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Pronominal Resolution and Gap Filling in Agrammatic Aphasia: Evidence from Eye Movements

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Abstract

This paper reports the results of three studies examining comprehension and real-time processing of pronominal (Experiment 1) and Wh-movement (Experiments 2 and 3) structures in agrammatic and unimpaired speakers using eyetracking. We asked the following questions: (a) Is off-line comprehension of these constructions impaired in agrammatic listeners?, (b) Do agrammatic, like unimpaired, listeners show eye movement patterns indicative of automatic pronominal reference resolution and/or gap-filling?, and (c) Do eyetracking patterns differ when sentences are correctly versus incorrectly interpreted, or do automatic processes prevail in spite of comprehension failure? Results showed that off-line comprehension of both pronoun and Wh-movement structures was impaired in our agrammatic cohort. However, the aphasic participants showed visual evidence of real-time reference resolution as they processed binding structures, including both pronouns and reflexives, as did our unimpaired control participants. Similarly, both the patients and the control participants showed patterns consistent with successful gap filling during processing of Wh-movement structures. For neither pronominal nor movement structures did we find evidence of delayed processing. Notably, these patterns were found for the aphasic participants even when they incorrectly interpreted target sentences, with the exception of object relative constructions. For incorrectly interpreted sentences, we found end of sentence lexical competition effects. These findings indicate that aberrant lexical integration, rather than representational deficits or generally slowed processing, may underlie agrammatic aphasic listener's comprehension failure.

Keywords

Aphasia; Agrammatism; Sentence comprehension; Filler-gap dependencies; On-line sentence processing; Wh-movement; Binding; Reflexives; Pronouns; Eye tracking

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Introduction

Difficulty comprehending complex sentences is a characteristic sign of agrammatic aphasia. In particular, comprehension problems arise for sentences with syntactic movement, such as object relative and object cleft constructions (Berndt et al. 1997; Caplan and Futter 1986; Caplan and Hildebrandt 1988; Caramazza et al. 2001; Caramazza and Zurif 1976; Grodzinsky 1986; Schwartz et al. 1980, and many others), as shown in (1) and (2), respectively.

(1) Jarad saw the girl who(m)$_i$ Zack kissed t_i.

(2) It was Mary who(m)$_i$ Zack kissed t_i.

Such sentences are derived by displacement—*movement*—of certain sentence constituents from an underlying position to a surface structure position (Chomsky 1986, 1993, 1995; Marantz 1995). Once moved, a *trace/copy*[1] is left behind and a co-referential relation is developed between the trace site (underlying position) and the moved element (the antecedent of the trace). This coreferentiality or coindexation between the trace (*t*) and its antecedent is depicted in the sentences above by the subscripted (i). Sentences with such movement are referred to as filler-gap structures because they involve a *filler* (the antecedent) and a *gap* (akin to the trace site or position from which the antecedent was derived), and comprehending these structures requires “filling the gap” when the gap site is encountered in sentences.

In addition to difficulty comprehending sentences with syntactic movement, some studies show that agrammatic aphasic listeners also experience difficulty comprehending pronominal structures, including reflexive (bound) and free pronoun constructions. Consider the following:

(3) Alex told [Zack$_i$ to trust himself$_i$].

(4) Alex$_i$ told [Zack to trust him$_i$]

Both structures involve co-indexation (i) with an antecedent. Reflexives, as in (3), require a c-commanded antecedent (that is, their antecedent is in the same clause); whereas pronouns, as in (4) do not because the antecedent is not in the same clause. Chien and Wexler (1990) first observed that children assign the adult interpretation to reflexives as in (3), but they fail to do so with pronouns as in (4), erroneously coreferencing the pronoun with the subject of the same clause. Some researchers in agrammatism have found a similar pattern (Avrutin et al. 1999; Grodzinsky et al. 1993; Jarema and Friederici 1994). However, others have found that agrammatic aphasic patients show difficulty interpreting both pronouns and reflexives (Edwards and Varlokosta 2007; Linebarger et al. 1983; Love et al. 1998). Differences in performance patterns across studies reflect, at least in part, differences in experimental methods used, which we address below. Importantly, without co-indexation with an antecedent, both structures lack meaning. In (3) the reflexive *himself* is coindexed with Zack; whereas, in (4) the pronoun *him* is coindexed with Alex. In this regard, these constructions are like movement structures in that they involve coindexation, however, they do not involve displacement of sentence elements to derive their surface form.

Theoretical accounts of sentence comprehension deficits in agrammatic aphasia, in particular deficits in comprehension of movement structures, fall into two general categories: representational and processing theories. Representational accounts attribute comprehension deficits to the inability to construct certain syntactic representations. For example, the Trace Deletion Hypothesis (TDH) and its variants (e.g., The Trace Based Account) (Grodzin-sky 1986, 1995) suggest that filler-gap structures cannot be comprehended because traces are absent from the syntactic representation. Along similar lines, the Double Dependency Hypothesis (Mauner et al. 1993) proposes that failure to develop dependency chains between

[1]The term *copy* is used in more current literature, rather than the term *trace*.

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moved constituents and the trace/copy underlies comprehension difficulties. Whereas healthy individuals are able to successfully comprehend filler-gap sentences by "reaccessing" the moved element (filler) in the vicinity of the trace (gap) and "coreference" the two elements (Frazier and Flores d'Arcais 1989; Garnsey et al. 1989; Hickok et al. 1992; McElree and Griffith 1998; Nicol 1988; Sussman and Sedivy 2003; Tanenhaus and Trueswell 1995; Traxler and Pickering 1996, and many others), persons with agrammatic aphasia are unable to compute these sentences correctly, putatively because traces are deleted from the linguistic representation and/or they cannot establish dependency chains. Therefore, agrammatic listeners are thought to use non-linguistic heuristics for sentence comprehension (Grodzinsky 1986).

Cross-modal priming (CMP) experiments provide some empirical support for representational accounts (Swinney and Zurif 1995; Zurif et al. 1993). In these experiments participants listen to sentences such as in (5) and respond to visual lexical decision probes, presented at the gap site (superscript *2) and other critical sentence regions (e.g., superscript *1).

(5) The priest enjoyed the drinki that the caterer was $*^{1}$ serving $*^{2}(t)_{i}$ to the guests.[2]

Crucially, some stimulus items presented for lexical decision are semantically related to the antecedent of the trace, whereas others are not. Results for unimpaired listeners indicate that when probe items are semantically related to the antecedent (as compared to when they are not), reaction times (RTs) to make a lexical decision are significantly faster at both the pre-gap and gap site. In addition, RTs to semantically related probes are significantly faster at the gap site compared to the pre-gap site. This performance pattern has been interpreted as indicative of reactivation of the antecedent of the trace; using the example above, "drink" (the antecedent to the trace) is reactivated at the trace site ($*^{2}$).

Importantly, agrammatic aphasic participants do not always show this pattern. Studies have found that although semantic priming is accomplished (i.e., aphasic listeners respond more quickly to semantically related as compared to unrelated probes), significant differences in RTs are not found at the gap as compared to the pre-gap site. These findings are compatible with a representational account of sentence comprehension deficits. Without traces and/or the ability to establish co-referential relations between the trace and its antecedent, gap filling cannot proceed normally. It is noteworthy, however, that Blumstein et al. (1998) did not find this effect. Their Broca-type aphasic participants showed normal patterns of gap filling. However, Blumstein et al. (1998) used a somewhat different paradigm: rather than cross-modal priming, they used unimodal priming, whereby both target sentences and lexical decision probes were presented auditory.

Others attribute comprehension failure to a processing deficit. Processing-deficit accounts suggest that the language processing system is weakened, causing it to function inefficiently. The architecture of the syntactic system is intact, however, processing deficiencies result in pathological computations, which in turn result in failed comprehension. For example, several researchers have found that sentence processing speed is slowed in aphasia. Data supporting this position also come from CMP experiments: rather than showing priming at the gap site, agrammatic aphasic listeners show priming downstream from the gap (e.g., to probes presented 650ms after the gap) (Burkhardt et al. 2003; Love et al. 2001). Dickey and Thompson (2004) also showed, using an anomaly detection task, that their Broca's aphasic participants successfully rejected semantic anomalies in Wh-movement structures, but their responses were 1000ms delayed compared to normal control participants.

[2]From Swinney and Zurif (1995, p. 233).

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The nature of slowed processing, however, has been interpreted differently across researchers. Burkhardt et al. (2003) proposed an Argument Linking deficit (after Piñango 2000), affecting syntactic-semantic processes that depend on a fully formed syntactic structure, such as thematic role assignment, especially in cases where syntactic movement reverses the canonical order of thematic roles. Another version attributes the slow down to delayed lexical, rather than syntactic, processing, per se. Love et al. (2001) suggested that delayed lexical activation in agrammatic aphasic, compared to normal control, participants crucially affects sentence comprehension (also see Cooper 1974).

Processing accounts also have been used to explain deficits in comprehension of pronominal structures (Grodzinsky et al. 1993; Pinango and Burkhardt 2001; Ruigendijk and Avrutin 2003). Again using CMP, Pinango and Burkhardt (2001), for example, found a delay in processing reflexive structures. Similar to cases with movement constructions, priming was found only at a window of 600 to 800ms downstream from the reflexive.

Experimental Paradigms for Studying Sentence Processing and Comprehension in Aphasia

One important issue relevant to sentence processing/comprehension research in agrammatism concerns the experimental paradigms that have been used. Many studies use offline methods such as sentence-picture matching to examine deficit patterns, whereas others employ on-line methods such as anomaly detection, CMP, and self-paced listening and reading. It is well known that offline methods are useful for documenting the success or failure of comprehending different sentence types, however, they offer little with regard to how sentences are computed in real time. On-line paradigms are required for this.

On-line methods, however, are not without limitations. Some are incapable of illuminating how processing proceeds throughout the entire sentence. For example, anomaly detection tasks are only capable of exposing processing problems in sentence regions where the anomalies are placed, which must be pre-selected by the experimenter depending on the sentence structures under study. Similarly, CMP allows analysis of processing abilities only at the position of lexical decision probes. As noted above CMP gap-filling experiments often place lexical decision probes prior to and after the verb, and sometimes also at additional points downstream from the verb or after sentence end. Although such experiments are capable of examining several critical processing points, as the number of probe points increase, so to does the complexity of the experiment, in that exponentially greater numbers of sentences and/or study participants are required relative to the number of probe points selected. Therefore, constructing and carrying out CMP experiments to provide a full picture of how processing proceeds throughout an entire sentence would be quite difficult, if not impossible.

