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Proform-Antecedent Linking in Individuals with Agrammatic Aphasia: A Test of the Intervener Hypothesis

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Abstract

Purpose—To evaluate processing and comprehension of pronouns and reflexives in individuals with agrammatic (Broca's) aphasia and age-matched control participants. Specifically, we evaluate processing and comprehension patterns in terms of a specific hypothesis -- the Intervener Hypothesis – that posits that the difficulty of individuals with agrammatic (Broca's) aphasia results from similarity-based interference caused by the presence of an intervening NP between two elements of a dependency chain.

Methods—We used an eye tracking-while-listening paradigm to investigate real-time processing (Experiment 1) and a sentence-picture matching task to investigate final interpretive comprehension (Experiment 2) of sentences containing proforms in complement phrase and subject relative constructions.

Results—Individuals with agrammatic aphasia demonstrated a greater proportion of gazes to the correct referent of reflexives relative to pronouns and significantly greater comprehension accuracy of reflexives relative to pronouns.

Conclusions—These results provide support for the Intervener Hypothesis, previous support for which comes from studies of *Wh*- questions and unaccusative verbs, and we argue that this account provides an explanation for the deficits of individuals with agrammatic aphasia across a growing set of sentence constructions. The current study extends this hypothesis beyond filler-gap dependencies to referential dependencies and allows us to refine the hypothesis in terms of the structural constraints that meet the description of the Intervener Hypothesis.

Keywords

Aphasia; Sentence Processing; Binding; Similarity-Based Interference

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Individuals with agrammatic aphasia (sometimes referred to as Broca's aphasia) typically have difficulty comprehending sentences containing syntactic dependencies. Previous investigations have explored these deficits in constructions that contain filler-gap dependencies (e.g. object relatives, *Wh-* questions) and referential dependencies between proforms (e.g. him/himself) and antecedents. The current study investigates real-time processing (Experiment 1) and final comprehension (Experiment 2) of sentences containing proforms in two participant groups: individuals with agrammatic aphasia (IWA-Ag) resulting from left-hemisphere brain damage and neurologically unimpaired age-matched control (AMC) participants.

Our purpose is to investigate how proform type (e.g., pronouns and reflexives) and distance from antecedent influence moment-to-moment processing and comprehension patterns. The focus of the current paper is on a particular theoretical account, the Intervener Hypothesis (Sheppard, Walenski, Love & Shapiro, 2015; Sullivan, Walenski, Love & Shapiro, 2016), which posits that sentence processing is negatively impacted when a sentence element of similar structure intervenes between two elements of a dependency chain. We begin here with a discussion of classical binding constraints and review of previous studies. We then describe the theoretical framework underlying the current study, the Intervener Hypothesis, and its relevance to our study.

Binding constraints

Proforms like *him* and *himself* are examples of referential dependencies: in order to be understood, they must be linked to another sentence element (or *antecedent*). Pronouns and reflexives differ in terms of the binding principles that constrain how referential dependencies are formed. Consider:

(1) The grandma$_a$ said that the baker$_b$ cleaned herself$_{a*/b}$.

(2) The grandma$_a$ said that the baker$_b$ cleaned her$_{a/b*}$.

Within the Government and Binding framework (Chomsky, 1981) the interpretation of the reflexive *herself* in (1) is constrained by binding principle A, which states that a reflexive must have a local antecedent; in (1), the noun phrase (NP) *the baker* serves as the local antecedent, where 'local' refers to the same clause in which the reflexive and its antecedent are positioned. The interpretation of the pronoun *her* in (2) is constrained by binding principle B, which states that a pronoun cannot take an antecedent within its local clause.

Sentences containing pronouns and reflexives also differ in other important ways. First, the dependency relation between a reflexive and antecedent can be determined using only syntactic information within the sentence. For sentences with pronouns (e.g., *The baker cleaned her*), syntactic information alone is insufficient to unambiguously determine the dependency relation between a pronoun and antecedent. Unlike reflexives, pronouns require access to discourse information in addition to syntactic information. For this reason, pronouns are sometimes said to be discourse-linked (D-linked; e.g., Avrutin, 2000, 2006) and thus add an additional level of complexity to be successfully processed. Second, and more to the purpose of the current investigation, the pronoun *her* in (2) is far from its antecedent NP *the grandma* and a sentence element of the same structure (*the baker;* DET N)

intervenes between the antecedent and the pronoun. For sentences such as (1), where the reflexive *herself* is close to its antecedent *the baker*, there are no sentence elements that intervene between the two elements of the dependency chain. The possibility we consider here is that the presence of an intervening element between a proform and antecedent creates a greater challenge for establishing the dependency chain in sentences containing pronouns relative to reflexives. In line with the Intervener Hypothesis detailed below, we posit that this difficulty arises as a result of similarity-based interference between the intervening NP and the antecedent NP in the dependency chain (see Gordon, Hendrick, & Johnson, 2004; Gordon, Hendrick, Johnson, & Lee, 2006 for unimpaired subjects; see Sheppard, Walenski, Love & Shapiro, 2015; Sullivan, Walenski, Love & Shapiro, 2016 for individuals with Broca's aphasia). A critical point here is what "between" means within a similarity-based interference framework. Select accounts of similarity-based interference characterize "between" in structural terms (Rizzi 1990). Note that in previous studies of the IH using filler-gap dependencies, a structural characterization was the only relevant one (Sheppard et. al. 2015, Sullivan et al. 2016). Additional accounts of similarity-based interference center on processes of working memory and the serial nature of linguistic input (Grodner & Gibson, 2005, Lewis & Vasisth, 2005, Lewis, Vasisth & Van Dyke, 2006; for related work in aphasia see: Beretta, 2001; Varkanitksa et al. 2016; Miyake, Carpenter & Just ,1994). The current study is the first investigation of the IH to tease apart the construct of interference by using sentence types that yield distinct predictions for linear versus structural interference, detailed below under *Current study*.

Binding constructions in aphasia

Several studies of IWA-Ag have found poor comprehension of binding constructions (Avrutin, Lubarsky & Greene, 1999; Choy & Thompson, 2010; Edwards & Varlokosta, 2007; Grodzinsky, Wexler, Chien, Marakovitz & Solomon, 1993; Love, Nicol, Swinney, Hickok & Zurif, 1998) Using a sentence-picture matching task[1], Grodzinsky et al. (1993) reported chance performance in sentences containing pronouns but good comprehension when they contain reflexives. However numerous other studies have found a different pattern, that is, chance or low performance for sentences containing either pronouns or reflexives (Choy & Thompson, 2010; Edwards & Varlokosta, 2007; Love et al., 1998).

Fewer studies have examined the online processing of sentences containing pronouns and reflexives in IWA-Ag. Using a cross-modal lexical priming method, Love et al. (1998) presented sentences like (3) below to investigate the time course of re-activation of the second noun phrase, *the skier* (the correct antecedent for the reflexive condition) at the offset of the overt anaphor 'him' and 'himself':

(3) The boxer said that **the skier** in the hospital would blame him/**himself** for the injury.

[1]In a sentence-picture matching task, participants listen to a sentence and then choose the picture (out of two or three) that best matches the sentence. This method is typically untimed and allows for the use of metalinguistic, conscious reflection in generating a response.

They found that while IWA-Ag incorrectly re-activated (primed) *the skier* after hearing the pronoun (*him*), no such facilitation was evident after the reflexive. We note here that this work only had three IWA-Ag and therefore the results should be interpreted with caution.

In another online study, but with an eye tracking-while-listening method, Choy and Thompson (2010) investigated the proportion of gazes to the correct referent using sentences of the type:

(4) **The soldier** told *the farmer* with glasses to shave **him**/*himself* in the bathroom.

In the reflexive condition, the authors state that unimpaired participants and IWA-Ag looked more to the correct referent than the incorrect referent during the reflexive and in the time window following the reflexive (the multi-word prepositional phrase). In the pronoun condition it is argued that looks to the correct and incorrect referent were not different during the pronoun but were significantly greater to the correct referent in the subsequent time window for both participant groups. The authors interpret their findings as evidence that IWA-Ag demonstrate a similar time course of pronoun-antecedent linking to unimpaired participants. However, looks to referents were summed in the time windows analyzed and reflexives and pronouns differ in duration, leading to a larger analysis window for reflexives relative to pronouns. In addition, the time window corresponding to the prepositional phrase was considerably longer than the proform time window. Although the patterns of both groups appear similar when gazes are summed over a multi-word prepositional phrase following the proform, the study did not analyze gaze behavior using a more fine-grained temporal scale.

Thus, though there are inconsistencies in the results of the studies reviewed here, there is reasonable evidence to suggest that IWA-Ag have difficulty processing and understanding sentences containing pronouns. Given the paucity of studies that measure online processing in aphasia, further work is needed to understand whether difficulty is encountered during online sentence processing of proform-antecedent dependencies. The studies described below allow for the investigation of final comprehension and of the minute by minute unfolding of sentences containing reflexives and pronouns in constructions that allow for the disentangling of the underlying processing costs associated with syntactic complexity and distance between overt anaphors and their structurally defined antecedents.

The Intervener Hypothesis

In addition to difficulty understanding the dependency relations in binding constructions, IWA-Ag have difficulty understanding dependency relations in sentences that have non-canonical word order and contain displaced constituents, such as *Wh*-questions, passives and object-extracted relative clauses (e.g., Caramazza & Zurif, 1976; Drai & Grodzinsky, 2006; Grodzinsky, 1990; Sheppard et al., 2015; Swinney & Zurif, 1995).

