects until 500ms downstream from that point. According to this slow-syntax hypothesis, lexical access of NPs (but notably, not predicates) should not be disrupted. Therefore, if there is a lexical disruption in Broca's aphasia for syntactically simple sentences, it is likely to be independent of any syntactic deficits.

1.1 Overview of Dissertation

The primary goal of this dissertation, then, is to investigate the time-course of lexical processing during on-line sentence processing of *syntactically simple sentences* containing *unambiguous* NPs in order to further explore the claims of the DLA in

contrast to those of the slow syntax hypothesis. The claims of these two accounts will be tested in a series of three studies for which each account makes specific and testable predictions. The second and third studies, described in more detail below, will explore whether slowing the rate of speech input or providing local contextual cues to an upcoming NP allow LWBA to evince on-time lexical access. In addition to directly testing the hypotheses of the two accounts of the sentence comprehension deficits in aphasia, the DLA and the slow syntax hypothesis, being able to elicit on-time or facilitated lexical access may have implications for potential applications to clinical interventions for the comprehension disorder. I return to this point in the conclusions section.

The first study in the series, reported in Chapter 3, examines lexical access during processing of syntactically simple, unambiguous sentences such as (2) below by neurologically unimpaired listeners and LWBA.

2) The boxer punched the golfer* after* the tr*emendou*sly antagonistic title fight

In contrast to the sentence stimuli used by Love et al (2008), these sentences follow canonical, subject-verb-object word order and contain no apparent syntactic dependencies. Lexical access for the object NP, *the golfer* in this example, will be examined at four time-points of interest: directly at the offset of the object NP, 400, 800, and 1200 ms downstream (indicated by the asterisks in (2)).

As all three of the studies presented in this dissertation will use the same

methodology, cross-modal picture priming (CMPP; Swinney & Prather, 1989), a quick methodological note here is warranted. In CMPP, participants hear a sentence, such as (2) above, and make a binary YES/NO decision for a visual picture probe that appears on a computer screen at a specified point during the uninterrupted sentence. Based on the principles of automatic semantic priming (Collins & Loftus, 1975; Neely, 1977), speeded reaction times (RTs) to this binary decision for probes that are related to material in the sentence as compared to when they are unrelated (priming) is taken as an indication of lexical access of that item (Onifer & Swinney, 1981; Swinney, 1979). So, for example, faster RTs to a binary decision regarding a picture of a golfer in (2) at the offset of the NP *the golfer* than RTs to the same picture of a golfer presented in an unrelated sentence would indicate that the NP *the golfer* had been accessed *at the time-point at which the picture was presented* in the related condition (for more details regarding this method, refer to the Methods sections of Chapters 3-5).

To review, the two accounts that are tested in this series of studies, the DLA and the slow syntax accounts, make distinct predictions as to when priming should be observed in sentences such as (2). If, as the slow syntax account claims, sentence comprehension deficits in Broca's aphasia are due to delayed structure-building, then for sentences like (2) where resources for structure-building are minimally taxed, the time-course of lexical activation should be similar to that of unimpaired control participants, that is, on-time, with priming found at the offset of the object NP. On the other hand, if, as the DLA claims, delayed lexical access is a hallmark of the disorder, regardless of the syntax of the sentence, lexical access should remain delayed with

priming not evident until a later probe position.

Chapter 4 presents an investigation of the effect of slowed speech rate on the time-course of lexical access during sentence processing for sentences such as (2). As the DLA claims that the breakdown in comprehension in Broca's aphasia is due to a mismatch in the time-course of availability of lexical information and the time at which that information is required by fast-acting processes such as syntactic dependency formation for successful comprehension, it is hypothesized that slowing the rate of speech will result in a relaxation of those time constraints. This relaxation should allow for "on-time" access of the lexical items, that is, at their offset. There is evidence from Love et al (2008, Experiment 2) to suggest that this would be the case. By presenting sentences slowed by 1/3, the LWBA were able to evince on-time lexical re-access at the gap, and improved offline comprehension of syntactically complex sentences. Considering that slowing rate of speech resulted in a pattern of improved processing for syntactically governed processes, the slow syntax account would appear to be supported if slowing the speech rate does not also result in facilitated lexical access.. Importantly, this study uses identical sentence stimuli and method (CMPP) with identical picture probes as the study presented in Chapter 3. Furthermore, the same subjects with Broca's aphasia who participated in that study are included in this follow-up study (with the exception of one subject who declined to participate). Enrolling the same participants across studies allows for a more direct comparison of the effect of rate of speech input on the time-course of lexical access during sentence processing by minimizing the contributions of variability introduced by those factors.

Foreshadowing the results of this study, I return briefly to a discussion of brain

–language relationships. As mentioned previously, one of the reasons that the sentence comprehension disorder in Broca's aphasia is so interesting for researchers is because of the specific pattern of language impairments that is characteristic of the disorder. By linking the particular aspects of language processing that are impaired in this population with the areas of the brain that are most often implicated in the lesions of individuals with Broca's aphasia, specifically, the left inferior frontal gyrus (L IFG), and superior temporal lobe, the functional contribution of these brain regions to language processing can be inferred. However, in many cases a diagnosis of Broca's aphasia is taken by researchers to automatically indicate damage to Broca's area, which may or may not be the case (Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004). Additionally, the variability in the amount of damage to these regions is typically not considered, and rather, all participants are treated as homogeneous members of a group. However, with recent advances in cytoarchitectonic mapping to functionally parcellate these brain regions (e.g., Amunts et al., 1999; see Chapter 4 for more details) the amount of damage to brain regions involved in language processing, including anterior portions of LIFG (BA45), posterior portions of LIFG (BA44) and portions of the superior temporal lobe corresponding to Wernicke's area (Te3) can be more accurately assessed in vivo for individuals following brain damage. This allows for individual differences in brain damage to these regions to be considered as a possible source of variability in behavioral measures such as priming. Furthermore, by correlating behavioral measures with particular brain regions, some light may be shed on the nature of the process underlying the behavioral measure. For example, BA45 has been linked in the literature to controlled semantic retrieval, whereas BA44

has been linked to structure-building and syntactic processing. In Chapter 4, priming at the first two probe positions will be compared with the proportion of lesion to these areas within individual participants. A significant relationship between BA45 and the change in priming due to slowed rate of speech would indicate that slowing rate of speech acts on the lexical-semantic system/controlled semantic retrieval, which would provide support for the DLA. In contrast, a significant relationship between BA44 and the change in priming due to slowed rate of speech would indicate that slowing rate of speech acts on the syntactic system/structure-building, which would provide support for the slow syntax hypothesis.

Chapter 5 will report on a study that explores the effects of structural and semantic processing cues on the time-course of lexical access in syntactically simple sentences. Previous research has shown that neurologically unimpaired listeners are able to use structural and semantic contextual information to narrow down and in some cases predict aspects of upcoming words (see Kamide, 2008 for review). There is also some evidence, albeit limited, to suggest that LWBA may be able to take advantage of these processing cues in a manner similar to control participants (Mack, Ji, & Thompson, 2013). Experimental sentences for the study will take the same form as those in the previous two studies, that is, canonical, syntactically simple sentences containing unambiguous noun phrases. However, an adjective providing a local processing cue will be presented immediately preceding the noun. The adjective will provide either a structural cue (NON-BIAS), a semantic cue (SEM BIAS) or a probabilistic cue (PROB BIAS) to the upcoming NP.

[SEM BIAS]	3a)	The duck led the **_dirty_**[1] _pig_[2] along the long and winding country road
[SEM NON-BIAS]	3b)	The duck led the **_dizzy_**[1] _pig_[2] along the long and winding country road
[PROB BIAS]	4a)	The doctor visited the **_gifted_**[1] _student_[2] after the unexpectedly turbulent helicopter ride
[PROB NON-BIAS]	4b)	The doctor visited the **_giddy_**[1] _student_[2] after the unexpectedly turbulent helicopter ride

In the structural, NON-BIAS cue conditions, the adjective provides information as to the word class of the upcoming word, but is itself devoid of any information that would allow a listener to predict the identity or access the semantic features of the upcoming NP. If the LWBA are able to use the adjectives in the NON-BIAS condition to evince a time-course of lexical activation similar to controls, this would suggest that cues to aid structure-building resulted in facilitated lexical access and would therefore provide support the slow syntax hypothesis. In the SEM BIAS condition, the adjective provides a semantic cue to the upcoming item, potentially allowing for pre-activation of features of the NP and resulting in facilitated or anticipatory priming. For example, the adjective _dirty_ in (3a) above, is highly semantically related to the NP _pig_. In the PROB BIAS condition, adjectives that frequently appear preceding the following NP are presented providing usage-based information. For example, the adjective _gifted_ in (4a) above, is commonly encountered prior to the word _student_. This usage-based information is argued by some linguistic models to be part of a lexical entry, particularly by constraint-based models and models of language learning (Seidenberg, 1997), and so might provide

another source of information to facilitate activation of the following lexical item. Based on this, if no effect is found when only the structural cue is provided by the adjective, but an additional cue, either semantic or probabilistic, results in facilitated lexical processing for LWBA, this would suggest, again, that the source of the lexical access delay is in fact slowed availability of the information contained in the lexical entry, in turn supporting the DLA. Additionally, this study provides the first known examination of whether individuals with Broca's aphasia are able to use anticipatory processing cues in the absence of the visual cues that are provided in visual word eye-tracking experiments. If so, this may more accurately reflect their ability to do so in more naturalistic language use situations (such as having an everyday conversation).

Finally, Chapter 6 will conclude by discussing the implications of the results of the studies reported in the previous three chapters on each of the posited models; the DLA, and the slow syntax account. Additionally, future directions and the potential impact of these outcomes on clinical intervention approaches will be discussed.

Before the studies are presented, the pertinent background will first be reviewed in more depth in Chapter 2. The Chapter will begin with a general overview of psycholinguistics and neural models of sentence processing in unimpaired listeners focusing on the lexical processing. Then, a brief review of the literature on sentence comprehension deficits in Broca's aphasia will be given including a discussion of both grammatical accounts, including but not limited to the slow syntax account, and lexical accounts, including but not limited to the DLA. Finally, the goals and contributions of the current studies will be reiterated, accounting for this information.

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CHAPTER 2:

Sentence Processing

2.0. Models of Sentence Processing in Unimpaired Listeners

Models that attempt to account for how neurologically unimpaired listeners process spoken language, and specifically for our interests here, lexical items encountered in sentences, generally fall into two broad categories: **modular and interactive**, differing primarily based on the time-course at which context is posited to be used.

Modular or autonomous models (Forster, 1979; Forster, 1976; Tanenhaus, Carlson, & Seidenberg, 1985) claim that language processing consists of a set of isolable, autonomous substages or modules, each of which are responsible for specific processes (e.g. Fodor, 1983) with little (or no) interaction among modules. These modules are generally feed-forward, meaning that the input to one module is dependent on the output of the previous operation in a 'linear' progression. On this account, the sub-processes are likened to stages through which lexical processing must proceed. Thus, lexical processing up to and including the lexical selection stage is autonomous, and driven only by bottom-up sensory information. Contextual information, therefore, is only used during the lexical integration stage. It is during this stage that the aforementioned semantic and syntactic constraints based on the preceding context are applied (Friederici et al., 1999).

Evidence supporting a modular view of sentence processing comes from, for example, a cross-modal priming study by Swinney (1979). Swinney (1979) presented LWBA sentences that were rated to be highly predictive of a particular reading of an ambiguity (see (1) and (2) below). Visual probes were presented at the offset of the

ambiguous word in Experiment 1 (*1) or three syllables downstream in Experiment 2

(*2). Visual probe words were either related to the contextually relevant meaning

("insect"), the contextually inappropriate meaning ("spy"), or were unrelated ("sew").

> (1) Rumor had it that, for years, the government building had been plagued
> with problems. The man was not surprised when he found several spiders,
> roaches, and other ***bugs*1*** in the comer*2 of his room. (Biasing context)
> (2) Rumor had it that, for years, the government building had been plagued
> with problems. The man was not surprised when he found several ***bugs**** in
> the corner of his room. (Neutral Context)

Swinney found a priming effect for both the contextually relevant ("insect")

and the contextually inappropriate ("spy") meanings at the offset of the ambiguous

word (at *1). Furthermore, this pattern was found in both the biasing and neutral

contexts. These results suggest that listeners exhaustively access all meanings of

words immediately after hearing them, regardless of a strong biasing context. By

three syllables downstream, a priming effect was found only for the contextually

coherent meaning, suggesting that context effects came into play at a post-access stage

of lexical processing. These findings are in-line with the predictions made by a

modular model of lexical processing in which the initial stages are impervious to

extra-lexical information.

In contrast, ***interactive*** models claim that multiple levels of representation are

constructed simultaneously and can interact with one another during processing, most

often in a parallel fashion. Examples of interactive processing models include

constraint-based and probabilistic models (Jurafsky, 1996; MacDonald et al., 1994;

McClelland & Elman, 1986; McRae, Spivey-Knowlton, & Tanenhaus, 1998;

Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Trueswell & Tanenhaus, 1994). Typically in these models, the lexical entries in memory are highly detailed and contain statistical information based on a listener's experience. According to these models, during lexical processing the incoming sensory information is considered simultaneously with the constraints imposed by the information contained in the lexical entries of the preceding context to evaluate activated candidates. The candidate that best fits all of the applied constraints from the sentence and the discourse is fully activated.

In "strongly interactive" models context can affect processing via expectancy-based priming, also referred to as anticipatory or predictive priming. In this kind of priming, in contrast to semantic priming, the preceding context can facilitate lexical access even in the absence of words that are directly semantically associated. Rather, words can be accessed based on how frequently they occur following a preceding word or how well they fit into the set of syntactic and semantic constraints imposed by the preceding sentence (Duffy, Henderson, & Morris, 1989; Morris, 1992).

Evidence supporting interactive models of sentence processing have primarily used methods other than cross-modal priming, such as the visual world eye tracking-while-listening tasks (VWP; Cooper, 1974; Tanenhaus et al., 1995) and event-related potentials (ERP; Kutas & Hillyard, 1984). Generally, VWP experiments require participants to listen to sentences while their eye movements and gazes (fixations) to a visual display on a computer screen are measured. Eye movements have been found

to be time-locked within 200ms to auditory language presentation, which allows approximation of real-time processing (Sussman & Sedivy, 2003).

In one such VWP study by Altmann and Kamide (1999), participants were asked to listen to sentences such as "The boy will *move* the cake" or "The boy will *eat* the cake" while viewing a visual scene containing several movable objects, but only one edible one. Participants were significantly more likely to look toward the cake in the condition for which the cake was the only plausible referent (the restrictive *eat* sentence condition) compared to when it was one of several plausible referents (in the unrestrictive *move* condition). Furthermore, the increase in looks to the cake in the restrictive condition occurred prior to the acoustic onset of the word *cake* itself. This pattern suggests that listeners are able to use semantic information from the context to anticipate or at least restrict the pool of referents of an upcoming NP *prior* to the onset of any overt (bottom-up) phonological information. However, as visual as well as linguistic context was afforded in this case, it is impossible to tell whether this same restrictive information would have resulted in anticipatory processing in the absence of the additional constraints imposed by the visual context.

Some insight into how context can affect lexical access in an anticipatory fashion in the absence of visual constraints comes from studies using event-related potentials (ERP). In this method, participants are presented with either auditory or visual stimuli while electrodes placed on the scalp record voltage changes in an ongoing electroencephalogram (EEG). The EEG signal reflects activity of populations of neurons with high temporally sensitivity, on the order of tens of milliseconds. The

changes are then time-locked to the onset of the stimuli and averaged across trials to get a picture of how the brain is responding to the particular stimulus type. Scalp-recorded ERPs consist of a series of positive and negative voltage peaks (or "components") that are distributed across time and can be distinguished by such characteristics as latency, amplitude, polarity, and scalp distribution.

One of these components, the N400 - so named because it is a negative-going component peaking approximately 400 ms after the stimulus - is generally attributed to semantic processing. The amplitude of the N400 has been found to be modulated by lexical predictability, regardless of the strength of the constraint of the sentence (Kutas & Hillyard, 1984). The predictability of a lexical item based on context is generally measured via a cloze task in which participants are asked to complete a sentence fragment with the first word that comes to mind. The cloze probability is the proportion of people who give a particular word as the most likely completion of a sentence fragment (Taylor, 1953). For example, in the sentence "The paint turned out to be the wrong shade," *shade* is a low cloze continuation of a high-constraint sentence, whereas in the sentence "He was soothed by the gentle wind," *wind* is a low cloze continuation of a low-constraint sentence; both of these types of endings elicited a similar N400. Researchers generally attribute this effect to ease of lexical access afforded by the context (e.g., Federmeier, 2007; Kutas & Federmeier, 2000).

An ERP study by DeLong, Urbach, and Kutas (2005) examined anticipation of a semantically plausible noun by a preceding narrative and verb. They presented sentences such as (3) and (4) below to participants while EEGs were recorded.

(3) The day was breezy, so the boy went outside to fly a kite.

(4) The day was breezy, so the boy went outside to fly an airplane.

The more expected noun required a different article (*a* *kite*) than the less expected

noun (***an*** *airplane*). Therefore, if participants were in fact anticipating a particular

lexical item, a violation should occur upon seeing the wrong version of the article, and

this violation should be reflected in the N400. The results did show a larger N400 in

the unexpected noun condition as early as the article, suggesting that a particular

lexical item had been anticipated. Furthermore, the results replicated those of Kutas

and Hillyard (1984), as the N400 amplitude to the unexpected article was inversely

correlated with the cloze probability of the noun. Although this particular study is a

reading study, similar effects have been found with auditory sentence presentation in

languages other than English (Van Berkum, Brown, Zwitserlood, Kooijman, &

Hagoort, 2005).

In general, recent sentence processing literature suggests that listeners are able

to use context in an interactive fashion, although perhaps not all type of information

and not in all circumstances. This may be related to a potential processing cost of

making an incorrect prediction, in which case a revision would need to be made,

compared to the relative benefit of making a correct prediction (Van Petten & Luka,

2012). Therefore, it is likely that an anticipatory processing cue would have to be

certain enough for the listener to risk that cost. Furthermore, as the results of few

cross-modal priming studies have supported interactive processing models, perhaps

CMP is not as sensitive to what might be smaller priming effects that *are* reflected in

other methods such as VWP and ERP. The study described in Chapter 5 will be able to directly address this question, as the effect of anticipatory processing cues will be evaluated in a cross-modal priming study.

As the study described in Chapter 4 will be investigating brain structure-function relationships by comparing the location and extent of brain damage and real-time processing measures, here a brief review of the brain regions implicated in language processing is provided. In general, neuroimaging studies have implicated three main brain regions in lexical processing during sentence comprehension for neurologically unimpaired listeners; left anterior temporal cortex, the left posterior temporal cortex, and the left inferior frontal cortex roughly corresponding to Broca's area (Lau, Phillips, & Poeppel, 2008). For our purposes here, the discussion will focus on the latter two regions.

Although information about objects and concepts is argued to be broadly distributed in the brain (for review, see Bookheimer, 2002), the **left posterior temporal cortex** (pITC) has been mainly identified in studies isolating **lexical access**. Sub-regions of the left posterior temporal cortex specifically implicated include the posterior middle temporal gyrus (pMTG), superior temporal sulcus (STS) and inferior temporal cortex (Gagnepain et al., 2008; Gold et al., 2006; Rissman, Eliassen, & Blumstein, 2003; Rodd, Davis, & Johnsrude, 2005). Importantly, although most studies of lexical access have used single word or word-list stimuli, the involvement of pITC in lexical access has been corroborated by studies employing sentence-level stimuli. For example, a recent study found that pMTG and pITC were recruited more

for sentences ending in lower cloze words compared to higher cloze words (Dien et al., 2008).

Activation of the **left inferior frontal cortex** (L IFG) during lexical processing has been associated with the **selection** of the intended words from among multiple competing lexical candidates, also sometimes referred to as controlled semantic retrieval (Buckner, Koutstaal, Schacter, & Rosen, 2000; Petersen, Fox, Posner, Mintun, & Raichle, 1988; Su, Fonteneau, Marslen-Wilson, & Kriegeskorte, 2012). Consistent with this view, LIFG has also been implicated in studies of lexical ambiguity resolution (Mason & Just, 2007; Rodd et al., 2005). For example, Rodd et al. (2005) had participants listen to sentences containing several semantically ambiguous words such as 'The *shell* was *fired* toward the *tank*,' frequency and length-matched control sentences with unambiguous words, or signal correlated noise. Significantly increased activation was found in bilateral IFG (pars triangularis, BA45) for the sentences with semantically ambiguous words compared to control sentences.

The Rodd et al. (2005) finding of BA45 activation in the absence of associated activation of BA44 is consistent with studies that have suggested a functional dissociation between those two sub-regions of LIFG (Friederici, 2011; Vigneau et al., 2006). Within this framework, anterior ventral IFG (BA45, although sometimes also considered to include BA47) is typically linked to semantic processing whereas posterior IFG (BA44) is typically linked to syntactic processing and structure-building (Poldrack et al., 1999; Wagner, Koutstaal, Maril, Schacter, & Buckner, 2000). For example, using dynamic causal modeling (a statistical procedure for estimating

coupling between brain regions over time) the strength of the connection between

pITC, linked to lexical access, and BA45 was enhanced during lexical decisions

(Heim et al., 2009). These results suggest that BA 45/47 and the pITC are part of a

network of brain regions involved in lexical processing.

2.1 Sentence Comprehension Deficits in Broca's Aphasia

Broca's aphasia is typically characterized by halting, non-fluent speech with

production of mainly root content words and omission of grammatical function words

(such as "is" and "the"). As such, historically, Broca's aphasia was primarily

considered a disorder affecting production, not comprehension. Researchers originally

surmised that comprehension was relatively spared because early studies with Broca's

patients showed that they were able to understand single words and simple sentences.

However, during the mid-to-late 1970's, researchers found that individuals with

Broca's aphasia also had comprehension deficits that could be revealed by minimal

experimental probing (Caramazza & Zurif, 1976). In particular, these patients

exhibited difficulty understanding sentences that did not follow canonical word order

(subject-verb-object, or SVO, in English). For example, sentences containing an

object-extracted relative clause like (5) below, in which the constituents are in non-

canonical word order often elicit chance performance in sentence-picture matching

tasks (Grodzinsky, 1990; Love & Oster, 2002):

(5) The boy$_i$ who the man pushed [t$_i$] was wearing a red shirt.

Since Caramazza and Zurif (1976), there have been a host of studies that have found similar patterns of impairment (see, for example, Blumstein & Milberg, 2000; Grodzinsky, 1995, 2000; Love et al., 2008; Zurif et al., 1993).

As previously introduced, some insight into the nature of these deficits can be gained by evaluating the syntax underlying the comprehension of these types of non-canonical sentences. For instance, in (2), the object of the verb (*the boy*) has been displaced from the underlying post-verb position to a position occurring earlier in the sentence, forming a syntactic dependency (Chomsky, 1981, 1986). Consequently, a "gap" or trace of the displaced noun phrase (NP) is left behind (as indicated by the [t] in (5) above). The displaced NP forms a syntactic chain with its underlying position (as indicated by the subscript 'i'). Furthermore, the verb 'pushed' assigns its thematic roles to these chains (e.g., the noun phrase doing the pushing, or the 'agent,' and the noun phrase receiving the pushing, or the 'theme') based on the underlying positions regardless of the actual ordering of the constituents in the sentence. Therefore, the role of Agent is assigned to the NP *the man* and the displaced NP, *The boy*, inherits the thematic role that was assigned to the direct object position via the chain formed with the trace. In order to successfully comprehend sentences like (5), a listener must connect the two non-adjacent positions that form the dependency.

