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Binding in agrammatic aphasia: Processing to comprehension

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Abstract

Background—Theories of comprehension deficits in Broca's aphasia have largely been based on the pattern of deficit found with movement constructions. However, some studies have found comprehension deficits with binding constructions, which do not involve movement.

Aims—This study investigates online processing and offline comprehension of binding constructions, such as reflexive (e.g., *himself*) and pronoun (e.g., *him*) constructions in unimpaired and aphasic individuals in an attempt to evaluate theories of agrammatic comprehension.

Methods & Procedures—Participants were eight individuals with agrammatic Broca's aphasia and eight age-matched unimpaired individuals. We used eyetracking to examine online processing of binding constructions while participants listened to stories. Offline comprehension was also tested.

Outcomes & Results—The eye movement data showed that individuals with Broca's aphasia were able to automatically process the correct antecedent of reflexives and pronouns. In addition, their syntactic processing of binding was not delayed compared to normal controls. Nevertheless, offline comprehension of both pronouns and reflexives was significantly impaired compared to the control participants. This comprehension failure was reflected in the aphasic participants' eye movements at sentence end, where fixations to the competitor increased.

Conclusions—These data suggest that comprehension difficulties with binding constructions seen in agrammatic aphasic patients are not due to a deficit in automatic syntactic processing or delayed processing. Rather, they point to a possible deficit in lexical integration.

Keywords

Broca's aphasia; Binding; Comprehension; Eyetracking; Sentence processing; Agrammatism

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Research on sentence comprehension in aphasia has shown that individuals with Broca's aphasia often exhibit a specific "asyntactic comprehension" pattern in which they show particular difficulty comprehending complex reversible sentences involving syntactic movement, such as passives, object wh-questions, object clefts, and object relative clauses (Beretta, Pinango, Patterson, & Harford, 1999; Berndt, Mitchum, & Wayland, 1997; Caramazza & Miceli, 1991; Salis & Edwards, 2008; Swinney & Zurif, 1995; Thompson, Tait, Ballard, & Fix, 1999; Zurif, Swinney, Prather, Solomon, & Bushell, 1993). This observation

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has led to several theoretical positions, including both representational and processing accounts. Grodzinsky (1986, 1989) posited the trace deletion hypothesis (TDH) (and its derivatives, see e.g., Grodzinsky, 1995, 2000), which attributes impaired comprehension in individuals with Broca's aphasia to deletion of traces from the syntactic representation. Normally, when a noun phrase is moved, a trace is left behind in the syntactic representation. However, according to the TDH there are no traces in the syntactic representation of agrammatic individuals. Therefore the syntactic relations that traces mediate cannot be computed by the agrammatic linguistic system. Assignment of thematic roles to moved noun phrases, which is normally transmitted through the trace, cannot take place, causing people with aphasia to resort to extralinguistic heuristics or guessing strategies, resulting in chance performance (Grodzinsky & Finkel, 1998). Similarly, the double dependency hypothesis (DDH) attributes the comprehension deficits in agrammatic Broca's aphasia to a selective deficit in the linguistic representation (Mauner, Fromkin, & Cornell, 1993). However, in contrast to the TDH, the DDH claims that what is impaired in Broca's aphasia is not the trace per se but rather formation of syntactic chains, which affects processing of syntactic referential dependencies. When there is only one dependency the resulting syntactic representation, although abnormal, is not ambiguous. However, when there are two or more dependencies the resulting representation is semantically ambiguous.

Others espouse that comprehension deficits in agrammatic aphasia are associated with a reduction in resources in working memory or processing capacity. Those who attribute comprehension deficits in aphasia to a restricted working memory capacity claim that syntactic processing in sentence comprehension requires a storage system in which small amounts of information are simultaneously stored and manipulated during a task (Caplan & Hildebrandt, 1988; Caplan & Waters, 1999; Carpenter, Miyake, & Just, 1995; Haarmann, Just, & Carpenter, 1997). According to this view, movement structures such as object relatives require more working memory, as moved noun phrases that have not yet been assigned a thematic role by the verb need to be maintained in memory (Gibson, 1991). A reduction in working memory can affect comprehension if the processing load requirement exceeds the individual's working memory capacity.

Yet others claim that a reduction in resources can affect comprehension through pathological delays in sentence processing. Burkardt, Pinango, and Wong (2003) suggest that slowed or delayed syntactic processing affects syntactic-semantic computations 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. This account is based on results of a cross-modal lexical decision study, which found 650 millisecond delays in priming with wh-movement structures in agrammatic individuals. Love, Swinney, and Zurif (2001) also found evidence of delayed processing in Broca's aphasia: their participants did not reactivate the antecedent at the trace site in movement structures. Again, using a cross-modal lexical decision, the patients showed delayed priming 650 milliseconds downstream of the trace site. However, Love et al. (2001) attributed this delay to slowed lexical processing, rather than syntactic-semantic computation. Delayed processing accounts are further supported by findings from studies using the anomaly detection task. Dickey and Thompson (2004) tested aphasic individuals in an auditory anomaly detection task where the participants were instructed to press a button as soon as a sentence started to sound anomalous. Aphasic participants were able to reject the anomalous sentences in movement structures, but their responses were 1000 milliseconds delayed compared to normal controls. These data suggest that slowed processing may underlie difficulty in processing complex structures such as movement constructions.