The focus of the current paper is on a recent account, the Intervener Hypothesis (IH), that aims to explain the comprehension deficits that are a hallmark of agrammatic (Broca's) aphasia (Sheppard, Walenski, Love, & Shapiro, 2015; Sullivan, Walenski, Love & Shapiro,

2016). In an eye tracking-while-listening study, Sheppard et al. (2015) presented *Who* and *Which* questions in subject- and object-extracted constructions:

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

(5) Who pushed the fireman yesterday afternoon?

(6) Who did the fireman push ____ yesterday afternoon?

(7) Which mailman pushed the fireman yesterday afternoon?

(8) Which mailman did the fireman push ____ yesterday afternoon?

The sentence types depicted in (5) and (7), subject-extracted *Wh*-questions, pose no particular difficulty for IWA-Ag. In both (6) and (8), the direct-object NP, *who* (6) and *which mailman* (8), have been displaced from their underlying position occurring after the verb *push* to the beginning of the sentence, leaving behind a 'gap' (in psycholinguistic terminology). In (8), note that the displaced NP, *which mailman*, crosses over an intervening argument position occupied by the subject NP, *the fireman*. The intuition here is that the intervening NP is considered as a possible element in the dependency chain and interferes with computing the dependency relation between the displaced *Wh*-phrase and its gap. Critically, per the IH, only in cases where the NPs in the sentence are similarly structured (e.g., contain a DET-N structure) will interference among the NPs occur. Thus, only (8) contains such a structure, since in (5) and (6), the displaced *Wh*-phrase (*who*) is a bare operator and thus has a distinct structure from the intervening NP (*the fireman*), and (7) is a subject-extracted *Wh*-question and thus does not meet the structural description for an intervener. In line with the predictions made by the IH, the performance of IWA-Ag in Sheppard et al. (2015) revealed chance accuracy and significantly more gazes to the incorrect referent compared to the correct referent for object-extracted *Which*-questions only (8).

Additional support for the IH comes from a study of unaccusative verbs in IWA-Ag. In a sentence-picture matching task, Sullivan et al. (2016) presented unaccusative verbs in complement phrase constructions and subject-extracted relative clauses:

(9) The girl observed that the boy disappeared ____ into the trees.

(10) The girl that observed the boy disappeared ____ into the trees.

According to the Unaccusativity Hypothesis, the single argument of the verb *disappeared* (noted in brackets) has been displaced from the underlying object position to a position earlier in the sentence, leaving behind a gap (Burzio, 1986; Perlmutter, 1978; Perlmutter & Postal, 1984)

In the complement phrase construction (9), no NP occurs (intervenes) between the single argument of the unaccusative verb, *the boy*, and its underlying position that occurs after the verb. In the subject-extracted relative clause (10), an NP (***the boy***) of the same structural type as the displaced constituent (*the girl*) occurs between the two elements of the dependency chain. Consistent with the predictions of the IH, IWA-Ag showed poor comprehension of intervener constructions (10) but good comprehension of non-intervener constructions (9).

Current study

On the surface, sentences containing pronouns and reflexives appear dissimilar to the sentence constructions described above. Namely, in the case of *Wh*-questions and unaccusative verbs, dependency chains are formed between a displaced constituent and an unpronounced, covert sentence element (the gap position). As such these constructions are examples of syntactic displacement. Though proforms do not involve syntactic displacement, they nevertheless form dependency chains that, in principle, could be sensitive to intervener effects. Consider:

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

(12) The grandma said that *the baker* cleaned *herself*.

(13) The baker that helped *the grandma* cleaned *her*.

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

Sentences (11) and (12) use complement phrase constructions, where the pronoun *her* in (11) refers to the non-local NP *the grandma* and the reflexive *herself* in (12) refers to the local NP *the baker.* Critical to the predictions of the IH, in (11) a noun phrase of the same structural type (i.e., DET N; in boldface) intervenes between the pronoun and antecedent. Sentences (13) and (14) use subject relative constructions, where the 'typical' short-distance reflexives and long-distance pronouns observed in (11) and (12) are reversed, that is, the personal pronoun *her* in (13) is near to its antecedent *the grandma* with no linearly intervening noun phrase. The reflexive *herself* in (14) is far from its antecedent *the baker* and a noun phrase of the same structural type intervenes between the two elements of the dependency chain. We note here that linear distance describes the proximity of sentential elements at the surface level, that is, the serial order of information presented in the auditory stream. Sentences (11) and (14) contain an NP that linearly intervenes between the proform and antecedent while sentences (12) and (13) do not. We discuss the distinction between linear distance and structural distance below.

When we examine the syntactic structure of sentences (11)–(14), a different characterization emerges. Figure 1 displays the syntactic structure (simplified) of the sentences containing complement phrases ((11), (12); Figure 1A) and subject relatives ((13), (14); Figure 1B) presented above.

The complement phrase constructions (Figure 1A) demonstrate a direct correspondence between linear and structural distance. By this we mean that the reflexive finds its antecedent within the local sentential clause (*the baker cleaned herself)* and the reflexive is linearly close to the antecedent. In contrast, the pronoun *her* is deeply embedded in the overall structure of the sentence and finds its antecedent *the grandma* in the specifier position of the overall sentence (i.e., the subject of the first determiner phrase). In subject relative constructions (Figure 1B), the reflexive is positioned within the verb phrase (*cleaned herself)* and its antecedent NP *the baker* is in the specifier position of the adjacent determiner phrase. In comparison, the antecedent of the pronoun, the NP *the grandma,* is deeply embedded in the overall structure of the sentence. When we compare pronoun conditions between sentence structures, we find that in one case (1A) the pronoun is deeply

embedded and in the other (1B), the antecedent is deeply embedded. In contrast, there is no distinction between level of embeddedness of the reflexive or its antecedent across structures. In both constructions, the reflexive is positioned within the verb phrase *cleaned herself*, and finds its antecedent *the baker* in the adjacent determiner phrase. Critically then, both pronoun conditions contain an NP that structurally intervenes between the pronoun and antecedent.

The goal of the present study is to test the Intervener Hypothesis in individuals with agrammatic (Broca's) aphasia using proforms. Furthermore, the current study presents an opportunity to tease apart the impact of linear and structural distance between proforms and antecedents on sentence processing. To this end the current study manipulates sentence structure to tease apart the relative contributions of proform type and the presence of an intervener, both in linear and structural terms. We use eye tracking-while-listening (Experiment 1) to investigate sentence processing and a sentence-picture matching task (Experiment 2) to probe final comprehension patterns in IWA-Ag and a group of neurologically healthy age-matched control participants (AMC). Given the IH, we predict poorer performance in sentences containing an intervening argument between a proform and its antecedent relative to sentences that do not have such an intervener.

Experiment 1: Online Processing of Pronouns and Reflexives

We begin with an eye tracking-while-listening experiment in a group of IWA-Ag and a group of neurologically healthy AMCs. The use of eye tracking allows us to investigate the moment-to-moment processing of sentences containing pronouns and reflexives in sentence structures with and without interveners.

Method

Participants

Group 1: Participants with agrammatic (Broca's) aphasia (IWA-Ag): Six IWA-Ag participated in the study (mean age at time of testing: 55 years; range: 39–64 years). All IWA-Ag experienced a single, unilateral left-hemisphere stroke, were native English speakers with normal or corrected-to-normal visual and auditory acuity, and were right-handed before their stroke. All participants were neurologically and physically stable (i.e., at least six months post-onset), with no reported history of alcohol or drug abuse, active psychiatric illness, intellectual disability, or other significant brain disorder or dysfunction. Diagnosis of agrammatic (Broca's) aphasia was based on the administration of standardized language assessments to determine the extent and severity of language impairment. Assessments included the Boston Diagnostic Aphasia Examination – Third Edition (BDAE-3; Goodglass, Kaplan & Barresi, 2000), S.O.A.P. (Subject-relative, Object-relative, Active and Passive) Test of Auditory Sentence Comprehension (Love & Oster, 2002) and Western Aphasia Battery (WAB-r; Kertesz, 2006). All participants demonstrated an auditory comprehension deficit that was defined as at- or below-chance performance on comprehension of non-canonically ordered sentences (object-relatives and passives) from the SOAP Test (Love & Oster, 2002). All of the participants were tested at the Language and Neuroscience Group Laboratory at San Diego State University and were paid $15 per

session. Demographic information and assessment scores for these participants are presented below in Table 1.

Group 2: Age-matched control (AMC) participants: Ten AMC participants were included in this study (mean age at time of testing: 62 years; range 56–70 years). All AMC participants were native English speakers with normal or corrected-to-normal visual and auditory acuity, with no reported history of alcohol or drug abuse, active psychiatric illness, intellectual disability, or other significant brain disorder or dysfunction.

Materials and Design—Participants were presented with auditory sentences arranged in two-sentence discourse sets while looking at a four-picture display (see Figure 2). All sentences were recorded by a female native speaker of English at a normal average rate of speech of 4.69 syllables per second. As demonstrated below in Table 2, proforms (reflexives, pronouns) were inserted into two distinct sentence types, complement phrase and subject relatives, allowing us to manipulate distance across the two proform types. A 5–8 syllable prepositional or adverbial phrase was added to the end of each sentence in order to collect eye-gaze data from onset of the proform to the end of the sentence. Examples of a discourse sentence and the four experimental sentence conditions (yielding a 2 X 2 design) are shown in Table 2.