2.1.1 Grammar-Oriented Accounts of Comprehension Deficits in Broca's Aphasia

The sentences that pose difficulty for LWBA generally have in common that they involve a dependency relation, such as the one in (5) described above. One class

of accounts claims that the cause of the impairment lies in the grammar; these are referred to as *grammar-oriented accounts*.

One of the most influential *grammar-oriented* accounts is the Trace Deletion Hypothesis (TDH; Grodzinsky, 1985, 1995, 2000 and many others). The TDH claims that LWBA are not able to represent the traces left behind by moved constituents. As a consequence, returning to (5) again, for example, the agent role is correctly assigned, but the theme role assigned to underlying direct object position does not co-refer with the displaced NP. Therefore, the displaced NP does not get a thematic role. Faced with this difficulty, the parser defaults to an agent-first heuristic, assigning the agent role to the first NP in the sentence, *the boy*. Because the role of Agent has already been assigned grammatically to the subject position, the sentence yields two agents. The listener with aphasia is forced to then guess which of the two interpretations is correct, resulting in at-chance performance with these constructions (Grodzinsky, 1995). Furthermore, LWBA are able to use semantic information to correctly resolve these conflicts. For example, non-canonical sentences such as "The ice cream that the man ate was delicious" are comprehended easily by LWBA offline, presumably because they are able to resolve the fact that 'ice cream' could not plausibly eat 'the man' (Caramazza & Zurif, 1976).

Importantly, the TDH acknowledges that the inability of LWBA to comprehend sentences containing dependencies could be either representational, that is, knowledge of traces is lost completely in these individuals, or due to a processing disruption that interferes with the timely use of the grammatical knowledge. Another

grammar oriented account that proposes an underlying processing deficit is the "slow syntax" account (Burkhardt et al., 2008; Piñango & Burkhardt, 2005; Piñango, 2000). This account claims that structure-building operations during sentence processing are delayed, including the "Merge" operation (Burkhardt et al., 2008). Merge is the only combinatorial principle in generative syntax (e.g. Chomsky, 1995), which combines two syntactic categories to form a larger constituent in the phrase structure representation. Because of this syntactic processing delay, semantic information becomes available prior to the point at which a complete syntactic representation has been built. This semantic information drives thematic role assignment before dependency relations have been formed. Subsequently, if the representation built by semantic information conflicts with the representation formed by the completed syntactic processing, they then compete. It is the competition between these two interpretations that is purportedly the source of the ultimate comprehension failure (Burkhardt et al., 2008).

Whether it is due to a failure to represent traces at all (representational deficit) or due to a failure to represent traces 'on time' (processing deficit), a great deal of evidence exists to support the presence of some form of syntactic deficit in individuals with Broca's aphasia. However, both the TDH and the slow syntax hypothesis are attempts primarily to explain patterns of off-line sentence comprehension. As discussed earlier, off-line comprehension tasks (e.g., sentence-picture matching) only measure the end product of sentence processing. Therefore, these hypotheses do not preclude the existence of a lexical processing deficit that then leads to what appears to

be a syntactic deficit. In fact, Piñango (2000) suggested that slow-structure building

might have resulted from slowness in lexical activation. Therefore, the next section

will discuss the hypothesis that lexical processing deficits underlie the syntactic

deficits in Broca's aphasia (note that for the sake of space and brevity, discussion of

other classes of accounts that are not directly relevant to the purposes of this paper has

been omitted, although see Caplan et al., 2007, for example).

2.1.2 Lexical Processing Accounts of Comprehension Deficits in Broca's Aphasia

As the name suggests, lexical processing accounts posit that the source of the

comprehension deficits in Broca's aphasia have their origin in either the representation

or processing of lexical items, or words. One such account is the delayed lexical

activation hypothesis (DLA; see Love et al., 2008). According to the DLA, lexical

items are accessed from the lexicon in a delayed fashion for LWBA aphasia.

Additionally, the DLA claims that syntactic processes rely on the timely progression

of lexical processes, including lexical access. Therefore, if lexical access is delayed,

this will result in the disruption of on-time availability of lexical representations for

syntactic processing and bring about comprehension failure as a consequence.

Evidence for the DLA has come from word level priming studies that have found

delayed priming effects for participants with Broca's aphasia compared with

neurologically unimpaired listeners (Prather, Zurif, Love, & Brownell, 1997; Prather,

Zurif, Stern, & Rosen, 1992). Evidence for delayed lexical activation during sentence

processing for LWBA was presented by Love et al. (2008). In this study, participants

listened to sentences containing an object-extracted relative clause, as in (3), below:

6) The audience liked *the wrestler*[i] [*1] that the[*2] parish priest condemned [t[i]] [*3] for[*4] foul[*5] language.

As with the object-relative sentence (2) discussed previously, in the object-extracted relative clause in (3), the direct object of the verb 'condemned' (i.e., 'the wrestler') has been displaced from its underlying position to a position occurring before the verb, leaving behind a "gap" or trace of the moved NP. This gap or trace (signified by [t]) co-refers with the moved NP. In their study, Love et al. (2008) measured priming at five positions during the ongoing auditory sentence (signified by the superscript numerals in (3). In contrast to the patterns of immediate access evinced by neurologically unimpaired listeners for the meaning of the antecedent ('the wrestler') at its offset (*1) and again at the gap (*3), participants with Broca's aphasia demonstrated delayed access. Specifically, they did not evince priming at the offset of the antecedent (*1) but did so 300 ms later (*2). Furthermore, they did not demonstrate re-access at the gap (*3) but did so 500 ms later (*5).

These results show that initial activation of the noun phrase serving as the antecedent is delayed, as well as its syntactically driven reactivation. The fact that both lexical activation and dependency building were delayed for LWBA suggests that the lexical delay interferes with timely syntactic processing, consistent with predictions extended by the DLA. Furthermore, the fact that LWBA are able to form syntactic dependencies, albeit in a delayed fashion, suggests that the deficit is not at the representational level, but rather due to disrupted processing. Notably, the design of the experiments in the Love et al. (2008) study does not exclude the possibility that delayed lexical access and delayed reactivation are driven by separate impaired

processes. However, the most parsimonious conclusion is one in which both are attributed to the same source, as the authors claim.

An additional finding from Love et al. (2008) supports the claim delayed lexical processing leads to the sentence comprehension deficit in Broca's aphasia. Participants with Broca's aphasia evinced the normal access/re-access pattern (and improved off-line comprehension) when speech input was slowed relative to normal input speed. This pattern indicates that the deficits could be overcome when the normal time constraints for re-access are relaxed. Furthermore, slowing the rate of speech also resulted in improved performance on an off-line, sentence-picture matching comprehension task, providing evidence that on-time lexical access is important for successful comprehension of complex sentences (Love et al., 2008, Experiment 2).

However, a VWP study by Choy (2011) failed to find effects of slowed speech rate. Choy had participants listen to two-sentence mini-stories (see example (7) below) that contained an object-cleft sentence describing a transitive event. Sentences were followed by a yes or no comprehension question.

(7) This story is about a boy and a girl. It was the boy who the girl kissed that day at school.
Did the girl kiss the boy? / Did the boy kiss the girl?

Although a significant difference was found between the neurologically unimpaired participants and participants with Broca's aphasia for both accuracy and fixation latency measures, no effect of rate of speech was found for either group.

There are several important differences between the two studies (Choy, 2011; Love et al., 2008) that may help to explain the disparate findings. In the Choy study, a speaker recorded the slow rate sentences, whereas for the Love et al. study, the slow rate sentences were derived from the regular rate sentences, which were slowed via software while maintaining pitch and prosody. As such, there is no way of knowing whether the same variables (e.g., vowel length, pause time between words) were affected in the two different studies, or whether pitch and prosody were maintained for the Choy (2011) study. Additionally as noted, the Choy (2011) study used object-cleft constructions whereas the Love et al. (2008) study used object-relative constructions. Object-relative constructions contain a more complex main clause as well as three nouns with semantic content (as opposed to two in object-clefts). It is possible that the greater complexity of the object-relative sentences in the Love et al. (2008) study allowed for greater benefit of slowing.

In contrast to the DLA, the lexical integration account of Thompson and colleagues suggests that comprehension deficits in Broca's aphasia are due to impairment in lexical integration (e.g., Choy & Thompson, 2010; Choy, 2011; Mack, Ji, & Thompson, 2013; Meyer, Mack, & Thompson, 2012; Thompson & Choy, 2009). Thompson and colleagues do concede that lexical access is delayed, and that the delay in turn impairs later-occurring lexical integration. However, they propose that it is the latter rather than the former that leads to failed sentence comprehension. For example, Dickey, Choy, and Thompson (2007) and Dickey and Thompson (2009) examined eye movements while participants with Broca's aphasia listened to sentences involving

movement such as wh-questions and object relatives. Similarly, Thompson and Choy (2009) examined eye movements while participants listened to sentences containing pronomial and wh-movement structures. The results of these studies revealed that while the participants with Broca's aphasia had delayed gazes to the pictures of the overt nouns, supporting the presence of a lexical access delay, they did not demonstrate delayed grammatical dependency processing. That is, at the trace or the anaphor, LWBA showed on-time gazes to the correct picture referent compared to unimpaired controls, even for sentences in which comprehension failed. Choy (2011) claims that collectively these VWP studies demonstrate that syntactic processing is largely intact for these individuals.

However, these same studies found that eye movement patterns diverged for the participants with Broca's aphasia and control participants *after* antecedent syntactic re-activation. Whereas control participants showed *continued* fixations toward the antecedent, individuals with Broca's aphasia showed increased fixations toward a competitor for incorrectly comprehended trials only. Thompson and Choy (2009) suggested that the increased looks to a competitor after re-activation may be due to difficulty integrating the re-activated lexical item into the sentential context. They claim that it is the lexical integration deficit, rather than delayed lexical access, which contributes to sentence comprehension failures in Broca's aphasia.

Regardless of the particular sub-process responsible, the role of a lexical processing deficit in the sentence comprehension difficulties in Broca's aphasia is strongly supported. Since lexical processing deficits may contribute to

comprehension difficulties, these difficulties might be mitigated or even eliminated if lexical processing could be facilitated. However, to date, the literature on anticipatory processing in aphasia is extremely limited, and is even more so in regards to sentence processing in Broca's aphasia. One recent VWP study by Mack et al. (2013) explored whether LWBA and neurologically unimpaired older control subjects were able to use verb meaning information to anticipate a subsequent NP. Similar to Altmann and Kamide (1999), Mack et al. (2013) had participants listen to sentences containing restrictive or unrestrictive verbs such as "Tomorrow, Susan will open/break the jar." In these sentences, one of the verb conditions (e.g. "open") selected for only one of the four visual objects displayed in an array (e.g. "jar"), whereas the other verb condition (e.g. "break") was compatible with all of the visual objects (e.g. jar, plate, stick, pencil). The results revealed that for both groups, gazes to the NP in the post-verbal region were facilitated in the restrictive condition compared to the unrestrictive condition. In other words, in the first 500 ms after hearing 'open,' LWBA (and older controls) had significantly more gazes to the jar than after hearing 'break.' This suggests that the LWBA are able to use the semantic restrictions (in this case imposed by the verb) to anticipate features of upcoming items.

Additionally, Choy (2011) found that LWBA more accurately answered yes/no comprehension questions about sentences containing predictable (high cloze) object NPs than sentences with low cloze object NPs (as in (8a) and (8b) below).

(8a) There was a bartender who banished the drunk/ There was a drunk who the bartender banished (high cloze).

(8b)   There was a bartender who banished the cyclist/ There was a cyclist who

the bartender banished (low cloze).

Furthermore, predictability had a larger effect on comprehension than

canonicity (i.e. non-canonical sentences containing high cloze NPs were

comprehended better then canonical sentences with low cloze NPs). However,

because this was an offline task, it is unclear whether LWBAwere able to use the

context on-line to facilitate lexical processing, or whether the information was used in

post-processing plausibility judgment (i.e. a 'bartender' is more likely to banish a

'drunkard'). Additionally, even with the contextual cues, LWBAaphasia still did not

comprehend the sentences as well as the unimpaired control group.

Overall, the results of Mack et al. (2013) and Choy (2011) suggest that the

ability to use contextual information is importantly, intact, for LWBA. However, it

must not be taken for granted that this ability to use context is superimposed on a

lexical processing deficit. Thus, the limited evidence available this far suggests that

contextual information can be used to mitigate, but not altogether eliminate this

deficit.

Goals of the Dissertation

This dissertation seeks to investigate the time-course of lexical access during

sentence processing in syntactically simple sentences for LWBA, as well as the

evaluate the effect of slowed rate of speech and local contextual cues on this time-

course. In doing so, this dissertation aims to provide evidence to help distinguish

between two competing accounts of sentence comprehension deficits for LWBA; the

slow syntax account and the delayed lexical activation hypothesis. Importantly, helping to identify the underlying source of this disorder will not only have the potential to inform neuro-cognitive models of sentence processing (by, for example, relating the linguistic skill affected by the processing impairment to location and extent of brain damage), but also will potentially inform more effective clinical intervention techniques. For instance, if the inclusion of semantically biased adjectives in sentences is able to facilitate lexical processing, perhaps this can be translated to a training technique in which family members and other conversational partners of individuals with Broca's aphasia are taught to use more descriptive words in their conversational exchanges.

Chapter 3 undertakes a real-time investigation of lexical access during processing of syntactically simple sentences, across aphasic and unimpaired listeners. This study seeks to determine whether LWBA show delayed lexical access for lexical items even in the absence of complex syntax, as predicted by the delayed lexical activation hypothesis. Chapters 4 and 5 investigate the effect of modifications to these sentence on the time-course of lexical access during sentence processing in Broca's aphasia that was examined in Chapter 3. Using the findings from Chapter 3, Chapter 4 asks whether slowing rate of speech has a faciliatory effect on the time course of lexical access for listeners with Broca's aphasia, and whether the presence and/or strength of the effect can be predicted by the proportion of damage to the brain areas implicated in language processing in the individual participants. Chapter 5 explores whether providing listeners with adjectives to serve as either a structural, semantic, or probabilistic cue mitigates the lexical processing delay that was observed in Chapter 3.

As discussed previously in this chapter, there is a paucity of studies that have investigated whether LWBA are able to take advantage of the processing cues that have ben shown to result in anticipatory processing for unimpaired listeners. This study aims to add to that literature by exploring not only if these listeners are sensitive to processing cues, but what kind. Chapter 6 discusses how the results of this dissertation extend our understanding of real-time lexical processing in aphasia. This final chapter discusses directions for future work in this field.

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CHAPTER 3:

The Time-Course of Lexical Activation During Sentence Comprehension in Aphasia

Preface

As established in Chapter 1, although studies of real-time sentence processing have found delayed lexical access for listeners with Broca's aphasia, these studies have either used sentence stimuli containing syntactic dependencies, or lexically ambiguous noun phrases. First, the use of such stimuli has obscured the ability to probe access to a single lexical meaning across a significant enough amount of time to chart it's activation time-course without potential interference from syntactic processing. Second, two competing accounts of the sentence processing impairment in Broca's aphasia, the DLA and the slow syntax hypothesis, make differing predictions about whether lexical access should be delayed for listeners with aphasia in syntactically simple sentences. The DLA predicts that lexical access should remain delayed in these circumstances while the slow syntax hypothesis predicts that it should not. This study thus serves two purposes: first, to chart the time-course of lexical activation during sentence processing for neurologically unimpaired listeners and listeners with Broca's aphasia in order to determine which account (the DLA or slow syntax) is supported by the data, and second, to serve as a "baseline" comparison with which to judge the effect of rate of speech and anticipatory processing cues on the time-course of lexical access, which will be explored in the studies described in subsequent chapters (Chapters 4 and 5 respectively).

The Time-Course of Lexical Activation During Sentence Comprehension in People With Aphasia

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Abstract

Purpose—To investigate the time-course of processing of lexical items in auditorily presented canonical (subject–verb–object) constructions in young, neurologically unimpaired control participants and participants with left-hemisphere damage and agrammatic aphasia.

Method—A cross modal picture priming (CMPP) paradigm was used to test 114 control participants and 8 participants with agrammatic aphasia for priming of a lexical item (direct object noun) immediately after it is initially encountered in the ongoing auditory stream and at 3 additional time points at 400-ms intervals.

Results—The control participants demonstrated immediate activation of the lexical item, followed by a rapid loss (decay). The participants with aphasia demonstrated delayed activation of the lexical item.

Conclusion—This evidence supports the hypothesis of a delay in lexical activation in people with agrammatic aphasia. The delay in lexical activation feeds syntactic processing too slowly, contributing to comprehension deficits in people with agrammatic aphasia.

Keywords

aphasia; syntax; slow rise-time; rate of speech; online; priming; sentence processing; neurolinguistics

Complex sentence types are often used as a means to examine the operations underlying sentence processing in people with normal comprehension and to examine how comprehension goes awry in people with agrammatic (Broca's) aphasia (hereafter referred to as agrammatic aphasia). These constructions, which may contain long-distance dependencies, have been characterized as complex because they do not follow canonical word order (subject–verb–object, or S–V–O, in English). Listeners with agrammatic aphasia often demonstrate difficulty comprehending these types of sentences. Several syntactic accounts have attempted to explain this difficulty, including proposed deficits in assigning thematic roles to displaced arguments (e.g., Friedmann & Shapiro, 2003; Grodzinsky, 2000) or slowed syntactic processing routines (Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008). In contrast, the delayed lexical access (DLA) hypothesis suggests that delayed lexical access feeds syntactic processing too slowly, leading to breakdowns of automatic structure building and contributing to the "syntactic" comprehension disorder that is observed in people with

agrammatic aphasia (Love, Swinney, Walenski, & Zurif, 2008; see also Myers & Blumstein, 2005).

The DLA hypothesis suggests that delayed lexical activation should also be observed in relatively simple, canonical constructions, and it is this hypothesis that we investigate in the current study. Unlike some of our previous efforts, however, we charted lexical activation across several probe points during sentence comprehension to examine the time-course of activation and decay without the additional processing required for complex syntax. Our approach was two-pronged: First, we examined the time-course of lexical access in a group of young, neurologically unimpaired control participants. There is a surprising lack of information about what occurs after a lexical item is activated in sentences during comprehension of simple canonical constructions in unimpaired populations. Second, we examined the time-course of lexical access in a group of participants with agrammatic aphasia to observe if lexical access is indeed delayed relative to normal, unimpaired processing and to further examine its time-course.

We begin with a brief review of the relevant literature, first probing lexical access in young, neurologically unimpaired participants. Previous research has demonstrated that when an unimpaired listener encounters a lexical item (e.g., a noun) in a sentence, its various properties, including its meaning(s), are activated. Consider the following (from Swinney, 1979):

$$\text{Rumor had it that, for years, the goverment building had been plagued with problems. The man was not surprised when he found several insects}^{*1} \text{ in the cor}^{*2}\text{ner of his room.} \tag{1}$$

Using the cross modal priming (CMP) technique, Swinney (1979) presented sentences, and during the temporal unfolding of the sentence, Swinney visually presented letter strings momentarily, either at the lexical point of interest (at the offset of *insects*; at *1) or three syllables downstream from the lexical item (*2). The participant was required to listen to the sentences for meaning and to make a lexical decision on the visually presented probes. These probes either were associatively related to the lexical item (e.g., ANT – related to *insect*) or were unrelated control probes (e.g., SEW). Results showed that participants' reaction times (RTs) to the lexical decision were significantly faster to the related probe relative to the unrelated probe at both probe positions. Thus, the lexical item of interest (in this example, *insects*) primed its associate, suggesting that when a word is encountered in a sentence, its meanings are activated, and this activation continues for (at least) approximately three syllables.

There have been very few studies like this examining the time-course of lexical access in simple, canonically ordered sentences that use the CMP technique with neurologically unimpaired participants when the lexical item of interest was not ambiguous. Most of the studies have been concerned with how lexical ambiguities are processed given a neutral or biasing context (and so are not discussed here). However, there have been several studies examining lexical priming of unambiguous words in more complex noncanonical sentences with both neurologically unimpaired populations and populations with language impairments. Consider an example from one of the more recent studies (Love et al., 2008; Experiment 1):

$$\text{The audience liked } \textit{the wrestler}^{*1} \text{ that the}^{*2} \text{ parish priest condemned}\_\_\_^{*3} \text{ for}^{*4}\text{foul}^{*5} \text{ language.} \tag{2}$$

In the object-extracted relative clause in Example 2, the direct object of the verb *condemned* (i.e., *the wrestler*) has been displaced to a position occurring well before the verb, leaving behind a "gap" or trace of the moved noun phrase. Using the CMP technique (described above), Love et al. (2008) measured priming at five positions (as shown above). Based on the observed priming patterns, unimpaired participants evinced access of the meaning of the filler of the gap (*the wrestler*) at the filler's offset (*1) and again at the gap (*3), with no priming found in between (*2).

This typical time-course of activation—immediate access, decay, then re-access at particular syntactic positions (e.g., gaps)—has not been observed in studies exploring online processing in individuals with agrammatic aphasia. Specifically, individuals who are agrammatic appear to show delayed activation of a noun's meanings during sentence processing, with lexical access not occurring until ~½ s past the appearance of the noun. This pattern has been observed using the CMP task (Love et al., 2008) as well as with the visual world eye-tracking method (Thompson & Choy, 2009). Using sentence (2) as an example, Love et al. (2008) found that participants with Broca's aphasia did not evince priming at the offset of the target noun (*1) but did 300 ms later (*2), and did not evince re-access at the gap (*3) but did 500 ms later (*5). Thus, the patterns observed for these participants with aphasia support the DLA hypothesis because the initial activation of the noun serving as the filler is delayed, as is its syntactically driven reactivation.

In addition, the findings (from Love et al., 2008, for example) further suggest that the deficit in understanding complex sentences with displaced arguments has its roots in a disorder of lexical access (see also Blumstein & Milberg, 2000; Myers & Blumstein, 2005; but see Ostrin & Tyler, 1993). Consistent with this suggestion, participants with Broca's aphasia evinced the normal access/re-access pattern (and improved off-line comprehension) when speech input was slowed, reinforcing the hypothesis that delayed lexical access underlies syntactic-like deficits and showing that the deficits could be overcome when the normal time constraints for re-access were relaxed (Love et al., 2008; Experiment 2). However, Thompson and colleagues (Choy & Thompson, 2010; Thompson & Choy, 2009) suggested that their findings from experiments using the visual world eye-tracking paradigm indicate delayed lexical access but relatively normal and on-time gap filling in participants with agrammatic aphasic. If Thompson and colleagues are correct, then the DLA hypothesis would suggest a disorder that is independent from any putative disorder in understanding complex sentences. We return to this point in our Discussion.

There are three important limitations to the work showing delayed lexical access, which suggest that we may have put the cart before the horse. First, as far as we are aware, there has been no priming study that has investigated the time-course of lexical activation with more than two probe positions. Second, the bulk of the evidence in people with aphasia has come from investigations of complex filler-gap constructions, as described above. Third, even in canonical sentences, the nature of the lexical access deficit in people with agrammatic aphasia is not clear. For example, Swinney, Zurif, and Nicol (1989) examined whether or not participants with agrammatic aphasia show the normal pattern of access of multiple meanings of ambiguous nouns during sentence comprehension. They found that their participants with agrammatic aphasia activated only the most frequent interpretation for an ambiguous noun in the immediate vicinity of the noun; only the secondary meaning was delayed. Given this result, we would assume that, when an unambiguous noun is encountered in a sentence, on-time lexical access should occur. Yet, in the Love et al. (2008) study described earlier, access of the meaning of an unambiguous noun did not occur until at least 300 ms after the noun for their Broca's participants.