Another characteristic of these methods is that they rely on a conscious, overt, behavioral response to generate the primary study data. That is, pressing a button to indicate a cognitive response is required and the time that it takes to do so (i.e., RT) serves as the primary dependent variable. In the case of anomaly detection, participants press a button when they encounter anomalies in sentences, that is, when the sentence "stops making sense"; in self-paced studies, participants press a button to advance written or spoken words in sentences; and in CMP a button press is required to perform the secondary, lexical decision, task. Requiring study participants to execute overt responses is generally not problematic in that most studies involve several conditions, all of which require the same response type. Thus, any effect of overt responding is controlled across study conditions. However, stroke aphasic patients often are motorically impaired (e.g., right upper extremity hemiparesis), requiring use of their (usually) nondominant hand. In addition, requiring an overt response increases task complexity, which may influence language processing.

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In addition, CMP paradigms require dual task performance. While participants listen to sentences, they too must attend to and respond to computer-generated lexical decision probes. Dual task performance is known to be impaired in persons with aphasia (Hula et al. 2007; Murray et al. 1998; Tseng et al. 1993); thus, this requirement adds a level of difficulty to the task. In addition, requiring an overt response and/or secondary task reduces the naturalness of language processing.

One final problem relevant to the aforementioned experimental paradigms is that when comprehension fails on certain experimental trials, it is difficult (and sometimes impossible) to determine the source of failure. For example, comprehension failure in anomaly detection paradigms is assumed when anomalies go undetected (i.e., a participant does not press a button indicating that the sentence does not make sense). In this case, it is impossible to determine the precise reason for this lack of detection because no further analysis of failed responses is possible. Self-paced paradigms and CMP do allow for analysis of failed items, however, sentence comprehension accuracy/failure is often not directly analyzed using these approaches.

Eyetracking While Listening—A relatively new method for studying language processing is eyetracking-while-listening, which has been used successfully to examine both word- and sentence-level processing in unimpaired language users (Allopenna et al. 1998; Tanenhaus et al. 1995; Sussman and Sedivy 2003). The paradigm uses a camera to track listeners' eye movements as they gaze at visual displays of pictures or objects. Notably, the paradigm does not require an overt (e.g., button press) response, nor does it rely on performance of a secondary language task (e.g., lexical decision). Eye movements are automatic and time-locked within 200ms to auditory language presentation (Altmann and Kamide 2004). Participants simply listen to sentences in real-time as their eye movements are tracked. The paradigm, therefore, approximates natural language comprehension. Eyetracking offers another advantage over other methods in that processing of the entire sentence can be observed as the sentence unfolds, which allows for analysis of processing in critical sentence regions (e.g., at the gap site) as well as that preceding or following these regions. Finally, and perhaps most importantly, eye movements occurring when sentences are incorrectly comprehended can be analyzed separately in order to determine the source of comprehension failure, a particularly relevant characteristic for studying sentence processing in aphasia. In addition, even when sentences are correctly comprehended, the time-course of processing can be analyzed to determine whether normal sentence computation routines are engaged or whether alternative processing strategies are used. In Table 1, we highlight these characteristics of eyetracking in relation to other available methods for studying sentence processing in aphasia.

Purpose

In this paper we summarize the findings of three studies in which we used eyetracking while listening to examine sentence processing in agrammatism. In these experiments we examined both comprehension accuracy and real-time processing of pronouns (Experiment 1) and movement structures (Experiments 2 and 3).[3] We discuss aphasic and unimpaired listeners' processing patterns for each sentence type with regard to whether or not comprehension failure reflects aberrant or delayed processing routines or whether real-time processes of aphasic listeners are similar to those engaged by normal listeners. Using the data derived across studies, we also address if (and how) real time processing differs for successfully versus unsuccessfully comprehended sentences in aphasic individuals.

[3]All studies are published or are submitted for publication elsewhere; therefore we refer the reader to these publications for additional detail for each. See Choy and Thompson (in press), Dickey et al. (2007) and Dickey and Thompson (submitted).

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Based on the literature cited above, we expected to find comprehension deficits for both types of constructions. We, therefore, hypothesized that comprehension problems in aphasia are not tied solely to processing traces of syntactic movement, because this problem would not account for deficits in comprehension of pronominal structures. Following with this prediction, we anticipated that our aphasic participants would show normal eye movement patterns when processing filler-gap sentences. Rather, we entertained the idea that failure to establish coreferentiality may underlie complex sentence comprehension impairment, because both pronominal and movement structures rely on this process. We also embraced the notion that aphasic listeners would show evidence of delayed processing for both types of constructions, particularly for unsuccessfully comprehended trials. Such delay would account for failed comprehension because gap filling and pronominal reference resolution occur too late to be useful for successful comprehension. Importantly, however, we designed our experiments to evaluate these hypotheses anticipating that perhaps an alternative explanation for complex sentence comprehension in aphasia would be revealed by our experimental manipulations using eyetracking.

Experiment 1

In this experiment we (Choy and Thompson in press) examined comprehension and processing of pronominal structures. Specifically we investigated sentences involving reflexive (e.g., himself) and pronoun (e.g., him) resolution.

Method

Participants—Eight agrammatic aphasic (seven males) and eight healthy age-matched individuals (three males) served as participants. The diagnosis of aphasia was made based on performance on the Western Aphasia Battery (WAB; Kertesz 1982). The aphasic participants showed mild to moderate language impairments, with Aphasia Quotients (AQs) ranging from 62 to 86.4 (mean = 71.6) (see Table 2), resulting from a single, thromboembolic stroke, occurring at least six month prior to the study. They ranged in age from 35 to 60 (mean = 50.03) at the time of testing. Based on spontaneous language sample analysis and other testing, the aphasic individuals showed agrammatic sentence production patterns and impaired comprehension of noncanonical sentences such as passives and object relatives. Both control and aphasic participants were right handed (with the exception of one left handed aphasic participant), native English speakers and demonstrated visual and hearing acuity within normal limits. All reported no prior (pre-morbid) history of speech-language, learning or neurological disorders. All participants provided signed informed consent prior to participation.

Materials—We developed stories and corresponding computer generated visual picture panels to be used as experimental stimuli. Each story included a critical sentence—either a reflexive or pronoun construction. Participants heard the stories and we observed and recorded their eye movement patterns as they listened to the critical sentence in each. Each story also was followed by an auditory comprehension probe, which allowed us to examine off-line comprehension ability. Sixty stories and corresponding panels were constructed, consisting of 40 experimental and 20 filler items. (In filler items, the pronominal critical sentence was replaced with a simple active sentence.) All included three sentences (see (6) below, for example). The first sentence introduced two story characters; the second (critical sentence) described a transitive event; and the third affirmed the event, without providing additional content. Following each story, experimental probe questions queried either the pronominal or reflexive in the transitive event; filler probe questions queried a common noun. All linguistic stimuli (stories and comprehension probes) were digitally recorded using SoundEdit 16 by a female, native speaker of English, speaking at a normal rate.

(6) Some soldiers and farmers were in a house.

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

And he did.

Comprehension probe 1: Did the farmer shave the soldier?

Comprehension probe 2: Did the farmer shave himself?

The visual panels, which accompanied each story, were presented in 3 × 3 arrays. Each contained two human referents associated with target or competitor items (e.g. soldier, farmer), a human distractor (e.g. patient), and an object mentioned in the story (e.g. glasses) in the four corners of the array (see Fig. 1). Because each story-panel was presented twice—once with a pronoun and once with a reflexive—the position of the four pictures was counterbalanced across the two presentations. In addition, the position of pictures was counterbalanced for all panels. All nouns in each panel were matched for frequency; the human characters were matched for gender; and none of the items in any given panel were semantically related or contained phonological overlaps. The story-panels were presented in pseudorandomized order and filler items were interspersed among the test items so that no more than two stories from the same condition were presented consecutively.

Procedure—Participants were seated at a comfortable distance in front of a computer monitor in a dimly lit room. A remote camera, situated below the computer monitor, was used to monitor and record eye movements. The stories and probe questions were presented through speakers with loudness adjusted to a comfortable listening level. Participants were instructed to listen closely to the stories while they looked at the computer monitor and to verbally answer the questions presented at the end of each story. Prior to beginning the experiment practice items were presented. The eyetracking system was calibrated to each participant's eyes at the beginning of the experiment and additional calibrations took place following practice items and after every fifteen trials thereafter. Eye movements were monitored by an Applied Science Laboratories (ASL) model 504 remote eye tracker, which was linked to a Dell computer. The remote camera sampled the position and direction of the participants' gaze once every 16 ms. Although the tracker was operating throughout the duration of the study, eye movements were recorded only for the critical sentence (sentence two) in each story, triggered by Superlab software (Cedrus).

Each critical sentence was divided into several regions for data analysis purposes (see Table 3) and the proportion of fixations to each picture in a panel was computed for each sentence region. Responses to the probe questions were recorded manually and the proportion of correct responses, by sentence type, was calculated for each participant group.

Results

Comprehension Probes—Control participants responded to the comprehension probes with high accuracy: 98% for reflexives (range: 90–100%) and 98% for pronouns (range: 90–100%). Aphasic participants' responding was 64% (range: 40–95%) and 65% (range: 50–95%) correct for reflexive and pronoun structures, respectively, which was significantly poorer than control participants' for both (Reflexives: $Z = -3.294$, $p = .001$, Mann–Whitney; Pronouns: $Z = -3.218$, $p = .001$, Mann–Whitney).

Eye Movements

Reflexives: The proportion of looks to the target, competitor, and object in the reflexive condition is plotted by sentence region in Fig. 2 for the control and aphasic groups. Looks to the distractor item are not plotted because they comprised a small proportion of looks and fluctuated minimally across regions. For the control group fixations to Noun 1 (NI) (the

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competitor in this condition) and Noun 2 (N2) (the target) corresponded directly with their mention. Results of statistical analyses using the Wilcoxon Signed Ranks Test showed significantly more looks to these items compared to the other pictured elements in their respective sentence regions ($Z = 2.524$, $p = .012$ and $Z = 2.524$, $p = .012$, respectively for N1 and N2). Increased fixations to the Object in the Object region also were seen, however, they were not significant ($Z = 0.280$, $p = .779$). For the aphasic group looks to N1, N2 and the Object showed up in the critical regions directly following those in which they were overtly mentioned, i.e., in the N2, Object, and Verb regions, respectively. Fixations to N2 in the Object region ($Z = 2.103$, $p = .035$) were significant, however, the numerical increase in fixations to N1 in the N2 region ($Z = 0.841$, $p = .4$) and to the Object at the Verb region ($Z = 0.280$, $p = .779$) were not.