In addition to movement structures, agrammatic aphasic individuals also exhibit difficulty comprehending binding constructions, such as reflexive and pronoun structures (Edwards &

Varlokosta, 2007; Grodzinsky, Wexler, Chien, Marakovitz, & Solomon, 1993; Love, Nicol, Swinney, Hickok, & Zurif, 1998; Rigalleau & Caplan, 2004). Rather than syntactic movement these constructions involve referential dependencies, which are difficult for patients to compute. Unlike expressions such as *Shakespeare* or *Canada*, which inherently select a reference from the universe of discourse, reflexives and pronouns like *himself* and *him* do not uniquely refer to specific entities and therefore lack meaning unless they are bound to a referential expression. Thus, binding involves co-indexation with a referential expression (known as the antecedent), which (based on linguistic theory) c-commands referentially dependent elements (Haegeman, 1994).

There are different binding conditions that govern reflexives versus pronouns. Reflexives must be bound in their local domain. In (1), the local domain for the reflexive, *himself*, is the subordinate clause, *Thomas to shave himself*. Hence, the only appropriate binder in this domain is *Thomas*. Reflexives cannot be bound by the higher subject *Justin* because it is outside the reflexive's local domain. Conversely a pronoun, which takes the same surface position in sentences such as (2), is not bound in its local domain. Rather, it is bound by the matrix subject, *Justin*, which lies outside the local domain.

(1) Justin told [Thomas$_i$ to shave himself$_i$].

(2) Justin$_i$ told [Thomas to shave him$_i$].

When encountering sentences such as (1) and (2), listeners establish a co-indexational relation between the reflexive or pronoun and its antecedent so that in (1) *himself* is co-indexed with *Thomas*, and in (2) *him* is co-indexed with *Justin*. It is through the mechanism of binding that referentially dependent elements receive reference from their antecedents.

Several studies have examined comprehension of binding structures in Broca's aphasia. Offline studies with pronouns have found low accuracy for aphasic participants as compared to unimpaired listeners (Edwards & Varlokosta, 2007; Grodzinsky et al., 1993; Love et al., 1998), with aphasic participants showing chance-level comprehension. Additionally, some studies show that aphasic comprehension of pronouns is significantly poorer than that of non-pronoun constructions (Avrutin, Lubarsky, & Greene, 1999; Jarema & Friederici, 1994). Studies examining reflexive comprehension have resulted in less-consistent findings. Some report significant deficits (Edwards & Varlokosta, 2007; Linebarger, Schwartz, & Saffran, 1983; Love et al., 1998), whereas others do not (Grodzinsky et al., 1993; Ruigendijk & Avrutin, 2003).

Online experiments have also found inconsistent performance patterns. In a cross-modal priming study, Love et al. (1998) showed abnormal priming for pronouns (i.e., facilitation effects for both correct and incorrect antecedents), but no priming effects were found for reflexives. However Pinango and Burkhardt (2001), using the same cross-modal lexical priming paradigm but varying the SOAs (stimulus onset asynchronies), found normal priming at longer SOAs of 600 ms to 800 ms, suggesting that rather than impaired binding, agrammatic aphasic patients' processing is delayed, which influences sentence comprehension ability. Collectively, these findings indicate that comprehension of binding constructions may be compromised in agrammatic individuals, although further research is needed to elucidate the extent to which both reflexives and pronouns are impaired.

Determining whether or not agrammatic individuals are impaired in comprehending binding constructions has implications for theories of sentence comprehension in aphasia. If both binding and movement are impaired, representational theories, i.e., the TDH, can be questioned, because binding structures do not involve movement. However, impairment of

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both binding and movement processing would provide support of the DDH because movement structures also involve co-reference processing. Consider the following passive sentence:

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(3)  The movie_i was produced t_i by some students.
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This sentence involves syntactic movement of *the movie* from the postverbal position to the sentential subject position of the sentence. In its original position is now a trace, denoted by t_i. Importantly, the trace is bound by the antecedent, *the movie*, as it is co-indexed and c-commanded by this antecedent. It is through this binding relation that *the movie* is interpreted in the position of the trace as the theme of the verb *produce*. Therefore, it is possible that a strict deficit in binding resolution may underlie difficulties seen for both movement and binding structures. Thus, further study of binding structures might help to unify theories of sentence comprehension impairments in agrammatism.

Slowed processing also may underlie comprehension impairments of both movement and binding structures in that a restricted processing capacity would slow the speed of both. The slowed-processing account does not make specific predictions about whether or not movement or binding is impaired in Broca’s aphasia, rather it suggests that comprehension failure results from slowed processing, which could putatively impair the ability to understand any sentence type. Similarly, a reduction in working memory capacity can also affect comprehension of both movement and binding structures as working memory is involved in the processing of both sentence types, especially in maintaining the antecedent for reactivation at the gap or pronominal.

One important consideration in studies examining sentence processing (and comprehension) concerns the experimental method used. Most of the aforementioned studies have used a cross-modal priming (CMP) paradigm, which requires study participants to listen to sentences and to simultaneously make (and execute) lexical decisions to probes presented at critical points in the sentences, One limitation of this method is the dual task performance requirement, which often is difficult for persons with aphasia (Murray, Holland, & Beeson, 1997; Tseng, McNeil, & Milenkovic, 1993). Further, CMP is only capable of examining processing at pre-selected points in sentences where the lexical decision probes are placed. This situation delimits the ability to detect processing deficiencies (or abilities) in sentence regions other than those probed. Anomaly detection has also been used to study sentence processing. However, like CMP, this strategy too requires pre-selection of anomaly placement. Another alternative is self-paced reading/listening, which requires participants to listen to or read the words of a sentence one at a time and to push a button to advance to subsequent words. This method allows the experimenter to compute reading or listening times for each word, thereby revealing specific points in sentences in which processing difficulty is encountered. However, both anomaly detection and self-paced reading/listening require participants to perform a button-press response, which may influence aphasic participants’ performance.