These limitations of past work yield the following questions about the time-course of "normal" lexical access that we address in the current study:

- Does activation of a noun's meaning decay?

- If so, is this decay linear or is it nonlinear and U-shaped, essentially showing reactivation in sentences without syntactic dependencies?

The latter question comes from the possibility that a lexical item is cyclically activated throughout the time-course of processing, making it available for further operations of the sentence processor. Further, we noted above that reactivation effects have been ubiquitously observed in constructions that have displaced arguments (with, for example, object-extracted relative clauses) in neurologically unimpaired participants. It is thus reasonable to also ask whether such re-access effects will be observed in canonical-ordered sentences that do not contain displaced arguments. Adding to these is a question about agrammatic aphasia: Do participants with agrammatic aphasia evince delayed activation of the meaning of an unambiguous noun in canonical sentences?

These questions are critical to accounts of sentence processing (both in adults without brain damage and in adults with aphasia) for the following reason: Several studies have suggested that, through a process called "integration, " a word's meaning is merged into the context of the sentence (Cairns, Cowart, & Jablon, 1981; Friederici, Steinhauer, & Frisch, 1999; Marslen-Wilson, 1987; Myers & Blumstein, 2008; Swaab, Brown, & Hagoort, 1997). And perhaps not surprisingly, there are several accounts that suggest that one limitation in aphasia is a disorder in lexical integration (Thompson & Choy, 2009). However, if there is such a lexical integration problem, its source might very well be the initial delay in lexical access (or, alternatively, in reduced activation of the lexical item; see Yee, Blumstein, & Sedivy, 2008). We consider delayed lexical access and its possible relation to a disorder of lexical integration in the Discussion section.

Experiment 1: Neurologically Unimpaired Participants

We examined these issues of the time-course of lexical access in simpler, canonical constructions in a group of college-age neurologically unimpaired participants in order to (a) reveal the time-course of lexical processing in canonical sentences, and (b) determine a standard of comparison for our participants with left-hemisphere damage (LHD) and agrammatic aphasia (Experiment 2).[1]

Method

Participants—One hundred and fourteen college-age students ($M = 20.9$ years, $SD = 3.4$, range: 18–33 years; 17 male, 97 female) from San Diego State University participated in this study. All participants were neurologically unimpaired right-handed native English speakers with no history of learning disability, head injury, or neurological disease, and no uncorrected vision or hearing impairments. Participants received course credit for their participation in the study.

Task—We used a cross modal picture priming paradigm (CMPP; Swinney & Prather 1989). Here, participants listened to uninterrupted auditory sentences and made binary, *human (yes)/not human (no),* decisions regarding visually presented black-and-white line drawings (visual probes). Each experimental sentence had two visual probes (each requiring

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[1]Prior published reports have shown no differences in priming patterns in CMP tasks when comparing college-age and older age-matched control participants (Love et al., 2008 and references therein; Stern, Prather, Swinney, & Zurif, 1991). Even so, we also include a small group of age-matched controls and describe our results in footnote 3.

a *yes* response): a related probe that was a representation of the noun phrase in the direct object position of the sentence, and a control probe that was unrelated to any word in the sentence (Figure 1). In this task, the visual probes are presented at key times during the ongoing sentence, and priming effects are measured by comparing RTs to the related and control probes at that point; faster RTs to the related probes indicate a priming effect. Importantly, priming effects in cross modal tasks reflect activation of the sentential prime at that point in the ongoing auditory sentence, not the integration of the visual probe into the sentence (Nicol, Swinney, Love, & Hald, 2006).

Materials—We created 40 experimental sentences with the following canonical sentential structure:

Subject	Verb	Object	Prepositional Phrase	
The boxer	punched	he golfer[*1]	after[*2]the tre[*3]mendou[*4]sly antagonistic discussion about th*e* title fight	(3)

In these sentences, the direct object noun (Object) was the lexical item of interest (e.g., *golfer* in Example 3 above) and was followed by a prepositional phrase that was designed to avoid the occurrence of another noun, and its lexical activation, within 2,000 ms of the direct object noun.

The experiment employed a switched target design in which the related probe for one sentence appeared as a control probe for a different sentence, whose related probe served as the control probe for its paired sentence (Figure 1). Thus, over all of the sentences, the set of related probes was identical to the set of control probes, minimizing the possibility that any observed priming effects are due to unimportant aspects of the pictures that might influence participants' RT (e.g., visual complexity differences).

Probe pictures were created by a cartoonist who drew black-and-white line drawings, each depicting the critical nouns for each of the 40 experimental sentences. The cartoonist also drew black-and-white line drawings for the filler sentences (described in more detail later). To ensure that the drawings accurately depicted the appropriate noun, all of the pictures were pretested on a group of 38 University of California, San Diego undergraduates (*M* age = 20.3 years, *SD* = 1.4; 15 male, 23 female) who participated for course credit. Participants were asked to label each of the drawings. Any drawing for which there was <75% agreement in labeling was removed and was modified by the cartoonist for clarity.

In order to establish the time-course of activation of the direct object noun, the related and control visual probes were presented at four positions in the ongoing auditory sentence (indicated approximately by the superscript numerals in Example 3 earlier). Probe position (PP) 1 occurred immediately at the offset of the direct object noun. Each subsequent probe position was 400 ms downstream from the previous probe position. This allowed us to chart a pattern of lexical activation of the direct object noun across 1,200 ms (PP4) after it was heard in the ongoing auditory stream.

In addition to the 40 experimental sentences, 60 filler sentences were created. Forty of the filler sentences were similar in length and structure to the experimental sentences but were paired with an animal (nonhuman) picture probe (requiring a *no* response). The other 20 filler sentences were of a different syntactic structure, to provide a variety of sentence forms. Of these 20 sentences, 10 were paired with a human picture probe, and 10 were paired with an animal picture probe to balance the number of "human" and "non-human" responses across the full set of items. 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. This was done to prevent the anticipation of probe positions. Finally, 10 practice sentences (also balanced for the number, order, and type of response) were added to the beginning of each script to familiarize the participant with the task as well as to allow the experimenter the opportunity to monitor the participants to ensure that they understood the task.

After the 10 practice items, the remaining 100 sentences (40 experimental; 60 filler) were intermixed and were pseudo-randomly ordered such that no more than three sentences in a given condition or with a particular response occurred in a row. The sentences were recorded by a female native English speaker at a normal rate of speech (4.6 syllables per second). Recording and editing were performed using Adobe Audition 3.0 software.

Design—We used a mixed between-within factors design to counterbalance all eight conditions (4 probe positions × 2 related/control probes). Given the number of factors in this study, we wanted to ensure that each participant contributed data to more than one probe position and to both related and control probes, so that each participant provided his or her own control data. This was accomplished by randomly assigning an individual participant to any two probe positions (e.g., PP1 & PP2, PP2 & PP3, etc.), with related/control probes counterbalanced across two visits.

Procedure—At the beginning of each session, participants were instructed that they would be performing a dual task—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 decision as quickly and accurately as possible (using a two-button response box) as to whether the picture was human (*yes* response) or not human (*no* response).

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 listen 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 (both yes/no decisions and millisecond accurate RTs for each decision). Each visual probe was presented for 1,000 ms, or until a response was made. Responses were recorded for up to 1,000 ms following the appearance of the picture probe, for a total time of 2,000 ms. An interstimulus interval (ISI) of 2,000 ms followed each sentence.

Analysis—All participants performed above chance on the task-related comprehension questions. Before analysis, two sentences were found to have script errors; all data from these two sentences and their paired sentences were removed (four sentences total). Data were first reviewed for button-press accuracy. Participants who responded incorrectly (wrong button press or no response) to >10% of the experimental sentences in either session were excluded ($n = 7$). For the remaining 107 participants, incorrect responses (2.03% of all data), RTs <300 ms, or overall outliers >1,150 ms (1.5 times the interquartile range, based on all correct responses) were removed (3.9% of the data), distributed roughly equally across participants and conditions. Finally, we screened out responses for each participant that were >2 *SD*s from his or her individual mean for each session (4.3% of the data). After completing this screening protocol, we eliminated seven of the 107 participants who were found to have mean RTs that were >2 *SD*s from the average of the participant means.

Analysis of the RTs from the remaining 100 participants was conducted using restricted maximum likelihood (REML) in a mixed-effects regression model. Included in this model were the crossed random effects on the intercept of participant and sentence and fixed effects of probe position (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 probe position and relatedness separately for each pair of probe positions 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 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 model (i.e., including all four levels of probe position) had BIC = 83,591.6, which improved to BIC = 80,129.2 when the random effect of participant was added, and improved again to BIC = 80,027.8 when the additional random effect of sentence was added, thus justifying the inclusion of both random effects. The follow-up models on pairs of probe positions showed similar improvements to model fit. Note that differences in BIC values >10 constitute very strong evidence of a better fit for the model with the smaller score (Kass & Raftery, 1995).

We predicted a priming effect at PP1, at the offset of the lexical item of interest in the sentence. We also predicted a null effect at PP2, given the Love et al. (2008) findings that activation decays at ~300–400 ms. Our predictions for the remaining two positions were less concrete, but we entertained the possibility that reactivation would occur at one of these positions; for example, if a working memory system requires the availability of a lexical item for further operations of the sentence processor. Thus, and central to the hypotheses under investigation, for a priori planned comparisons of related and control probes at each probe position, 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); for studies with similar analyses, see Love, Walenski, and Swinney (2009) and Walenski, Mostofsky, and Ullman (2007).

Results

Mean RTs and standard errors for each condition are shown in Table 1. A priori planned comparisons revealed significantly faster RTs for picture probes when related to the sentence prime than when unrelated to the prime, at PP1, 13 ms control – related difference; $t(6386) = 2.33$, $p = .02$, but not at PP2, –4 ms control – related difference; $t(6387) = 0.78$, $p = .43$, PP3, 5 ms control – related difference; $t(6387) = 0.96$, $p = .34$, or PP4, –8 ms control – related difference; $t(6386) = 1.24$, $p = .21$. Overall, there was a significant interaction between probe position and relatedness, $F(3, 6387) = 2.66$, $p = .047$, which is consistent with changes in related/control differences across the sentence. Neither the main effect of probe position, $F(3, 639) = 0.63$, $p = .60$, nor relatedness, $F(1, 6387) = 0.29$, $p = .59$, reached significance.

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[2]This model combines traditionally separate $F1$ and $F2$ analyses into a single statistical test.

In order to further pin down the time-course in the decay of activation across the sentence, we examined the change in activation (i.e., the interaction between probe position and related/control differences) across each pair of probe positions beginning with PP1, the point just at the offset of the lexical item in the sentence. The Probe Position × Relatedness interaction was significant for PP1 versus PP2, $F(1, 3301) = 4.84$, $p = .03$, not significant for PP1 versus PP3, $F(1, 3309) = 0.84$, $p = .36$, but again significant for PP1 versus PP4, $F(1, 3155) = 6.15$, $p = .01$.[3] These results will be discussed after we present Experiment 2.[4]

Experiment 2: Participants With LHD and Agrammatic Aphasia

We examined whether individuals with agrammatic aphasia evince a similar pattern of lexical activation and decay as neurologically unimpaired individuals. According to the DLA hypothesis (Love et al., 2008), we expected a delay in the rise-time of a priming effect for participants with agrammatic aphasia, suggesting that significant priming should not be observed at PP1. Other hypotheses, such as the slowed-syntax hypothesis (Burkhardt et al., 2008), would not predict such a delay in canonical sentences.

Method

Participants—A total of eight participants with unilateral LHD and agrammatic aphasia met criteria for participation (mean age at time of testing: 56.7 years; range: 32.7–86.7 years). Demographic information for these participants is presented in Table 2. All participants had experienced a single, unilateral left-hemisphere stroke and were native English speakers with normal or corrected-to-normal visual and auditory acuity. They were right-handed before their stroke. Diagnosis of agrammatism was made based on the administration of standardized language testing to determine each participant's severity of agrammatic language impairment; specifically, fluency and auditory comprehension ability. Testing included the Boston Diagnostic Aphasia Examination—Third Edition (BDAE–3; Goodglass, Kaplan, & Barresi, 2000), Western Aphasia Battery (WAB; Kertesz, 2006), and SOAP (Subject-relative Object-relative Active and Passive) Test of Auditory Sentence Comprehension (Love & Oster, 2002).

As the DLA hypothesis makes the specific claim that a lexical deficit underlies comprehension deficits in people with agrammatic aphasia, participants were considered for inclusion if they showed evidence of such comprehension deficits, which we defined here as at or below chance on comprehension of sentences with noncanonical order (object-relative and passive sentences) from the SOAP. 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 or intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). Participants were tested at the Cognitive Neuroscience Laboratory at San Diego State University and were paid $15 per session.

Materials—The same materials as those used in Experiment 1 were used.

Design—Unlike the mixed-factorial design that was used in Experiment 1, here we employed a fully within-subjects design for the participants with aphasia. The four probe

positions, 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. The order of presentation of the eight conditions was counterbalanced across participants. Sessions were separated by at least 1 week, and most often, 2 weeks.

Procedure—The general procedure was the same as that used in Experiment 1, except that (a) responses were recorded for up to 3,000 ms from the onset of each picture and (b) a more extensive training session was implemented.

<u>Training protocol:</u> To ensure that our participants with aphasia were performing reliably on the binary picture decision task and that they understood this dual-task paradigm, a training session was given before the experimental script at each of the eight visits. For this training, participants were trained on the binary picture decision. Participants were told that a picture would appear in the middle of the screen and they were to identify whether the picture was human or not by pressing a button labeled *yes* for human or *no* for not human, as quickly as possible. The list consisted of 20 items: 10 human and 10 nonhuman. This picture-only training list was repeated as many times as needed until the participant was able to reliably perform the task. None of the pictures used in the training task was repeated in the scripts. Participants were instructed to make their responses using the hand ipsilateral to their lesion (left hand). Once the experimenter felt that the participant understood the binary decision task and was ready to move on to the dual-task experiment, participants were then given the instructions as described in Experiment 1.

Analysis—All participants performed above chance on the task-related comprehension questions. All participants responded to the button-press decision with >90% accuracy ($M = 98.8\%$; $SD = 2.2\%$; range: 93%–100%). Before analysis, incorrect responses (1.2% of all data) were removed. There were no RTs <300 ms or >2,000 ms; thus, no overall outliers were removed. A 2-SD participant screening was then performed for each participant separately for each condition (5.1% of the data). In all other respects, the data were analyzed the same way as for Experiment 1. The inclusion of crossed random effects was examined as in Experiment 1, with model fit improving from BIC = 30,725.8 with no random effects, to BIC = 28,353.4 adding the random effect of participant, and to BIC = 28,333.5 adding the random effect of sentence, thus justifying the inclusion of both random effects.

Results

Mean RTs and standard errors for each condition are shown in Table 3. As for Experiment 1, the a priori comparisons of the related and control probes for each probe position are of primary importance to address the question of when (i.e., at which probe position) any priming effects reach significance. A priori planned comparisons of the RTs for related compared to control picture probes revealed a nonsignificant priming effect at PP1, 10 ms control – related difference; $t(2347) = 1.37$, $p = .17$, a significant priming effect at PP2, 18 ms control – related difference; $t(2347) = 2.41$, $p = .02$, and nonsignificant control – related differences at PP3, 0 ms; $t(2347) = 0.16$, $p = .87$, and PP4, 6 ms; $t(2358) = 0.49$, $p = .62$. The overall interaction between probe position and relatedness did not reach significance, $F(3, 2349) = 1.02$, $p = .38$, though main effects of probe position, $F(3, 2347) = 12.1$, $p < .0001$, and relatedness, $F(1, 2353) = 4.9$, $p = .03$, did. Despite the nonsignificant overall interaction, we also examined the change in priming over the course of the sentence, as in Experiment 1.

To examine whether there was any change in activation across the sentence, we looked at the interaction between probe position and related/control differences across each pair of probe positions. Unlike what we found for the control participants, none of these interactions

reached significance. However, the change in related/control differences between PP2 and PP3 and PP4 combined yielded an interaction with trend significance, $F(1, 1752) = 2.88$, $p = .086$, suggesting that the priming effects are indeed decaying for the participants with agrammatic aphasia as the sentence continues.

Discussion

The primary intent of this study was to investigate the time-course of lexical activation and decay in simple, canonical constructions both in young, neurologically unimpaired control participants and in participants with agrammatic aphasia. Our first aim was to map the normal time-course of lexical access during ongoing sentence processing. Our second aim was to examine the accounts that have been proposed in the literature regarding the underlying comprehension deficit in agrammatic aphasia; specifically, the DLA hypothesis (Love et al., 2008; Prather, Zurif, Shapiro, & Swinney, 1991; Swinney, Zurif, Prather, & Love, 1996), the slowed syntax hypothesis (Avrutin, 2006; Piñango, 2000), and the lexical integration deficit (Thompson & Choy, 2009).

We first discuss the data from Experiment 1 exploring lexical access in our young, neurologically unimpaired control group. We predicted that unimpaired participants would activate the meaning of an unambiguous noun at that word's offset and that the activation would decay soon after. What was unknown were details about the time-course of decay; whether or not, for example, the decay would be gradual and linear across the sentence, or whether the activation of the noun's meaning would decay rapidly and then reappear further downstream.

The results from Experiment 1 revealed significant priming at the offset of the target noun and no further significant priming effects for the remainder of the probe positions. These patterns suggest that the meaning of an unambiguous noun in a sentence is activated immediately when that noun is encountered, and then decays rapidly (by 400 ms). This rapid decay is buttressed by the finding of a significant interaction between the first two probe positions.[5]

For our participants with agrammatic aphasia, we predicted that the initial access of a noun's meaning during sentence comprehension would be delayed relative to the normal pattern. The results indeed showed no significant priming at the offset of the noun, but significant priming was observed 400 ms from the initial position. Even so, there was a 10-ms priming effect at the offset of the noun, suggesting that activation of the meaning of the noun had begun but had not reached threshold. Furthermore, we observed a remarkable similarity of the activation curves between the two participant groups (see Figure 2), with the patterns for our participants with agrammatic aphasia pushed downstream relative to the patterns of the neurologically unimpaired participants. These patterns strongly support the DLA account of agrammatic aphasia described in the introduction.

One important corollary of the DLA hypothesis is that it is the source of the syntactic comprehension deficits that are evinced by some participants with agrammatic aphasia (Love et al., 2008). Recall from the introduction that these individuals not only show delayed lexical access, but they also show delayed re-access effects *downstream* from the

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[5]There is an upward tick at the third probe position after the rapid decay found at the second position, and there is no interaction between the first probe position at the offset of the lexical item and the third probe position (800 ms past the initial activation). This pattern might suggest that the meaning of the noun is becoming active again well after its initial activation. The functional role of such reactivation would be to make the item available for further operations of the sentence processor. Although our results are empirically too thin to allow any strong conclusions regarding this hypothesis, these data hint that re-access effects in canonical structures remain a possibility; additional experiments should be able to resolve this issue.

gap position, when such effects are typically found in the immediate vicinity of the gap for healthy participants in sentences that have displaced arguments. Though in principle there could be two independent disorders—delayed lexical access and a syntactic comprehension disorder—a more parsimonious explanation is that there is a single processing disorder, and that the delay in lexical access disallows the on-time construction of long-distance dependencies, resulting in an easily observable off-line comprehension disorder. This account is buttressed by the finding that slowing down speech input for participants with Broca's aphasia results in both on-time lexical access as well as on-time gap filling. Furthermore, slowing down input yields better off-line performance as well (Love et al., 2008).

However, we noted in the introduction that recent evidence from eye-tracking studies has suggested on-time gap filling for participants with agrammatic aphasia (Thompson & Choy, 2009), contrary to what we have found using cross modal methods (Love et al., 2008; Love, Swinney, & Zurif, 2001; Swinney et al., 1996). The off-line comprehension deficit, according to this view, stems from an additional deficit—a "lexical integration" problem. The evidence for this account comes from data that purport to show delayed looks to a relevant picture of a filler noun phrase when it is mentioned in the sentence, but on-time looks to the picture of the filler when the listener encounters a gap. Although our present study only examined lexical access during the comprehension of canonical structures, it is critical to the evaluation of the DLA hypothesis— and its corollary of delayed lexical *re*-access in syntactically complex structures—that the evidence for intact gap filling in agrammatic aphasia be closely scrutinized.

Consider, then, the results reported in Thompson and Choy's (2009) important effort, where they examined processing of object-extracted *who* questions (Experiment 2) and object-extracted relative clauses (Experiment 3). An example from Experiment 2 reported in Thompson and Choy is shown below:

$$
\begin{aligned}
&\text{This story is about a boy and a girl.}\\
&\text{One day, they were at school.}\\
&\text{The girl was pretty, so the boy kissed the girl.}\\
&\text{They were both embarrassed after the kiss.}\\
&\textit{who did the boy kiss that day at school}?\\
&(\textit{wh}\text{–question probe})
\end{aligned}
\tag{4}
$$

A visual array was presented to the participants as they were listening to the story, and the eye movements to the pictures in the array were recorded. In the current example, a picture of a "girl" (the relevant item that should be "activated" in the *who*-question above), a "boy" (a relevant distractor that is mentioned in the sentence), "schoolhouse," and "door" were presented in a four-picture square array. For analysis, the auditory input for the *who*-questions was divided into regions:

$$
\text{who did } \frac{\text{Region 1}}{\text{the boy}} \quad \frac{\text{Region 12}}{\text{kiss}} \quad \frac{\text{Region 3}}{\text{that day at}} \quad \frac{\text{Region 4}}{\text{scholl?}}
\tag{5}
$$

Note that the *who*-question involves a displaced direct object argument (i.e., *who*, displaced from its canonical position that occurs directly after the verb *kiss*), which gets its reference from the preceding context ("the girl was pretty, so the boy kissed the girl"). Thus, the idea behind this experiment was to examine if participants with agrammatic aphasia look to the referent when encountering the gap (i.e., region 2) from which the object noun phrase (*who,* linked to *the girl* in the discourse) has been displaced. If these participants evince timely

looks to the picture of the noun phrase "girl," then according to Thompson and Choy (2009), this would be evidence for an intact syntactic processor. If so, this result would be evidence against the corollary of our DLA hypothesis that delayed lexical access underlies the syntactic processing disorder, and would contradict prior findings in people with aphasia not only of disrupted syntactic processing (see introduction), but also of delayed re-access effects at structurally defined gaps (Burkhardt et al., 2008; Love et al., 2008).

Thompson and Choy (2009) reported that control participants and those with agrammatic aphasia evinced a significant theme preference at the verb (region 2; e.g., when hearing the verb *kiss*, they were significantly more likely to look at the picture of the direct object than the subject). This pattern strongly suggested that the participants with agrammatic aphasia were showing normal, on-time gap filling in such *wh*-questions, given the visual world paradigm. This finding suggested that agrammatic aphasia does not involve a deficit in computing syntactic representations, even though these participants may have delayed lexical access.

However, the finding of on-time gap filling with *who*-questions does not generalize to other question types, those that more clearly fit the deficit pattern observed in people with agrammatic aphasia. Consider the results from Thompson and Choy's (2009) Experiment 3, where object-extracted relative clauses were examined. Thompson and Choy found a significant theme preference only in the region *following* the gap (see Figure 10, p. 277), unlike what was found for the object-extracted *who*-questions from Experiment 2 (p. 271; see also Figure 7, p. 272). Given the exquisite temporal sensitivity of the eye-tracking method, why should there be a distinction in the time-course for the two construction types? That is, why should object-extracted *who*-questions be understood within a normal time-course, when the comprehension of other question types appears to be delayed?