As discussed briefly in our Introduction, sentences (1a) and (1b) contain complement phrases headed by the complementizer *that*. Sentence (1a) contains a short distance reflexive where *herself* refers to the local NP *the baker*. Sentence (1b) contains a long distance pronoun where *her* refers to the non-local NP *the grandma* and contains an intervening NP **the baker** between the pronoun and its antecedent. Sentences (1c) and (1d) are subject relatives: (1c) contains a long distance reflexive where *herself* refers to the first NP *the baker* and the second NP **the grandma** intervenes between the reflexive and antecedent. Sentence (1d) contains a short distance pronoun, where *her* refers to the second NP *the grandma*. This manipulation resulted in 160 unique discourse sets, with 40 additional discourse sets created as filler items to add variety. The order of mention of the two NPs was counterbalanced across sentence types with the order of mention in the discourse sentence matching that of the target sentence. For each discourse set, a four picture display was constructed that contained the two characters mentioned in the sentence and possible referents for the proform, the inanimate NP mentioned at the end of the discourse sentence, and an unrelated inanimate NP. Pictures were placed in the corner quadrants of the screen and were counterbalanced across positions. The discourse sets were counterbalanced across two presentation lists and were completed at separate visits at least one week apart.

Procedure—Participants sat facing a Tobii X120 eyetracker and were positioned with their eyes at a distance of 60cm from the eyetracker. The eyetracker was calibrated at the beginning of each experimental session. Stimuli were presented with E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Each trial began with a 500ms fixation cross, followed by a 250ms blank screen. The four-picture display was presented for 1000ms before the discourse sentence began, followed by a 250ms pause and the experimental sentence. The picture display remained onscreen 500ms after the experimental sentence (see Figure 2).

Participants were given a 10 item practice session to familiarize themselves with the task and ask any questions. It also served as an opportunity for the experimenter to ensure participant compliance and allowed for instruction if needed. For all trials, gaze location was sampled at 60hz in each of the four quadrants and thus eye gaze location was recorded every 17ms throughout each trial. 25% of target trials were followed by a simple yes/no question that probed only comprehension of the discourse sentence and did not probe the proform-antecedent relation of the target sentence. These yes/no questions were used to maintain attention and participants responded using a button response box. An example picture display, sentence set and timing parameters for a single trial are shown in Figure 2.

Analysis and Results

We defined four rectangular areas of interest (AOIs) of the same size around each of the pictures in the display. When data were available from both eyes, gaze location was computed as their average. When gaze location was available from only one eye, gaze location was computed on that eye alone. When gaze location was not available from either eye, the sample was excluded from further analyses. Gaze samples that were outside any of the four AOIs were excluded from further analyses. A gaze was conservatively defined as six consecutive samples within the same AOI (a total of 102ms; see Manor and Gordon, 2003). Gazes that did not meet this criterion were not included for analysis. The resulting data set included gazes to the four AOIs that lasted at least 102ms.

To determine overall accuracy of gaze data, we calculated for each subject and each item the proportion of gazes to the correct referent (time looking at the correct referent divided by time looking at the incorrect referent and two distractor pictures). The analysis window began at the onset of the proform and continued for 1000ms. The analysis window was shifted 200ms forward to account for delay in eye movements (Allopena, Magnuson & Tanenhaus, 1998). To avoid problems with analyzing raw proportions in linear models, proportions were transformed using the empirical logit transformation (see Jaeger, 2008). Raw proportions are reported within the text for ease of interpretation. Analyses were conducted using R version 3.3.1 (R Core Team, 2016), the *lme4* package (Bates, Maechler, Bolker & Walker, 2015), and the *eyetrackingR* package (Dink & Ferguson, 2016).

Age-matched control (AMC) participants

Proportion of gazes to correct referent: To evaluate if performance differed between sentence structures we compared mean proportion of gazes to the correct referent over the 1000ms window in complement phrase and subject relative constructions in an analysis of variance. We found no significant effect of sentence structure ($F(1, 1415) = 0.78$, $p = 0.38$). Mean gazes to the correct referent for the conditions of interest are presented in Table 3.

To begin, we submitted mean proportion of gazes to the correct referent across the 1000ms time period as the dependent measure in an analysis of variance with distance (2: long, short) and proform (2: pronoun, reflexive) as within-subjects factors. Note that the degrees of freedom are large because they based on the total number of observations. There were main effects of distance ($F(1, 1413) = 21.80$, $p < .001$), where the proportion of gazes to the correct referent was higher for short compared to long distance conditions, and proform

(F(1, 1413) = 13.71, p < .001), where gazes to the correct referent were higher for reflexive compared to pronoun conditions. There was no significant interaction between distance and proform (F(1, 1413) = 0.79, p = 0.37).

Next, we conducted a series of follow-up comparisons (one-way ANOVAs) to investigate the impact of distance within each proform level (long pronoun vs. short pronoun; long reflexive vs. short reflexive) and the impact of proform within each distance level (long pronoun vs. long reflexive; short pronoun vs. short reflexive).

Analysis of distance: As shown in Table 3, the long pronoun condition (M = 0.32, SD = 0.11) yielded significantly fewer gazes to the correct referent relative to the short pronoun (M = 0.37, SD = 0.09) condition (F(1, 703) = 7.26, p < 0.01) and the long reflexive condition (M = 0.38, SD = 0.13) yielded significantly fewer gazes to the correct referent than the short reflexive (M = 0.47, SD = 0.08) condition (F(1, 710) = 14.79, p < 0.001).

Analysis of proform: The short pronoun condition (M = 0.37, SD = 0.09) yielded significantly fewer gazes to the correct referent relative to the short reflexive (M = 0.47, SD = 0.08) condition (F(1, 703) = 9.86, p < 0.01), see Table 3. The long pronoun condition (M = 0.32, SD = 0.11) also yielded fewer gazes to the correct referent relative to the long reflexive (M = 0.38, SD = 0.13) condition; however, after correcting the significance value for multiple comparisons (0.05/4 = 0.0125), the effect of proform was no longer significant (F(1, 710) = 4.27, p = 0.04).

Time-course analyses

Gazes to correct and incorrect referent: To investigate the continuous time-course of gazes, we calculated the proportion of gazes to each of the four AOIs within 100ms bins across the entire 1000ms window. Figure 3 displays the proportion of gazes to the correct NP (NP1 for long distance conditions, NP2 for short) and to the incorrect NP. The proportion of gazes to the inanimate NP mentioned at the end of the discourse sentence and the distractor inanimate NP constituted a minority of overall gazes (mean gazes to discourse NP < 0.22, mean gazes to distractor NP < 0.10 in all conditions), suggesting that participants primarily devoted their gazes to the correct and incorrect referents of the proform. For this reason, gazes to the two inanimate NPs are not plotted in Figure 3.

Visual examination of these results reveal that, in the short distance conditions (Figures 3A and 3B), participants showed a higher proportion of gazes to the correct NP over the entire window. Recall that in the short distance conditions, NP2 is both the correct referent of the proform and the most recent NP in the auditory stream. Notably, the difference in the proportion of gazes to the correct and incorrect referents is smaller in the short pronoun condition (3A) relative to the short reflexive condition (3B). Nonetheless, similar gaze patterns can be seen for both short distance conditions, where gazes to the correct referent (NP2) exceed those to the incorrect referent from the onset of the proform and continue over the analysis period.

In the long distance conditions (Figures 3C and 3D), participants showed a higher proportion of gazes to the incorrect NP (i.e., NP2) at the beginning of the time window, followed by an

increase in gazes to the correct NP (i.e., NP1) and a decrease in gazes to the incorrect NP. In the long reflexive condition (3D), gazes to the correct NP began increasing immediately following the onset of the proform and exceeded the proportion of gazes to the incorrect NP between 300 and 400ms post proform onset. In the long pronoun condition (3C), gazes to the correct NP also began increasing immediately following the onset of the proform, reaching a peak between 500–600ms post proform onset. Although the proportion of gazes to the correct NP did not exceed those to the incorrect NP, the pattern of gazes reflects a steady increase in gazes to the correct NP accompanied by a steady decrease in gazes to the incorrect NP.

This descriptive analysis suggests that participants tended to look at the NP they most recently encountered in the auditory stream (NP2) at the onset of the proform. In the short distance conditions, where NP2 was also the correct referent of the proform, participants continued to direct their gazes at NP2. In the long distance conditions, where NP1 was the correct referent, participants shifted their gazes to the correct NP immediately following the onset of the proform.

Growth curve analysis: To statistically evaluate differences between conditions over time, we conducted a growth curve analysis using mixed effect models (GCA; Mirman, Dixon & Magnuson, 2008) with the continuous time course of gazes to the correct referent as the dependent variable. To implement the GCA model, we calculated the proportion of gazes to the correct referent within 100ms bins across the 1000ms window. The model included fixed effects of proform (pronoun, reflexive) and distance (long, short) and random effects of subjects and items. To determine the best fitting model, first, second and third order orthogonal polynomials (corresponding to linear, quadratic and cubic growth curves, respectively) were added individually and improvements in model fit were assessed using model comparisons. The resulting model included fixed effects of proform (pronoun, reflexive) and distance (long, short), the interaction of each time term and factor (proform, distance) and random effects of subjects and items on all time terms. The proform and distance factors were contrast coded using sum-coding with the proportion of gazes to correct referent in pronoun conditions contrasted with reflexive conditions and proportion of gazes to the correct referent in long-distance conditions contrasted with short-distance conditions. Figure 4 presents the continuous time course of gazes to the correct referent for each condition.

The growth curve analysis revealed a significant main effect of distance (Estimate = −0.21, SE = 0.05, t = −4.143, $p < 0.001$) and proform (Estimate = −0.19, SE = 0.05, t = −3.73, $p < 0.001$), indicating a higher proportion of gazes to the correct referent in the short versus long conditions and in the reflexive versus pronoun conditions. The analysis also revealed a significant interaction between distance and the linear time term (first-order orthogonal polynomial; Estimate = 0.29, SE = 0.11, t = 2.66, p = 0.008) indicating a steeper rise in the time-course of gazes to the correct referent in long distance versus short distance conditions.