With regard to reference resolution, both groups showed an increase in fixations toward the antecedent (target) of the reflexive (i.e., N2) in the pronominal region (i.e., Pro and PP regions) as they heard the reflexive in critical sentences, with fixations in the PP, but not the Pro region, significantly above chance for both groups (control group: $Z = 2.521$, $p = .012$; aphasic group: $Z = 2.380$, $p = .017$). Planned comparisons of the proportion of target versus competitor fixations performed for the pronominal (i.e., Pro and PP) regions also showed a reliable target preference in the PP region for both groups: (control group: $Z = 2.836$, $p = .005$; aphasic group: aphasic: $Z = 2.68$, $p = .007$). These target preferences did not persist into the Post-Offset region for either participant group (control group; $Z = 1.791$, $p = .073$; aphasic group: $Z = 1.474$, $p = .141$).

In order to determine whether the aphasic eye movements were delayed compared to control participants' eye movements, a time to initial fixation analysis was performed. Results showed significant delays for the aphasic participants compared to control participants only in the Noun 1, $Z = 2.521$, $p = .010$ and Noun 2 regions, $Z = 2.205$, $p = .028$, but not in the Object region, $Z = 1.155$, $p = .279$. In addition, there was no delay in eye movements toward the correct antecedent of the reflexives for the aphasic participants compared to the normal controls ($Z = 0.293$, $p = .833$).

Pronouns: The proportion of looks to the target, competitor, and object in the pronoun condition is plotted by sentence region in Fig. 3 for the control and aphasic participant groups. As in the reflexive condition, few looks to the distractor were seen across sentence regions; therefore, these data are not plotted. As in the case of reflexives, both groups of participants looked toward the pictures corresponding to the overtly named nouns (i.e., N1, N2 and Object) as they were mentioned in the stories. Once again, the regions in which increased looks materialized were different for the two participant groups. The control group showed increased fixations to N1, N2 and Object in the Noun 1, Noun 2 and Object regions, respectively, which were significant for N1 in the Noun 1 region ($Z = 2.521$, $p = .012$), N2 in the Noun 2 region ($Z = 2.033$, $p = .042$), and for the Object in the Object region ($Z = 2.103$, $p = .035$). Looks to these items were delayed for the aphasic group, showing up in regions directly following the region in which they were presented. Fixations to N1 in the Noun 2 region ($Z = 1.960$, $p = .05$) and to N2 in the Object region ($Z = 2.533$, $p = .011$) were significant; whereas fixations to the Object in the Verb region ($Z = 0.280$, $p = .779$) were not.

With regard to reference resolution, both groups showed an increase in fixations to N1, the antecedent (target) of the pronoun, in the PP region, which was significantly above chance (control group: $Z = 2.521$, $p = .012$; aphasic group: $Z = 2.524$, $p = .012$). Planned comparisons of the proportion of target versus competitor fixations were also performed for the pronominal (i.e., Pro and PP), and post-offset regions. The target-competitor difference was significant in the PP region for the aphasic participants, $Z = 2.423$, $p = .015$, and the controls, $Z = 2.051$, p

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= .04. Fixations to the competitor (incorrect antecedent) were not significant in any of the postverbal regions for either control or aphasic participants.

Time to initial fixation analysis was also performed to determine any processing delays. Results again showed a significant delay in looks for the aphasic subjects compared to controls for Noun 1, $Z = 2.521$, $p = .010$, and Noun 2, $Z = 2.626$, $p = .007$, but not for the Object, $Z = 0.084$, $p = .442$. However, there was no pronoun resolution delay for the aphasic participants ($Z = 0.021$, $p = .878$).

Successful Versus Failed Comprehension: We compared the eye movement patterns for aphasic participants' correctly and incorrectly comprehended trials in order to determine whether or not processing routines differ when comprehension fails versus when it is successful. For this purpose we examined looks to target and competitor items, (N1 or N2) because they are directly linked to correct or incorrect processing of pronominal constructions (see Fig. 4).

For both structures the correct and incorrect trials were similar to one another in sentence regions in which pronominal resolution occurred; however, differences emerged toward sentence end. For reflexives, a significant target advantage (greater looks to the target compared to the competitor) was found in the PP region on correct trials, $Z = 3.256$, $p = .001$, which was sustained in the Post-Offset region, $Z = 2.217$, $p = .027$. On incorrect trials, this increase in looks to the target occurred in the Pro region, $Z = 2.3$, $p = .021$. But, unlike the correct trials, looks to the target and competitor were indistinguishable in later regions (PP region: $Z = 0.832$, $p = .405$; Post-Offset region: $Z = 0.809$, $p = .242$).

A similar pattern was noted in the pronoun condition: on both correct and incorrect trials, a significant target (N1) preference was seen in the PP region (i.e., significantly greater looks to N1 as compared to N2) ($Z = 2.107$, $p = .035$ for correct trials; $Z = 2.047$, $p = .041$ for incorrect trials), although increased looks toward the target began in the Pro region when comprehension failed ($Z = 2.362$, $p = .018$). Once again, the primary difference between correct and incorrect trials was seen at sentence end (i.e., in the Post-Offset region), where there was no difference between target and competitor looks ($Z = 0.803$, $p = .422$), a pattern that was not seen on correctly comprehended trials, but one identical to that seen for incorrect reflexive trials.

Discussion

Results of this study showed significant comprehension difficulty for both constructions under study. However, the eye movement patterns for the aphasic participants were similar to those of the unimpaired listeners, with two exceptions. First, although both groups looked toward the overtly named nouns as well as the antecedents of both the reflexives and pronouns as they were mentioned in the critical sentences, the aphasic participants showed delayed processing of overtly mentioned nouns (e.g. farmer, soldier). However, they showed no delays in pronominal resolution. Rather fixations to the correct antecedent for both reflexives and pronouns occurred in the same sentence region for both participant groups. Notably, this latter effect was seen for the aphasic participants not only when comprehension was successful, but also on incorrectly comprehended items (albeit the evidence for this was weaker on failed attempts).

The second difference between the two groups emerged in the Post-Offset sentence region. Whereas, the control participants maintained looks to the pronominal antecedent at sentence end, the aphasic group showed an increase in activation of competitor items in this region, which was seen only when comprehension failed. When it did not, the aphasic participants retained fixation to the antecedent of the pronominal in the Post-Offset region, as did the normal controls.

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These results indicate that comprehension deficits in aphasia are not limited to movement constructions, thus any theory of sentence comprehension deficits needs to account for deficits in pronoun constructions as well. Further, the observation that the aphasic participants successfully built syntactic structure and processed co-reference in a timely manner, but eventually looked away toward the competitor on trials in which comprehension failed, suggests that their comprehension deficits do not stem from an automatic syntactic processing deficit. A delayed processing account also does not fit with these data. We discuss alternative interpretations of the present findings in the general discussion below.

Experiment 2

Experiment 1 showed that agrammatic aphasic individuals have difficulty comprehending reflexive and pronoun constructions. However, impaired comprehension was not associated with impaired automatic co-referential processing ability. Rather it was associated with an increase in activation of competitors at the end of the sentence. These results suggested that comprehension failure in aphasia does not result from aberrant syntactic parsing. Evidence of delayed processing also did not emerge in Experiment 1, except for initial lexical activation, indicating that our aphasic participants' comprehension difficulty could not be explained by a delay in pronominal resolution. In our second experiment, we (Dickey et al. 2007) investigated comprehension and online processing of Wh-movement constructions in Broca's aphasia. Our primary goal was to observe whether aphasic individuals exhibit particular difficulty processing movement constructions, compared to the non-movement (pronominal) constructions that we examined in the first experiment. In this experiment we investigated real-time processing of object extracted wh-questions and yes–no questions using eye tracking.[4] Object wh-questions involve syntactic (Wh-) movement, whereas, yes–no questions do not.[5]

Method

The stimuli and eyetracking procedures used in Experiment 2 were identical to those used in Experiment 1. We again used stories and corresponding picture arrays, followed by sentence comprehension probes to observe automatic sentence processing routines as well as off-line sentence comprehension.

Participants—Twelve individuals with a diagnosis of agrammatic Broca's aphasia (nine males) and eight healthy age-matched individuals (three males) served as participants. The aphasic participants were mild to moderately impaired based on performance on the Western Aphasia Battery (WAB; Kertesz 1982), with AQs ranging from 30 to 89.5 (mean of 67.6). (See Table 4.) They ranged in age from 34 to 78 (mean = 55.33) and were at least 6 months post onset of a single stroke affecting the left perisylvian region at the time of the study, with the exception of one participant whose stroke was in the right hemisphere. Narrative language sample analysis indicated speech production patterns consistent with agrammatism and testing using a battery of language tasks developed in the Aphasia and Neurolinguistics Research Laboratory at Northwestern University showed relatively spared auditory comprehension of canonical sentences in the face of impaired comprehension of noncanonical structures with syntactic movement. All participants, both control and aphasic (with the exception of one left-handed aphasic participant), were right handed, native English speakers and demonstrated good visual and hearing acuity. None of the participants reported, nor did we have record of, prior (pre-morbid) history of speech-language, learning or neurological disorders. All participants provided signed informed consent prior to the study.

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[4]In Dickey et al. (2007), we also studied object cleft structures, which we do not include here due to a design flaw that precluded our drawing conclusions based on the object cleft data.

[5]We note that both structures entail verb movement, but Wh-movement is involved only in wh-questions.

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Materials—Forty pairs of stories and corresponding 3 × 3 visual panels were constructed to examine wh- and yes–no question processing. Twenty of the story-panel items served as target items while the remaining items were fillers (i.e., "where" questions, and thematic role reversed yes–no questions). All stories consisted of four sentences with a transitive event in the third sentence. At the end of each story a comprehension probe, either a wh-question or a yes–no question, was presented as in (7) below. In this experiment the probe questions served as the critical sentences.

(7) This story is about a boy and a girl.

One day, they were at school.

The girl was pretty, so the boy kissed the girl.

They were both embarrassed after the kiss.

Who did the boy kiss that day at school? (wh-question probe)

Did the boy kiss the girl that day at school? (yes–no question probe)

The visual panels contained two human referents (e.g. boy (agent), girl (theme)), a location (e.g. school) mentioned in the story, and a distractor (e.g. door). All four nouns were matched for frequency and controlled for phonological overlap and semantic relatedness. A sample panel, i.e., that which accompanied the story in (7), is shown in Fig. 5. The position of the four elements in each panel (e.g., agent, theme, location, and distractor) was counterbalanced across trials. The story-panel pairs were pseudorandomized and filler items were interspersed among the test items so that no more than two stories from the same condition occurred consecutively.