Before suggesting an answer, we note that there are additional data that support such a distinction between question types, including data from participants with normal development (Friedmann, Belletti, & Rizzi, 2009), participants with specific language impairment (Friedmann & Novogrodsky, 2011), and adult psycholinguistics (De Vincenzi, 1991), and, more relevant to the present study, data from participants with aphasia. Hickok and Avrutin (1996), Thompson, Tait, Ballard, and Fix (1999), and Salis and Edwards (2008) found evidence for a distinction between object-extracted *who*-questions and *which*-noun phrase questions, with the former yielding unambiguous evidence for intact comprehension in participants with Broca's aphasia and the latter for the most part yielding significantly worse comprehension (see also van der Meulen, 2004).

Given these intriguing results from intact as well as disordered populations, several hypotheses regarding a distinction between question types have emerged. Here we briefly consider only one, an account that refers to the linguistic underpinnings of the questions, generalizes to multiple question types, and is buttressed by findings from several literatures (as noted below). Though the details of this account take us beyond the scope of the present paper, the intervener hypothesis suggests that when the filler (i.e., displaced argument) and an intervening noun phrase are similar in linguistic properties, interference occurs, disallowing normal thematic role assignment to the displaced argument. Consider the following:

Which student did the soldier push_ _ _ _ into the street? (6)

who did the soldier push_ _ _ _ into the street? (7)

In the *which*-noun phrase construction in Example 6, the noun phrase *the soldier* intervenes between the displaced argument (which student) and its gap that occurs immediately after the verb. Both of these noun phrases are referential; that is, they both refer to an individual, and thus the intervener interferes with thematic role assignment to the displaced argument. However, in the *who*-question in Example 7, the intervener (the soldier) is a distinct linguistic object from the displaced argument, who, the latter of which is nonreferential, and thus no interference occurs, rendering *who*-questions easier to understand. Such an account has been suggested in several studies of comprehension in people with agrammatic aphasia, including those reported in Friedmann (2008), Friedmann and Shapiro (2003), and Grillo (2005). Furthermore, this account has strong support from the linguistic literature (e.g., relativized minimality; see Rizzi, 1990, 2004) as well as from the psycholinguistic literature (see, for example, Gordon, Hendrick, Johnson, & Lee, 2006; Warren & Gibson, 2005). Thus, not all complex constructions turn out to be problematic in people with agrammatic aphasia; those that are problematic (e.g., object-extracted relative clauses) reveal delayed processing using the visual world eye-tracking method in Thompson and Choy (2009); those that are not (e.g., object-extracted *who*-questions) reveal on-time processing. The results of the former are consistent with the findings reported using the CMP methodology.

The interaction of lexical and syntactic deficits found in people with agrammatic Broca's aphasia suggests some unresolved issues. First, though Love et al. (2008) claimed that a lexical access deficit underlies the purported syntactic deficits in people with aphasia, it is not presently clear how delayed lexical access can account for the patterns of sparing and loss found with specific syntactic structures that we have described in this paper (e.g., object-extracted *who* and *which*-noun phrase constructions). Second, Thompson and colleagues (Choy & Thompson, 2010; Thompson & Choy, 2009) suggested that the deficit in syntactic comprehension is best explained by a lexical integration deficit. If lexical integration is indeed problematic in people with agrammatic aphasia, an initial delay in lexical activation may still be its origin. Further work exploring lexical access, integration, and syntactic comprehension using other complex constructions should be able to resolve these issues.

To conclude, the results of our study show that, for young, neurologically unimpaired participants, the meaning of a lexical item is activated at the immediate temporal offset of the relevant lexical item in the sentence and then rapidly decays. For our participants with agrammatic aphasia, a different pattern emerged, suggesting that lexical activation may begin when the noun is encountered but does not reach threshold until later in the speech stream (in our study, 400 ms). We suggest that this lexical delay may feed syntactic processing too slowly, compromising the ultimate comprehension of some complex constructions that contain displaced arguments.

Acknowledgments

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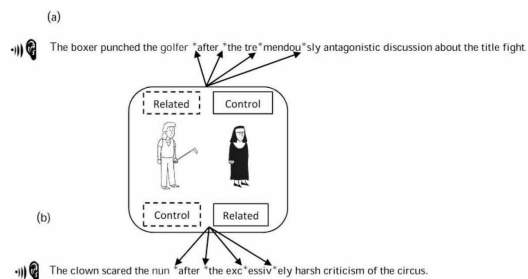
FIGURE 1.
(a) A sample sentence and corresponding probe pictures from the online cross modal picture priming task in Experiments 1 and 2. The sentence was presented auditorily at a normal speech rate. Probe pictures were presented at the offset of the direct object noun in each sentence (italics) and at three subsequent test points at 400-ms intervals. 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 direct object noun for one sentence were used as the unrelated control pictures for the direct object noun of another sentence (e.g., as indicated by the dashed box around animal trainer), so that over all items, the related and control sets of pictures were identical, avoiding response time confounds due to differences between pictures.

The boxer punched the golfer [*1] after [*2] the tre [*3] mendou [*4] sly antagonistic discussion about the title fight.

	PP1	PP2	PP3	PP4
unimpaired controls	13 *	-4	5	-8
aphasics	10	18 *	0	6
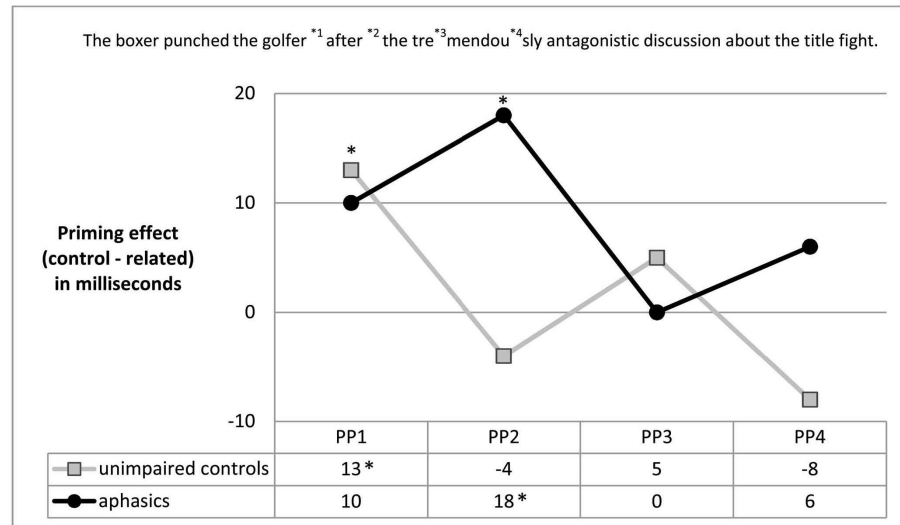
FIGURE 2.
Priming effects (control – related reaction times) for unimpaired control participants (from Experiment 1) and participants with aphasia (from Experiment 2) across four probe positions (PP).
*$p < .05$.

TABLE 1

Mean reaction times (and standard error) in ms to control and related probes at each probe position (PP) for the young, neurologically unimpaired control participants.

	PP1	PP2	PP3	PP4
Control	647 (4.9)	639 (5.3)	650 (4.7)	649 (5.5)
Related	634 (4.8)	643 (5.2)	645 (4.9)	657 (5.8)
(Control − related)	13 ms [*]	−4 ms	5 ms	−8 ms

[*]
$p < .05$.

TABLE 2

Demographic and lesion information for the participants with aphasia.

Participant	BDAE severity	WAB aphasia quotient	SOAP canonical	SOAP noncanonical	Gender	Age at testing (years; months)	Time post stroke	Education	Lesion location
LHD009	3	76.3	75%	55%	M	59;11	11;7	5 years college	Large L lesion involving inferior frontal gyrus (BA 44,45)
LHD019	1	54.1	90%	20%	F	60;2	15;1	High School	L MCA embolic stroke; distribution encompasses broad left frontal lobe region
LHD040	2	76.7	60%	60%	M	61;1	5;4	BA	Small L subcortical lesion involving the basal ganglia
LHD043	2	79.6	80%	55%	M	86;8	5;8	MA	L MCA lesion involving the frontal lobe with extension to the insula and caudate nucleus
LHD101	2	82.4	95%	35%	M	60;10	4;5	PhD	Large L Lesion involving posterior inferior frontal gyrus (BA44) with posterior extension
LHD130	4	81.1	95%	65%	M	57;3	1;9	BA	L IPL with posterior extension sparing STG
LHD138	2	N/A	70%	25%	M	32;8	11;7	Some college	L MCA infarct
LHD140	2	72.9	80%	30%	F	35;10	10;3	BA	L MCA infarct with distribution encompassing broad left frontal lobe region

Note. BDAE= Boston Diagnostic Aphasia Examination – Third Edition (Goodglass, Kaplan, & Barresi, 2000); WAB = Western Aphasia Battery (Kertesz, 2006); SOAP = Subject-relative, Object-relative, Active and Passive Test of Auditory Sentence Comprehension (Love & Oster, 2002). L = left; MCA = middle cerebral artery; IPL = inferior parietal lobule; STG = superior temporal gyrus.

TABLE 3

Mean reaction times (and standard error) in ms to control and related probes at each probe position for the participants with aphasia.

	PP1	PP2	PP3	PP4
Control	787 (9.0)	789 (9.6)	771 (8.2)	758 (8.0)
Related	777 (8.1)	771 (8.4)	771 (8.7)	752 (8.2)
(Control – Related)	10 ms	18 ms[*]	0 ms	6 ms

[*]
$p < .05$.

Chapter 3, in full, is a reprint of material as it appears in Ferrill, M., Love, T., Walenski, M., Shapiro, L. (2012). The time course of lexical activation during sentence comprehension in people with aphasia. *American Journal of Speech-Language Pathology,* 21, S179-189. The dissertation author was the primary investigator and author of this paper.

CHAPTER 4:

The Effect of Rate of Speech Manipulation on the Time-Course of Lexical Activation
During Sentence Comprehension in Aphasia

THE EFFECT OF RATE OF SPEECH MANIPULATION ON THE TIME-COURSE OF LEXICAL ACTIVATION DURING SENTENCE COMREHENSION IN APHASIA

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ABSTRACT

Purpose: To investigate the effect of slowed speech rate on the time-course of processing of lexical items in auditorily presented canonical (subject-verb-object) constructions for participants with left-hemisphere damage and Broca's aphasia.

Method: A cross modal picture priming (CMPP) paradigm was used to test 7 participants with agrammatic aphasia for priming of a lexical item (direct object noun) during ongoing processing of sentences that have been slowed by 1/3 from the typical rate of speech. Priming for the lexical item was assessed at 4 time time-points; immediately after it was initially encountered in the ongoing auditory stream and at 3 additional time points at 400-ms intervals. For 4 of the 7 participants who had lesion data available, patterns of priming at regular and slow rate, as well as the change in priming across rates, were compared to the extent of lesion to three brain regions of interest hypothesized to contribute to sentence processing.

Results: Although there were no significant effects of rate of speech for the group overall, the intersubject variability was highly correlated with the amount of lesion involvement of BA45, a brain region that has been linked to lexical-semantic processing.

Conclusion: This evidence supports the hypothesis that a deficit in lexical, and not syntactic processing, underlies the slow-rise time observed for individuals with Broca's aphasia.

Keywords: aphasia, syntax, slow rise-time, rate of speech, online, priming, sentence processing, neurolinguistic

INTRODUCTION

One of the hallmarks of agrammatic Broca's Aphasia is the inability to comprehend certain complex sentence constructions such as those that do not follow canonical word order (Subject-Verb-Object, in English) (Caramazza & Zurif, 1976; Grodzinsky, 1990; Love & Oster, 2002). The underlying disorder is still the source of much debate. Several different types of hypotheses have been proposed to explain these deficits including accounts that posit that the locus of the deficit exists at the lexical level and others that propose a breakdown at the structural level. Structural hypotheses propose that individuals with Broca's aphasia have difficulty processing syntactic elements due to depleted processing resources (Caplan & Waters, 1999), or deficient syntactic representations (Grodzinsky, 2000). Of particular interest, the Syntax Hypothesis (i.e., "slow syntax;" Avrutin, 2006; Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008; Piñango, 2000) posits that it is the syntactic system itself (or the syntax-discourse interface) that is slowed or weakened, leading to difficulty forming syntactic dependencies.

Lexical hypotheses on the other hand propose that access to information in lexical entries is either incomplete (Milberg & Blumstein, 1981) or delayed during sentence comprehension. Specifically, the Delayed Lexical Activation Hypothesis (DLA) proposes that delayed access or activation of the meaning of a lexical item in a sentence feeds syntactic routines too slowly (Love, Swinney, Walenski, & Zurif, 2008; Prather, Love, Finkel, & Zurif, 1994; Prather, Zurif, Stern, & Rosen, 1992). Past research has suggested that if linguistic information is not available in the timeframe

associated with normal processing, a breakdown of language processing can occur (Frederici & Kilborn, 1989).

Although the idea of lexical access in Broca's aphasia being characterized by having a slow-rise time has existed for some time (see prior work by Love, Swinney, & Zurif, 2001; Prather, Zurif, Love, & Brownell, 1997; Prather, Zurif, Stern, & Rosen, 1992; Swinney, Zurif, & Nicol, 1989) recently a spate of research papers using different methods have been published offering additional support (Choy, 2011; Dickey et al., 2007; Dickey & Thompson, 2009). For example, a cross-modal priming (CMP) study investigating patterns of lexical activation and syntactic re-activation during sentence comprehension in Broca's aphasia was recently presented by Love, Swinney, Walenski, and Zurif (2008). In this study, participants listened to sentences containing an object-extracted relative clause, as in (1), below:

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

In the object-extracted relative clause in (1), the direct object noun phrase (NP) of the verb *condemned* (i.e., *the wrestler*) has been displaced from its underlying position to a position occurring before the verb, leaving behind a copy or trace of the moved NP. The copy and the displaced NP form a syntactic chain; the copy is deleted from the representation and thus only the displaced NP can be pronounced (note that in psycholinguistic terminology, the displaced NP is the "filler" and the positon from which it is displaced is the "gap"). In their study, Love et al. (2008) measured priming (speeded reaction time to a related compared to unrelated probes) at five positions

during the ongoing auditory sentence (signified by the superscript numerals in (1)). It is believed that priming is an indirect measure of lexical access. In contrast to the patterns of immediate access (i.e., priming) evinced by neurologically unimpaired listeners for the meaning of the antecedent ('the wrestler') at its offset (*1) and again at the gap (*3), participants with Broca's aphasia demonstrated delayed access. Specifically, they did not evince priming at the offset of the antecedent (*1) but did so 300 ms later (*2). Furthermore, they did not demonstrate re-access at the gap (*3) but did so 500 ms later (*5).

These results show that initial activation of the noun phrase serving as the antecedent is delayed, as well as its syntactically driven reactivation. Love et al. (2008) suggested that the fact that both lexical activation and gap filling were delayed for listeners with Broca's aphasia suggests that the lexical delay interferes with timely syntactic processing, consistent with predictions extended by the DLA. Furthermore, the fact that listeners with Broca's aphasia are able to form syntactic dependencies, albeit in a delayed fashion, further supports the hypothesis that the deficit is due to disrupted processing. The authors suggest that both the delay in activating the antecedent and the delay in reactivating it at the gap are attributed to the same source.

An additional finding from Love et al. (2008) supports the claim delayed lexical processing leads to the offline sentence comprehension deficit in Broca's aphasia. Participants with Broca's aphasia evinced normal access/re-access patterns (and improved off-line comprehension) when speech input was slowed to 3.4 syllables per second relative to normal input speed (between 4-6 syllables per second in English; Dellwo & Wagner, 2003; Skodda & Schlegel, 2008). This pattern indicates

that the deficits could be overcome when the normal time constraints for re-access are relaxed. Furthermore, slowing the rate of speech also resulted in improved performance on an off-line, sentence-picture matching comprehension task, providing evidence that on-time lexical access is important for successful comprehension of complex sentences (Love et al., 2008, Experiment 2).

However, a recent eye tracking study by Choy (2011) failed to find effects of slowed speech rate. Choy had participants listen to two-sentence mini-stories (see example (2) below) containing an object-cleft sentence describing a transitive event while eye movements to pictures representing the nouns mentioned in the story were recorded. Sentences were followed by a yes/no comprehension question.

(8) This story is about a boy and a girl. It was the *boy*$_i$ who the girl kissed ___ that day at school.

Did the girl kiss the boy?/Did the boy kiss the girl?

Similar to the sentences containing an object extracted relative clauses used by Love et al. (2008), the object-cleft sentences in (2) contain a displaced NP ('the boy') that co-refers with its underlying position at the gap. Although a significant difference in comprehension accuracy was found between the participants with Broca's aphasia and a group of neurologically unimpaired control participants (with the participants with Broca's aphasia performing at-chance), in contrast to the findings of Love et al. (2008), no effect of speech rate on comprehension was found for either group. No effect of speech rate (slowed from 4.6 syllables per second to a slow rate of 3.4 syllables per second) was found for mean latency of fixations (gazes) to the nouns

either, although gazes were delayed for the participants with Broca's aphasia compared to the control group, supporting a claim of delayed lexical access. Lastly, Choy (2011) found that mean latency of fixations to the displaced NP at the gap, while also not affected by rate, was not significantly different for the participants with Broca's aphasia compared to the control group, suggesting that the participants with aphasia were able to form syntactic dependencies in a timely manner.

There are several important differences between the two studies (Choy, 2011; Love et al., 2008) that may help to explain the disparate findings. First, in the Choy (2011) study, a speaker recorded the slow rate sentences, whereas for the Love et al. study, the slow rate sentences were derived from the regular rate sentences, which were slowed via software while maintaining pitch and prosody. As such, there is no way of knowing whether the same variables (e.g., vowel length, pause time between words) were affected in the two different studies, or whether pitch and prosody were maintained for the Choy (2011) study. Second, as noted, the Choy (2011) study used object-cleft constructions whereas the Love et al. (2008) study used object-relative constructions. Object-relative constructions contain a more complex main clause as well as three nouns with semantic content (as opposed to two in object-clefts). It is possible that the greater complexity of the object-relative sentences in the Love et al. (2008) study allowed for greater benefit of slowing. Furthermore, cleft sentences bring focus to one constituent of the sentence, in this case the object, or the NP of interest at the gap, by placing it after *It was*. It is possible that focusing attention on this NP allowed for facilitated re-activation. Third, before the object-cleft sentence containing the gap, participants in the Choy (2011) study were first exposed to the NPs

of interest in a canonical discourse sentence. The repetition effects due to the additional exposure to the critical NPs may have resulted in the timely re-activation at the gap. Finally, the eye tracking method used by Choy (2011) provides visual contextual support in the form of a narrowed set of visual referents that are available to the listener before and during the sentence. Although eye tracking is a relatively commonly used method, it has not been resolved how results from such studies relate to predictions about linguistic processing in the absence of visual context (Huettig, Rommers, & Meyer, 2011; Kamide, Altmann, & Haywood, 2003).

Further evidence for delayed lexical activation for listeners with Broca's aphasia comes from a recent study by Ferrill, Walenski, Love, and Shapiro (2012) who used CMP to investigate the time-course of lexical access in syntactically simple, canonically word ordered sentences. Although the previous studies described have demonstrated delayed activation of lexical items, they have done so in the context of syntactically complex constructions potentially limiting the implications of the findings on the DLA. Specifically, it is possible that the lexical delay was due to the syntactic complexity of the experimental sentences themselves. Ferrill et al. (2012) sought to address this issue by examining lexical access in syntactically simple sentences. Additionally, the study questioned whether lexical access for individuals with Broca's aphasia followed a typical pattern but was just delayed, or whether the pattern of lexical access deviated completely, for example, with activation being maintained longer or decaying sooner than unimpaired listeners. Using the Cross Modal Picture Priming technique (CMPP), Ferrill et al. (2012) presented sentences such as (3) below:

(3) The boxer punched the golfer[*1] after[*2] the tre[*3]mendou[*4]sly antagonistic

discussion about the title fight.

In these sentences the direct object noun phrase was the lexical item of interest (e.g., *the golfer*), and was followed by a prepositional phrase, designed to avoid the occurrence of another noun phrase – and its lexical activation – within 2000 ms of the direct object NP. Related and control probe pictures (golfer-nun) were presented at four positions of interest (again, indicated with asterisks): immediately after the lexical item, and 400, 800, and 1200 msec downstream (more detail can be found in the Method section, below). Priming was found for neurologically unimpaired participants immediately after the lexical item (*1), as was expected from previous studies (Swinney, 1979), and decayed rapidly thereafter. For individuals with Broca's aphasia, significant priming was not found until 400 msec downstream (*2), demonstrating that the lexical delay is, indeed, independent of complex syntax. Interestingly, the pattern of access for individuals with Broca's aphasia appeared almost identical to that of the neurologically unimpaired participants, albeit "shifted" by 400 msec.

Taken together, the results of recent studies investigating the time-course of initial lexical activation of an NP have consistently shown that access is delayed. The question remains, then, whether slowing the rate of speech will allow a slowed lexical activation system to yield 'normal' patterns of lexical access as predicted by the DLA, or whether slowing input only allows for on-time formation of syntactic dependencies as found in Love et al. (2008). If the latter is the case, as would be predicted by the

Slow Syntax hypothesis, slowing the rate of speech should have no effect on lexical access in syntactically simple sentences. In the following study, then we adapt the materials from Ferrill et al. (2012) by slowing the rate of speech in the same manner as Love et al. (2008).

Experiment 1: Cross-modal priming investigation

Method

<u>Participants</u>

A total of 7 unilateral left hemisphere damaged (LHD) participants with Broca's aphasia and who have a sentence comprehension deficit met criteria for participation (mean age at time of testing: 53.1 years; range: 33.2-71.8 years). Demographic information is presented in Table 4-1. Notably, all the participants were the same as were presented in Ferrill, et al., 2012 with the exception of LHD043, who was unable to complete the required visits for this study. All participants had experienced a single, unilateral left hemisphere stroke and were native English speakers with normal or corrected-to-normal visual and auditory acuity, and were right-handed prior to their stroke. Diagnosis of Broca's aphasia was made based on the administration of standardized language testing to determine each participant's severity of language impairment; specifically, fluency and auditory comprehension ability. Testing included the Boston Diagnostic Aphasia Examination (BDAE-version 3; Goodglass, Kaplan, & Barresi, 2001), Western Aphasia Battery - Revised (WAB-R;

Kertesz, 2006), SOAP (Subject-relative Object-Relative Active and Passive) test of auditory sentence comprehension (Love & Oster, 2002). As the DLA hypothesis makes the specific claim that a lexical deficit underlies comprehension deficits in agrammatic aphasia, participants were considered for inclusion if they showed evidence of such comprehension deficits, which we defined here as at or below chance on comprehension of sentences with non-canonical word order (object-relative and passive sentences) from the SOAP. All patients 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, no history of active psychiatric illness or intellectual disability, and no history of other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). Participants were tested at the Language And Neuroceince Group (LANG) Laboratory at San Diego State University and were paid $15 per session.