One method that has been successfully used to examine word-level and sentence-level comprehension is eyetracking. For example, Sussman and Sedivy (2003) studied processing of sentences with syntactic movement (i.e., object wh-questions) and sentences with no movement (i.e., yes–no question) by examining eye-movements to a visual display as participants listened to stories about the displayed items. Only after each story, when the participants’ eye movements were no longer being tracked, were they required to respond to either a wh-question or a yes/no question, in order to evaluate offline comprehension. Results revealed evidence of gap filling for wh-questions, which was not observed for yes–no questions. Dickey, Choy, and Thompson (2007) replicated Sussman and Sedivy’s (2003) results with young and older unimpaired listeners and found that participants with agrammatic, Broca's aphasia showed eye movement patterns consistent with automatic gap filling. In addition, the aphasic participants' gap-filling effects occurred in timely manner; that is, the patients "filled the gap" by showing increased eye fixations to the antecedent of the moved element in sentences at the gap site. It also is of interest to note that evidence of automatic gap filling was noted even when offline comprehension failed. However, the eye movement patterns differed at sentence end for failed trials. These findings contrasted with those derived from earlier studies using CMP and anomaly detection task, which showed either a lack of gap filling or delayed gap filling for similar wh-movement structures.

Eyetracking offers a particular advantage in examining language processing in aphasic individuals as eye control and vision are often spared. In addition, the method of eyetracking while listening involves a simple task where the participant is only required to listen to the sentence while looking at a visual display. There are no secondary processing tasks required, hence approximating natural language comprehension. In addition, eyetracking offers an advantage over other online methods in that it allows observation of processing over the entire sentence as it unfolds in real time. Finally, the eye movements derived for correctly and incorrectly comprehended sentences can be analysed separately in order to determine the source of comprehension failure.

The present study seeks to investigate whether deficits in Broca's aphasia extend to binding constructions, and in doing so, evaluates theories of agrammatic comprehension. Eyetracking was used to examine binding processing in agrammatic aphasia and age-matched control participants. We examined both offline comprehension and real-time processing of binding to discern if (and how) aphasic processing patterns diverge from that of normal listeners. Specifically, we examined eye movements for patterns of co-reference processing of both reflexive and pronouns.

METHOD

Participants

Eight aphasic individuals (seven males) with the diagnosis of agrammatic Broca's aphasia and eight healthy age-matched controls, matched for age and education, participated in the study. All participants were native English speakers. The aphasic participants' ages ranged from 36 to 60 (M = 50.03, SD = 9.37), whereas those of the controls ranged from 35 to 77 (M = 47.83, SD = 13.55). There were no statistical differences between the control group and the aphasic group in terms of age or education (see Table 1). All participants also demonstrated good visual and hearing acuity and did not have complicating medical conditions such as psychiatric disturbances, alcohol/drug abuse and pre-morbid speech, language and learning disorders. Patients' hearing acuity was screened with a pure-tone audiometer at 60db at 500 Hz, 1000 Hz, and 2000 Hz and patients' vision and oculomotor performance was screened with a task in which patients were asked to look at certain pictures of items on the screen and follow the fingertip of the examiner with their eyes. All participants provided informed consent prior to the study.

The aphasic participants were recruited from the Aphasia and Neurolinguistics Research Laboratory at Northwestern University. Aphasia type and severity were assessed using the Western Aphasia Battery (WAB; Kertesz, 1982). The selection criteria for the aphasic participants are as follows. All participants were mildly to moderately impaired, with WAB Aphasia Quotients (AQs) ranging from 62 to 86.4 (M = 71.6, SD = 8.6) and comprehension scores ranging from 8 to 9.8 (M=8.6, SD=0.6). (See Table 2.) Their aphasia resulted from a single-episode, left-hemisphere stroke and they were all at least 1 year post-stroke at the time of testing (M = 4.8 years). All aphasic participants showed agrammatic speech production and impaired comprehension of complex movement sentences such as passives or object relative sentences in the face of relatively spared comprehension of simple active sentences. Sentence comprehension data derived from administration of the Northwestern Assessment of Verbs and Sentences (NAVS; Thompson, experimental version) are shown in Table 2. The NAVS is a test developed for research purposes in the Aphasia and Neurolinguistics Research Laboratory at Northwestern University to detail aphasic sentence comprehension and production deficits. The test is currently being standardised for publication.

Materials

Materials for the study consisted of 60 pairs of stories and panels depicting objects mentioned in the stories. Of the story–panel pairs, 40 served as experimental items while the remaining 20 served as fillers. All stories had the same structure consisting of three sentences: an introductory sentence, which introduced two animate NPs involved in the story (e.g., *Some soldiers and farmers were in a house*), a second sentence containing the critical transitive event (e.g., *The soldier told the farmer with a glasses to shave him/himself in the bathroom*), and a final closing sentence (e.g., *And he did*). Filler stories included active critical sentences without a reflexive or pronoun (e.g., *The pastor told the choirboy with crutches to sing a song at school*). The rationale for using such filler items was to minimise the expectation of reflexives and pronouns in the critical second sentence. Each test story was used twice, once with a reflexive and once with a pronoun. Four independent raters who were native speakers of English were asked to rate the grammaticality, plausibility, and naturalness of the sentences and stories on a 5-point scale. Only stories that were rated higher than 4 on these parameters by all raters were used as stimuli for the study.