Procedure—As in Experiment 1, participants were instructed to look at the visual panels, listen to the stories presented, and answer the questions following each story with a verbal response. Eye movements were tracked and recorded during probe question computation and responses to the probe questions were recorded. The proportion of correct responses, by sentence type, was computed for each participant group to ascertain how well the probe questions were comprehended.

Each target question was segmented into regions for data analysis purposes (see Table 5). The proportion of fixations to each picture in a panel corresponding with each sentence region was computed for each item.

Results

Comprehension Probes—Control participants demonstrated high accuracy in comprehending both yes–no (95% correct) and object wh-questions (100% correct). Accuracy for the aphasic participants, as expected, was better and less variable for yes–no questions as compared to wh-questions (mean comprehension of yes–no questions = 86.7% (range: 60–100%) cf. mean of wh-questions = 70% (range: 0–100%)). Group comparisons showed that the aphasic participants comprehended object wh-questions, but not yes–no questions, more poorly than the unimpaired listeners (wh-questions: $t(18) = 3.05$, $p = .007$, yes/no questions: $t(18) = 1.83$, $p = .084$). These results are similar to those found in previous studies, indicating that questions with Wh-movement are more impaired than yes–no questions, which do not involve Wh-movment.

Eye Movements—Analysis of the eye movement data for wh-questions revealed very few fixations to the inanimate and location distractors in the visual panels during critical sentences (i.e., only 11 and 6% of all fixations, respectively). Therefore, we examined fixations to the agent and theme pictures only, and computed a theme preference value for each sentence region, that is, the proportion of theme minus agent fixations, which served as the primary

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dependent variable. This provided a straightforward way to observe gap filling effects because a positive theme preference would reflect a preference for looks to the theme (target) over the agent (competitor) in the gap/object region, but not in others, for wh-questions.

Yes–No Questions: The theme preference for yes–no questions, for both the unimpaired and aphasic listeners, is plotted by sentence region in Fig. 6. The two subject groups showed no significant theme preference differences across regions, with the exception of the subject region (Region 1) in which controls, but not aphasic, participants showed a negative theme preference, reflecting more looks to the agent in this region ($t(7) = 2.29$, $p = .054$).

Wh-Questions: Figure 7 displays the theme preference for wh-questions by sentence region. These data indicate that neither participant group showed a significant theme preference in the Subject Region (Region 1). However, for both groups a significant theme preference emerged in the Verb Region (Region 2) (aphasic: $t(11) = 3.37$, $p = .008$; control: $t(7) = 2.52$, $p = .04$), which provided visual evidence of automatic gap filling. At later regions in the sentence, the control and aphasic participants' eye movement patterns converged. However, the theme preference was maintained by the control, but not by the aphasic, participants in the Gap/Object ($t(7) = 4.65$, $p = .002$) and Location regions ($t(7) = 2.94$, $p = .022$) (Regions 3 and 4, respectively).

Successful Versus Failed Comprehension: Separate analyses were undertaken for the aphasic participants' data in order to examine eye movement patterns for correctly and incorrectly comprehended trials. Results of this analysis, shown in Fig. 8, revealed that fixation patterns did not differ significantly for the successful or failed items until Regions 4 and 5, the Location and Post-Offset regions. In these regions, a negative theme preference was found, which was significant in the Post-Offset region ($t(17) = 2.55$, $p = .021$).

Discussion—The comprehension accuracy data derived from this experiment replicated those reported in previous studies of agrammatic aphasia in that comprehension of sentences with Wh-movement (object extracted wh-questions) was poorer than non-movement structures (yes–no questions). This performance pattern was reflected in the eye movement data. Whereas, the aphasic and control participant groups showed similar processing patterns for yes–no questions, the eye movement data diverged for the two groups for wh-questions.

Interestingly, in the Verb (Region 2) and Gap/Object (Region 3) regions (the trace/copy site), the eye movement patterns of the two groups were quite similar. In fact, a theme preference was noted for both groups in these regions. This pattern of looks, associating the moved element (filler) with the trace (gap) position, is consistent with previous eyetracking studies with unimpaired subjects, interpreted as visual evidence of gap-filling (Sussman and Sedivy 2003). Where the aphasic and control data differed was in the Location and Post-Offset sentence regions. However, these differences disappeared when we separately analyzed the eye movements for successful and failed comprehension trials. That is, when comprehension failed, the aphasic patients looked to the agent toward the sentence end, likely reflecting their mis-interpretation of these sentence. These late-emerging looks to the competitor on incorrect trials were also found in Experiment 1 and provide further evidence that aphasic processing deficits do not result from failure to compute the syntactic structure of sentence.

What is even more striking is that for the aphasic participants, automatic gap filling occurred even when sentences were incorrectly comprehended as noted when we compared the processing routines engaged for successful and failed trials. This finding also supported the findings of Experiment 1 in which we found that processing of pronominal structures proceeded normally even for failed trials. These data suggest that the difficulty that aphasic listeners experience in comprehending movement sentences is not due to an impairment in processing

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movement, per se, because online processing of movement dependency proceeded in a normal manner.

In addition, we found no evidence that automatic online processing of movement was delayed, in that theme preferences were noted in the same temporal vicinity, that is, in the same sentence locations, for the aphasic participants as for controls. It is of interest to note, however, that for yes/no questions delayed lexical activation was noted in the Subject region. That is, the aphasic participants showed a theme, rather than an agent preference (negative theme preference) in this region, that was not seen for the controls. This finding is similar to that noted in Experiment 1, indicating that aphasic listeners do evince delays in lexical processing. However, this did not influence their ability to fill gaps or resolve pronominals in a timely manner.

Experiment 3

Results of Experiments 1 and 2 showed that agrammatic aphasic listeners had difficulty comprehending both pronominal and Wh-movement constructions, but not yes/no questions, which do not involve either reference resolution or Wh-movement. Analysis of the eye movement data from both experiments showed that neither syntactic computation itself, nor delayed processing, could explain these patterns. In Experiment 3, we (Dickey and Thompson 2006, submitted) extended our study of sentence processing in aphasia to another sentence type with Wh-movement—object relative constructions.

Method

In this Experiment, we once again used an eyetracking paradigm to observe on-line automatic sentence processing routines in healthy and aphasic volunteers. To evaluate off-line sentence comprehension participants were required to respond manually, using a mouse-point, rather than verbally (as in Experiment 2) to comprehension probes.

Participants—Eight agrammatic Broca's aphasic (six males) and 14 healthy age-matched individuals (eight males) served as participants. As in Experiments 1 and 2, we studied aphasic participants who presented with mild to moderate aphasia, based on scores on the Western Aphasia Battery (WAB; Kertesz 1982), with AQs ranging from 60.8 to 87.6 (mean = 75.48). Scores derived from administration of the WAB are shown in Table 6. The aphasic participants ranged in age from 38 to 67 (mean = 56.1) and were at least 6 months post onset of a single thromboembolic stroke, affecting the left perisylvian region at the time of the study. Again, the aphasic subjects showed production patterns consistent with agrammatism based on analysis of spontaneous language samples, and they presented with relatively spared auditory comprehension, with the exception that comprehension of non-canonical sentences with syntactic movement was impaired. All study participants, including both the control and aphasic individuals, were right-handed (with the exception of one left-handed aphasic male), native English speakers, with unimpaired visual and auditory acuity. All participants reported no prior (pre-morbid) history of speech-language, learning or neurological disorders and all provided signed informed consent prior to participation.

Materials—Forty-eight stories and corresponding visual arrays were constructed for the experiment, which included target object relative structures as well as passive and subject relative filler items.[6] All stories included a three-sentence sequence, with a transitive event in sentence two. A comprehension probe sentence was presented immediately following each story (see (8) below, for example). These probe sentences directed participants to “point to” one of the pictures in the visual array.

[6]See Dickey and Thompson (2006, submitted) for eye movement patterns associated with passive and subject relative structures.

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(8) One day a bride and groom were walking in the mall.

The bride was playful, so the bride tickled the groom.

A clerk was amused.

Point to who the bride was ticking in the mall. (object relative comprehension probe)

The 3 × 3 arrays accompanying each story contained three humans (e.g. bride (agent), groom (theme), clerk (distractor)) and a location (e.g. mall) mentioned in the story. The position of the four pictures was counterbalanced across trials, so that the agent, theme, location, and distractor occurred equally often in each position in the array. A example visual panel, that presented with the story in (8), is shown in Fig. 9.

The story-panel pairs were pseudorandomized and filler items were interspersed among the test items. The task began with a filler item.

Procedure—The procedures used in Experiment 3 were identical to those used in Experiment 2. Eye movements were recorded in real time as participants listened to the critical comprehension probe sentences. Participants responded to probe items using a mouse to point to one of the pictures on the screen.

Each probe sentence was segmented into regions for data analysis purposes (see Table 7). The proportion of fixations to each picture in a panel corresponding with each sentence region was computed for each item.

Results

Comprehension Probes—Comprehension accuracy for control participants was 100% for the structures under study. In contrast, the aphasic participants' comprehension was significantly poorer than that of the controls: 36.5% correct (range: 16.7–75%) ($Z = 4.437$, $p = .000$, Mann–Whitney).

Eye Movements—For each sentence region, we computed the mean proportion of fixations to each item in the visual panels. We then computed the theme preference (the proportion of theme fixations minus agent fixations) for each sentence region, as in Experiment 2. A positive theme advantage indicated a preference for the theme (target) over the agent (competitor).

The theme preference for aphasic and control participants across sentence regions for object relative constructions is shown in Fig. 10a. As can be seen, the aphasic and control individuals demonstrated similar patterns. In Region 1, during which listeners heard “Point to who” and Region 2 (the Subject Region, e.g., “the bride”) neither group exhibited a theme preference. However, in Region 3, the Verb Region (“was tickling”), Region 4, the prepositional phrase region (“at the mall”), and the Post-Offset region, a theme preference emerged for both aphasic and control participants. Using the Wilcoxon Signed Ranks Test, a significant theme preference was found for control participants in Region 3 ($Z = 3.297$, $p = .001$), Region 4 ($Z = 3.059$, $p = .002$) and at Post-Offset ($Z = 3.181$, $p = .001$). The aphasic individuals showed a significant theme preference in Region 4 ($Z = 2.032$, $p = .042$) and the Post-Offset region ($Z = 2.521$, $p = .012$), but not in Region 3 ($Z = 0.674$, $p = .5$). Comparing the theme preference between subjects, a significant difference was found only at the Post-Offset region, with aphasic individuals exhibiting a weaker preference than controls (Mann–Whitney $Z = 2.187$, $p = .029$).