Table 4-1. Demographic and lesion information for participants with aphasia

Patient	BDAE[a] Severity	WAB[b] Aphasia Quotient	SOAP[c] Canonical	SOAP[c] Non-canonical	Gender	Age at Testing	Time Post Stroke	Education	Lesion location[d]
LHD009	3	76.3	75%	55%	M	50;2	9;8	5 yrs college	Large L lesion involving inferior frontal gyrus (BA 44,45)
LHD019	1	54.1	90%	20%	F	61;1	16;1	High School	L MCA embolic stroke; distribution encompasses broad left frontal lobe region
LHD040	2	76.7	60%	60%	M	71;9	5;11	B.A.	Small L subcortical lesion involving the Basal Ganglia
LHD101	2	82.4	95%	35%	M	61;8	3;9	PhD	Large L lesion involving posterior inferior frontal gyrus (BA44) with posterior extension
LHD130	4	81.1	95%	65%	M	58;1	2;8	B.A.	L IPL with posterior extension sparing STG.
LHD138	2	N/A	70%	25%	M	33;3	12;1	some college	L MCA infarct
LHD140	2	72.9	80%	30%	F	36;0	10;7	B.A.	L MCA infarct with distribution encompassing broad left frontal lobe region

[a] BDAE = Boston Diagnostic Aphasia Examination
[b] Western Aphasia Battery
[c] Subject-relative, Object-relative, Active and Passive
[d] L = left; MCA = middle cerebral artery; IPL = inferior parietal lobule; STG = superior temporal gyrus

Task

In this Cross-Modal Picture Priming task (CMPP; Swinney & Prather, 1989),
participants listened to uninterrupted auditory sentences and made binary, HUMAN
(YES) /NOT HUMAN (NO), decisions to visually presented black and white line
drawings (visual probes). Each experimental sentence had 2 visual probes (each
requiring a YES response)- a related probe that was a representation of the noun
phrase in the direct object position of the sentence, and a control probe that was
unrelated to any word in the sentence (Figure 4-1). In this dual task, the visual probes
are presented at key times during the ongoing sentence, and priming effects are
measured by comparing reaction times to the related and control probes at that point –
faster reaction times to the related probes indicate a priming effect. Importantly,

priming effects in cross-modal tasks reflect activation of the sentential prime at that point in the ongoing auditory sentence, not the integration of the visual probe into the sentence (Nicol, Swinney, Love, & Hald, 2006).

Materials

Materials were identical to those used in Ferrill et al. (2012). 40 experimental sentences were presented with the following canonical Subject-Verb-Object sentential structure:

3. <u>Subject</u>   <u>Verb</u>   <u>Object</u>   <u>Prep Phrase</u>

The boxer   punched   the golfer [1]   after [2]the tre[3]mendou[4]sly antagonistic discussion about the title fight.

In these sentences the direct object noun (Object) was the lexical item of interest (e.g., *the golfer* in example 3 above), and was followed by a prepositional phrase, designed to avoid the occurrence of another NP – and its lexical activation – within 2000 ms of the direct object NP.

Again, following Ferrill et al. (2012), the experiment employed a switched target design, in which the related probe for one sentence appeared as a control probe for a different sentence, whose related probe served as the control probe for its paired sentence (Figure 4-1). Thus over all the sentences, the set of related probes was identical to the set of control probes, minimizing the possibility that any observed priming effects will be due to unimportant aspects of the pictures that might influence

reaction time (e.g., visual complexity differences). Refer to Ferrill et al. (2012)

for a more detailed description of picture probe development and selection.

(a)

The boxer punched the *golfer* *after *the tre*mendou*sly antagonistic discussion about the title fight.
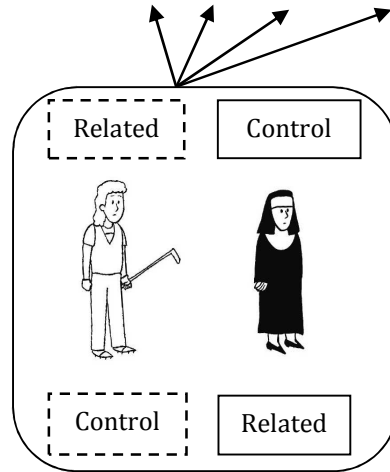
(b)

The clown scared the *nun* *after *the exc*essiv*ely harsh criticism of the circus.
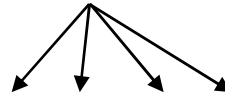
Figure 4-1. Switched-target sentence design

To establish the time-course of activation of the direct object NP, the related and control visual probes were presented at four positions in the ongoing auditory sentence (indicated approximately by the superscript numerals in example 4 above). Probe position (PP) 1 occurred immediately at the offset of the direct object NP. Each subsequent probe position was 400 ms downstream from the previous NP. This tactic allowed us to chart a pattern of lexical activation of the direct object NP across 1200 ms (PP 4) after it was heard in the ongoing auditory stream.

In addition to the 40 experimental sentences, 60 filler sentences were created. Forty of the filler sentences were similar in length and structure to the experimental sentences, but were paired with an animal (non-human) picture probe (requiring a NO response). The other 20 filler sentences were of a different syntactic structure, to provide a variety of sentence forms. Of these 20 sentences, 10 were paired with a human picture probe, and 10 with an animal picture probe to balance the number of 'human' and 'non-human' responses across the full set of items. 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 the end of the sentences. This tactic is used to prevent the anticipation of probe positions. Finally, ten practice sentences (also balanced for the number, order and type of response), were added to the beginning of each script to familiarize the participant with the task, as well as to allow the experimenter the opportunity to monitor the participants to ensure they understood the task.

After the 10 practice items, the remaining 100 sentences (40 experimental; 60 filler) were intermixed and pseudo-randomly ordered such that no more than three sentences in a given condition or with a particular response occurred in a row. The sentences were recorded by a female native English speaker at a normal rate of speech (M= 4.6 syllables per second). Integral to this experiment, the rate of speech of the auditory sentences was digitally slowed to an average rate of 3.1 syllables per second while preserving pitch and intelligibility. Recording and editing were performed using Adobe Audition 3.0[©].

Design

This study employed a fully within-subjects design. The four probe positions, combined with the related/control variable, yielded 8 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. The order of presentation of the 8 conditions was counterbalanced across participants. Sessions were separated by at least one week, and most often two weeks.

Procedure

Training protocol: To ensure that our participants with aphasia were performing reliably on the binary picture decision task and that they understood the dual task instructions, a training session was given before the experimental script at each of the 8 visits. Participants were told that a picture would appear in the middle of the screen and they were to decide whether the picture was human or not by pressing a button labeled "YES" for human, or "NO" for not human, as quickly as possible. The list consisted of 20 items, 10 human and 10 non-human. This picture-only training list was repeated as many times as needed until the participant was able to reliably perform the task. None of the pictures used in the training task were repeated in the scripts. Participants were instructed to make their responses using the hand ipsilateral to their lesion (left hand). Once the participants understood the binary decision task, they were introduced to dual task experiment.

Prior to the cross-modal portion of the experiment, participants were instructed that they would be performing a dual task - 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 decision as quickly and accurately as possible (using a two button response box) as to whether the picture was HUMAN (YES response) or NOT HUMAN (NO response).

To encourage attention to the sentences and keep participants on task, they 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 subjects to attend to the sentences. Tempo (ver. 2.1.5) controlled the timed presentation of auditory and visual stimuli and the collection of participant responses (both YES/NO decisions and millisecond accurate reaction times for each decision). Each visual probe was presented for 1000 milliseconds, or until a response was made. Responses were recorded for up to 3000 milliseconds following the appearance of the picture probe. An interstimulus interval (ISI) of 2000 milliseconds followed each sentence.

Analysis

All participants performed above chance on the task related comprehension questions. Data were first reviewed for button-press accuracy. All participants responded to the button press decision with greater than 90% accuracy ($\bar{X} = 98.6\%$;

SD= 1.4%; range: 95.8%-99.7%). Prior to analysis, incorrect responses (1.5% of all data) were removed. There were no RTs less than 300 ms or greater than 2000 ms, thus no overall outliers were removed. Responses to two picture probes ('golfer' and 'acrobat') were removed as the average reaction time across all participants was greater than two standard deviations above the mean compared to reaction times for other picture probes. Finally, a two standard deviation participant screening was then performed for each participant separately for each condition (4.7% of the data). As in Ferrill et al. (2012), an analysis was then conducted on the remaining data using a restricted maximum likelihood (REML) in a mixed-effects regression model with crossed random effects on the intercept of Participant and Sentence (which combines traditionally separate F1 and F2 analyses into a single statistical test) and fixed effects of Probe Position (1 vs. 2 vs. 3 vs. 4), Relatedness (Related vs. Control), and their interaction. The models were fit with an unstructured covariance matrix for each random effect. Type III *F*-tests are reported for main effects and interactions. All analyses were conducted using SAS version 9.4 (SAS Institute, Inc.). All *p*-values are reported two-tailed.

Based on the rationale that a slowed input rate and a slowed lexical activation system will combine to yield "normal" priming patterns, we expected that significant priming would be revealed at PP1, the offset of the lexical item of interest in the sentence, as this was the finding for neurologically unimpaired participants in Ferrill et al. (2012).

Results

Mean reaction times and standard errors for each condition are given in Table 4-2.

Table 4-2. Mean reaction times (and standard error) in milliseconds to related and control probes at each probe position for the patients with aphasia (N=7)

	Probe Position			
	PP1	PP2	PP3	PP4
Control	759 (10.1)	763 (8.3)	746 (10.1)	752 (8.0)
Related	763 (10.1)	757 (8.0)	745 (10.6)	759 (8.7)
(control - related)	-4 ms	6 ms	1 ms	-7 ms

Neither the overall interaction between probe position and relatedness ($F(3, 1950)=0.44$, $p=0.72$, nor the main effect of relatedness ($F(1, 1949)=0.03$, $p=.85$) reached significance, though the main effect of probe position did ($F(3, 1949)=5.69$, $p<0.01$) with earlier probe positions eliciting slightly longer reaction times overall. *A priori* planned comparisons of the reaction times for related compared to control picture probes revealed a non-significant priming effect at probe position 1 (-4 ms control - related difference; $t = -0.42$, $p = 0.67$), probe position 2 (6 ms control - related difference; $t = 0.72$, $p = 0.47$), probe position 3 (1 ms; $t= -0.24$, $p = 0.91$), and probe position 4 (-7 ms; $t = -0.81$, $p = 0.41$).

Interim Discussion

The primary intent of this study was to investigate the effect of slowed rate of speech on the time course of lexical activation in simple, canonical (S-V-O)

constructions in order to address the underlying deficit in the formation of dependency relations in Broca's aphasia. We hypothesized that a slowed input rate and a slowed lexical activation system would combine to yield 'normal' patterns of lexical access. Instead we found, contrary to expectations, that slowing the rate of speech did not evince "typical" priming patterns, and in fact, overall there was no significant priming found at any of the probe positions. On the surface it would appear that these results support the findings of Choy (2011), who also failed to find an effect of slowed rate of speech on lexical access. On the other hand, these results do not account for the findings described in Love et al. (2008), or at the very least suggest that slowed rate has a differential effect on lexical access and dependency linking.

However, when we examined the individual priming patterns for our participants with Broca's aphasia, interesting patterns emerged. Although not statistically significant at the individual subject level, one of our subjects who demonstrated delayed priming in Ferrill, et al. (2012) at a regular rate of speech did show the expected effect of slowing – that is, the participant primed earlier in the slow speech condition compared to the regular rate condition (LHD101). Three subjects that showed earlier priming effects at regular rate demonstrated no priming at any probe position at the slowed rate, akin to the pattern of results seen for the neurologically unimpaired control group in Love et al. (2008) when rate of speech was slowed (LHD009, LHD019, and LHD040). Another two subjects who demonstrated positive priming across multiple probe points at regular rate of speech continued to show that effect, only with priming strengthened at slowed rate (LHD140, and LHD138). These patterns suggest that there may be some other unaccounted for

variable or variables, that is, other than those that were used to initially classify our participants with Broca's aphasia, that affects their response to the slowed rate. To further understand this variability, we introduce a different approach to analyzing the behavioral data, based on neuroanatomical data.

Cytoarchitectonic Probability Maps

High inter-subject variability has long been recognized as a hallmark of agrammatic, Broca's aphasia (Berndt, Mitchum, & Haendiges, 1996). However, recently more attention has been paid to the potential contribution of damage to individual brain regions. For example, the voxel-based lesion-symptom mapping (VLSM) technique has been used to statistically compare lesion location with performance on a range of behavioral measures (e.g., (Bates et al., 2003; Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004, and many more). However, VLSM has not yet been applied to associate areas of brain damage with measures of on-line language processing, such as priming measures, likely due to the large number of subjects required for such an analysis. Furthermore, VLSM is prone to the challenges imposed by spatial normalization of lesioned brains in that these brains often have greater differences than those imposed by typical individual variability, which complicates the registration process and has the potential to misrepresent lesion extent and location (Andersen, Rapcsak, & Beeson, 2010; Ripollés et al., 2012). Finally here, individual brain regions within the template to which the lesioned brains are aligned are often segmented based on macrostructural landmarks, such as sulci and gyri. These landmarks vary morphologically from one individual to the next, and

moreover do not correlate well with the changes in the underlying cellular structure (cytoarchitecture), which more likely demarcate functionally independent units (Amunts et al., 1999; Zilles & Amunts, 2010).

A novel approach comparing the proportion of lesion in brain regions of interest (ROIs) in participants with aphasia to on-line behavioral measures was recently undertaken by Walenski et al. (2012). In this study, the boundaries of the brain regions of interest (ROIs), rather than being determined based on spatial normalization of the high resolution anatomical scan to a macroanatomical template, were determined based on a cytoachitectonically defined 'map,' the Jülich–Düsseldorf cytoarchitectonic probabilistic brain atlas (Mohlberg, Eickhoff, Schleicher, Zilles, & Amunts, 2012). This atlas was developed based on statistical examination of laminar distribution of cell densities in 10 post-mortem brains. The parcellated brain regions from all ten brains were then superimposed on each other and each three dimensional volume at the resolution of the anatomical scan (voxel) was assigned to the brain area with the highest overlap, or probability. In this way, the probability map of a certain brain ROIs could be registered to the high resolution anatomical scan of the brain of the person with aphasia itself, both avoiding some of the potential pitfalls of normalizing and providing a way to more accurately identify functionally independent brain regions in lesioned brains. Additionally, given defined lesion boundaries, areas of overlap between the lesion and the probability maps can be calculated to derive the proportion of that particular region that is implicated in the lesion. By statistically comparing the lesion extent in the a-priori defined ROIs with the results from their on-

line behavioral task, Walenski et al. (2012) were able to draw some inferences about the functional contribution of those brain regions to linguistic process underlying their behavioral measure. They found that, at least for the certain type of sentences containing syntactically complex constructions that were tested, there was a relationship between lesions in left inferior frontal cortex (BA44) and left temporal cortex (Te3) and behavioral outcomes (priming effects). Specifically, their results found that damage to left inferior frontal gyrus, specifically BA44, disinhibited activation, whereas damage to left Te3 led to inhibited activation and resulted in delayed priming effects. This is consistent with previous research suggesting that the temporal lobe is the locus of stored lexical and conceptual knowledge, and when more intact, drove activation (Friederici, 2002; Tranel, Damasio, & Damasio, 1997; Ullman, 2001), whereas left inferior frontal regions have been linked to *strategic control* of phonological and semantic processing (Bedny, Hulbert, & Thompson-Schill, 2007; Fiez, 1997; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Furthermore, the relative damage to these two regions jointly determined the magnitude and timing of that individual's priming effect. Lesion proportion to the more anterior portion of Broca's area (BA45) did not significantly contribute to the priming patterns in this case. This finding is perhaps not surprising given that the experimental sentences were syntactically complex, and BA44, but not BA45, has been linked to syntactic processing and syntactic working memory where as BA45 has been linked to the maintenance and control of lexical knowledge (Friederici, 2002).

In an attempt to account for some of the intersubject variability in response to the slow rate of speech from Experiment 1, Experiment 2 co-opts the analysis

approach from Walenski et al. (2012).

Experiment 2: Structure-function analyses

Methods

Participants

The participants for this analysis consisted of a subset (N=4) of the seven subjects from Experiment 1. LHD138 was unable to complete a high-resolution anatomical magnetic resonance imaging (MRI) scan due to medical contra-indications and therefore was excluded from the analyses. Two additional participants (LHD040 and LHD130) were excluded due to the their brain lesions not extending into the a-priori defined brain regions of interest for these analyses.

Probability Maps, Lesion Co-registration and Quantification

MRI images were acquired with a 3T GE Signa HDx MR scanner (Milwaukee, Wisconsin) and an 8-gradient head coil. Each participant lay supine inside the MRI scanner during testing with motion restricted by foam padding around the head and a piece of medical tape placed under the chin. A high resolution anatomical scan (FSPGR; TR = 7.772 msec; TE = 2.976 msec; flip angle = 12º; FOV = 256 mm; matrix 256 × 192; 172 sagittal slices, resolution = 1mm^3 voxels) was obtained for each participant.

Whole brain and lesion masks were created manually for each participant, using the Analysis of Functional NeuroImages software (AFNI; Cox, 1996). Probabilistic maps of cytoarchitectonic areas from the Jülich Brain Mapping Project

(Amunts et al., 1999; Zilles & Amunts, 2010) were transformed on each participant's

brain based on a non-linear registration; the transformation was determined solely by

the non-lesioned brain areas (Hömke et al., 2009). Each voxel from the anatomical

scan was assigned a probability of belonging to a particular anatomical region, and

counted as belonging to that region for probabilities greater than 0.5 (Morosan,

Schleicher, Amunts, & Zilles, 2005). Thus for each participant we computed the

proportion of lesioned tissue in particular cytoarchitectonic areas, as well as for the

entire left hemisphere (Table 4-3). The particular areas we investigated were left

BA44 (opercular part of inferior frontal gyrus) and BA45 (triangular part of inferior

frontal gyrus), corresponding to Broca's area in inferior frontal gyrus (for precise

anatomical boundaries of these regions, see Amunts *et al.*, 1999), as well as left Te3

(roughly the posterior two-thirds of BA22), corresponding to Wernicke's area (for

precise anatomical delineation of this area, see Morosan et al., 2005). Probability maps

for the 3 regions of interest are shown on a reference brain (colin27) in Figure 4-2.
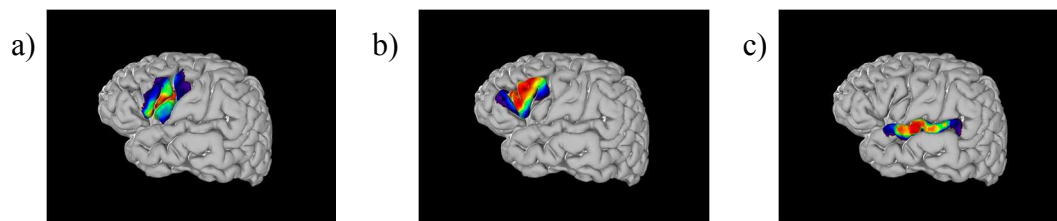
Figure 4-2. Probability maps from the Julich Brain Mapping Atlas for each of the three regions of interest used in the structure-functional analyses in Experiment 2: a) BA44, b) BA45, and c) Te3. Note that the hot colors (red) represent maximal overlap and cool colors (blue) represent minimal overlap

Priming effect size and lesion analysis

      Behavioral response time data from Experiment 1 was used in this analysis. As

a reminder, incorrect responses, and responses for each participant that were more

than 2 standard deviations from their individual mean for each condition were

removed prior to all analysis. We computed priming effect sizes for each participant at

each probe position by recoding the related/control probe variable as 0 (related) or 1

(control) for each response, and correlating this new variable with the screened

response times for each response using a standard Pearson correlation. The resulting r-

value yielded an effect size, with values ranging from -1 (inhibition) to 1 (priming). In

order to directly compare the contribution of damage to the brain regions of interest on

lexical access at slow rate of speech to the contribution at regular rate of speech,

priming effect sizes were additionally calculated based on the original data, screened

in an identical manner to that described in Experiment 1, from Ferrill et al (2012) for

these participants. Priming effect sizes for each condition are shown in Table 4-3.

Table 4-3. Proportion of lesioned tissue in each ROI and the left hemisphere for
individual participants

Patient	BA44	BA45	TE3	Total Left Hemisphere
LHD009	70.4	26.8	46.2	14.4
LHD019	82.3	85.4	99.7	24.7
LHD101	46.3	9.7	98.8	15.1
LHD140	87.7	73.5	100	25.8

      To assess the structure-function relationship between priming patterns and

lesion location and extent, the r-value (behavioral) effect sizes were used as the dependent measure in ordinary least-squares regression analyses, with separate analyses at each probe point. Analyses focused on probe point 1 (NP offset) and probe point 2 (400 msec downstream) as those were the focus of our hypotheses from Experiment 1. Proportion of lesioned tissue in the entire left hemisphere (hereafter: total lesion size) was included as an independent variable in each analysis. Due to the limited number of degrees of freedom in the model, separate analyses were performed with the proportion of lesioned tissue in BA44, BA45, and Te3 as independent variables.

Results

Calculated priming effect sizes for each participant at both rates at each probe position are given in Table 4-4.

Table 4-4. Priming effect sizes (r) for each participant (N=4) at each probe position/rate of speech

	Priming Effect Size					
Patient	Slow Rate PP1	Slow Rate PP2	Regular Rate PP1	Regular Rate PP2	PP1 Rate Difference (Reg-Slow)	PP2 Rate Difference (Reg-Slow)
LHD009	-0.185	0.1425	0.0877	-0.0197	0.2726	-0.1622
LHD019	-0.067	0.0109	0.2253	0.2184	0.2923	0.2075
LHD101	0.1259	0.1292	-0.06877	0.3141	-0.1946	0.1849
LHD140	0.1882	0.1442	0.1060	0.0603	-0.0821	-0.0839

For the slowed rate of speech, at the NP offset (PP1), a significant effect was found for BA45 (B=-1.4, t(1)=-36.12, p=0.01; 95% CI: [-1.9, -0.9]), but not for either BA44 or Te3 controlling for total lesion size. Overall, the model including BA45 and total lesion size was a significant fit to the data (F(2,1)=739.38, p=0.03), with an adjusted R^2 (proportion of variance explained) of 0.99. The directions of the significant effects indicate that greater damage to BA45 corresponded to smaller priming effects (negative coefficient) at slowed rate of speech.

For the regular rate of speech at PP1, again a significant effect was found for BA45 exclusively (B=0.008, t(1)=38.24, p=0.01; 95% CI: [-.005, 0.01]). However, this effect was in the opposite direction, indicating that greater damage to BA45 corresponded with larger priming effects at regular rate. Again, the model including BA45 and total lesion size was a significant fit to the data (F(2,1)=1397.99, p=0.02), with an adjusted R^2 (proportion of variance explained) of 0.99. In line with both of the previous findings, the proportion of lesion involvement in BA45 also significantly corresponded to the change in priming due to the change in rate, that is, when, using a difference score as a dependent measure, obtained by subtracting the priming effect size at the slowed rate from the priming effect size at regular rate (B=2.176, t(1)=36.49, p=0.03; 95% CI: [1.4, 2.9]). The direction of these effects suggest that more damage to BA45 corresponded to more priming at regular rate compared to slow rate of speech at PP1. No significant effects were found between proportion lesion to any brain ROI and priming effects at either rate of speech for the downstream probe point (PP2).

Interim Discussion

We examined three regions known to be involved in sentence processing (BA44, BA45, and Te3), each precisely delineated by probability maps based on their cytoarchitectonic structure. We found that damage to BA45 predicted the amount of priming (or inhibition) at the offset of the NP in our participants with Broca's aphasia, with more damage corresponding to stronger priming at regular rate and weaker priming at slow rate. The proportion of lesion involvement in BA45 also predicted the *change* in priming across the rates, further validating the independent findings at each of the rates. Importantly, this effect was bi-directional, meaning that participants with less damage to BA45 evinced weaker priming at PP1 at regular rate and stronger priming at slow rate, after controlling for total lesion size.