Each story was followed by a comprehension probe, which tested offline comprehension of the critical event in the second sentence as seen in (4). For the test stories, the probe questions queried either a pronoun, “Did the farmer shave the soldier?”, or a reflexive structure, “Did the farmer shave himself?”. The answer to the first probe question was “no” for the reflexive condition and “yes” for the pronoun condition, whereas the answer to the second probe question was “yes” for the reflexive and “no” for the pronoun condition. Half of the stories for each condition included probe questions of the first form and the other half used probe questions of the second form. Hence, overall there were an equal number of questions requiring “yes” and “no” responses. For the fillers, the probe questions were of the form “*Did the choirboy/pastor sing the song?*”. The answer to half of the filler probes was “yes” and the answer to the other half was “no” (see Appendix for the complete set of stimuli.) The stories were digitally recorded by a female native speaker of English at a natural pace with standard intonation using SoundEdit (Macromedia).

(4) *Story*

Some soldiers and farmers were in a house.

The soldier told the farmer with glasses to shave him/himself in the bathroom.

And he did.

Probe Question

Did the farmer shave the soldier?

The verbs included in the second sentence were all reversible transitive verbs and the two human referents, (e.g., *soldier* and *farmer*), inanimate objects (e.g., *glasses*) mentioned in the stories, and distractor items (human nouns) used on the visual panels (see below) (e.g., *patient*) were controlled for lemma frequency, syllable length, and phonological onset. The three human nouns were matched for gender.

For each story a visual panel such as in Figure 1 was constructed containing the nouns mentioned in each story. The panel was divided into a 3 × 3 grid with a fixation cross in the centre of the panel. The panel contained four items, one in each corner: the two possible antecedents (e.g., *soldier* and *farmer*) and the inanimate object (e.g., *glasses*) that were mentioned in the story and a human distractor (e.g., *patient*), which was not mentioned in the story. The inanimate object was included to detract participants' gaze from the previously mentioned item (e.g., *farmer*). This way, eye movements to the pronoun or reflexive would not reflect residual activation of the previous noun. The distractor noun served as a control in comparing looks to antecedents of either the pronoun or reflexive.

The position of each item on the panel was pseudo-randomised across stories and the panels in adjacent trials never had the same elements appearing in the same positions. Further, the items appeared equally often in each position across panels. This ensured that all items were equally likely to appear in any of the four positions on any given trial. Further, the positions of the objects were evenly distributed across experimental conditions. Participants were just as likely to see the object in one of the positions for stories for the reflexive condition as they were for stories for the pronoun condition.

The pictures for the nouns were obtained from 100,000 ClipArt (GSP Limited) or from www.clipart.com. The pictures were edited as 4 × 3 inch black and white pictures and copied onto the panels with Adobe Photoshop. Pictures for all four nouns for all test stories were matched in style of drawing as well as in size and were rated by four independent raters for differences in prominence of the four pictures that would attract more or less looks than the other pictures in a rest condition. The pictures that were judged to be different in prominence in the panel by more than one rater were edited to match the prominence of the other pictures or substituted with different pictures. The raters were also asked to point to the nouns named, and any pictures that raters had difficulty recognising were omitted or substituted.

Two pseudo-randomised scripts were developed. Both scripts contained 20 test stories with reflexives and 20 test stories with pronouns. The stories that included reflexives in script 1 were used with pronouns in script 2 and vice versa. The stories were pseudo-randomly selected for either the reflexive or pronoun condition so that the lemma frequency of items on the panels was balanced across conditions. The same 20 filler stories were used for both scripts. The order of stories in the two scripts was pseudo-randomised so that no more than two stories with the same condition (either reflexive or pronoun) occurred consecutively. The auditory and visual stimuli were assembled into the two scripts using SUPERLAB (Cedrus).

Procedure

Testing was completed in one session of approximately 1 hour. At the beginning of the session participants were given two practice stories before being presented with the test stimuli. Participants were instructed to listen to the stories while looking at the monitor. They were also instructed to verbally answer the questions at the end of the story. The auditory and visual stimuli were presented using SUPERLAB. The auditory stimuli were presented via loudspeakers and the visual stimuli were presented on a Macintosh monitor. First, a blank screen appeared on the computer monitor for 1500 milliseconds. The blank screen served as a signal that the next item was starting. Then a panel appeared on the screen, which remained visible throughout the whole trial. The story began 1000 milliseconds after the panel appeared in order to allow time for scene apprehension. Once the story was complete there was a beep, followed by a comprehension probe that the participants answered orally. After responding, the experimenter pressed the space bar on the keyboard, which advanced to the next trial. The next trial then began with a blank screen, as described above.

Eye movements were monitored and recorded by an Applied Science Laboratories (ASL) remote eyetracker model 504 while the participants looked at the panels and listened to the story. The camera assessed eye position by monitoring the offset between the infrared reflection from the surface of the cornea and the infrared reflection off the retina and passing through the pupil. This offset was calibrated for each participant at the beginning of the experimental session, and checked every 10 trials by having the participant look at nine numbers on the screen. Participants were told to move only their eyes, not their body or head, if possible. No chinrest or headrest was used to stabilise movement.