Successful Versus Failed Object Relative Comprehension: Separate analyses were undertaken to examine eye movement patterns for the aphasic participants' correctly and incorrectly comprehended trials. Results are shown in Fig. 10b, indicating that the eye movements were qualitatively different for correctly and incorrectly comprehended object

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relatives in all sentence regions, with the exception of Region 1. In Region 2, a numerical, but non-significant, theme preference emerged for incorrect trials ($Z = 0.730$, $p = .465$), which was not seen when the correct and incorrect trials were analyzed together (cf. Fig. 10a). This pattern was similar to that seen in early sentence regions in Experiments 1 and 2, reflecting possible lexical access difficulty. In Region 3 (the Verb Region), a theme preference emerged for correctly comprehended trials. Although not significant ($Z = 0.674$, $p = .5$), this shift in preference is suggestive of successful gap filling on correct, but not on incorrect trials. This finding further suggests that the lack of a significant theme preference in this region when all trials were analyzed together could be attributed to the incorrect trials. In both Region 4 and in the Post-offset Region, the theme preference was retained and was significant for correct trials (Region 4: $Z = 2.032$, $p = .042$; Post-offset: $Z = 2.521$, $p = .012$), but decreased for incorrect trials, and was absent in the Post-offset Region in which a negative theme preference emerged, with performance not significantly different than chance (Region 4: $Z = 1.483$, $p = .138$; Post-offset: $Z = 0.169$, $p = .866$).

Discussion

Results derived for object relatives in Experiment 3 replicated those found for object-extracted wh-questions in Experiment 2. Both aphasic and control listeners showed almost identical eye-movement patterns during early sentence regions and both groups showed fixations to the picture corresponding to the moved element emerging in the Verb/Gap region. We interpret this pattern as visual evidence of gap filling, as have others (Dickey et al. 2007; Sussman and Sedivy 2003). Where the eye movements of the two groups diverged was in the Post-offset Region, which was revealed by our analysis of correctly and incorrectly comprehended sentences. That is, for correct responses, the theme preference was retained in the Post-offset Region, but when comprehension failed, this preference disappeared.

One difference that emerged in Experiment 3 was that, unlike the findings from Experiment 2, evidence of gap filling was not seen for the incorrect responses. We discuss this difference across studies in the general discussion below.

General Discussion and Conclusions

Results of these experiments provide new insights into our understanding of a (now) longstanding observation that complex sentence comprehension is impaired in aphasia. We found that, indeed, comprehension of pronominal structures—both pronoun and reflexive resolution—is impaired in agrammatic aphasia. We also found that agrammatic aphasic listeners have difficulty comprehending Wh-movement constructions. Across studies, the aphasic individuals showed significantly lower accuracy for all binding and Wh-movement constructions compared to the control participants. These findings largely support those derived from previous studies.

Most importantly, we found using a new methodology—eyetracking while listening—to examine automatic online syntactic processing, that the source of these impairments is likely not related to an inability to form, or compute, syntactic representations. Results derived from all three experiments showed eye movement patterns that were quite similar for both normal and aphasic participants for all structures studied. Indeed, we found evidence of automatic pronominal resolution of reflexives/pronouns as well as automatic gap filling of Wh-movement structures. In addition, a compelling finding was that even for incorrectly comprehended pronominal and object wh-question structures, when the aphasic participants ultimately misinterpreted sentences, their eye movements revealed normal processing patterns. In Experiment 1, pronoun and reflexive resolution proceeded normally, occurring after the verb was encountered in the Pro and/or PP region for both correctly and incorrectly interpreted sentences. Similarly, for wh-questions in Experiment 2, an object advantage was noted in the

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region of the verb for both trial types. This pattern did not emerge in Experiment 3 perhaps due to the complexity of object relative structures compared to, for example, object extracted wh-questions. The former involve movement in an embedded clause, whereas in the latter movement occurs in the matrix clause. Indeed, syntactic complexity influences sentence processing, with syntactic embedding being one of the key indices of complexity (Thompson and Shapiro 2007; also see Yngve 1960, and others), and syntactic embedding is known to be difficult for aphasic listeners (Caplan et al. 1997). Considering the data from the present study, wh-questions were comprehended at a mean of 70% accuracy, whereas that for object relatives was 36.5%, indicating that the latter structures presented greater difficulty for agrammatic listeners. Perhaps the greater processing resources required for object relatives diminished these listeners' ability to engage automatic gap-filling operations.

In addition, the aphasic and control subjects showed similar temporal resolution during sentence processing across experiments. That is, we did not find evidence of delayed syntactic processing for either of the pronominal constructions that we studied, object extracted wh-questions, or object relatives. In spite of their sentence comprehension difficulty, when listening to pronominal constructions, the aphasic listeners demonstrated significant fixations toward the correct antecedent of the reflexive/pronoun, mainly in the PP region, as did the normal control participants, where reference resolution is expected to occur. When processing Wh-movement structures, aphasic, like normal listeners, showed increased looks to the antecedent of moved sentence constituents in the vicinity of the gap (trace/copy site), after hearing the verb. Based on these collective findings across studies, we conclude that a general delay in syntactic computation does not underlie agrammatic sentence comprehension.

Rather than delays in syntactic processing, some evidence of delayed lexical access was found for the aphasic participant. In Experiment 1, clear delays were noted when the lexical items were first introduced in the critical sentences. When listening to both pronominal structures, eye movements to Noun 1 or Noun 2 on the display panels showed up one segment downstream from that of the normal listeners. Similarly, for yes–no questions, studied in Experiment 2, processing of the first noun (agent) was delayed. When the agent was encountered, the aphasic participants showed greater looks to the picture corresponding to the theme (theme preference) than to the agent of sentences, a pattern that was not seen for the normal listeners; the controls showed strong looks to the agent (a negative theme preference), in the subject region. We detected a similar pattern for object relatives on incorrect trials, with greater looks to the theme, rather than to the agent in Region 2, when the agent was mentioned in critical sentences. These delays in lexical access support the findings of Love et al. (2001). However, we did not find such delays for wh-questions and, importantly, these delays did not preclude the patients' timely pronominal resolution or gap-filling.

The primary difference that emerged in the eye movement data between control and aphasic participants was that the aphasic individuals, but not the normal controls, showed increased looks to competitor items in the Post-Offset region, for all structures. Interestingly, this late-emerging competition between the target and competitor was only apparent when the aphasic participants incorrectly interpreted sentences. After timely reference resolution and gap filling, the aphasic participants shifted their gaze to competitor items. However, when the aphasic listeners correctly interpreted sentences, these aberrant sentence-end effects were not seen. Like the control participants, on correct trials, the aphasic participants continuously held their gaze to the object corresponding to the pronominal or the antecedent of the trace throughout Post-Offset sentence regions. For the movement constructions, these sustained eye movement could perhaps be attributed the subjects' preparation of a response to the probe question. However, the Post-Offset increase in looks to the competitor appeared even in Experiment 1, in which the critical pronoun construction was embedded in the story and eye movements were tracked when no question answering was required.

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What, then, is the source of complex sentence comprehension failure in agrammatic aphasia? The data presented here show that both pronominal and movement structures are impaired; thus, any parsimonious theoretical account of aphasic comprehension deficits would need to account for both. Clearly representational deficit accounts do not apply, particularly those focused on trace deletion and/or the inability to develop dependency chains. First, representational accounts predict that automatic processing of movement should be qualitatively different for aphasic and unimpaired individuals because they are constructing qualitatively different syntactic representations. For example, if traces are deleted, syntactic processing must proceed without them, which would result in an inability to compute and comprehend movement structures correctly. Indeed, our findings showed successful filler-gap processing; thus, it is unlikely that deleted trace/copy representations are responsible for the problems that aphasic patients have comprehending them. Furthermore, our participants showed successful syntactic processing even when comprehension failed for pronominals and object wh-questions. Secondly, representational theories do not address deficits in comprehension of pronominal structures. Indeed, these constructions do not entail movement processes, yet they are impaired in agrammatism. In addition, the results showed that our aphasic participants showed normal ability to resolve dependency chains. We found this for both pronominal and filler-gap structures.

The findings from our experiments also do not coincide with predictions of slowed-processing accounts: that automatic processing of syntactic dependencies is slower for aphasic as compared to age-matched controls. We found no evidence that automatic gap filling or pronominal resolution was delayed in the aphasic groups for either correctly or incorrectly comprehended structures. Both were resolved in a timely manner similar to that noted for healthy control participants.

Our findings fit best with an alternative account, which considers lexical integration, the process of integrating lexical information into higher order representations relevant to the preceding context, which is required to successfully interpret appropriate sentential meaning. A pervasive finding derived in our studies was end-of-sentence lexical competition effects, which materialized when we analyzed the eye movement patterns of incorrectly versus correctly comprehended sentences. Competition effects emerged for the former, but not the latter, indicating a fundamental processing pattern associated with comprehension failure. The role that lexical integration plays in comprehension deficits in aphasia has been discussed in previous research. Swaab et al. (1998) showed, for example, in an ERP study of N400 effects that aphasic listeners have intact access to multiple meanings of polysemous words, however, they show significant impairments in selection of appropriate meanings when these words are encountered in sentence contexts. In another study Swaab et al. (1997) found that aphasic listeners, in particular those with low comprehension ability, evinced reduced and delayed N400 effects (as compared to unimpaired listeners) when processing sentences with end-of-sentence semantic anomalies, e.g., in sentences like“*The girl dropped the candy on the sky*”. They interpreted these findings as resulting from a lexical integration deficit. The findings from our research support this idea. Our patients were able to process the lexical items as well as the syntactic structure of sentences in real-time, yet they often failed to derive correct sentence interpretations. Further, when, and only when, comprehension failed, they demonstrated lexical competition effects, manifest by looks to competitor rather than target items at sentence end, indicating impaired ability to integrate lexical information into the syntax to solve sentences. This interpretation provides an account for both pronominal and movement structure comprehension deficits and suggests that impairments in comprehending both sentence types may result from the lexical integration failure.