Interestingly, this pattern of a greater proportion of damage to portions of Broca's area equating to greater priming is similar to that found by Walenski et al. (2012), although in their case, the correlation involved BA44 not BA45. This difference is perhaps not surprising however, given that multiple lines of evidence suggest functional differences between these two regions (Friederici, 2011; Vigneau et al., 2006). While posterior portions of Broca's area (including BA44) are implicated in syntactic processing and syntactic working memory of the kind that were involved in the Walenski et al., (2012) sentences, BA45 is typically linked to semantic processing (Poldrack et al., 1999; Wagner et al., 2000). For example, using dynamic causal modeling (a statistical procedure for estimating coupling between brain regions over time) the strength of the connection between posterior inferior temporal regions,

linked to lexical storage and access, and BA45, was enhanced during lexical decisions

(Heim et al., 2009). These results suggest that BA 45 is part of a network of brain

regions involved in lexical processing. Importantly, the direction of the effect

observed here for BA45 – priming effect sizes increase with increasing damage –

suggests that this region plays an inhibitory role in its undamaged state.

GENERAL DISCUSSION

The main goal of this study was to investigate the effect of slowed rate of

speech on the time-course of lexical activation in simple, canonical (S-V-O)

constructions for listeners with agrammatic Broca's aphasia. To review, adding to a

body of evidence, Ferrill et al (2012) found that lexical access was delayed for

listeners with Broca's aphasia for these kinds of sentence constructions, even in the

absence of syntactic complexity. According to the Delayed Lexical Activation

Hypothesis (DLA), it is this delayed lexical activation which disrupts other fast-acting

processes, such as those involved in the reactivation of a lexical item at a gap in

sentences involving syntactic displacement, and ultimately resulting in failed sentence

comprehension.

Previous studies, such as Love et al (2008), have found a facilitory effect of

slowed speech rate on lexical reactivation at a syntactic gap, evincing essentially a

'normal-like' pattern. However, these studies for the most part have not examined the

effect of rate of speech manipulation on initial lexical access, so it remains unclear

whether the benefit of the slowed rate on gap-filling was due to speeded lexical access

a the DLA claims, or whether slowing the rate of speech generally allowed for the

relaxation of the time constraints for the still-delayed lexical access to interact with these other fast-acting processes. This latter explanation would be more coherent with a slow-syntax account of sentence comprehension deficits in aphasia.

It should be noted here that studies finding on-time gap filling using a slowed speech rate are not limited to studies using the CMP paradigm. For instance, Dickey & Thompson (2009) examined eye movements while participants listened to discourse sentences followed by comprehension probes containing an object-extracted relative clause and found on-time gazes at the gap to the displaced NP. Although Dickey and Thompson (2009) presented their sentences at a rate of slightly over 174 words per minute, within the preferred listening range for adults, closer inspection of their sentence stimuli revealed that, based on the average syllable length of the words in their sentences, the average syllable per second speaking rate was 3.88 across sentence types, below the typical range of around 4-6 syllables per second (Radeau, Morais, Mousty, & Bertelson, 2000). This rate, in fact, was closer to the 3.8 syllables per second that was used in the slow rate condition for the offline sentence picture-matching task by Love et al (2008), which found a beneficial effect of the slowed rate on final comprehension of sentences containing these gaps.

Seeking to directly compare the effect of slowed speech rate on lexical access in a group of participants with Broca's aphasia who had demonstrated delayed access at a typical rate of speech, Experiment 1 employed the same participants and experimental materials as Ferrill et al (2012). Contrary to the predictions of the DLA, there was no clear group effect of rate, with priming effects failing to reach significance at the offset of the NP as well as all of the downstream probe positions.

These results appeared to support the findings of Choy (2011) who also failed to find an effect of rate on both the time-course of initial lexical activation as well as syntactically driven re-activation. However, inspection of individual differences in the response to slow rate of speech suggested that there might be some patterns that could be uncovered, based on a heretofore unconsidered source of variability.

Experiment 2 sought to take advantage of a novel analysis technique that functionally related the behavioral results from Experiment 1 to the extent of lesion, as defined by cytoarchitectonically informed probability maps, in three different brain areas that have been implicated in language processing. This was an exploratory analysis conducted on a subset of the participants from Experiment 1 for which lesion data was available, and as such the patterns are by no means definitive. However, we found that after controlling for total lesion size, the proportion of damage to BA45, a brain region that has been linked to lexical processing, was predictive of priming at NP offset (PP1) for both regular rate of speech (with more damage corresponding to more priming) and slow rate of speech (with more damage corresponding to less priming), as well as the change in priming across rates. Put another way, participants who were priming at the offset of the noun at regular rate were no longer doing so at slowed rate, and participants who were showing weak priming or inhibition at regular rate were showing stronger priming at slowed rate. These patterns suggest that the beneficial effect of slowed rate is isolated to those individuals who had the most marked delay in lexical access to begin with, those individuals with less damage to BA45. This finding that more brain damage would result in more "typical-like" patterns" may seem initially to be somewhat counterintuitive, but briefly consider the

role that BA45 is argued to play in sentence processing. Many researchers have suggested that, whereas lexical categorization and retrieval is subserved by the superior and medial temporal gyri, BA45 is responsible for semantic working memory and lexical selection, that is maintenance of the aspects of the lexical entry that are compatible with sentence context. For example, in neuroimaging studies, increased activity in BA45 has been linked to resolution of lexical ambiguities, words for which there are more than one possible meaning, and who's intended meaning is clarified by the context (Mason & Just, 2007; Rodd et al., 2005). Therefore, if BA45 is damaged, it's function as a "gatekeeper" is reduced, allowing for uninhibited expression of the retrieved lexical item. Consistent with this idea, Vuong and Martin (2010) found that individuals with damage to left inferior frontal gyrus (LIFG) involving BA45 took longer than a non-LIFG control subject to resolve lexical ambiguities in sentences in which the context was biased towards the subordinate, or less frequent meaning. It is possible that only the aspects of lexical access that were reflected in our task for this experiment, that is reaction times to a typical picture exemplar of the NP, are indeed "typical" in this population and that other irregularities in the *quality* of lexical access would be apparent with further experimentation.

If it had not been for considering additional neuroanatomical variables to explain the intersubject variability, the individual patterns would have averaged each other out (as was shown in the overall group analysis) and the effect of the slowed rate would have been obscured or overlooked. This finding may help explain why Choy (2011) was unable to find an effect of the slow rate condition in her study.

Of course, several limitations to this study exist, most notably the limited

number of subjects. This tactic was motivated by the desire to maintain consistency across this study and Ferrill et al (2012) in order to be able to directly compare the results, although future studies will need to expand upon this number to confirm whether the conclusions still hold. Additionally, the small number of subjects limited the number of brain regions that could be simultaneously examined in these models. Future analyses may consider not just the contribution of lesions in of Broca's and Wernicke's Areas to the time-course of lexical processing, but perhaps other brain regions in the temporal lobes that have been implicated in the lexical-semantic network. Finally, it is not clear yet how much rate of speech needs to be slowed in order for a benefit to be noted. Slow speaking rates for just the studies referenced in this paper range from 2.2 syllables per second to 3.8 syllables per second, a 63% difference, with some findings suggesting that a rate that is too slow may be disruptive rather than helpful, especially if faced with a limited working memory (Tomoeda, Bayles, Boone, Kaszniak, & Slauson, 1990). It is likely that as individual patterns of lexical delay exist, so do patterns of ideal speech rate.

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CHAPTER 5:

The Use of Local Anticipatory Processing Cues During Sentence Comprehension in
Aphasia

THE USE OF LOCAL ANTICIPATORY PROCESSING CUES DURING

SENTENCE COMPREHENSION IN APHASIA

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ABSTRACT

Purpose: To investigate the effect of structural and semantic processing cues on the time-course of processing of lexical items in auditorily presented canonical (subject-verb-object) constructions for neurologically unimpaired participants and participants with left-hemisphere damage and Broca's aphasia.

Method: A cross modal picture priming (CMPP) paradigm was used to test 45 college-aged neurologically unimpaired control participants (YNC), 9 older neurologically unimpaired control participants, and 9 participants with Broca's aphasia for priming of a lexical item (direct object noun) following an adjective serving as either a structural, semantic, or probabilistic cue (to test for these effects on anticipatory priming), and at the offset of the noun during ongoing processing of syntactically simple sentences.

Results: There was no effect of the processing cues for the YNC group, although the strength of the cue was positively correlated with priming across items, suggesting that stronger cues were indeed utilized. The AMC group in contrast showed effects of the probabilistic cue, whereas the participants with Broca's aphasia were sensitive to the semantic cue.

Conclusion: these results suggest that individuals with Broca's aphasia are able to use semantic information provided by the context to mitigate the lexical processing delay that is typically found during sentence processing in this group.

Keywords: aphasia, syntax, slow rise-time, online, priming, sentence processing, neurolinguistic

INTRODUCTION

Though Broca's aphasia is traditionally defined as an expressive language impairment (Goodglass, Kaplan, & Baressi, 2001), listeners with Broca's aphasia typically evince sentence comprehension deficits as well (Caramazza & Zurif, 1976; Yosef Grodzinsky, 2000; Love et al., 2008), among others). These comprehension deficits are characterized by difficulty understanding certain types of sentences that contain complex syntax. For example, consider the following sentences:

1) The girl was kicked by the boy.

2) The pizza was eaten by the boy.

Both of these sentences are passivized, in that the noun receiving the action of the verb actually precedes the verb[1]. A semantically reversible sentence is shown in example (1), 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 (2), 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 Broca's aphasic patients were presented with semantically reversible (e.g. example 1) and non-reversible (e.g. example (2)) sentences in a sentence-to-picture matching task, they demonstrated chance performance for the reversible sentences (Caramazza & Zurif, 1976). These findings, and others like it, which have

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[1] English follows the strict canonical word order of Subject-Verb-Object (SVO). Thus in grammatical sentences where the object precedes the verb, it is considered a more complex, non-canonical structure.

demonstrated that Broca's patients have comprehension deficits for non-canonical sentences (e.g., (Yosef Grodzinsky, 2000; Hickok, Zurif, & Canseco-Gonzalez, 1993; Love et al., 2008; Schwartz, Saffran, & Marin, 1980; Sussman & Sedivy, 2003; Trueswell & Tanenhaus, 1994; Zurif et al., 1993), have historically led to the comprehension breakdown in Broca's aphasia to be viewed as being syntactic in nature. However, in this same sentence-to-picture matching task, participants with Broca's aphasia demonstrated *above-chance* performance non-reversible constructions, suggesting that these listeners have access to the semantic knowledge from the lexicon needed to correctly parse the sentence (e.g., boys can eat pizzas but pizzas cannot eat boys) when it is provided, at least in a *temporally unconstrained* (offline) task.

Indeed, research exploring *real-time* (on-line) processing in Broca's aphasia has suggested that the root cause of the comprehension impairment may be due to a delay in lexical access causing this critical semantic information to be unavailable for fast-acting syntactic processes, such as those needed to reconstruct non-canonical sentences like (1). For example, Love et al. (2008) had individuals with Broca's aphasia and their unimpaired age-matched counterparts listen to sentences such as (3):

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

 In the object-extracted relative clause in (3), the direct object noun phrase (NP) of the verb *condemned* (i.e., *the wrestler*) has been displaced from its underlying position to a position occurring before the verb, leaving behind a copy or trace of the moved NP.

The copy and the displaced NP form a syntactic chain; the copy is deleted from the representation and thus only the displaced NP can be pronounced (note that in psycholinguistic terminology, the displaced NP is the "filler" and the position from which it is displaced is the "gap"). In their study, Love et al. (2008) measured priming at five positions during the ongoing auditory sentence (signified by the superscript numerals in (3)). In contrast to the patterns of immediate access evinced by neurologically unimpaired listeners for the meaning of the antecedent (*the wrestler*) at its offset (*1) and again at the gap (*3), participants with Broca's aphasia demonstrated delayed access. Specifically, they did not evince priming at the offset of the antecedent (*1) but did so 300 ms later (*2). Furthermore, they did not demonstrate re-access at the gap (*3) but did so 500 ms later (*5).

These results show that initial activation of the noun phrase serving as the antecedent is delayed, as well as its syntactically driven reactivation. The fact that both lexical activation and gap filling were delayed for listeners with Broca's aphasia supports the claim that the lexical delay interferes with timely syntactic processing. The finding of delayed lexical access during sentence processing for listeners with Broca's aphasia has been replicated by other groups using various other methods (Choy, 2011; Dickey et al., 2007; Dickey & Thompson, 2009) and in syntactically simple sentences (Ferrill et al., 2012).

An additional finding from Love et al. (2008) supports the claim that delayed lexical processing leads to the offline sentence comprehension deficit in Broca's aphasia. Participants with Broca's aphasia evinced normal access/re-access patterns

(and improved off-line comprehension) when speech input was slowed relative to normal input speed. This pattern indicates that the deficits could be overcome when the normal time constraints for re-access are relaxed. Furthermore, slowing the rate of speech also resulted in improved performance on an off-line, sentence-picture matching comprehension task, providing evidence that on-time lexical access is important for successful comprehension of complex sentences (Love et al., 2008, Experiment 2).

However, an alternate explanation for these results is also available. The "slow syntax" account (Burkhardt et al., 2008; Piñango & Burkhardt, 2005; Piñango, 2000) claims that structure-building operations during sentence processing are delayed for listeners with Broca's aphasia, including the "Merge" operation (Burkhardt et al., 2008). Merge is the only combinatorial principle in generative syntax (e.g. Chomsky, 1995), which combines two syntactic categories to form a larger constituent in the phrase structure representation (e.g., merging the Determiner, *the*, with the Noun, *golfer* to form the NP, *the golfer*). Because of this syntactic processing delay, semantic information becomes available prior to the point at which a complete syntactic representation has been built. This semantic information drives thematic role assignment before dependency relations have been formed. Subsequently, if the representation built by semantic information conflicts with the representation formed by the completed syntactic processing, they then compete. It is the competition between these two interpretations that is purportedly the source of the ultimate comprehension failure (Burkhardt et al., 2008). It is possible, then, that the slowed

rate of speech presented in Love et al. (2008, experiment 2) eased the time constraints on structure-building and resulted in the on-time lexical re-access and improved offline comprehension observed in that study. The question arises, then, whether semantic processing, and hence lexical access, can be facilitated in the absence of facilitated structure-building, or vice-versa, in order to distinguish between these two accounts.

In this paper, we describe a study where we use local cues embedded in the sentence context to potentially mitigate the processing delay observed for listeners with Broca's aphasia. Research in sentence processing has suggested that unimpaired listeners are, in certain cases, able to use information from context to predict, or anticipate, upcoming material before that material is even presented (Altmann & Mirković, 2009; DeLong, Urbach, & Kutas, 2005; Kamide, 2008, and many others). For example, Altmann and Kamide (1999) had participants listen to sentences such as *The boy will move the cake* or *The boy will eat the cake* while viewing a visual scene containing several movable objects, but only one edible one. In the condition with the restrictive verb (*eat*) that is only compatible with one possible object in the scene, participants were significantly more likely to look toward the edible object, that is the cake, than in the unrestrictive verb (*move*) condition, even before the acoustic offset of the verb. This pattern suggests that listeners are able to use semantic information from the verb in conjunction with the constraints afforded by a visual context, to anticipate an upcoming theme. Furthermore, these constraints can be applied even *prior* to the onset of any overt (bottom-up) phonological information. However, this contextual

information may or may not have resulted in anticipatory processing of a *specific* lexical item in the absence of the additional constraints imposed by the visual context, as could be the case during naturalistic sentence processing.

Other evidence suggests that listeners *do* use contextual information predictively in the absence of visual context. For example, DeLong et al. (2005) had participants read sentences such as *The day was breezy, so the boy went outside to fly...* which were then followed by a relatively expected ending *(a kite)* and unexpected ending (*an airplane*), each requiring a different Determiner (*a* or *an*) that agrees with the noun. They found a larger N400 effect, an ERP component sensitive to context-dependent semantic anomaly, at the Determiner preceding the less predictable ending (*an*), indicating that readers were anticipating a specific noun. Although this was a reading study, similar effects have been found with auditory sentence presentation (Van Berkum et al., 2005).

Given, then, that unimpaired listeners have been shown to to use contextual information predictively to anticipate upcoming lexical items in sentences, we then ask whether this same contextual information can be exploited to mitigate the delay in lexical access for listeners with Broca's aphasia. To address this question, we took advantage of the structural and semantic properties of adjectives. Adjectives can provide a salient <u>structural</u> cue indicating that a noun is forthcoming. Although the Determiner *the* should serve as a structural cue to an upcoming noun, in addition to the fact that Determiners, at least in English, are generally shorter in duration compared to adjectives, there is evidence to suggest that closed class words such as Determiners

may pose a particular processing challenge for listeners with Broca's aphasia (e.g., ter Keurs, Brown, Hagoort, & Stegeman, 1999). Adjectives can also provide a salient *semantic* cue, describing unique features of the noun they modify. As discussed earlier, listeners with Broca's aphasia arguably have a relatively intact lexical-semantic system and are able to use semantic information to aid in sentence comprehension for offline, sentence-to-picture matching tasks (Caramazza & Zurif, 1976). What is less certain is the time-course at which that information is made available by the context, although there is evidence to suggest that semantic priming is delayed in this population (P A Prather et al., 1997).

Aside from the flexibility that adjectives provide, they also have the advantage of providing a *local* cue. Many of the studies addressing predictive processing as described above, have used contexts containing potentially several sources of predictive information. For example, in the sentence *He loosened the tie around his neck*, much of the information that enables a reader or listener to predict the word *neck* is likely to already be available after the word *tie*. This complication makes it difficult to isolate the temporal effect of predictive cues. With adjective-noun pairs, in contrast, the predictive effect can be isolated to the adjective. Furthermore, the kind of predictive information that is provided can be experimentally manipulated. The predictability of a lexical item based on context is generally measured via a cloze task in which participants are asked to complete a sentence fragment with the first word that comes to mind. The cloze probability is the proportion of people who give a particular word as the most likely completion of a sentence fragment (Taylor, 1953).

However, that cloze value can reflect lexical pre-activation due to the presence of semantically related words in the context (*tie* and *neck*, in our example) or due to the statistical likelihood (or probability) that a word will follow a given context, based on the listener's experience (Mcdonald & Shillcock, 2003; Trueswell & Tanenhaus, 1994). There is some limited evidence to suggest that listeners with Broca's aphasia are able to use probabilistic information to make parsing decisions, however, these cues are used more slowly compared to unimpaired controls (Dede, 2012).

To recap, we ask whether any of these sources of local contextual information (structural, semantic, or probabilistic) provided by an adjective can be used to facilitate lexical access for listeners with Broca's aphasia when a noun is encountered in an ongoing auditory sentence. If the delay is due to impaired structure-building, as claimed by the slow syntax account, the presence of an adjective serving as a structural cue should facilitate on-time access. Rather, if the delay is due to impaired access to the semantic information associated with a lexical item, semantically biasing or probabilistically biasing adjectives should provide some benefit. Our predictions regarding the differences between the two biasing adjective conditions are less clear, as both types of information have been shown to be used by listeners with Broca's aphasia, although in a delayed fashion. We first examine the effect of these cues on lexical access in a group of college-age neurologically unimpaired participants (Experiment 1) followed by a group of older neurologically unimpaired participants (Experiment 2) to determine a standard of comparison for our participants with Broca's aphasia (Experiment 3).

Experiment 1: Neurologically Unimpaired Participants

Method

Participants

Forty-five college-age students (M = 21.33 years, SD = 2.22, range: 18–29 years; 3 male, 42 female) from San Diego State University participated in this study. All participants were neurologically unimpaired right-handed native English speakers with no reported history of learning disability, head injury, or neurological disease, and no uncorrected vision or hearing impairments. Participants received course credit for their participation in the study.

Task

We used a cross modal picture priming paradigm (CMPP; Swinney & Prather, 1989) where participants listened to uninterrupted auditory sentences and made binary, *human (yes)/not human (no),* decisions on visually presented black-and-white line drawings (visual probes). Each experimental sentence had two visual probes (each requiring a yes response): a related probe that was a representation of the noun phrase in the direct object position of the sentence, and a control probe that was unrelated to any word in the sentence (Figure 5-1). In this task, the visual probes are presented at key times during the ongoing sentence, and priming effects are measured by comparing RTs to the related and control probes at that point; faster RTs to the related

probes indicate a priming effect. Importantly, priming effects in cross modal tasks reflect activation of the sentential prime at that point in the ongoing auditory sentence, not the integration of the visual probe into the sentence (Nicol et al., 2006).

Materials

The test items consisted of 30 sentences in each of two experimental conditions for a total of 60 experimental sentences. Compare the following sentences:

[SEM BIAS] 4a) The duck led the **_dirty_**[1] _pig_[2] along the long and winding country road

[SEM CONTROL] 4b) The duck led the **_dizzy_**[1] _pig_[2] along the long and winding country road

[PROB BIAS] 5a) The doctor visited the **_gifted_**[1] _student_[2] after the unexpectedly turbulent helicopter ride

[PROB CONTROL] 5b) The doctor visited the **_giddy_**[1] _student_[2] after the unexpectedly turbulent helicopter ride

All experimental sentences contained adjectives (shown bolded & italicized) prior to the object NP (the target NP, shown in _italics_) providing a structural cue to the presence of an upcoming NP. Sentences in the SEM BIAS condition - sentence (4a) - contained semantically biased adjectives (**_dirty_**) to cue the semantic content of the target NP (_pig_; see details for adjective selection under SEM Adjective Generation Pretest, below). Sentences in the PROB BIAS condition – sentence (5a) – contained adjectives (**_gifted_**) that have a moderately high transitional probability (TP; average 25.12%), meaning that they frequently occur preceding the target NP (_student_). TP,

here, is the probability of encountering a second word (w2) given that a first word

(w1) has been encountered, (P(w2|w1)), estimated from corpus frequencies. For *gifted*

student, for example, TP is calculated as the number of times the phrase *gifted student*

appeared in the corpus divided by the total number of times *gifted* appeared in the

corpus (McDonald & Shillcock, 2003). All frequencies and TP values were generated

using the Corpus of Contemporary English (Davies, 2008).

To control for the effect of the presence of an adjective in general, each biasing

adjective type also had a control condition ((2b) and (3b)) which contained adjectives

matched for length in syllables and frequency (t(59) = 0.04, p=0.97 for PROB

condition, t(59)= 0.08, p=0.94 for SEM condition), but which had both low semantic

(0% for both conditions) and TP values (M=0.08% and 0.1%, respectively).

Importantly, to differentiate the potential effects of adjective type, biasing adjectives

in the SEM condition had very low TP (M = 0.06%), and adjectives in the PROB

condition were infrequently generated in the descriptive adjective generation task

(M=0.16%). The frequencies of the adjectives in the two adjective conditions did

differ significantly (2297 occurrences for the TP condition compared to 8207

occurrences for the SEM condition per million words, t(59)= 2.92, p=0.005).

SEM Adjective Generation Pretest

As the careful control of material is mandatory in psycholinguistic

experimentation, pre-testing of potential stimuli was conducted before data

collection began as outlined below. Here, semantically biased adjectives for noun phrases were first generated by a separate group of unimpaired participants.

Thirty-four SDSU undergraduates (mean age=20.1 yrs., SD=1.4) participated for course credit. Participants were monolingual, native English speakers with no exposure to a foreign language before the age of six, were right-handed, had no reported history of brain injury, emotional or learning disorders, and had normal-to-corrected vision and hearing.