The eyetracking data were collected using EYENAL (ASL analysis software). The position and direction of the eye movements were sampled every 16 ms by the remote eyetracker. The measurements of interest were the number and latency of the looks to each item on the panel as it was mentioned in the stories. Looks to items counted as a fixation only when eye gaze was maintained on the same position for four consecutive samples (or approximately 64 ms). This is above the 50 ms needed for foveal information acquisition (Rayner & Pollatsek, 1989). As the for the fixation algorithm, ASL default settings were used (i.e., 0.5 degrees used to determine when a fixation began; 1 degree used to determine whether subsequent data samples were part of the same fixation; and 1.5 degrees used to determine which data samples should be averaged together to determine the final fixation coordinates).

Answers to the probe questions were recorded manually by the examiner during the experiment. A member of the Aphasia and Neurolinguistics Laboratory served as an independent judge, attended 25% of the sessions, and scored the offline comprehension responses. Reliability for these checks was 95% or above for all participants.

Data analysis

The proportion of correct responses for each experimental condition was calculated and accuracy of aphasic participants was compared to that of normal controls for the two test conditions. Accuracy on the probes for the reflexive condition was compared to that for the pronoun condition for aphasic participants.

Eye movement patterns for the reflexive and pronoun conditions were computed using the EYENAL data analysis program. Eye movement data in filler stories were collected but not analysed. Fixations were counted as looks towards an item when the fixation fell within the quadrant of the 3 × 3 panel in which the item was located. Fixations were analysed only for the critical sentences, i.e. those that contained either a reflexive or a pronoun, which were divided into seven temporal regions associated with words of each critical sentence (see Table 3.)

Fixations to pictured items were computed in each temporal region. The regions for the overt nouns (Noun 1, Noun 2, and Object) extended from the onset of the noun to the onset of the following word. The V region extended from the onset of the embedded verb until the onset of the reflexive or pronoun, the Pro region extended from the onset of the reflexive or pronoun to the onset of the final prepositional phrase, and the PP region extended from the onset of the prepositional phrase to the offset of the phrase. A Post-offset region also was included, extending 200 ms from the offset of the sentence. Of these, the most critical analysis regions for examining reflexive or pronoun reference resolution were the Pro region and the PP region because these regions follow the reflexive or pronoun in the sentence stream. This estimate is based on results obtained with unimpaired individuals in which participants looked towards the target more than the competitor approximately 200 ms after the offset of the pronoun (Arnold, Eisenband, Brown-Schmidt, & Trueswell, 2000). In addition to the Pro and PP regions where reference resolution was projected, the region preceding the pronominal (i.e., V region) was analysed to serve as a baseline for eye movements before the presentation of the pronominal and a Post-offset region was analysed to examine delayed eye movements and end of sentence effects. The temporal boundaries of each sentence region were shifted 200 ms downstream for the purposes of analysis, in order to compensate for the time required to program and execute a saccade and fixate on an object associated with a word (Tanenhaus & Spivey-Knowlton, 1996).

The fixation data from EYENAL were transferred to EXCEL (Microsoft) for further analysis. For each participant, fixation proportions to the items on the panel were calculated for each sentence region over all sentences in each condition. To do this, fixations to each item on the panel were summed and the proportion of fixations to each panel object out of the total fixations made during that region was calculated. This total included fixations to the target, competitor, object, and distractor elements on the screen.

In addition to the proportional analysis, a time analysis was conducted to test whether there was a delay in processing in individuals with aphasia. The times to fixation for each overt noun, reflexive, and pronoun were compared between the aphasic and control participants.

RESULTS

Comprehension probes

Accuracy data for the offline comprehension probes are reported as the proportion of correct responses for each structure. Control participants exhibited good comprehension in both conditions, with accuracy at 98.1% for reflexives and 97.5% for pronouns. Conversely, the aphasic participants' comprehension was significantly lower than that of the controls: 63.8% and 65.0% accurate for reflexives and pronouns, respectively, Mann-Whitney test: $Z = 3.294$, $p = .001$ (reflexives); $Z = 3.218$, $p = .005$ (pronouns). Analysis of the aphasic group's data showed that there was no difference between reflexives and pronouns, Wilcoxon signed ranks test $Z = .687$, $p = .492$, and correlational analysis showed a significant correlation between performance in the two conditions, Spearman $r = .761$ $p = .028$. However, comprehension of reflexives did not differ significantly from chance, Wilcoxon signed ranks test $Z = 1.682$, $p = .093$, whereas pronouns were significantly better than chance, Wilcoxon signed ranks test $Z = 2.384$, $p = .017$. Individual results for the aphasic individuals on the comprehension probes are given in Table 4, indicating that three of the eight participants showed identical accuracy in the both conditions, four participants showed better accuracy for the pronoun condition compared to the reflexive condition, and only one participant showed better accuracy for the reflexive condition compared to the pronoun condition.

Eye movement patterns

The eye movement data across regions for reflexive and pronoun are plotted in Figure 2 and Figure 3, respectively, for aphasic and control participants. The lines in the graphs have been smoothed and error bars represent standard errors (*SE*s).