In conclusion, we return to our earlier discussion of methodologies used to examine sentence processing in aphasia. Indeed, the current results highlight the advantages of using an

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eyetracking paradigm for this purpose. The paradigm allowed close inspection of automatic, unconscious eye movements of our participants as they listened to naturally presented target sentences in real-time. We did not need to use a secondary language task, such as lexical decision, as is required in CMP paradigms. Given the lexical integration and competition effects that emerged in our studies, the requirement to perform an unrelated lexical task as part of the experiment might have obscured our results and perhaps precluded one of our major discoveries that gap filling and pronoun resolution proceed normally in agrammatic aphasia. We also were able to observe processing of entire sentences as they unfolded. We were not bound by a need to pre-select certain processing points in sentences, as is required with other methods, allowing us to look not only at the gap site or at the position of pronominal resolution, but also both upstream and downstream of these sites. Finally, the eyetracking paradigm allowed us to examine and separately analyze processing routines engaged for correctly and incorrectly comprehended sentences. This enabled another key findings that downstream lexical competition effects occur when aphasic participants misinterpret sentences.

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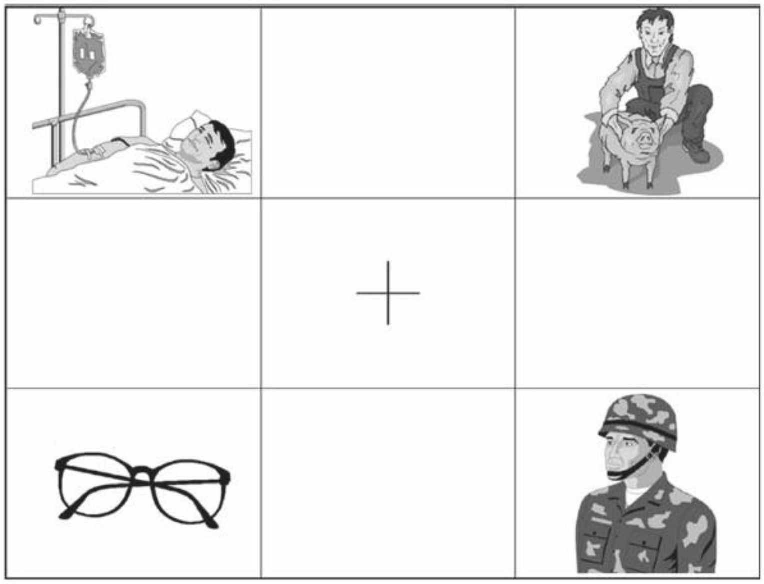

Fig. 1.

Sample visual picture panel using in Experiment 1. In the reflexive condition, e.g., *The soldier told the farmer with glasses to shave himself in the bathroom*., the farmer is the target and soldier is the competitor. For the pronoun condition, e.g., *The soldier told the farmer with glasses to shave him in the bathroom*., the soldier is the target and the farmer is the competitor

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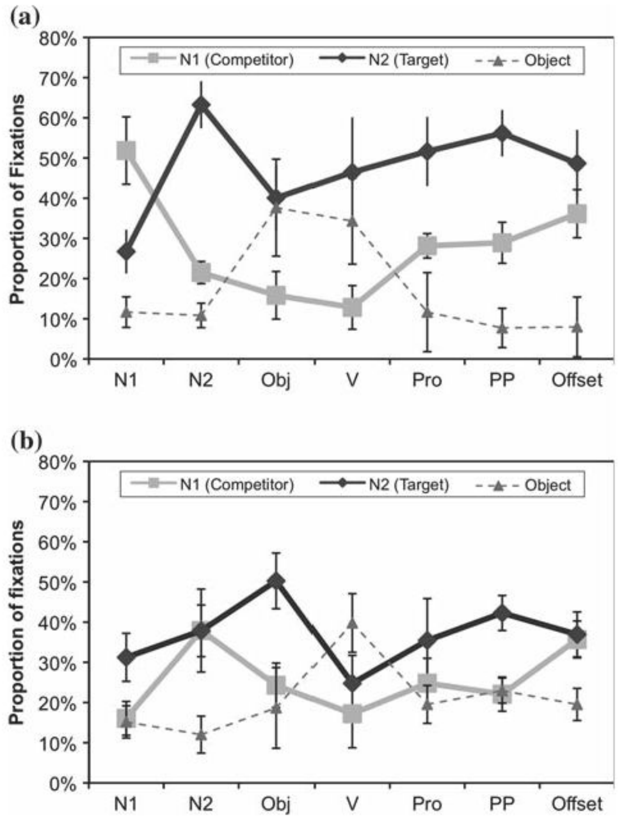

Fig. 2.

Proportion of fixations to target, competitor, and object items displayed in the visual panels across sentence regions in the reflexive condition for control participants (**a**) and aphasic participants (**b**). Error bars represent standard errors

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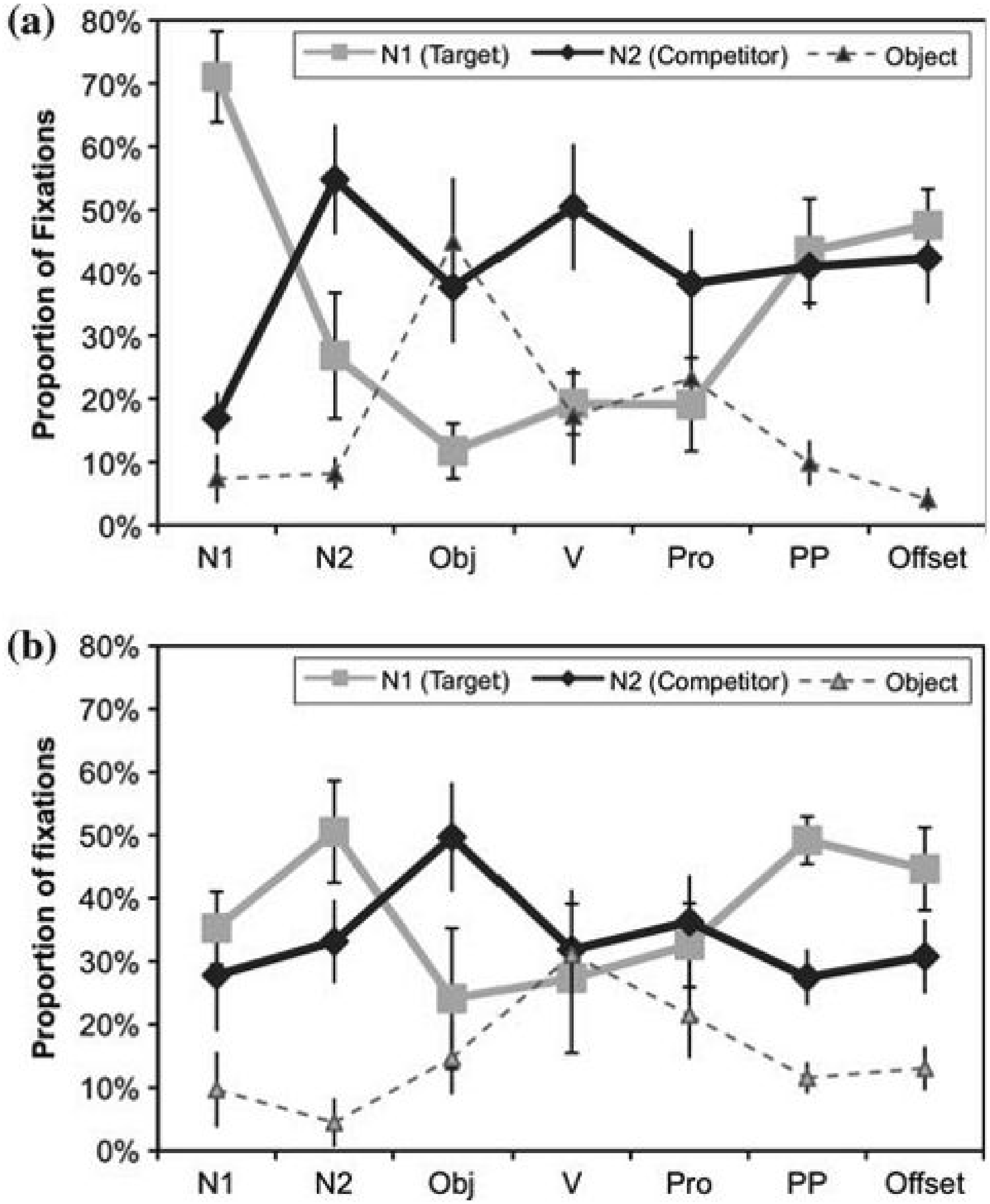

Fig. 3.

Proportion of fixations to target, competitor, and object items displayed in the visual panels across sentence regions in the pronoun condition for control participants (**a**) and aphasic participants (**b**). Error bars represent standard errors

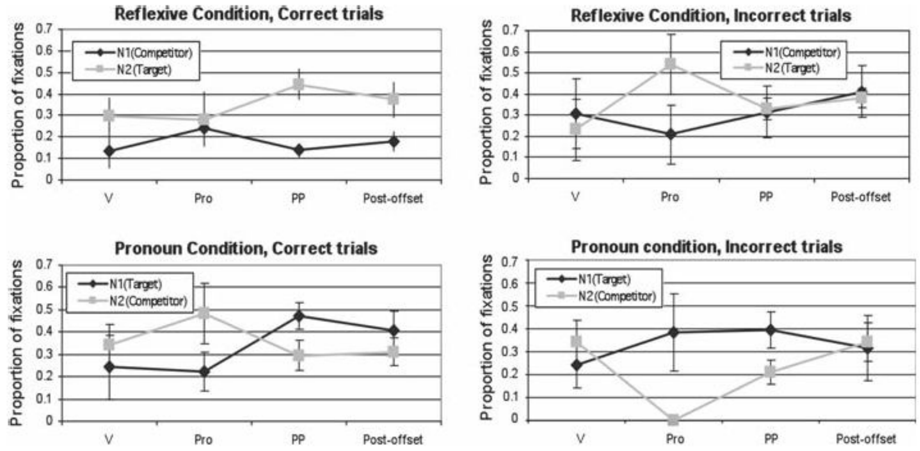

Fig. 4.
Proportion of fixations to target and competitor items across sentence regions for correct and incorrect trials for the aphasic participants

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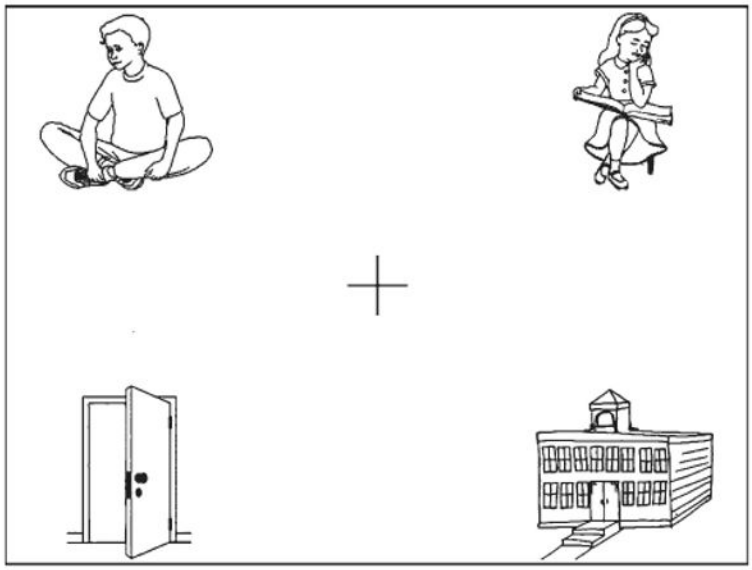

Fig. 5.