Individuals with agrammatic (Broca's) Aphasia (IWA-Ag participants)

Proportion of gazes to correct referent: As with the age-matched control group, we first evaluate whether performance differed between sentence structures by comparing mean proportion of gazes to the correct referent over the 1000ms window in complement phrase and subject relative constructions in an analysis of variance and found no significant effect of sentence structure ($F(1, 912) = 0.38$, $p = 0.54$). We continue our analysis of individuals with Broca's aphasia by submitting the overall mean proportion of gazes to the correct referent as the dependent measure in an analysis of variance with distance (long, short) and proform (pronoun, reflexive) as within-subjects factors. Mean proportion of gazes to the correct referent for IWA-Ag participants are presented in Table 4.

This analysis yielded a main effect of proform only ($F(1, 910) = 8.96$, $p = .003$), where the proportion of gazes to the correct referent was higher for reflexive compared to pronoun conditions. There was no significant main effect of distance ($F(1, 910) = 2.21$, $p = 0.14$) and no interaction between distance and proform ($F(1, 910) = 0.39$, $p = 0.54$).

As we did earlier, we conducted a series of follow-up comparisons (one-way ANOVAs) to investigate the impact of distance within the two proform levels (long pronoun vs. short pronoun; long reflexive vs. short reflexive) and the impact of proform within the two distance levels (long pronoun vs. long reflexive; short pronoun vs. short reflexive).

Analysis of distance: The long pronoun condition yielded fewer gazes to the correct referent ($M = 0.27$, $SD = 0.13$) relative to the short pronoun condition ($M = 0.29$, $SD = 0.12$) and the long reflexive condition yielded fewer gazes to the correct referent ($M = 0.34$, $SD = 0.15$) than the short reflexive condition ($M = 0.39$, $SD = 0.16$); however, after correcting the significance value for multiple comparisons, the effect of distance was non-significant ($p > 0.15$ for both comparisons).

Analysis of proform: The long pronoun condition yielded fewer gazes to the correct referent ($M = 0.27$, $SD = 0.13$) relative to the long reflexive condition ($M = 0.34$, $SD = 0.15$) but again, was non-significant at the adjusted significance value ($p > 0.08$). The effect of proform was significant in the short distance comparison, where the short pronoun condition yielded fewer gazes to the correct referent ($M = 0.29$, $SD = 0.12$) relative to the short reflexive condition ($M = 0.39$, $SD = 0.16$; $F(1, 452) = 6.41$, $p = 0.01$).

Time course analyses

Gazes to correct and incorrect referent: Following the same procedure as the AMC group, we calculated the proportion of gazes to each of the four AOIs within 100ms bins across the 1000ms window. Figure 5 displays the proportion of gazes to the correct referent (NP1 for long distance conditions, NP2 for short) and incorrect referent AOIs for IWA-Ag. As with the AMC group, the proportion of gazes to the inanimate NP mentioned at the end of the discourse sentence and the distractor inanimate NP constituted a minority of overall gazes (mean gazes to discourse NP < 0.22, mean gazes to distractor NP < 0.18 in all conditions), providing evidence that IWA-Ag participants primarily devoted their gazes to the correct and

incorrect referents of the proform. For this reason, gazes to the two inanimate NPs are not plotted in Figure 5.

In the short distance conditions (Figures 5A and 5B), the difference in the proportion of gazes remained relatively stable across the 1000ms window. However, the long distance conditions reveal a different pattern: in the long reflexive condition, gazes to the incorrect referent began to decrease at 600ms and in the long pronoun condition, gazes to the correct referent began to increase at 600ms as gazes to the incorrect referent began to decrease. In the reflexive conditions (Figures 5B and 5D), IWA-Ag showed a higher proportion of gazes to the correct referent (NP2 for short reflexive, NP1 for long reflexive). A complementary pattern can be seen for the pronoun conditions, where participants showed a higher proportion of gazes to the incorrect referent (NP1 for short pronoun, NP2 for long pronoun).

In contrast to the AMC group, IWA-Ag did not demonstrate a clear preference for the NP that was most recently encountered in the auditory stream (NP2). Rather, IWA-Ag tended to look at the most recent NP in the short reflexive condition (the correct referent) and long pronoun conditions (the incorrect referent). The opposite pattern can be seen in the short pronoun and long reflexive conditions, with IWA-Ag preferring the first NP that occurred in the auditory stream, resulting in greater gazes to the incorrect referent for the short pronoun condition but greater gazes to the correct referent for the long reflexive condition. Furthermore, unlike the performance of the AMC participants in the long distance conditions, who began shifting their gaze to the correct referent (NP1) immediately after the onset of the proform, IWA-Ag did not begin to look away from the incorrect NP until between 600–700ms post proform onset in the long distance conditions.

Growth curve analysis: We then conducted growth curve analysis in the same manner as the AMC group by calculating the proportion of gazes to the correct referent within 100ms bins across the entire 1000ms window. The model included fixed effects of proform (pronoun, reflexive) and distance (long, short) and random effects of subjects and items. First, second and third order orthogonal polynomials were added individually and improvements in model fit were assessed using model comparisons. The addition of the second and third order time terms did not improve model fit over the model that included the linear time term alone. The best fitting model included fixed effects of proform (pronoun, reflexive) and distance (long, short), the interaction of the linear time term on each factor (proform, distance) and random effects of subjects and items on the linear time term. Proform and distance factors were contrast coded using sum-coding. Figure 6 presents the continuous time course of gazes to the correct referent for each condition for IWA-Ag participants.

The analysis revealed a significant main effect of proform (Estimate = −0.183, SE = 0.058, t = −3.131, p = 0.002) but no main effect of distance or interaction between the linear term and either distance or proform. These results indicate a significantly higher proportion of gazes to the correct referent for the reflexive versus pronoun conditions.

Summary of Results from Experiment 1

In our investigation of the real-time processing of sentences containing pronouns and reflexives with and without interveners, we employed a variety of analysis techniques. We

began by comparing the overall proportion of gazes to correct referent in two participant groups, IWA-Ag and AMC. These analyses revealed that AMC participants showed an advantage in gazes to the correct referent in sentences that did not contain an intervener (short distance conditions) relative to those that did (long distance conditions). The AMC participants also demonstrated an advantage for sentences containing reflexives relative to pronouns. The effect of distance between a proform and antecedent was further confirmed via one-way ANOVAs, which demonstrated an advantage for short distance pronouns relative to long distance pronouns, and short distance reflexives relative to long distance pronouns. The effect of proform type was evident in our comparison of short reflexives versus short pronouns and long reflexives versus long pronouns, although the difference in gazes was statistically significant only for the short pronoun versus short reflexive comparison.

While this analysis method provides an informative picture of overall patterns, it is limited in terms of temporal resolution. To examine the time-course of gaze patterns at a more fine-grained level, we examined the time-course of gazes to the correct and incorrect referent in each of the four conditions. This descriptive analysis revealed that AMC participants tended to look at the most recent NP (NP2) in the auditory stream when they encountered the proform. In the short distance conditions, where NP2 was also the correct referent of the proform, participants continued to direct their gazes to NP2 over the course of the analysis window. The relative advantage of reflexives compared to pronouns is also evident in the short distance conditions, where the difference between gazes to the correct versus incorrect referent, and the overall proportion of gazes to the correct NP are greater in the short reflexive condition. In contrast, the long distance conditions required participants to shift their gaze from the most recent NP in the auditory stream (NP2) to the first NP of the sentence after the proform was encountered. The time-course graphs of gazes to the correct and incorrect referent for AMC participants (Figure 2) in long distance conditions reflect an immediate and steady increase in gazes to the correct referent (NP1). Evidence for the relative advantage of the reflexive compared to the pronoun is observed in the form of a higher proportion of gazes to the correct referent in the long reflexive relative to the long pronoun conditions. Further evidence for the advantage of reflexives comes from the observation that gazes to the correct referent reached a peak roughly 200ms earlier in the long reflexive relative to the long pronoun condition for AMC participants.

To statistically evaluate the time-course of gazes to the correct referent across conditions, we employed growth curve analyses using mixed effect models. These analyses confirmed the outcomes of both the more coarse grained ANOVAs and the descriptive analyses, by revealing an advantage for short versus long distance conditions and reflexive versus pronoun conditions. Additionally, the significant interaction between distance and the linear time term confirms our observation that the long distance conditions demonstrated a steep rise in gazes to the correct referent relative to the short-distance conditions.

We repeated the same suite of analyses for IWA-Ag and discovered striking differences between the IWA-Ag and AMC participant groups. In terms of the overall proportion of gazes to the correct referent, IWA-Ag demonstrated an advantage for reflexive relative to pronoun conditions. This advantage was also statistically significant in the short reflexive

relative to short pronoun comparison. While IWA-Ag participants did indeed demonstrate a numerically larger proportion of gazes to the correct referent in the long reflexive versus long pronoun condition, the advantage for the reflexive condition was not statistically significant. Similarly, the overall proportion of gazes to the correct referent was greater for long distance relative to short distance conditions, but these differences did not reach statistical significance.

In the short distance conditions, gazes to the preferred referent (correct-NP2 for short reflexives; incorrect-NP1 for short pronouns) remained relatively stable over the analysis window. However, the long distance conditions revealed a decrease in gazes to the incorrect referent around 600ms post proform onset. This pattern is in contrast to that observed for our AMC participants, who tended to re-orient their gazes to the correct referent immediately following proform onset in long distance conditions. While AMC participants demonstrated a clear preference for the most recently encountered NP (NP2) at the beginning of the analysis window, IWA-Ag tended to direct their gazes at the most recent NP (NP2) in the short reflexive and long pronoun conditions but demonstrated the opposite pattern (preferring NP1) in the long reflexive and short pronoun conditions.