Reflexives—The proportion of looks to each item in the reflexive condition is plotted by sentence region in Figure 2 for both participant groups. Both groups moved their eyes toward the nouns (i.e., Noun 1, Noun 2, and Object) as they were overtly mentioned in the story. However, the regions in which fixations to these objects materialised differed for the two participant groups. We compared the fixations to each item to chance using the Wilcoxon

Signed Ranks Test. The control group showed a direct correspondence between fixations to N1, N2, and Object in the region of Noun 1, Noun 2, and Object, respectively. Fixations to N1 in the Noun 1 region ($Z = 2.524$, $p = .012$) and to N2 in the Noun 2 region ($Z = 2.524$, $p = .012$) were significant, whereas fixations to the Object at the Object region were not significant ($Z = 0.280$, $p = .779$). For the aphasic group, fixations to N1, N2, and the Object emerged in the critical regions directly following those in which they were overtly mentioned, i.e., in the Noun 2, Object, and Verb regions, respectively. The fixations to N2 in the Object region ($Z = 2.103$, $p = .035$) were significant; however, the numerical increase in fixations to N1 in the Noun 2 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 of the reflexive, both groups showed an increase in fixations toward the correct antecedent (target) of the reflexive (i.e., N2) in the post-verbal regions and both groups showed a peak in the proportion of fixations to the target in the pronominal region (i.e., Pro and PP regions). We compared the fixations to the target and competitor in the post-verbal regions to chance using the Wilcoxon Signed Ranks Test. Comparison of target fixation to chance revealed that, for both control and aphasic participants, fixations to the target were not significant in the Pro region (control: $Z = 0.280$, $p = .779$; aphasic: $Z = 1.682$, $p = .092$), but were significant at the PP region (control: $Z = 2.521$, $p = .012$; aphasic: $Z = 2.380$, $p = .017$). Fixations to the target persisted into the Post-offset region for both participant groups (control: $Z = 2.033$, $p = .042$; aphasic: $Z = 2.240$, $p = .025$). Fixations to the competitor (incorrect antecedent) were not significant in any of the post-verbal regions for either control or aphasic participants. 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 using the Mann-Whitney Test. Both control and aphasic participants showed a significant target preference (greater looks to the target compared to the competitor) in the Pro region (control: $Z = 2$, $p = .05$; aphasic: $Z = 2.423$, $p = .015$) and PP region (control: $Z = 2.836$, $p = .005$; aphasic: $Z = 2.68$, $p = .007$). Target preference was not significant in the Post-offset region (control: $Z = 1.791$, $p = .073$; aphasic: $Z = 1.474$, $p = .141$).

Pronouns—As in the case with reflexives, both groups of participants looked towards the pictures corresponding to the nouns (i.e., N1, N2, and Object) as they were mentioned. Once again, the regions in which increased fixations materialised differed for the two participant groups. The control group showed increased fixations to N1, N2, and Object at the area of N1, N2, and Object respectively. Fixations to N1 at the Noun 1 region ($Z = 2.521$, $p = .012$), fixations to N2 at the Noun 2 region ($Z = 2.033$, $p = .042$), and fixations to the Object at the Object region ($Z = 2.103$, $p = .035$) were significant compared to chance. On the other hand, the aphasic group showed delayed looks, which showed up in the regions directly following the region in which they were presented. Fixations to N1 in the Noun 2 region ($Z = 1.960$, $p = .05$), N2 at the Object region ($Z = 2.533$, $p = .011$) were significant, while fixations to the Object at the Verb region ($Z = 0.280$, $p = .779$) were not significant.

Despite these differences in fixations in early sentence regions, both participant groups again showed an increase in fixations to the target in the post-verbal regions in the same region. As shown in Figure 3, marked increases in fixation to the target were noted in the PP region for both control and aphasic groups. Comparison of target fixation to chance in the post-verbal regions (Pro, PP regions) revealed that, for both control and aphasic participants, fixations to the target were not significant in the Pro region (control: $Z = 0.862$, $p = .389$; aphasic: $Z = 0.318$, $p = .075$) but were significant in the PP region for both groups (control: $Z = 2.521$, $p = .012$; aphasic: $Z = 2.524$, $p = .012$). Fixations to the target persisted numerically in the Post-offset region for both participant groups, but were only significant for the control participants (control; $Z = 2.524$, $p = .012$; aphasic: $Z = 1.521$, $p = .128$). Fixations to the competitor (incorrect antecedent) were not significant in any of the post-verbal regions for either control or aphasic participants. 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 preference was significant in the PP region for both the aphasic and control participants (control: $Z = 2.051$, $p = .04$; aphasic: $Z = 2.423$, $p = .015$). However, target preference was not significant in the Pro region (control: $Z = 1.647$, $p = .20$; aphasic: $Z = 0.373$, $p = .709$) or the Post-offset region (control: $Z = 1.684$, $p = .092$; aphasic: $Z = 0.477$, $p = .633$).