Sample visual array used in Experiment 2. For structures such as “Who did the boy kiss that day at school”? and “Did the boy kiss the girl that day at school”?, the boy is the agent and the girl is the theme

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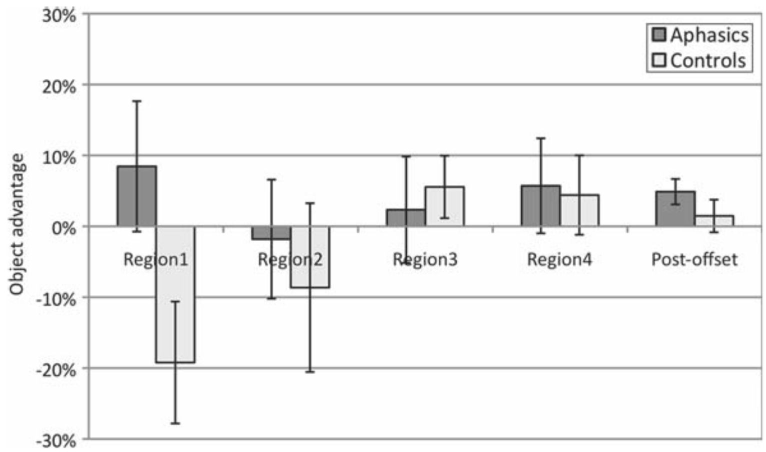

Fig. 6.

Theme preference for yes–no questions, for both the unimpaired and aphasic listeners, across sentence regions. The theme preference computed the difference for theme minus agent fixations. For the question, "Did the boy kiss the girl that day at school"?, fixations to the girl minus fixations to the boy were computed. Region 1 = Subject; Region 2 = Verb; Region 3 = Object/Gap; Region 4 = Location, and Post-offset. Error bars reflect standard errors

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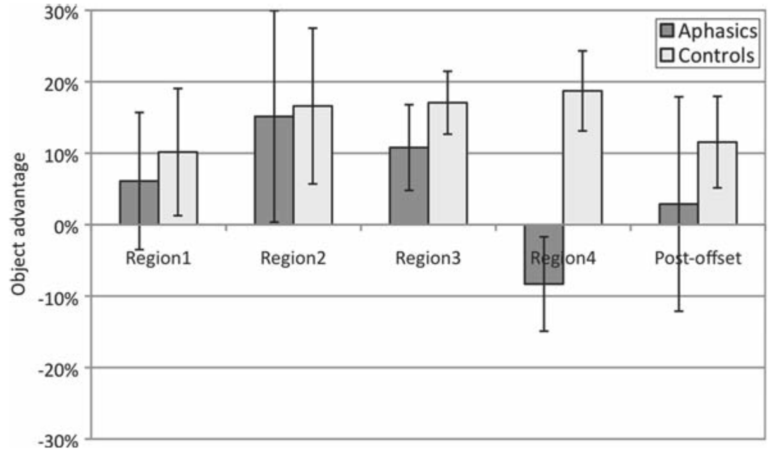

Fig. 7.
Theme preference for object extracted wh-question structures, for both the unimpaired and aphasic listeners, by sentence region. The theme preference computed the difference score for theme minus agent fixations. For the question, "Who did the boy kiss that day at school"?, fixations to the girl minus fixations to the boy were computed. Region 1 = Subject; Region 2 = Verb; Region 3 = Object/Gap; Region 4 = Location, and Post-offset. Error bars reflect standard errors

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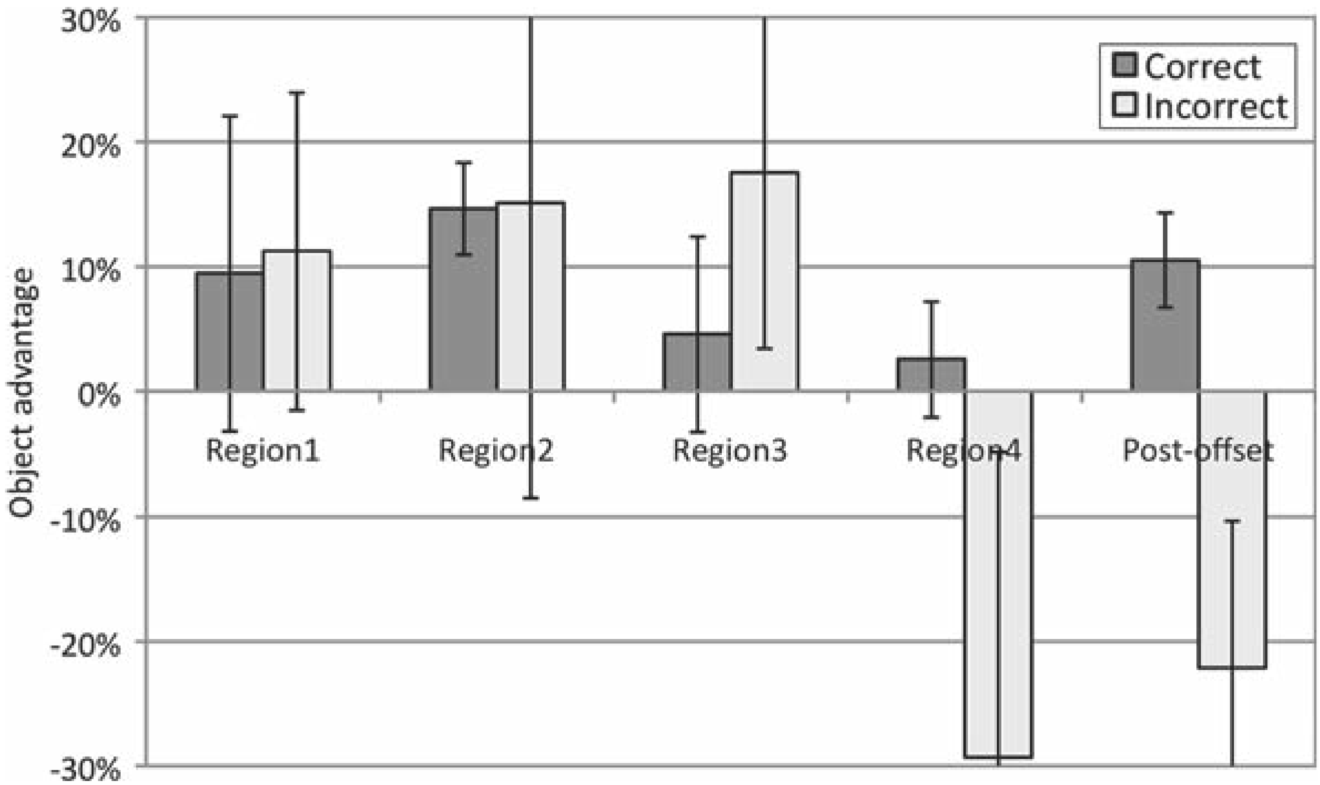

Fig. 8.
Theme preference found for aphasic participants' correctly and incorrectly comprehended sentences by sentence region. The theme preference computed the difference score for theme minus agent fixations. Note the theme preference for incorrect responses in Regions 2 and 3, which shifted to a negative theme preference in Regions 4 and 5, coinciding with their incorrect interpretation of the sentence. Region 1 = Subject; Region 2 = Verb; Region 3 = Object/Gap; Region 4 = Location, and Post-offset. Error bars reflect standard errors