Turning now to our statistical evaluation of the time-course of gazes to the correct referent, we discovered that the best fitting model included linear change over time, but did not improve with the addition of non-linear time terms (i.e., quadratic or cubic growth curves). Consistent with our descriptive analysis and visual inspection of the time course, IWA-Ag participants demonstrated more stable gazes to the selected referent relative to AMC participants, who showed clear change over time. This final analysis further confirmed the advantage for reflexive conditions relative to pronoun conditions, despite the fact that the correct referent was the most recently encountered NP (NP2) for the short reflexive condition, and the first NP in the long reflexive condition. We reserve our discussion of the theoretical significance of these findings for the general discussion and turn now to Experiment 2.

Experiment 2: Offline Comprehension of Pronouns and Reflexives

Our second experiment investigated the effects of interveners and proform type using a sentence-picture matching task so that we could measure final comprehension of our sentences. Here we use the same sentence types and participants as Experiment 1.

Method

Participants—All participants from Experiment 1 (six IWA-Ag participants and ten AMC participants) participated in Experiment 2.

Materials and Design—Ten target sentences from each of the four conditions used in Experiment 1 were included (short reflexive, long pronoun, short pronoun, long reflexive; 40 sentences total). For each sentence, a pair of color line drawings was created. The same two characters were depicted in each drawing. In one picture, the transitive action described in the pronoun conditions was depicted and in the other, the reflexive action described in the reflexive conditions was depicted. The 40 picture pairs were randomized such that the same

condition did not repeat within 3 items. The position of the target (correct) picture was counterbalanced such that 50% of the time the correct picture was on the top and vice versa. An example picture pair is provided in Figure 7.

Procedure—Participants were instructed to listen carefully to the sentences and point to the picture that best matched the sentence they just heard. Participants were familiarized with the task with four practice items (one from each condition) and feedback was provided for practice items. The experimenter spoke each sentence aloud and repetitions were allowed upon the participant's request.

Analysis and Results

To determine comprehension accuracy, participant responses for the four sentence conditions were subjected to unequal variance t-tests comparing response accuracy to chance performance (50%) for each group. For each group (AMC, IWA-Ag), a paired t-test was performed to determine if there was a statistical difference in comprehension accuracy among the four conditions. Paired t-tests were also performed to determine if there was a statistical difference between long versus short distance conditions and pronoun versus reflexive conditions.

Comprehension accuracy for both subject groups is shown in Table 5.

AMC participants' results revealed ceiling effects, with 100% accuracy for short-distance conditions and 97.73% accuracy for long-distance conditions. Accuracy for pronoun and reflexive conditions was 99.95% and 98.18%, respectively. Comprehension accuracy for each condition was significantly above chance ($p < 0.001$ for all comparisons). Paired t-tests revealed no significant difference between conditions ($p > 0.05$ for all comparisons).

For IWA-Ag, comprehension accuracy was significantly greater than chance in the short-reflexive ($t(5) = 10.95$, $p < 0.001$) and long-reflexive ($t(5)=6.74$, $p < 0.001$) conditions. The opposite was true for the Pronoun conditions: neither the short-pronoun ($t(5) = 1.83$, $p = 0.13$) nor long-pronoun condition ($t(5) = 1.58$, $p = 0.18$) was significantly different than chance. Paired t-tests revealed no significant difference between conditions ($p > 0.06$ for all comparisons). However, comprehension accuracy in reflexive conditions was significantly greater than in pronoun conditions ($t(11) = 2.87$, $p = 0.015$). Descriptively, accuracy was highest for the short-reflexive condition (90%), followed by long-reflexives (83.33%) and short-pronouns (70%). Accuracy was lowest in the long-pronoun condition (63.33%).

Discussion

We begin our discussion with the offline sentence-picture matching performance. IWA-Ag demonstrated above chance comprehension of sentences containing reflexives while comprehension of those containing personal pronouns did not differ from chance. Additionally, comprehension of sentences containing reflexives was significantly better than those containing pronouns. The presence of an intervening NP between a proform and antecedent in the long-distance conditions did not significantly affect comprehension accuracy, although accuracy was numerically higher in the short relative to long distance

conditions. The comprehension difficulty in sentences containing pronouns is in contrast to age-matched control participants, for whom comprehension of all sentence types was at or near ceiling. The comprehension deficits of our IWA-Ag align with prior studies that report comprehension deficits with binding constructions (Love et al., 1998; Edwards & Varlokosta, 2007; Thompson & Choy, 2010) and studies that report good comprehension of sentences containing reflexives relative to pronouns (Grodzinsky et. al., 1998; Love et al., 1998).

The purpose of the eye tracking-while-listening task was to investigate how the distance between a proform and antecedent, and the resultant intervening noun phrase, impact real-time sentence processing in IWA-Ag. Specifically, we couched this inquiry with respect to the Intervener Hypothesis, support for which comes from studies of *Wh*-questions (Sheppard et al., 2015) and sentences containing unaccusative verbs (Sullivan et al., 2016) -- constructions that are examples of syntactic displacement (see also Santi, Friederici, Makuuchi & Grodzinsky, 2015, for additional support).

The current study is the first to test the Intervener Hypothesis in sentences that contain referential dependencies between two overt (i.e., spoken) sentence elements, while previous studies tested sentence constructions that involve syntactic movement. In such constructions (*Wh*-questions and unaccusative verbs), a dependency is formed between an NP and a phonologically empty trace position (referred to as *filler-gap* dependencies). For listeners to successfully establish the dependency chain in sentence constructions that involve syntactic movement, they must draw on their knowledge of the syntactic structure of the sentence.

With respect to the sentence types used in the current study, we couched the Intervener Hypothesis in terms of linear distance between a proform and antecedent. Under this description, the long distance conditions contained a noun phrase (of the same structural type as the antecedent) that occurred between the proform and antecedent, while the short distance conditions did not. For example, in the long distance pronoun construction (e.g., *The grandma* said that **the baker** cleaned *her*) the pronoun *her* co-refers with its antecedent, *the grandma*, and an NP, **the baker**, intervenes between the two elements of the dependency. In the short distance counterpart (e.g., The baker that helped *the grandma* cleaned *her*) there is no such intervening NP. As the current study investigated real-time processing of auditory sentences, linear distance can also be understood in terms of *temporal distance*. As such, in the short distance conditions, the correct referent of the proform was the noun phrase that most recently occurred in the auditory stream while the same NP (NP2) was the incorrect referent of the proform in the long distance conditions.

Results from AMC participants suggest that listeners are sensitive to *temporal distance* between a proform and antecedent: In the long distance conditions, AMC participants tended to look at the picture representing the NP that most recently occurred in the auditory stream, beginning at the onset of the proform and then quickly re-oriented their gazes to the correct, long distance NP (NP1). In the short distance conditions, where the most recent NP (NP2) was also the correct referent of the proform, AMC participants directed their gaze to the picture representing NP2 at a higher proportion than to NP1 beginning at the onset of the proform and continued to do so over the entire analysis window.

Results from IWA-Ag reflect a qualitatively different pattern than our AMC participants. IWA-Ag tended to look at the picture representing the most recent NP (NP2) in the long distance pronoun condition, but showed the opposite pattern in the long distance reflexive condition, resulting in a higher proportion of gazes to the incorrect NP for long distance pronouns but a higher proportion of gazes to the correct NP for long distance reflexives. Gaze patterns in the short-distance conditions evinced a complementary pattern: IWA-Ag participants tended to look at the picture representing the most recent NP in the short-distance reflexive condition, but looked more at the picture representing the first NP (NP1) in the short-distance pronoun conditions. This pattern resulted in a higher proportion of gazes to the correct referent in the short-reflexive condition, but a higher proportion of gazes to the incorrect referent in the short-pronoun condition.

If we recast the gaze patterns of our IWA-Ag participants in terms of NP1 and NP2, rather than correct and incorrect NP, gazes to NP1 were greater for the long-reflexive and short-pronoun conditions while gazes to NP2 were greater for short-reflexive and long-pronoun conditions. Recall that the short reflexive and long pronoun conditions used a complement phrase clause structure (e.g., **The grandma** said that *the baker* cleaned **her**/*herself*) while the short pronoun and long reflexive conditions used a subject relative clause structure (e.g., *The baker* that helped **the grandma** cleaned **her**/*herself*). Thus, for complement phrase conditions, gaze patterns of IWA-Ag revealed a preference for the second NP (again, correct referent for short reflexive but incorrect for long pronoun conditions). Gaze patterns in subject relative conditions revealed a preference for the first NP, and furthermore reflected that IWA-Ag tended to look at the picture representing NP1 as early as the onset of the proform.

Given these patterns, consider the syntactic structures (simplified) of the sentence types used in the current study, previously shown in Figure 1; for ease of discussion, we repeat it here as Figure 8.

As described in our introduction, complement phrase constructions (Figure 8A) demonstrate a direct correspondence between **linear** and **structural** distance. The antecedent of the reflexive (*the baker*) is both within the local clause (*the baker cleaned herself)* and the most recent NP in the auditory stream. In contrast, the pronoun is deeply embedded in the overall structure of the sentence and finds its antecedent (*the grandma*) in the matrix subject position of the overall sentence. In the subject relative construction (Figure 8B), the antecedent of the pronoun (*the grandma*) is deeply embedded in the overall structure of the sentence. In contrast, there is no distinction between the level of embeddedness of the reflexive or its antecedent across structures: the reflexive is positioned within the verb phrase, *cleaned herself*, and finds its antecedent *the baker* in the adjacent determiner phrase. As a result, reflexive conditions have fewer nodes between the position of the reflexive and antecedent compared to pronoun conditions. Furthermore, both pronoun conditions require the crossing of a noun phrase of similar structure to the correct referent prior to reaching its position.