Time to fixation—Analyses comparing time to fixation between the aphasic and control groups to Noun 1, Noun 2, and the Object as well as to the target (correct antecedent of the pronoun or reflexive) on hearing the pronominal were also undertaken. This was done by computing the time from onset of each sentential element as the critical sentences unfolded to initial fixation on the corresponding pictured items for each. For Noun 1, Noun 2, and Object, fixation times were computed from the onset of each respective noun; fixation times for the Pronoun/Reflexive were computed from the onset of the reflexive or pronoun. The elements subjected to time analysis are underlined in (6).

```
   (6) The soldier told the farmer with glasses to shave him/himself in the
bathroom.
         Noun1            Noun2          Object       Pronoun/Reflexive
```

Results, depicted in Figure 4, showed significantly delayed fixations for the aphasic participants compared to controls (using a Mann-Whitney Test) for Noun 1, $Z = 2.196$, $p = .028$, and Noun 2, $Z = 2.489$, $p = .013$, but not for the Object, $Z = 0.732$, $p = .464$. There was no delay in fixations towards the correct antecedent of the reflexives, $Z = 0.293$, $p = .77$, or pronouns, $Z = 0.21$, $p = .878$, for the aphasic participants compared to the normal controls.

Correct versus incorrectly comprehended trials—In order to discern whether correctly and incorrectly comprehended sentences involved different sentence processing patterns for the aphasic participants, we compared eye movement patterns for the two trial types (see Figure 5). This analysis was not conducted for the control participants as few incorrect trials were noted for this group.

Results showed that the two trial types elicited different eye movement patterns in both the reflexive and pronoun conditions. For both structures the correct and incorrect trials were similar to one another in sentence regions in which pronominal resolution occurs; however, differences emerged towards sentence end. On correct trials for the reflexives, the aphasic participants showed a target (N2) preference starting in the PP region. Target preference was statistically significant in a Mann-Whitney Test for the PP region $Z = 3.256$, $p = .001$, and the Post-offset region, $Z = 2.217$, $p = .027$. On incorrect trials, a significant target preference emerged at the Pro region, $Z = 2.3$, $p = .021$. However, unlike the correct trials, target preference was not maintained 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: when comprehension was successful, the aphasic participants showed a significant target (N1) preference in the PP region, $Z = 2.107$, $p = .035$. Numerically, there were more fixations to the target compared to the competitor in the Post-offset region, but the difference was not significant, $Z = 1.847$, $p = .065$. On incorrect trials the target preference was significant in the Pro region, $Z = 2.362$, $p = .018$, and the PP region, $Z = 2.047$, $p = .041$, but not in the Post-offset region, $Z = 0.803$, $p = .422$.

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We further analysed time to fixation between correctly and incorrectly comprehended trials. Figure 6 shows the average time to initial fixation for the pronominal in the correct and incorrect trials for the aphasic participants. Statistical analysis of the data revealed no differences between fixations towards the target in correct or incorrect trials in either the reflexive condition, Mann-Whitney $Z = 1.025$, $p = .306$, or the pronoun condition, Mann-Whitney $Z = 1.171$, $p = .242$.

DISCUSSION

Results of this study replicated findings from offline comprehension studies that reported agrammatic Broca's aphasic participants' difficulty in comprehending both reflexive and pronoun constructions. Aphasic participants performed significantly more poorly than the controls on both constructions. Additionally, the results showed equal levels of impairment for reflexive and pronoun constructions, suggesting that the different locality conditions of the reflexive and pronoun did not influence aphasic comprehension. This finding is in line with Love et al. (1998) who also found similar levels of performances for reflexives and pronouns, but in contrast to Grodzinsky et al. (1993) who found a distinction in aphasic comprehension between the two structures. The disparity in results between studies might be attributable to differences in the sentence stimuli used. Love et al. (1998) used embedded sentences, similar to those used in the present study (e.g., "The *boxer* said that the *skier* in the hospital had blamed *him/himself* for the recent injury"), in which both the target and the competitor of the pronominal were included. On the other hand, Grodzinsky et al. (1993) used simple sentences that only contained one potential antecedent ("Is *mama bear* touching *her/herself*?"). The simpler structure used by Grodzinsky et al. (1993) may have disproportionately aided comprehension of reflexives (i.e., *herself*) because the correct antecedent was provided in test sentences, whereas the correct antecedent for the pronoun (i.e., *her*) was not.

The comprehension data from the present study also indicate that comprehension deficits in Broca's aphasic patients with agrammatism extend to sentences other than those with syntactic movement. The pre-test data for the aphasic participants showed that they did indeed have difficulty comprehending both wh- and NP-movement structures and the experimental findings showed deficits for both reflexive and pronoun constructions.

Turning to the online data, similar eye movement patterns were found for the control and aphasic groups. Both showed fixations to all nouns when they were initially presented in critical sentences and, in addition, fixations to the referent of the reflexive/pronouns were noted on their mention. However, one difference emerged for the two participant groups: fixations to the initial nouns emerged immediately for the control group, whereas these fixations emerged in regions immediately following the nouns for the aphasic group, with time to fixation significantly delayed for the aphasic group. In spite of this difference, both groups showed increased fixations towards the target (correct antecedent) on hearing the reflexive/pronoun in the same region. For both groups, significant fixations towards the target occurred primarily in the PP region. This pattern was similar to the eye movement patterns found with unimpaired individuals' pronoun processing (Arnold et al., 2000) and was construed as evidence of successful co-reference processing. We note that this pattern cannot be explained by residual or delayed fixations to N2, as participants frequently made eye movements towards the Object, looking away from N2 on hearing the object, before showing increased fixations on the target again on hearing the reflexive or pronoun, as seen in Figure 2 and Figure 3. In addition, N2 was the referent for the target in the reflexive condition, but not in the pronoun condition, and therefore fixations to target in the Pro and PP Region did not result from residual or delayed fixations to N2.