To generate the semantically biasing adjectives, participants were presented with a series of 120 pictures of potential experimental NPs and were asked to write the first word that came to mind to appropriately describe the item pictured. The pictures were presented one at a time via Microsoft PowerPoint software and the task was self-paced. The thirty items with the highest level of agreement were selected for further use in the current study (mean = 35.32%, SD=15.7%, Range 11.76%-71.43%).

Study Design

The experiment employed a switched target design in which the related probe for one sentence appeared as a control probe for a different sentence, whose related probe served as the control probe for its paired sentence (Figure 5-1).

(a) The duck led the ***dirty/dizzy* pig**** along the long and winding country road

Related · Control · Control · Related

(b) The rhino passed the ***tall/tame* giraffe**** between the spectacularly beautiful waterfalls
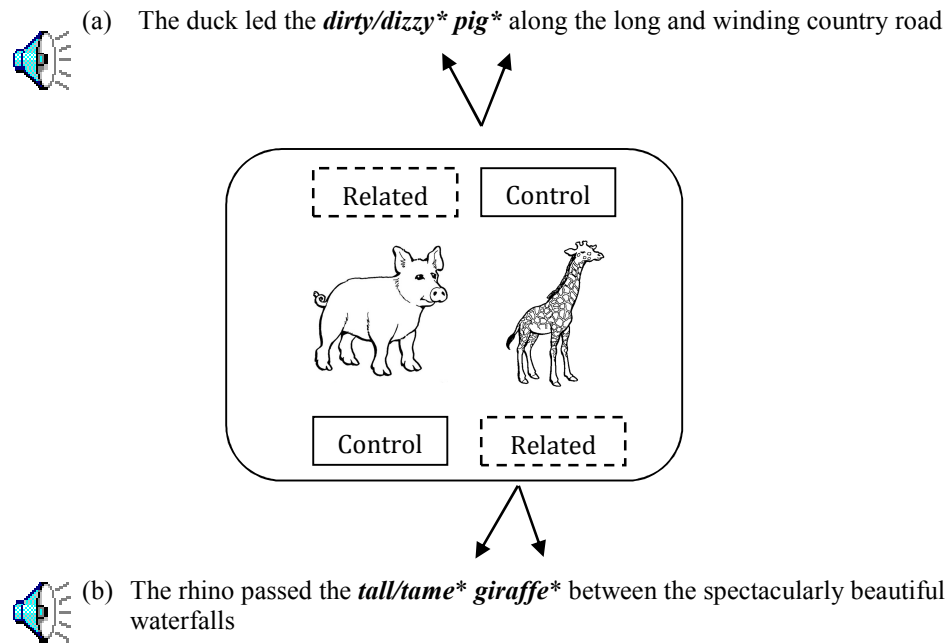
Figure 5-1. A schematic of the counterbalanced design utilized in this study

Thus, over all of the sentences, the set of related probes was identical to the set of control probes, minimizing the possibility that any observed priming effects are due to properties of the pictures that might influence participants' RT (e.g., visual complexity differences). Probe pictures were black and white line drawings obtained from clip art resources or the Internet, each depicting the critical noun for each of the 60 experimental sentences. Black-and-white line drawings were also obtained for the filler sentences (described in more detail later).

Related and control visual probes were presented at two positions in the ongoing auditory sentence (indicated by the superscript numerals in Examples (4a-5b) earlier). Probe position (PP1) occurred immediately at the offset of the adjective (to test for anticipatory activation of the forthcoming noun) and probe position 2 (PP2)

occurred immediately at the offset of the direct object noun.

In addition to the 60 experimental sentences, 40 filler sentences were created with a different syntactic structure from the experimental items, to provide a variety of sentence forms. These sentences were also paired with an animal (nonhuman) picture probe (requiring a 'no' response) to allow for a balance of "human" and " nonhuman" responses across the full set of items. 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. This tactic is used to prevent the anticipation of probe positions. Finally, 10 practice sentences (also balanced for the number, order, and type of response) were added to the beginning of each script to familiarize the participant with the task as well as to allow the experimenter the opportunity to monitor the participants to ensure that they understood the task. After the 10 practice items, the remaining 100 sentences (60 experimental; 40 filler) were intermixed and were pseudo-randomly ordered such that no more than three 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 (4.76 syllables per second; note that this rate is almost identical to the rate of 4.6 syllables per second from Ferrill et al., 2012). Sentences were recorded in a sound proof booth using Audacity software and editing was performed using Adobe Audition 3.0 software.

Experiment Design: Summary

We used a mixed between-within factors design to counterbalance all eight conditions (2 probe positions x 2 related/control picture probes x 2 biasing/control adjective). To do so 8 lists (4 list pairs) were created with 15 of the 60 experimental sentences presented in each of the 4 conditions (SEM BIAS, SEM CONTROL, PROB BIAS, PROB CONTROL) with related/control probes counterbalanced across two visits. Thus, each participant provided his or her own control data at one probe position. Participants were randomly assigned to a given list pair.

Procedure

At the beginning of each session, participants were instructed that they would be performing a dual task – 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 decision as quickly and as accurately as possible (using a two-button response box) as to whether the picture was human (yes response) or not human (no response). 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. Participants were probed for comprehension following 25% of sentences. 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 listen to the sentences. E-Prime
Professional (Version 2) software was used to control the timed presentation of
auditory and visual stimuli and the collection of participant responses (both yes/no
decisions and millisecond accurate RTs for each decision). Each visual probe was
presented for 1000 ms, or until a response was made. Responses were recorded for up
to 1000 ms following the appearance of the picture probe, for a total time of 2000 ms.
An interstimulus interval (ISI) of 2000 ms followed each sentence.

Analysis

Data were first reviewed for accuracy. All participants performed above-
chance on the task-related comprehension questions and responded correctly to > 90%
of the button-presses during experimental sentences in both sessions. Next, incorrect
responses (1.2% of all data), RTs <300 ms, or overall outliers > 923 ms (1.5 times the
interquartile range, based on all correct responses) were removed (4.7% of the data),
distributed roughly equally across conditions. All responses for two of the
experimental items were excluded as these were found to have average RTs beyond
two standard deviations above the overall mean for all experimental items. Finally, we
screened out responses for each participant that were >2 SDs from his or her
individual mean for each session (3.0% of the data).

Analysis of the remaining RTs was conducted using restricted maximum
likelihood (REML) in a mixed-effects regression model. Included in this model were

the crossed random effects on the intercept of participant and sentence and fixed effects of probe position (1 vs. 2), relatedness versus control, adjective type (SEM vs PROB vs CONTROL), and their interactions. The models were fit with an unstructured covariance matrix for each random effect. Follow-up models examined the interaction of probe position and relatedness separately for each pair of probe positions 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.

Based on prior research demonstrating that neurologically unimpaired listeners are able to use contextual information to predict specific upcoming lexical items even before those items are encountered, we predicted a priming effect at PP1, the offset of the adjective in the biasing conditions (SEM and PROB). We expected no processing benefit of an unbiasing control adjective, as there would be no reason to have access to any information about the upcoming noun in that condition. We furthermore expected a priming effect at PP2, the offset of the object NP in all conditions, based on previous studies that have shown that neurologically unimpaired listeners evince immediate, automatic access to lexical items when they are encountered in a sentence (Ferrill et al., 2012; Swinney, 1979)

Thus, for a priori planned comparisons of related and control probes at each probe position, 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 (2008) and Littell, Milliken, Stroup, Wolfinger, and Schabenberger (2006); for studies with similar analyses, see Love, Walenski, & Swinney (2009), Walenski, Mostofsky, & Ullman (2008).

Results

Mean reaction times and standard errors for each condition are given in Table 5-1.

Table 5-1. Mean reaction times (and standard error) in milliseconds to related and control probes at each probe position for the young, neurologically unimpaired control group (Experiment 1)

	PP1 (Adjective Offset)			PP2 (Object NP Offset)		
	BIAS		NON-BIAS	BIAS		NON-BIAS
	SEM	PROB		SEM	PROB	
Control	632 (6.8)	633 (6.4)	624 (6.4)	600 (7.3)	606 (7.2)	603 (6.9)
Related	633 (7.3)	630 (6.5)	622 (6.9)	605 (7.8)	595 (7.0)	594 (7.2)
Control-	-1 ms	3 ms	-2ms	-5 ms	11 ms	9 ms

Main effects of bias (BIAS vs NON-BAS; $F(1, 117)=1.48$, $p=.23$), bias type (SEM vs PROB; $F(1, 117)=1.42$, $p=.24$), relatedness (of the picture probe; $F(1, 4691)=0.86$, $p=.36$) and probe position ($F(1, 43)=1.62$, $p=.21$) all failed to reach significance, as did all interactions.

A priori planned comparisons of the reaction times for related compared to control picture probes revealed a non-significant priming effect at probe position 1 for the SEM BIAS condition (-1 ms control - related difference; $t = -0.06$, $p = 0.94$), and the PROB BIAS condition (3 ms control - related difference; $t = 0.49$, $p = 0.62$) as well as for the NON-BIAS control condition (collapsed across SEM and PROB; -2 ms control - related difference; $t = -1.07$, $p = 0.28$). An overall priming effect was found at probe position 2, collapsed across all conditions (6 ms control - related difference; $t = 1.89$, $p = 0.05$).

Comparisons of RTs to the related probe picture in BIAS compared to NON-BIAS conditions also failed to reach significance for both SEM and PROB conditions at PP1 ($t=-0.25$, $p= 0.8$; $t=1.39$, $p=0.16$ respectively), further suggesting that the presence of the biasing adjective did not result in predictive processing.

Discussion

As expected, an overall priming effect was found at PP2, the offset of the object NP consistent with previous reports of immediate lexical access when a noun is encountered in an ongoing auditory sentence for neurologically unimpaired listeners. In contrast and contrary to predictions, no effect of the semantics of probabilistic cues was seen at PP1, the adjective offset. One possible explanation for this effect is that the NPs might not have been predictable enough from the context, on average, to make anticipatory processing beneficial. That is, making an incorrect prediction can

incur a processing cost and, therefore, if a level of certainty of the upcoming material is not attained, this cost might outweigh any potential processing benefit gained from making the prediction in the first place (DeLong et al., 2005; Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007). To further explore this hypothesis, an analysis was performed to examine whether TP scores (for the PROB condition) or agreement scores on the adjective generation pretest (for the SEM condition) significantly correlated with priming effects at PP1 for this group. Interestingly, higher TP scores (B= 0.31, p=0.04) but not scores on semantic agreement scores (B=0.01, p = 0.93) were significantly correlated with greater priming effects. This pattern suggests that unimpaired listeners may be sensitive to probabilistic cues more so than semantic cues, and additionally, that these cues need to be relatively strong in order for these listeners to commit to specific predictions.

In contrast to the patterns of lexical access and re-access during sentence processing (more "automatic" aspects of comprehension) which have been shown to be relatively similar for older compared to younger listeners (Love et al., 2008; Stern, Prather, Swinney, & Zurif, 1991), the use of contextual information during predictive processing has been shown to differ across these populations. Some studies have shown, for example, that older adults benefit more from the semantic content provided by context compared to younger adults (Madden, 1988; Stine & Wingfield, 1994). Older adults' increased sensitivity to semantic context is further supported by studies that have found larger semantic priming effects for older adults in lexical decision and pronunciation latency for target words when preceded by a sentence or single word

prime (see Laver & Burke, 1993 for review). On the other hand, some studies have found that older adults make use of contextual information *less* efficiently, and perhaps in a delayed manner (DeLong, Groppe, Urbach, & Kutas, 2012; Federmeier, Mclennan, Ochoa, & Kutas, 2002). For example, Mack, Ji, & Thompson (2013) replicated Altmann and Kamide (1999) with a group of older neurologically unimpaired participants. For this experiment, the researchers had participants listen to sentences containing restrictive or unrestrictive verbs such as "Tomorrow, Susan will open/break the jar." In these sentences, one of the verb conditions (e.g., "open") selected for only one of the four visual objects displayed in an array (e.g., "jar"), whereas the other verb condition (e.g., "break") was compatible with all of the visual objects (e.g., jar, plate, stick, pencil). The results revealed that, in contrast to the younger participants from Altmann and Kamide (1999) who fixated the target object during and following the restrictive relative to the unrestrictive verb, there was a lack of effect of verb type for the older listeners until 500 msec after verb offset, supporting the claim that semantic prediction processes may be slowed due to aging.

Therefore, before establishing the effect of the different types of local predictive cues on the time-course of lexical access during sentence processing for listeners with Broca's aphasia, Experiment 2 will first test the effect of these cues in an older control group.

Experiment 2: Neurologically Unimpaired Older Participants

Method

Participants

Nine older neurologically intact participants (AMC group; 3 males, M age =
60.4 years) were recruited from the local San Diego community, via public
advertisements. All were right-handed (defined by 70% right-handed responses on the
Edinburgh handedness inventory; Oldfield, 1971) native English speakers (with no
foreign language acquisition prior to age 6), had no reported history of neural trauma
or neurological disease, had no active psychiatric diagnoses, had no history of drug
and/or alcohol abuse, and had no history of developmental speech, language, or
learning disorders. AMC participants were administered the Mini-Mental State Exam
(MMSE; Folstein Folstein, & McHugh, 1975) and the Wide-Range Intelligence Test
(Glutting, Adams, & Shelow, 2000) assessment of neurocognitive functioning to
screen for dementia or cognitive disorders. Age-matched participants received $15 per
experimental session.

Materials

The same materials were used as in Experiment 1.

Design

Unlike the mixed-factorial design that was used in Experiment 1, here we
employed a fully within-subjects design for the older control participants. The two
probe positions combined with bias (BIAS and NON-BIAS), and the related/control

picture probe 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. The order of presentation of the eight conditions was counterbalanced across participants. Sessions were separated by at least 1 week, and most often, 2 weeks.

<u>Analysis</u>

As was the case with the younger neurologically unimpaired group, all participants performed above-chance on the task-related comprehension questions and responded correctly to > 90% of the button-presses during experimental sentences in all sessions. Incorrect responses (1.1% of all data), RTs <300 ms, or overall outliers > 882 ms (1.5 times the interquartile range, based on all correct responses) were removed (5.5% of the data), distributed roughly equally across conditions. All responses for three of the experimental items were excluded as they were found to have average RTs beyond two standard deviations above the overall mean for all experimental items. Finally, we screened out responses for each participant that were >2 SDs from his or her individual mean for each session (3.9% of the data).

Analysis of the remaining RTs was conducted using restricted maximum likelihood (REML) in a mixed-effects regression model. Included in this model were the crossed random effects on the intercept of participant and sentence and fixed effects of probe position (1 vs. 2), relatedness versus control, adjective type (SEM vs PROB) as well as bias (BIAS vs NON-BIAS) and their interactions. The models were

fit with an unstructured covariance matrix for each random effect. Follow-up models examined the interaction of probe position and relatedness separately for each pair of probe positions and are presented in the Results section accordingly. Type III F tests are reported for main effects and interactions.

As discussed, results of studies exploring the use of contextual processing cues in older adults have been mixed, with some studies suggesting that they benefit to a greater degree than younger listeners from these cues and other studies suggesting that they either do not use these cues, or use them in a delayed fashion. Therefore, it is difficult to make clear predictions regarding the pattern of results that we expect. Generally, if older listeners are more reliant on these cues, we should expect to find a significant priming effect in the biasing (either SEM, PROB, or both) conditions at PP1, compared to the younger unimpaired listeners. On the other hand, if use of these cues is delayed, we expect to find, as we did with the younger listeners, no significant priming effects at PP1, with retained priming effects across conditions at PP2. Correlation analyses of priming effects and both TP and adjective agreement scores were performed as a follow-up to the effects found in Experiment 1.

We computed t-tests of the differences of the least square means from the full model based on a priori planned comparisons of related and control probes at each probe position. Again, all p values are reported two-tailed. Degrees of freedom (reported in the t tests below) were computed using the Satterthwaite approximation.

Results

Mean reaction times and standard errors for each condition after screening

(described above) are given in Table 5-2.

Table 5-2. Mean reaction times (and standard error) in milliseconds to related and
control probes at each probe position for the older, neurologically unimpaired control
group (Experiment 2)

	PP1 (Adjective Offset)			PP2 (Object NP Offset)		
	BIAS		NON-BIAS	BIAS		NON-BIAS
	SEM	PROB		SEM	PROB	
Control	617 (7.1)	614 (6.5)	603 (6.7)	576 (8.3)	561 (7.2)	565
Related	610 (7.8)	597 (6.4)	613 (6.9)	555 (7.7)	557 (8.3)	560
Control-	7 ms	17 ms	-10ms	21 ms	4 ms	5 ms

Main effects of bias type (SEM vs PROB; $F(1, 112)=13.24$, $p<.001$), relatedness (of

the picture probe; $F(1, 3657)=6.58$, $p=0.01$) and probe position ($F(1, 3560)=298.85$,

$p<.0001$) all reached significance. Bias (BIAS vs NONBIAS; $F(1, 112)=0.35$, $p=.56$),

and all interactions failed to reach significance with exception of bias x relatedness

$F(1, 3657)=5.82$, $p=0.02$, with RTs to related pictures on average being slightly longer

in the NON-BIAS condition than RTs to related pictures in the BIAS conditions,

whereas RTs to unrelated pictures were slightly longer on average in the BIAS

conditions compared to the NON-BIAS condition.

A priori planned comparisons of the reaction times for related compared to

control picture probes revealed a significant priming effect at probe position 1 for the

PROB BIAS condition (17 ms control - related difference; $t = 1.89$, $p = 0.05$), and an

effect approaching significance for the SEM BIAS condition (7 ms control - related

difference; $t = 1.76$, $p = 0.08$). Additionally, this effect of bias at PP1 was significant

when collapsed across bias type (t= 2.57, p=0.01). No effect of the NON-BIAS

condition was found at PP1 (collapsed across SEM and PROB; -9 ms control - related

difference; $t = -1.45$, $p = 0.15$). A strong and significant overall priming effect was

found at probe position 2, collapsed across all conditions (9 ms control - related

difference; $t = 2.85$, $p = 0.004$).

Discussion

Like the younger neurologically unimpaired listeners, an overall priming effect

was found at PP2, the offset of the object NP for the older listeners, supporting

previous research that has found similar patterns of lexical access when overt NPs are

encountered in an ongoing auditory sentence between younger and older listeners.

However, in contrast to the younger group, the older participants evinced significant

priming for the upcoming NP at the offset of the adjective (PP1) in the probabilistic

cue condition (PROB) and approaching significance in the semantic condition (SEM).

These patterns suggest that this group used the local contextual cues to anticipate the

upcoming lexical item. This finding appears to support the view that older listeners

are better able to take advantage of, or are more reliant on, contextual information to

aid in language processing, at least at this level of constraint. Follow-up analyses

between RTs and TP and adjective generation agreement did not reveal any significant

correlations, suggesting that older listeners are treating all levels of cueing equally, in

contrast to the younger listeners who appeared to require a higher level of constraint before using these cues.

Having established a standard of comparison, now we turn to the examination of our participants with Broca's aphasia. In addition to the evidence discussed earlier suggesting that listeners with Broca's aphasia are able to use semantic and probabilistic information more generally during language processing, there is some evidence, although limited, that suggests that these listeners are specifically able to take advantage of predictive processing cues. For example, Mack et al., (2013) also extended their study evaluating the use of semantic information in restrictive compared to unrestrictive verbs to listeners with Broca's aphasia. They found that, as was the case with the older control participants, listeners with Broca's aphasia evinced significantly more gazes to the target NP *the jar* in the restrictive *(... will open the…)* compared to the unrestrictive condition *(…will break the…)* in the first 500 ms after encountering the verb.

Additionally, Choy (2011) found that listeners with Broca's aphasia more accurately answered yes/no comprehension questions about sentences containing predictable (high cloze) object NPs than sentences with low cloze object NPs (as in (6a) and (6b) below).

> 6a) There was a bartender who banished the drunk/There was a drunk who the bartender banished (high cloze).

6b) There was a bartender who banished the cyclist/There was a cyclist

who the bartender banished (low cloze).

Furthermore, predictability had a larger effect on comprehension than canonicity (i.e., non-canonical sentences containing high cloze NPs were comprehended better then canonical sentences with low cloze NPs). However, because this was an offline task, it is unclear whether listeners with aphasia were able to use the context on-line to facilitate lexical processing, or whether the information was used in post-processing plausibility judgment (i.e., a 'bartender' is more likely to banish a 'drunkard'). Additionally, even with the contextual cues, listeners with Broca's aphasia still did not comprehend the sentences as well as the unimpaired control group.

Overall, the results of Mack et al. (2013) and Choy (2011) suggest that the ability to use contextual information is, importantly, intact for listeners with Broca's aphasia. However, it is certainly unclear whether this ability to use context is superimposed on a lexical processing deficit. Thus, the limited evidence available so far suggests that contextual information can be used to mitigate, but not altogether eliminate, this deficit.

Experiment 3: Participants with LHD and agrammatic aphasia

Methods

Participants

A total of nine left-hemisphere damaged (LHD) participants with Broca's aphasia and who have a sentence comprehension deficit met criteria for participation (mean age at time of testing: 55.3 years; range: 36-75 years). Demographic information for these participants is presented in Table 5-3.

Table 5-3: Demographic table for the participants with Broca's aphasia (Experiment 3)

SUBJECT	GENDER	TPS*	BDAE [a] Severity	WAB [b] AQ	SOAP [c] Canonical	SOAP [c] Non-Canonical
LHD009	M	12;3	3	67.7	75%	55%
LHD101	M	6;4	2	82.6	95%	35%
LHD130	M	5;2	4	90.5	75%	55%
LHD132	M	8;10	4	93	85%	55%
LHD138	M	14;11	2	70.1	70%	25%
LHD140	F	12;11	2	75.7	80%	30%
LHD142	M	3;5	3	80.6	100%	65%
LHD159	F	3;4	3	92.4	65%	25%
LHD169	M	2;6	1	28**	80%	40%

[a] BDAE = Boston Diagnostic Aphasia Examination
[b] Western Aphasia Battery
[c] Subject-relative, Object-relative, Active and Passive
* TPS = Time post-stroke
** = Low score reflects superimposed motor speech impairment

All participants had experienced a single, unilateral left-hemisphere stroke and were native English speakers with normal or corrected-to-normal visual and auditory acuity. They were right-handed before their stroke. Diagnosis of Broca's aphasia was made based on the administration of standardized language testing to determine each participant's severity of agrammatic language impairment; specifically, fluency and auditory comprehension ability. Testing included the Boston Diagnostic Aphasia Examination—Third Edition (BDAE–3; Goodglass, Kaplan, & Barresi, 2000), Western Aphasia Battery (WAB-R; Kertesz, 2006), and SOAP (Subject-relative Object-relative Active and Passive) Test of Auditory Sentence Comprehension (Love & Oster, 2002).

As the delayed lexical activation hypothesis makes the specific claim that a lexical deficit underlies comprehension deficits in some people with Broca's aphasia, participants were considered for inclusion if they showed evidence of such comprehension deficits, which we defined here as at- or below-chance performance on the comprehension of sentences with noncanonical word order (object-relative and passive sentences) from the SOAP. 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 or intellectual disability, and/or other significant brain disorder or dysfunction (e.g., Alzheimer's/dementia, Parkinson's, Huntington's, Korsakoff's). Participants were tested at the Language and Neuroscience Group (LANG) laboratory at San Diego State University and were paid $15 per session.

<u>Materials</u>

The same materials as in Experiments 1 and 2 were used.

<u>Design</u>

As in experiment 2, here we employed a fully within-subjects design for the participants with aphasia. To recap, the four probe positions, 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. The order of presentation of the eight conditions was counterbalanced across participants. Sessions were separated by at least 1 week, and most often, 2 weeks.