Returning to the findings of the current study, IWA-Ag demonstrated a higher proportion of gazes to the correct referent of reflexives relative to pronouns. A similar pattern was found in comprehension accuracy scores, where reflexives were significantly better than pronouns.

When we frame the Intervener Hypothesis in terms of structural distance, the observed pattern of results provides clear support: gazes to the correct referent were higher in the sentence conditions where the proform and antecedent were structurally close to each other and did not contain an intervening NP of similar structure; comprehension accuracy revealed a similar pattern.

The results of the current study allow us to refine the Intervener Hypothesis. Within this account, we characterize an intervener as a sentence element of similar structure to a target referent that intervenes between two elements of a dependency chain. Furthermore, we limit our use of *intervenes* to exclusively refer to the underlying syntactic structure of the sentence and not linear/temporal order. Importantly, this refinement allows us to test the Intervener Hypothesis in sentences that contain dependency relations between overt sentence elements, as in the current study, *and* to those between covert (or phonologically empty) positions as demonstrated in previous studies of the IH in *Wh*-questions (Sheppard et. al., 2015) and sentences containing unaccusative verbs (Sullivan et. al., 2016).

To our knowledge, no previous study has investigated the online processing of sentences containing pronouns and reflexives in IWA-Ag using subject relative constructions. Nonetheless, the findings of the current study demonstrate a number of similarities with previous studies of online processing of proforms. Love et al. (1998) used a cross modal lexical priming method and found that IWA-Ag demonstrated priming of the incorrect antecedent of the pronoun in complement phrase constructions. As with the current study, the incorrect antecedent was closest to the pronoun in both linear and structural distance. Taken together, the findings from these two studies provide converging evidence that the processing of pronouns in complement phrase constructions is made more difficult by the presence of intervening NP. Choy and Thompson's (2010) eye tracking-while-listening study also used complement phrase constructions containing pronouns and reflexives and found that the number of fixations to the correct antecedent were significantly greater than to the incorrect antecedent in the time window corresponding to the reflexive. The same pattern was not true for the correct antecedent of the pronoun, for which fixations to the correct antecedent were not significantly greater than to the incorrect antecedent during the pronoun, but increased during the prepositional phrase following the pronoun. Similar to the current study, the results of Choy and Thompson (2010) reflect that when a reflexive is embedded in a complement phrase construction, and is thus structurally and temporally closer to its antecedent, gaze behavior favors the correct antecedent as early as the onset of the reflexive. Importantly, neither of these past studies tested long-distance reflexives and short-distance pronouns, and thus could not, in principle, fully reflect on the Intervener Hypothesis, which we have remedied in our study.

We end our discussion with a note on limitations. One caveat for the current study is the small sample size of our IWA-Ag participant group (n=6). While this study was a fully within subjects design, future work that presents data from larger participant groups may aid in verifying the results reported here. Additionally, the advantage for reflexives over pronouns demonstrated by IWA-Ag creates a challenge for disentangling the predictions of theories that point to discourse-linking as a source of difficulty for pronouns from the Intervener Hypothesis. However, discourse-linking also suggests a disadvantage for both

subject- and object-extracted *Which*-NP questions, given that the referent for a *Which*-question is an individual (e.g, *Which boy*) taken from a set of such individuals (e.g., the set of boys, based on the discourse; see, for example, Avrutin, 2000, Shapiro, 2000). Again, Sheppard et al. (2015) found that only object-extracted *Which*-questions were difficult for participants with aphasia.

In conclusion, the current study is the first to investigate the Intervener Hypothesis in sentences containing proforms in IWA-Ag. This account aims to provide a single explanation for sentence comprehension and processing deficits in IWA-Ag. Under this account, the presence of a sentence element that intervenes between two elements of a dependency chain leads to greater processing difficulty. We further specify that an *intervener* is of the same structural type as the target element in a dependency chain and that *intervene* is properly characterized in terms of the underlying syntactic structure of a sentence, rather than the more surface temporal order of the auditory stream. In our view, the strength of the Intervener account lies in its ability to account for deficits across a range of sentence constructions while pointing to a single causal mechanism: interference from similarly structured sentence elements. Support for this hypothesis now comes from sentences containing filler-gap dependencies (*Wh*-questions, Sheppard et. al., 2015; unaccusative verbs, Sullivan et. al., 2016) and here, proform-antecedent dependencies.

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References

Allopenna PD, Magnuson JS, Tanenhaus MK. Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. Journal of Memory and Language. 1998; 38:419–439.

Avrutin S, Lubarsky S, Greene J. Comprehension of contrastive stress by Broca's aphasics. Brain and Language. 1999; 70(2):163–186. [PubMed: 10550225]

Avrutin S. Comprehension of discourse-linked and nondiscourse-linked questions by children and Broca’s aphasics. Language and the brain: Representation and processing. 2000:295–313.

Avrutin, S. Weak syntax. In: Grodzinsky, Y., Amunts, K., editors. Broca’s region. Oxford, UK: Oxford University Press; 2006. p. 49-62.

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

Beretta A. Linear and structural accounts of theta-role assignment in agrammatic aphasia. Aphasiology. 2001; 15(6):515–531.

Burzio, L. Italian syntax: A government-binding approach. Dordrecht: Reidel; 1986.

Caramazza A, Zurif EB. Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. Brain and Language. 1976; 3:572–582. [PubMed: 974731]

Chomsky, N. Lectures in Government and Binding. Dordrecht: Foris; 1981.

Choy JJ, Thompson CK. Binding in agrammatic aphasia: Processing to comprehension. Aphasiology. 2010; 24(5):551–579. [PubMed: 20535243]

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

Drai D, Grodzinsky Y. A new empirical angle on the variability debate: Quantitative neurosyntactic analyses of a large data set from Broca's Aphasia. Brain and Language. 2006; 96:117–128. [PubMed: 16115671]

Edwards S, Varlokosta S. Pronominal and anaphoric references in agrammatism. Journal of Neurolinguistics. 2007; 20:423–444.

Goodglass, H., Kaplan, E., Barresi, B. Boston Diagnostic Aphasia Examination-Third Edition (BDAE-3). Psychological Corporation; San Antonio, TX: 2000.

Grodner D, Gibson E. Consequences of the serial nature of linguistic input for sentenial complexity. Cognitive Science. 2005; 29(2):261–290. [PubMed: 21702774]

Gordon PC, Hendrick R, Johnson M. Effects of noun phrase type on sentence complexity. Journal of Memory and Language. 2004; 51:97–114.

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

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

Grodzinsky, Y.Shapiro, LP., Swinney, D., editors. Language and the brain: Representation and processing. San Diego, CA: Academic Press; 2000. p. 295-313.

Grodzinsky Y, Wexler K, Chien YC, Marakovitz S, Solomon J. The breakdown of binding relations. Brain and Language. 1993; 45(3):396–422. [PubMed: 8269332]

Jaeger TF. Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. Journal of memory and language. 2008; 59(4):434–446. [PubMed: 19884961]

Kertesz, A. Western aphasia battery. San Antonio: PsychCorp; 2006.

Lewis RL, Vasishth S. An activation-based model of sentence processing as skilled memory retrieval. Cognitive Science. 2005; 29(3):375–419. [PubMed: 21702779]

Lewis RL, Vasishth S, Van Dyke JA. Computational principles of working memory in sentence comprehension. Trends in Cognitive Sciences. 2006; 10(10):447–454. [PubMed: 16949330]

Love T, Nicol J, Swinney D, Hickok G, Zurif E. The nature of aberrant understanding and processing of pro-forms by brain-damaged populations. Brain and Language. 1998; 65:59–62.

Love T, Oster E. On the categorization of aphasic typologies: The SOAP (a test of syntactic complexity). Journal of Psycholinguistic Research. 2002; 31(5):503–529. [PubMed: 12528429]

Manor BR, Gordon E. Defining the temporal threshold for ocular fixation in free-viewing visuocognitive tasks. Journal of Neuroscience Methods. 2003; 128:85–93. [PubMed: 12948551]

Mirman D, Dixon JA, Magnuson JS. Statistical and computational models of the visual world paradigm: Growth curves and individual differences. Journal of Memory and Language. 2008; 59(4):475–494. [PubMed: 19060958]

Miyake A, Carpenter PA, Just MA. A capacity approach to syntactic comprehension disorders: Making normal adults perform like aphasic patients. Cognitive Neuropsychology. 1994; 11(6):671–717.

Perlmutter, DM. Proceedings of the Fourth Annual Meeting of the Berkeley Linguistics Society. Berkeley: University of California, Berkeley Linguistics Society; 1978. Impersonal passives and the Unaccusative Hypothesis; p. 157-189.

Perlmutter, DM., Postal, P. The 1-Advancement Exclusiveness Law. In: Perlmutter, D., Rosen, C., editors. Studies in Relational Grammar. Chicago: University of Chicago Press; 1984. p. 281-126.

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

Rizzi, L. Relativized minimality. Cambridge, MA: MIT Press; 1990.

Santi A, Friederici AD, Makuuchi M, Grodzinsky Y. An fMRI Study Dissociating Distance Measures Computed by Broca's Area in Movement Processing: Clause boundary vs Identity. Frontiers in psychology. 2015; 6:654. [PubMed: 26042078]

Shapiro LP. Charting the time-course of language processing. Brain and Language. 2000; 71:224–226. [PubMed: 10716850]

Sheppard S, Walenski M, Love T, Shapiro LP. The Auditory Comprehension of Wh-Questions in Aphasia: Support for the Intervener Hypothesis. Journal of Speech, Language and Hearing Research. 2015; 58:781–797.