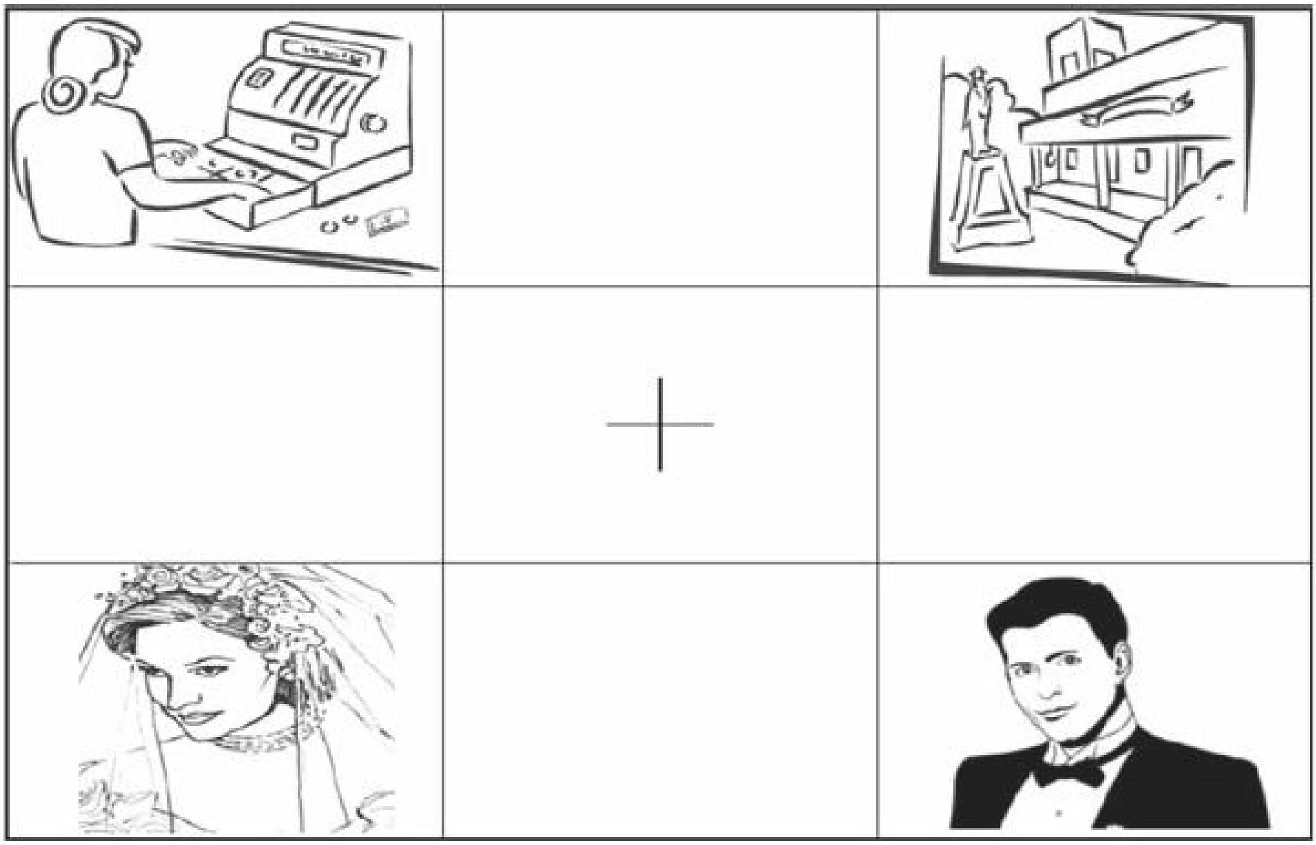

Fig. 9.
Sample visual array used in Experiment 3. For the critical sentence: *Point to who the bride was ticking in the mall*., agent (competitor) = bride; Theme (target) = groom; Location = Mall; distractor = clerk

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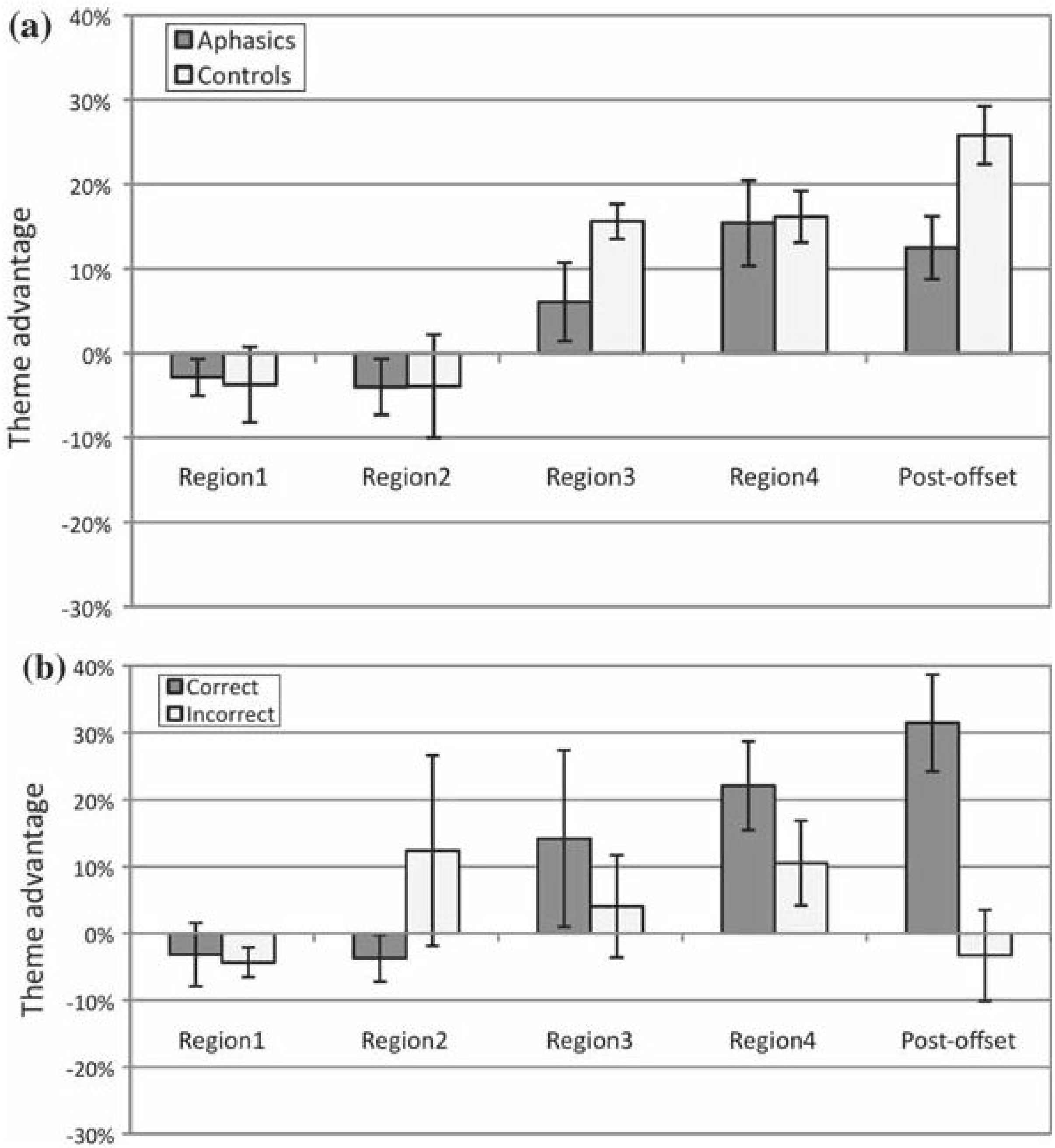

Fig. 10.
Eye movement patterns occurring across sentence regions during object relative sentence processing. **a** Eye fixation (theme preference) data for aphasic and unimpaired control participants. **b** Eye fixations (theme preference) during correct and incorrect trials for the aphasic participant group

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Table 1

Characteristics of on-line sentence processing research paradigms

Characteristic	Anomaly detection	Self-paced reading/listening	Crossmodal priming	Eyetracking while listening
Number of critical points studied in sentences is limited	Yes. Number and placement of anomalies is finite and controlled by the examiner	No. Processing speed can be measured at any point in the sentence	Yes. Number and placement of lexical decision probes is finite and controlled by the examiner	No. Eye movements can be measured at any point in the sentence
Relies on performance of an overt, consciously controlled behavioral response to generate primary data	Yes. Requires button press when anomalies are encountered/ detected	Yes. Requires button press response to advance written or spoken words	Yes. Requires button press to perform lexical decision	No. Overt responding is not required; eye movements are automatic
Requires dual language task performance	No. Only requires listening to sentences	No. Only requires reading or listening to words in sentences	Yes. Requires lexical decision to be made while listening to sentences	No. Only requires listening to sentences
Task reflects natural sentence processing	No. Detecting anomalous words in sentences is not part of natural sentence processing or comprehension	No. Sentences are not naturally processed or comprehended word by word, in either written or spoken form	No. Consciously performing two different language tasks is not part of natural sentence processing or comprehension	Yes. Participants listen to critical sentences naturally while unconscious eye movements are recorded
Can be used to evaluate failed comprehension	No. Failed anomaly detection only is measured	Yes. Reading times for correctly and incorrectly comprehended sentences could be computed, however, comprehension accuracy is generally not computed on a sentence-by-sentence basis	Yes. Reaction times at various probe sites for correctly and incorrectly comprehended sentences could be computed, however, comprehension accuracy is generally not computed on a sentence-by-sentence basis	Yes. Eye movements for correctly and incorrectly comprehended sentences can be analyzed separately

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Table 2

Western aphasia battery data for Experiment 1 participants

Participant	Aphasia quotient (AQ)	Fluency	Comprehension	Repetition	Naming
A1	64.5	4	8.55	5.6	7.1
A2	74.4	5	8.6	7.2	8.4
A3	86.4	5	9.4	9.8	9.0
A4	66.8	2	8.5	9.4	7.5
A5	62.0	4	8.25	5.0	6.3
A6	78.6	5	9	6.6	8.7
A7	75.6	5	8.4	9.4	7.0
A8	64.1	2	8	6.6	5.8
Mean	71.6		8.6	7.5	7.5

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Table 3

Sentence region segments used to examine eye movements during the unfolding of pronominal constructions in Experiment 1

	Noun1		Noun 2		Object	Verb	Pro	PP	Post-Offset
Reflexive construction	The soldier	told	the farmer	with	glasses	to shave	himself	in the bathroom	…
Pronoun construction	The soldier	told	the farmer	with	glasses	to shave	him	in the bathroom	…

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Table 4

Western aphasia battery data for Experiment 2 participants

Participant	Aphasia quotient (AQ)	Fluency	Comprehension	Repetition	Naming
A1	64	4	8	6.4	6.6
A2	85.8	5	6.9	8.8	8.2
A3	64.1	4	8.95	6.7	5.4
A4	30	5	8.1	1.2	0.7
A5	74.4	5	8.6	7.2	8.4
A6	75	4	9.9	7	8.6
A7	64.8	4	8	5.2	6.8
A8	66.8	2	8.5	9.4	7.5
A9	78.6	6	9	6.6	8.7
A10	54.2	4	7.2	6	4.9
A11	64.5	4	8.55	5.6	7.1
A12	89.5	9	9.95	8.8	8
Mean	67.64	4.66	8.47	6.58	6.74

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Table 5

Sentence region segments used to examine eye movements during the unfolding of question structures, either object wh-questions or yes–no questions, in Experiment 2

		Region 1 ***Subject***	**Region 2** ***Verb***	**Region 3** ***Gap/object***	**Region 4** ***Location***
Object wh-question	Who did	the boy	kiss	that day at	school?
Yes-no question	Did	the boy	kiss	the girl at	school?

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Table 6

Western aphasia battery data for Experiment 3 participants

Participant	**Aphasia quotient (AQ)**	**Fluency**	**Comprehension**	**Repetition**	**Naming**
A1	80.4	4	9.1	9.4	8.7
A2	87.6	5	10	9.7	9.1
A3	79.6	5	9.9	6.4	9.5
A4	60.8	4	8.0	6.6	5.8
A5	73.5	4	9.3	6.5	7.9
A6	67.2	4	8.3	5.2	7.1
A7	72.4	5	9.2	7.0	7.9
A8	82.4	5	9.2	8.8	9.2
Mean	74.48	4.5	9.13	7.45	8.2

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Table 7

Sentence region segments used to examine eye movements during the unfolding of object relative constructions, in Experiment 3

	Region 1	**Region 2**	**Region 3**	**Region 4**
Object relative	Point to who	the bride	was tickling	at the mall