<u>Procedure</u>

The general procedure was the same as that used in Experiment 1, except that (a) responses were recorded for up to 3000 ms from the onset of each picture, and (b) a more extensive training session was implemented.

<u>Training Protocol</u>

To ensure that our participants with aphasia were performing reliably on the binary picture decision task and that they understood this dual-task method, a training session was given before the experimental script at each of the eight visits. For this training, participants were trained on the binary picture decision. Participants were told that a picture would appear in the middle of the screen and they were to identify

whether or not the picture was human by pressing a button labeled *yes* for human or *no* for not human, as quickly as possible. The list consisted of 20 items: 10 human and 10 nonhuman. This picture-only training list was repeated as many times as needed until the participant was able to reliably perform the task. None of the pictures used in the training task was repeated in the scripts. Participants were instructed to make their responses using the hand ipsilateral to their lesion (left hand). Once the experimenter felt that the participant understood the binary decision task and was ready to move on to the dual-task experiment, participants were then given the instructions as described in Experiment 1.

Analysis

All participants performed above chance on the task-related comprehension questions. All participants responded to the button-press decision with >90% accuracy ($M = 98.8\%$; $SD = 2.2\%$; range: 93%–100%). Before analysis, incorrect responses (1.2% of all data) were removed. There were no RTs <300 ms or >2000 ms; thus, no overall outliers were removed. A 2-*SD* participant screening was then performed for each participant separately for each condition (5.1% of the data). In all other respects, the data were analyzed the same way as for Experiment 1.

Based on previous studies that have suggested that listeners with Broca's aphasia are able to take advantage of contextual information to facilitate language processing in a similar manner to older control participants, we hypothesized that our participants with Broca's aphasia would, too, show that benefit. However, as that processing advantage is superimposed on an existing lexical delay, we expected that

priming would not be evident at PP1, as was the case with the older controls, but rather at PP2, the noun offset. These cues then would facilitate lexical access to a "normal-like" pattern compared to the pattern of lexical access evinced by neurologically unimpaired participants during sentence processing in the absence of these contextual cues, but not completely eliminate the delay. To review, if the delay is due to impaired structure-building, as claimed by the slow syntax account, we predict that merely the presence of an adjective (across all conditions) serving as a structural cue will facilitate priming at PP2. Rather, if the delay is due to impaired access to the semantic information associated with a lexical item, we predict that the semantically biasing or probabilistically biasing adjective should provide some benefit. Our predictions regarding the differences between the two biasing adjective conditions are less clear, as both types of information have been shown to be able to be used by listeners with Broca's aphasia, although in a delayed fashion.

Results

Mean reaction times and standard errors for each condition are given in Table 5-4.

Table 5-4. Mean reaction times (and standard error) in milliseconds to related and control probes at each probe position for the participants with Broca's aphasia (Experiment 3)

	PP1 (Adjective Offset)			PP2 (Object NP Offset)		
	BIAS		NON-BIAS	BIAS		NON-BIAS
	SEM	PROB		SEM	PROB	
Control	717 (9.9)	681 (8.4)	694 (8.0)	735 (9.9)	695 (8.6)	719
Related	690 (7.8)	685 (7.5)	692 (8.3)	712 (9.6)	699 (9.0)	712 (9.7)
Control-related	27 ms	4 ms	3 ms	23 ms	-4 ms	7 ms

Main effects of bias type (SEM vs PROB; $F(1, 115)=21.55$, $p<.0001$), relatedness (of the picture probe; $F(1, 3883)=6.07$, $p=0.01$) and probe position ($F(1, 3791=27.28$, $p<.0001$) all reached significance. The interaction between probe position and bias type ($F(1, 3791)=13.06$, $p<0.001$), bias type and relatedness ($F(1, 3883)=10.29$, $p=0.001$), and the three-way interaction between probe position, bias, and bias type ($F(1, 3791)=6.77$, $p=0.009$) reached significance as well. The main effect of bias (BIAS vs NONBIAS; $F(1, 115)=0.08$, $p=.78$), and all other interactions failed to reach significance.

A *priori* planned comparisons of the reaction times for related compared to control picture probes revealed a significant priming effect at probe position 1 for the SEM BIAS condition (27 ms control - related difference; $t = 3.03$, $p = 0.003$). Significantly, this effect held at PP2 as well (23 ms control - related difference; $t = 2.82$, $p = 0.005$). Priming was not found for any other individual condition, although collapsed across bias (BIAS and NON-BIAS) and bias type (SEM and PROB), overall, priming was significant at PP2 (8 ms control - related difference; $t = 2.12$, $p = 0.03$

Table 5-5. Summary of priming patterns for all 3 participant groups

	PP1			PP2		
	BIAS		NON-BIAS	BIAS		NON-BIAS
	SEM	PROB		SEM	PROB	
YNC [a]	-	-	-		*	
AMC [b]	**	*	-		*	
		* (collapsed)				
LHD [c]	*	-	-	*	-	-
					* (collapsed)	

[a] YNC=Young, neurologically unimpaired control group (Experiment 1)
[b] AMC = Older, age-matched unimpaired control group (Experiment 2)
[c] LHD = Left hemisphere damaged participants with Broca's aphasia (Experiment 3)
* = Significant priming, p<0.05 (2-tailed)
** = Priming trend, p=0.08 (2-tailed)
Note that t-tests for priming effects at each condition at PP2 were not conducted for the YNC and AMC control groups, as no a-priori hypotheses were made about these conditions

Discussion

Although the results from all three participant groups failed to meet our initial predictions, the results for our participants with Broca's aphasia were perhaps the most surprising. In contrast to our older control group who showed sensitivity to probabilistic contextual cues, the listeners with Broca's aphasia demonstrated significant priming in the SEM condition only, suggesting that they are perhaps not as able to take advantage of usage-based lexical information during sentence processing, but were able to take advantage of lexical-semantic information. This pattern may initially appear counter-intuitive, as access to semantic information has been demonstrated to be impaired, and at the least delayed, in this population. However, as was discussed previously, the intactness of the semantic system may be a relative area of strength for listeners with Broca's aphasia; rather, it is the processing of this information that poses the challenge. In fact, increasing access to the semantic network is the principle behind semantic feature analysis, a therapy approach that has been demonstrated to improve naming ability and fluency in connected speech (Davis & Stanton, 2005).

Perhaps more importantly though, the beneficial effect on the time-course of lexical access in the SEM condition was not observed to only shift the time-course of lexical processing to facilitate lexical access when the NP was encountered, but listeners with Broca's aphasia were actually able to use this semantic information to predictively access the semantics of an upcoming NP. This finding is further supported by follow-up analyses that found that adjective generation agreement

scores, but not TP scores, significantly correlated with the priming effects at PP1 for the listeners with Broca's aphasia. That is, items for which unimpaired listeners generated the same adjective more often to describe the target NP resulted greater facilitation for RTs to the picture related to the sentence compared to an unrelated picture, reflecting predictive access to that NP.

General Discussion

The main goal of this study was to investigate the effect of local predictive cues on the time-course of lexical access during sentence comprehension for neurologically unimpaired listeners and listeners with Broca's aphasia. To review, listeners with Broca's aphasia demonstrate difficulty comprehending certain types of syntactically complex sentences (Caramazza & Zurif, 1976, and many others). Research exploring *real-time* (on-line) processing in Broca's aphasia has suggested that the root cause of the comprehension impairment may be due to a delay in lexical access, causing this critical semantic information to be unavailable for fast-acting syntactic processes (Love et al., 2008). However, other research has suggested that structure-building operations during sentence processing are delayed for listeners with Broca's aphasia, including the "Merge" operation (Burkhardt et al., 2008).

In an attempt to distinguish between these two accounts, we asked whether semantic processing, and hence lexical access, can be facilitated in the absence of facilitated structure-building, or vice-versa. In order to address this question, we took

advantage of the structural and semantic properties of adjectives. Structurally, adjectives provide a salient cue that a noun phrase is imminent. If indeed structure-building is impaired for our participants with Broca's aphasia, we predicted that this structural cue (the presence of an adjective) should allow for facilitated lexical processing, shifting the time-course of lexical access from a delayed pattern to one in which priming is evinced immediately at the offset of the object NP. Adjectives can also provide a semantic cue by pre-activating features of the subsequent NP. We investigated the effect of two types of information that have been shown to result in anticipatory lexical access in some studies with neurologically unimpaired listeners; semantic information and probabilistic information. We predicted that if the lexical access delay for our listeners with Broca's aphasia was due to impaired access to lexical-semantic information, a semantic cue would facilitate the time-course of lexical access in addition to, the effect of the structural cue provided by the presence of the adjective.

In Experiment 1 we found that a group of younger neurologically unimpaired listeners did not show any evidence of lexical prediction when provided with either semantic or probabilistic contextual information. However, upon closer examination, it was found that the transitional probability of the adjective-noun pair, or how frequently the noun follows the given adjective when it occurs in the corpus, correlated with the priming effects seen at the offset of the adjective. This pattern suggests that, although there was no overall priming effect found for all of the items, younger neurologically unimpaired listeners are using probabilistic information

predictively, although they require a high level of constraint or certainty to do so.

In Experiment 2, we found that older neurologically unimpaired listeners also used probabilistic information provided by the adjective to predict an upcoming NP at the offset of the adjective. However, in contrast to the younger listeners, the older listeners used this information in an identical fashion across all levels of transitional probability, suggesting that they benefit more from the semantic content provided by context compared to younger adults.

Finally, in Experiment 3 we found that listeners with Broca's aphasia were not able to take advantage of the probabilistic information from the context as the control subjects had, but rather showed a processing benefit when they were provided with a *semantic* cue to the upcoming noun. Importantly, this effect was found not only to shift the time-course of lexical processing from a delayed pattern to one in which access was evident immediately at the noun offset, but also these semantically biasing adjectives were able to provide a salient enough cue to eliminate the processing delay altogether, allowing the listeners with Broca's aphasia to evince a pattern that was identical to the older neurologically unimpaired listeners. In contrast, no facilitation was found for the non-biasing adjectives, suggesting that solely the presence of an adjective providing a structural cue did not allow for any shift in time-course of lexical processing. Overall, then, these results support the hypothesis that it is delayed access to semantic information in the lexicon, not delayed structure-building, that results in the pattern of impaired offline sentence comprehension for certain types of sentences observed for listeners with Broca's aphasia.

However, to fully test the claim that delayed lexical access feeds syntactic processing too slowly, resulting in a processing breakdown, future studies should explore the effect of these adjectives on lexical re-access in sentences containing syntactic gaps, as in Love et al. (2008). If this hypothesis is borne out, this facilitated lexical access should result in on-time re-access. Alternately, it is a possibility that there are two co-occurring independent impairments - a lexical access impairment, and a syntactic impairment - in which case re-access at a syntactic gap may remain delayed.

Aside from the implications that the set of findings from these experiments have on models of language processing in Broca' aphasia, they also have the potential to inform clinical intervention techniques. For example, these results suggest that training the conversational partners of individuals with Broca's aphasia to use more descriptive information in their exchanges may facilitate comprehension. Additionally, the results further validate research that has found an effect of treatment that is targeted at facilitating access to the semantic network in for individuals with Broca's aphasia, as that system appears to be an area of relative strength with which to compensate for other causative sources of comprehension breakdown.

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CHAPTER 6:

Conclusion

The primary aim of this dissertation was investigate the time-course of lexical activation during on-line sentence processing to further elucidate the underlying nature of the comprehension disorder evinced by listeners with Broca's aphasia (LWBA). To review, LWBA demonstrate difficulty comprehending certain types of sentences, particularly those that do not follow canonical word order (subject-verb-object). Although many theories have been put forth to explain these difficulties, two in particular were evaluated in this dissertation: the slow syntax hypothesis (Avrutin, 2006; Burkhardt et al., 2008; Piñango, 2000) and the delayed lexical activation hypothesis (DLA; Love et al., 2008; Prather et al., 1997). Whereas the DLA claims that slowed access to lexical items disrupts their availability for other fast-acting processes, such as syntax, the slow syntax hypothesis posits that it is syntactic structure formation itself that is slowed. This dissertation set up a series of studies to test the predictions made by each of these accounts.

Chapter 3 presented a study exploring the time-course of lexical access during processing of *syntactically simple sentences* containing *unambiguous* NPs in neurologically unimpaired listeners and LWBA. According to the claims made by the DLA, lexical access should be delayed for LWBA in all sentence types, simple and complex. On the other hand, the slow syntax hypothesis predicts on-time lexical access in the 'simple' case, with delayed activation observed only in the cases where sentences contain syntactic dependencies. Whereas the neurologically unimpaired listeners showed significant priming, indicating lexical access, immediately at the offset of the object NP, replicating previous research, the LWBA evinced a priming pattern that was temporally protracted by 400 ms. Furthermore, the pattern

demonstrated by the LWBA was qualitatively similar to the pattern evinced by the unimpaired control participants but pushed downstream. As a reminder, no previous study had evaluated the time-course of lexical access during sentence processing for LWBA in the absence of syntactically complex sentence constructions or in the context of evaluating access patterns of lexically ambiguous words. The patterns of results in the present study, then, strongly support the DLA.

Having established that lexical access is delayed for listener's with Broca's aphasia, Chapter 4 presented an examination of the effect of slowed rate of speech on the time-course of lexical access in Broca's aphasia. As a reminder, previous research from Love et al (2008) had found that slowing rate of speech by 1/3 resulted in on-time re-access at a syntactic gap as well as improved offline comprehension of syntactically simple sentences for LWBA. However, Love et al. did not explore the effect of slowing rate of speech on the time-course of <u>initial</u> lexical access (that is, at the point where the lexical item of interest was first encountered in the sentence). According to the claims made by the DLA, the slow-rise time of activating lexical items causes a temporal mismatch with fast-acting process such as those involved in syntactic processing, and thus slowing rate of speech should relax these temporal constraints and yield what appears to be a normal time-course. On the other hand, failure to find an effect of slowed rate of speech on the time-course of lexical processing would appear to support the slow syntax hypothesis.

Several interesting findings were brought to light by this study. First, no effect of the slowed rate of speech was found for the overall group of LWBA, with no

significant priming found in any condition. Rather than facilitating lexical processing, slowing rate of speech eliminated any priming, as was observed for the neurologically unimpaired control group in Love et al (2008). Initially, then, the current findings appear to support the predictions made by the slow syntax hypothesis. However, closer inspection of the response of individual subjects to the rate of speech manipulation ran contrary to that claim. Rather than observing no effect, slowing the rate of speech input revealed opposite effects across sub-groups of subjects, facilitating access for some LWBA and hindering it for others, resulting in an overall net null effect that eliminated the patterns at the individual level.

By using an individual measure, proportion of lesion to three brain regions that have been implicated in different aspects of sentence processing, a large amount of this intersubject variability was accounted for. The brain regions evaluated included sub-regions of Broca's area in the inferior frontal gyrus, BA44 and BA45, as well as a portion of the superior temporal gyrus corresponding to Wernicke's area, Te3. The proportion of these areas involved in the brain lesion was compared to the following behavioral outcomes at the first two probe positions (at the NP offset and 400 ms downstream): priming at regular rate , slow rate, as well as the change in priming across rates. The proportion of lesion to BA45, a brain region which has been linked to controlled semantic processing, was significantly correlated with priming at both regular and slow rate, with more damage to BA45 resulting in earlier priming (at noun offset) and less damage resulting in later priming (at the downstream probe point). Additionally, the proportion of lesion to BA45 also significantly correlated with the

change in priming across rates, with more benefit of slowing found for those

participants who had initially demonstrated more delayed access. Importantly, this

relationship was *not* found for the proportion of damage to BA44, a brain region

which has been linked to syntactic processing (Friederici, 2002), suggesting that rate

of speech acts primarily on lexical processing routines, supporting the DLA and

providing additional evidence against the slow syntax hypothesis. Additionally, the

fact that individual lesion variability was able to explain a null result at the group level

brings into question the findings of other research that has failed to find an effect of

slowed speech rate (e.g., Choy, 2011). However, it remains possible that slowing rate

of speech has an effect on both lexical processing and structure-building, and that the

limitations of this study (the small number of subjects, for example) underlie the lack

of significant findings.

   To follow up on this possibility, Chapter 5 presented a study exploring the

effect of anticipatory processing cues on the time-course of lexical access in college-

aged neurologically unimpaired participants, older neurologically unimpaired

participants, and LWBA. To review, there is evidence to suggest that unimpaired

listeners are able to use constraining information from the context to narrow down,

and in some cases predict, specific features of upcoming lexical items (e.g., Altmann

& Mirković, 2009; Kamide, 2008). The studies presented in this chapter took

advantage of anticipatory processing to ask whether structural, semantic, or

probabilistic cues were able to facilitate lexical processing in Broca's aphasia. The

slow syntax account should predict that providing a cue to the word class of the

upcoming lexical item would facilitate structure-building and result in on-time priming. In contrast, the DLA hypothesizes that a structural cue should have no effect on the time-course of lexical processing. Instead, anticipatory processing cues that bear on the semantic content of the upcoming lexical item, in effect pre-activating aspects of that item, were hypothesized to facilitate lexical processing.

Interestingly, the results of the study described in Chapter 5 revealed that overall priming was found at the offset of the object NP for the young, neurologically unimpaired group, again replicating earlier studies finding immediate access in this population, yet no effect of any of the cues was found. However, the strength of the cue significantly and positively correlated with priming effects, suggesting that young unimpaired listeners were using the cues, but needed a higher level of confidence to rely on them to make predictions. In contrast, the older neurologically unimpaired listeners did show an effect of the cues, relying more on probabilistic cues than semantic cues, however. This finding supports prior research that has suggested older listeners rely more on contextual cues for sentence processing compared to younger listeners.

Finally, the LWBA also showed an effect of the cues, although an effect of the semantic bias condition rather than the probabilistic bias condition was observed. Furthermore, the semantic cue not only facilitated lexical access by allowing for priming immediately at the offset of the NP, but it actually shifted lexical access to the adjective offset, eliciting anticipatory access to the meaning of the upcoming lexical item. In this condition, the LWBA were in fact not delayed in comparison with the

older control group from this study. These findings suggest that LWBA may be able to tap into an intact semantic system if given enough support, to overcome other potential sources of processing impairment. Overall then, the finding that the LWBA were sensitive to lexical-semantic cues, but not structural cues once again supports the DLA and offers evidence against the slow syntax account.

The results of all the studies described in this dissertation have several broad implications. First, in regards to unimpaired sentence processing, Chapter 3 was able to replicate previous research that has suggested that unimpaired listeners immediately and automatically access the meanings of lexical items when they are encountered even in syntactically simple sentences containing unambiguous words. Perhaps more interesting though, Chapter 5 demonstrated that overall, young neurologically unimpaired listeners may not use local contextual cues to predictively activate a lexical item unless the context is highly constraining for that particular lexical item. This possibility supports research that has found a processing cost for wrongly predicted words in highly constraining contexts but not weakly constraining ones (Federmeier et al., 2007). In contrast, the older neurologically unimpaired group did predict an upcoming noun given usage-based probabilistic cues, although their use of semantic cues also approached significance, supporting research that has suggested that older listeners are more reliant on contextual information, perhaps as a compensatory mechanism (Balota, Black, & Cheney, 1992) . Although this finding appears to run contrary to literature that has suggested that older adults are less able to take advantage of predictive processing information, the current results suggest that

perhaps there is an interaction between the effect of aging and the strength of the cue. Furthermore, the studies suggesting that older adults are less able to use these cues typically report high intersubject variability, with preserved ability related to higher vocabulary scores (Wlotko, Federmeier, & Kutas, 2012). As vocabulary was not considered in this study, it remains a possibility that these findings would differ given a different set of older participants with presumably lower vocabulary scores.

The implications of the studies on sentence processing in Broca's aphasia are even more numerous. First, as summarized in the discussion of the individual experiments, the results of these studies strongly support the presence of a lexical access delay in Broca's aphasia, which may ultimately be the underlying basis of the comprehension disorder for these listeners. The presence of a lexical delay was evidenced by the finding from Chapter 3 that lexical access remained delayed for LWBA even in the absence of complex syntax. Furthermore, in Chapter 4 it was found that the effect of slowed rate, which was shown by Love et al (2008) to facilitate lexical re-access at syntactic gaps, was related to the proportion of lesion to BA45, a brain region implicated in controlled lexical-semantic, but not syntactic processing. This finding suggests that the facilitory effect of slowed rate from Love et al (2008) on syntactic processing was, in fact, related to the underlying effect of speech rate on the time-course of lexical access, which then eased the time-constraints on that fast-acting process. This finding also highlights the importance of considering individual variability, particularly about the location and extent of brain lesions in studies of sentence processing in Broca's aphasia, and aphasia in general. For example, not all

individuals who have been classified as having Broca's aphasia based on standardized

aphasia batteries have lesions in or confined to Broca's area, and not all individuals

with lesions in Broca's area have Broca's aphasia (Bates et al., 2003; Dronkers et al.,

2004; Mohr, 1976; Thothathiri, Kimberg, & Schwartz, 2012). These patterns,

unsurprisingly, suggest that there is heterogeneity in the lesion profile of participants

in any single study, especially those which assign aphasia subtypes based behavioral

profiles alone with limited or no consideration of brain lesion variables. As has been

discussed previously, different brain regions are hypothesized to contribute

differentially to sentence processing. Thus this source of subject variability could

confound the results of any study attempting to identify the locus of comprehension

deficits in Broca's aphasia, or perhaps just as importantly, deficits in any 'type' of

aphasia.

Lastly, in the study on use of anticipatory processing cues discussed in Chapter

5, LWBA were not only able to use semantic information to facilitate lexical access,

but to eliminate the delay altogether, evincing priming patterns comparable to the

older neurologically unimpaired control group. These results add to the very limited

number of studies that have explored predictive processing during sentence

comprehension in aphasia, and furthermore specified the type (semantic, but not

structural, or probabilistic) that listeners with Broca's aphasia are able to take

advantage of. Furthermore, the fact that the LWBA were able to use the semantic cues

suggests that semantic knowledge is an area of relative strength for LWBA (notably in

contrast to other hypotheses that suggest a weakened semantic system; e.g., Blumstein

& Milberg, 2000), and that it is the retrieval of that information that is impaired. Thus, with cues to aid retrieval, the processing deficit appears to be mitigated. As was suggested earlier, this finding may have implications for informing effective treatment approaches. For example, prior research has demonstrated generalization of training more complex syntactic forms on the comprehension and production of less complex forms (e.g., Thompson, Shapiro, Kiran, & Sobecks, 2003). Perhaps, given this, training more complex, less frequent adjective-noun pairs will generalize to comprehension and production of less frequent nouns by way of cueing from the associated adjective.

Furthermore, the finding of priming patterns that were comparable to control participants presents another opportunity to directly test the claims of the delayed lexical activation hypothesis. Since the DLA claims that delayed lexical access is the underlying cause of the syntactic processing delay, and ultimately the comprehension breakdown observed in LWBA, the DLA would predict that this facilitated lexical access should also result in on-time re-access at a syntactic gap. A future study may explore this prediction by providing a semantically biasing adjective prior to the object NP in sentences containing an object-extracted relative clause, such as those used by Love et al (2008) and testing from priming at the object gap.

In sum, this dissertation provided evidence supporting the delayed lexical activation account of comprehension deficits in LWBA. This work served to expand what is currently understood about lexical access in this population, and will hopefully serve as an impetus for further much-needed work in this arena. Better understanding

the real-time processing impairments that ultimately contribute to comprehension

impairments in Broca's aphasia is important for both informing neurolinguistic models

of language processing, as well as developing more effective clinical treatment

approaches.

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