Sullivan N, Walenski M, Love T, Shapiro LP. The comprehension of sentences with unaccusative verbs in aphasia: a test of the intervener hypothesis. Aphasiology. 2016:1–15.

Swinney D, Zurif E. Syntactic processing in aphasia. Brain and Language. 1995; 50(2):225–239. [PubMed: 7583188]

Varkanitsa M, Kasselimis D, Fugard AJ, Evdokimidis I, Druks J, Potagas C, Van de Koot H. Syntactic predictions and asyntactic comprehension in aphasia: Evidence from scope relations. Journal of Neurolinguistics. 2016; 40:15–36.

- Individuals with Broca's aphasia show difficulty with proform-antecedent dependencies
- Intervener Hypothesis points to similarity-based interference as source of difficulty
- Eye tracking data supports proposal made by the Intervener Hypothesis
- Findings extend scope of the Intervener Hypothesis beyond filler-gap dependencies

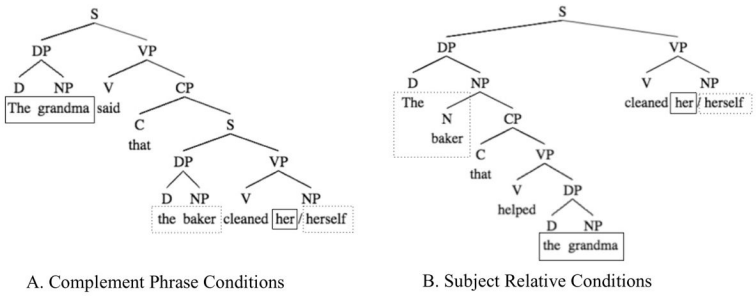

Figure 1.
Syntactic tree structure of sentence types

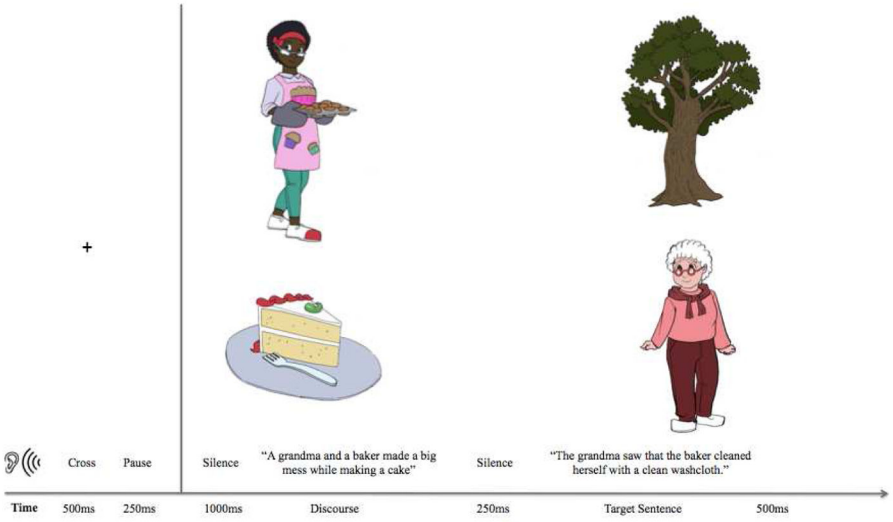

Figure 2.
Example picture display and timing parameters for Experiment 1

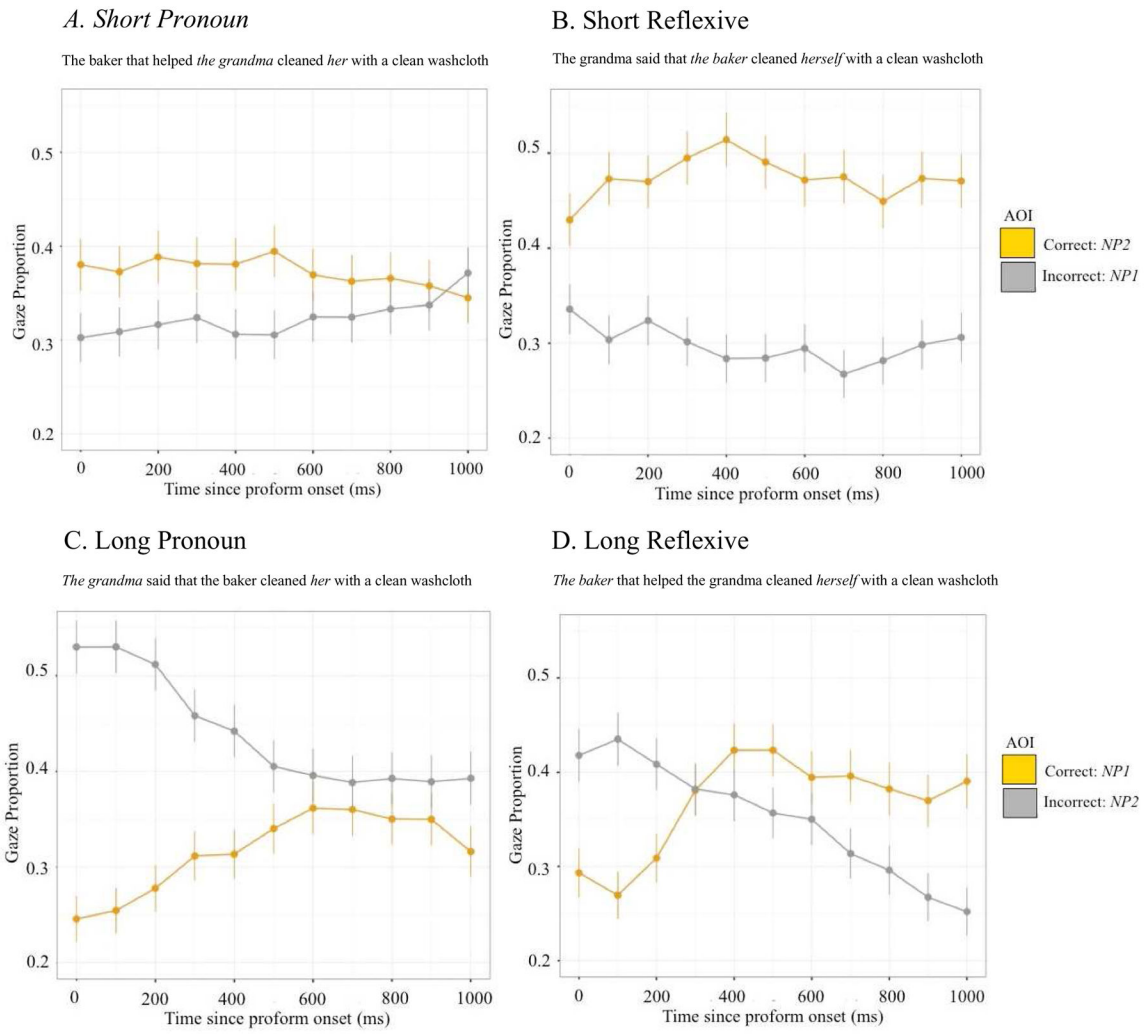

Figure 3.

AMC participants: Gazes to correct and incorrect referent AOIs. Proportions were calculated in 100ms bins beginning at the onset of the proform (shifted 200ms to account for gaze delay) and continuing for 1000ms. Error bars represent standard error of the mean.

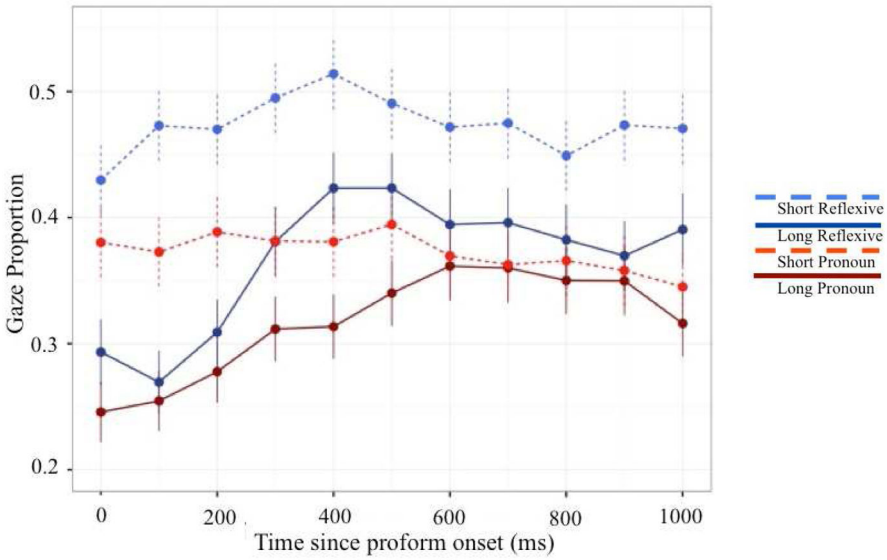

Figure 4.

AMC Participants: Time-course of gazes to correct referent AOI. Proportions were calculated in 100ms bins beginning at the onset of the proform (shifted 200ms to account for gaze delay) and continuing for 1000ms. Error bars represent standard error of the mean.

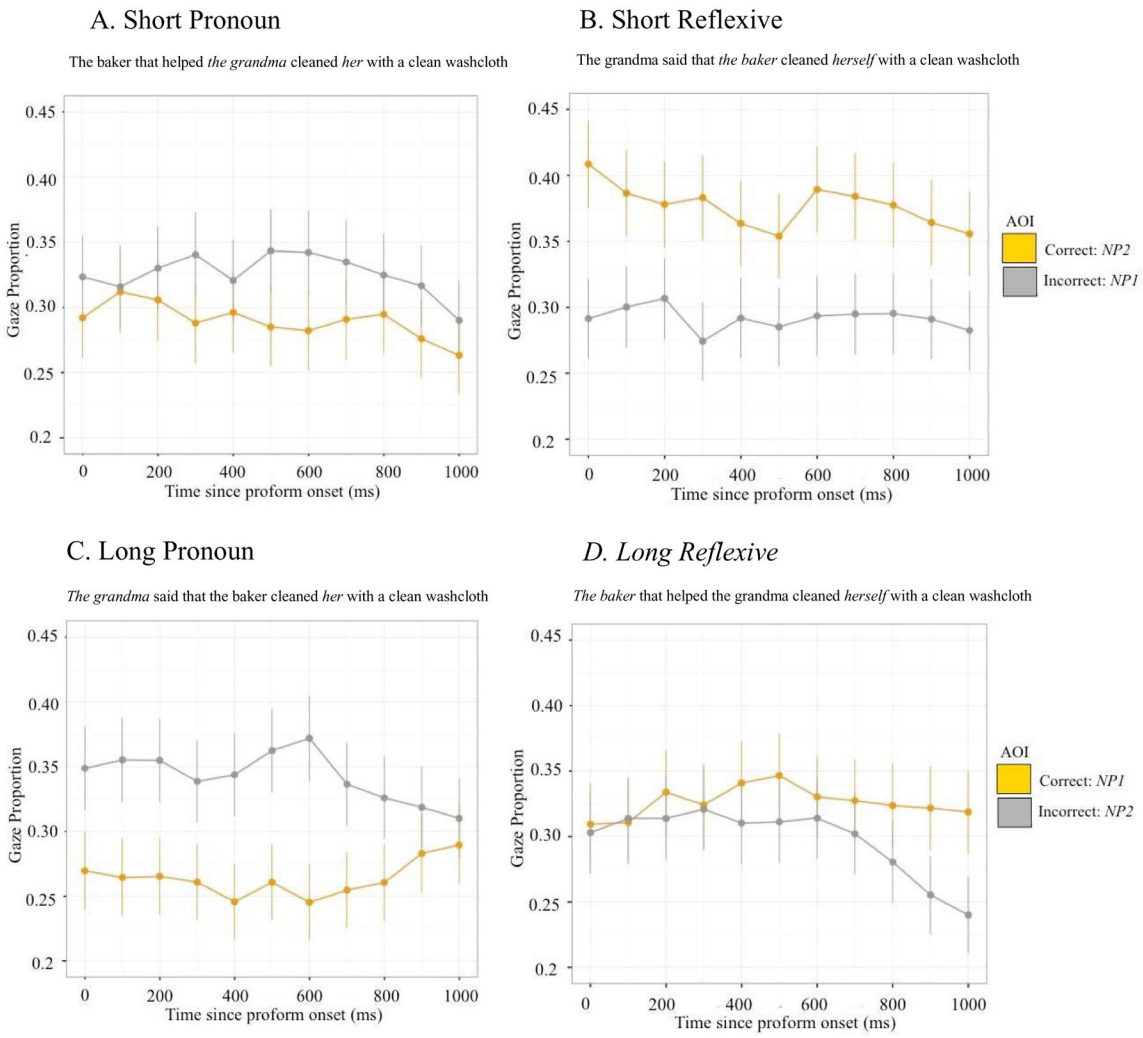

Figure 5.

IWA-Ag participants: Gazes to correct and incorrect referent AOIs. Proportions were calculated in 100ms bins beginning at the onset of the proform (shifted 200ms to account for gaze delay) and continuing for 1000ms. Error bars represent standard error of the mean.

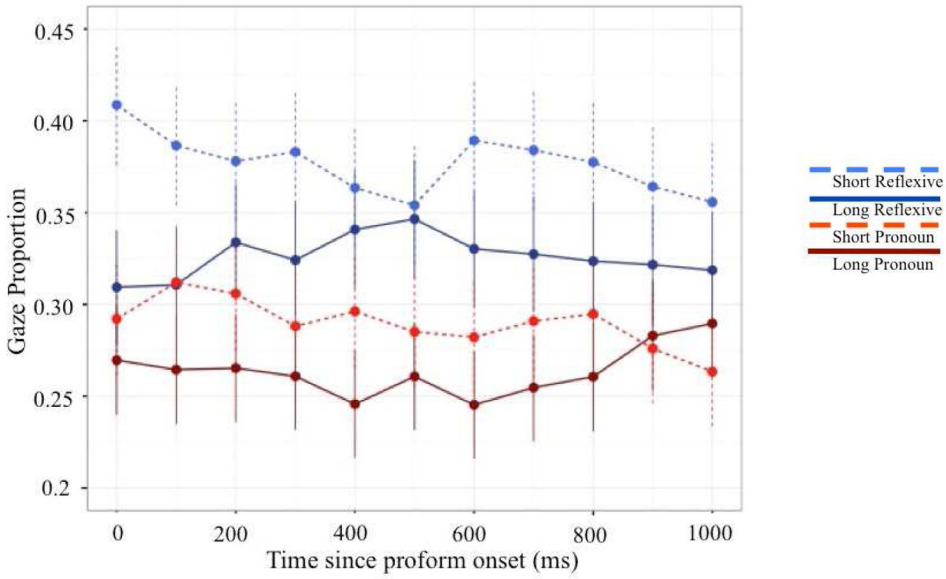

Figure 6.

IWA-Ag Participants: Time-course of gazes to correct referent AOI. Proportions were calculated in 100ms bins beginning at the onset of the proform (shifted 200ms to account for gaze delay) and continuing for 1000ms. Error bars represent standard error of the mean

Figure 7.

Example picture pair for Experiment 2: sentence-picture matching task

Long Pronoun/*Short Reflexive*: **The grandma** said that *the baker* cleaned **her**/*herself* with a clean washcloth. *Long Reflexive*/**Short Pronoun**: *The baker* that helped **the grandma** cleaned **her**/*herself* with a clean washcloth

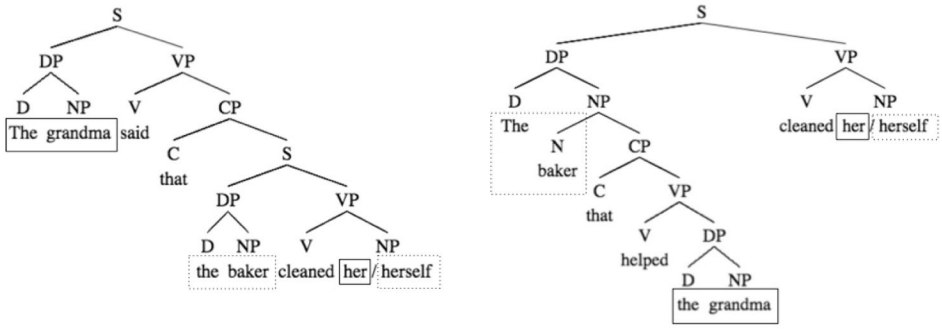

Figure 8.
Syntactic tree structure of sentence types

Table 1

Demographic information for participants with Broca's aphasia

Participant	Gender	BDAE† Severity Level	Years Post Stroke	Age at Testing	Education	SOAP‡ Canonical	SOAP§ Non- canonical
LHD101	M	2	7	64	Ph.D.	95%	35%
LHD130	M	4	5	61	4 years of college	95%	65%
LHD132	M	4	9	51	4 years of college	85%	55%
LHD140	F	2	13	39	4 years of college	80%	30%
LHD159	F	3	3	61	2 years of college	100%	70%
LHD169	M	1	3	57	High School	80%	40%

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

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

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

Table 2

Example experimental sentences by condition

1	***Discourse Sentence***			**A grandma and a baker made a big mess while baking a cake.**
		Distance	**Proform**	
1a	Complement Phrase	Short	Reflexive	The grandma said that the baker cleaned herself with a clean washcloth.
1b		Long	Pronoun	The grandma said that **the baker** cleaned her with a clean washcloth.
1c	Subject Relative	Long	Reflexive	The baker that helped **the grandma** cleaned herself with a clean washcloth.
1d		Short	Pronoun	The baker that helped the grandma cleaned her with a clean washcloth.

Table 3

AMC Participants: Mean gazes (and standard deviation) to correct referent

	Pronouns	Reflexives	Distance Mean
Long Distance	0.315 (0.105)	0.382 (0.130)	**0.349 (0.120)**
Short Distance	0.367 (0.094)	0.470 (0.084)	**0.418 (0.102)**
Proform Mean	**0.341 (0.101)**	**0.426 (0.116)**	

Table 4

LHD Participants: Mean gazes (and standard deviation) to correct referent

	Pronouns	Reflexives	Distance Mean
Long Distance	0.271 (0.126)	0.340 (0.146)	**0.305 (0.135)**
Short Distance	0.295 (0.117)	0.395 (0.155)	**0.345 (0.141)**
Proform Mean	**0.283 (0.117)**	**0.367 (0.146)**	

Table 5

Mean comprehension accuracy (and standard deviation) for AMC and LHD participants.

AMC Participants			
	Pronouns	**Reflexives**	***Distance Mean***
Long Distance	99.09 (3.02)	96.36 (6.74)	**97.73 (5.28)**
Short Distance	100 (0)	100 (0)	**100 (0)**
Proform Mean	**99.95 (2.13)**	**98.18 (5.01)**	

LHD Participants			
	Pronouns	**Reflexives**	***Distance Mean***
Long Distance	63.33 (20.66)	83.33 (12.11)	**73.33 (19.23)**
Short Distance	70 (26.83)	90 (8.94)	**80 (21.74)**
Proform Mean	**66.67 (23.09)**	**86.67 (10.73)**	