Effects of object control were also considered in interpreting fixations to the target in the Pro and PP regions. A pervasive pattern for both aphasic and control participants was the overall high level of looks to N2 in the post-verbal areas in both reflexive and pronoun conditions, which was not observed in regions of the matrix clause. This pattern coincides with expectations based on a linguistic phenomenon known as *Object Control*. In an embedded infinitival clause without an overt subject such as *to shave himself*, the empty subject is “controlled” by an antecedent in the matrix clause. The verb, *tell* (the verb used in the matrix clause in all of the stimuli) is an object-control verb, which requires the empty subject in the embedded clause to be controlled by the object of the matrix clause. Hence, *the farmer* is interpreted as the person doing the shaving. Therefore, effects of object control materialised as an overall higher proportion of fixations to N2, which was the target in the reflexive condition and the competitor in the pronoun condition. However, despite effects of object control, there were nevertheless further increases in fixations in the Pro and PP regions towards the Target, which was N1 in the pronoun condition and N2 in the reflexive condition. Hence, although object control may account for some of the target preference in the post-verbal areas in the reflexive condition, it fails to account for the fixation patterns seen in the pronoun condition. Furthermore, the pattern found in the pronoun condition suggests that object control effects emerged in the area of the V, but that subsequent fixations to the target of the pronominal were made in the PP region after the pronominal, suggesting that increases in fixations in the regions of the pronominal are indeed due to effects of binding processing and not object control, even in the reflexive condition.

The increased fixations noted in the Pro and PP regions were therefore interpreted as visual evidence of automatic reference resolution in binding processing. Both control and aphasic individuals showed an increase in fixations towards the correct referent of the pronominal on hearing the pronominal in both the reflexive and pronoun conditions. Furthermore, the aphasic individuals showed an increase in fixations towards the correct referent even when they incorrectly comprehended the sentence. These results suggest that individuals with Broca’s aphasia are not impaired in processing binding and are able to process the reference of both reflexives and pronouns on encountering the pronominal in sentences. Hence, although aphasic participants show deficits in comprehending binding constructions, the comprehension deficits did not result from impairments in automatic binding processing.

In addition, aphasic individuals did not show delays in processing binding, despite showing delayed processing of overtly mentioned nouns (N1, N2). For the correctly comprehended trials, the participants showed a very similar pattern to control participants in which there were clear increases in fixations to the target in the PP region, indicating that aphasic individuals process reflexive and pronoun constructions in a manner similar to that of normal controls, assigning proper reference to reflexives and pronouns in a timely manner. As for the incorrect trials, significant increases in fixations to the target occurred in the Pro region on hearing the reflexive or pronoun. The Pro region is the earliest point in which reference resolution can occur, extending from the onset of the reflexive or pronoun until the onset of the PP. Although the region in which the increases emerged in the proportional analysis was earlier for incorrect as compared to correct trials, the time to fixation analysis revealed no significant differences between times to fixation on hearing the reflexive or pronoun for the two trials types, nor was there a difference between aphasic participants and normal controls. It is worth mentioning that Dickey et al. (2007) also found faster fixation times on incorrect trials in a study examining eye movements during processing of filler-gap constructions. These results are in contrast to studies using cross-modal lexical decision or semantic anomaly detection tasks in which processing delays have been observed (Burkhardt et al., 2003; Dickey & Thompson, 2004; Love et al., 1998, 2001). The difference between results from these studies on the one hand and our study on the other might stem from the fact that, in cross-modal lexical decision and anomaly detection tasks, a delay in lexical processing in itself can influence the main task of lexical decision, lexical priming, or semantic anomaly detection. Many studies have in fact suggested that individuals with Broca's aphasia exhibit delays in lexical processing (Prather, Zurif, Stern, & Rosen, 1992). Our study also found that individuals with Broca's aphasia are significantly delayed in processing individual lexical items in sentences.

The difference between activation of the overt nouns and activation of the already active antecedent may have resulted from differences relevant to lexeme versus lemma activation. Previous studies have suggested that only the lemma is activated at the anaphor and not the lexeme, as no frequency effect have been found with anaphoric lexical access and frequency is thought to reside in the lexeme (Simner & Smyth, 1999). Hence, the delay with only the overt nouns may be due to a delay in processing lexemes that are not found with lemmas. However, regardless of why delays in lexical processing occurred for the overt nouns, these delays did not influence syntactic processing of the binding constructions as revealed by the timely reference resolution exhibited by the aphasic participants.

Although both correct and incorrect trials for the aphasic participants resulted in fixations towards the correct antecedent immediately after hearing the reflexive or pronoun, a qualitatively different pattern of eye movements for correct and incorrect trials emerged in both reflexive and pronoun conditions. The difference between correct and incorrect trials emerged not at the pronominal regions, but rather at the end of the sentence in the form of increased fixations to the competitor when sentences were incorrectly comprehended. The fact that the aphasic participants successfully built syntactic structure and processed binding relations in a timely manner but eventually looked away towards the competitor on trials in which comprehension was unsuccessful suggests that comprehension deficits are not due to a syntactic or lexical activation deficit.

These results replicate the results previously obtained with wh- questions. Dickey et al. (2007) used the same eyetracking-while-listening paradigm to study agrammatic Broca's aphasic wh-question processing, finding that the aphasic participants were able to successfully gap-fill in a timely manner even when comprehension failed. Additionally, crucial difference in eye movement patterns between control and aphasic groups emerged at the end of the sentence where aphasic individuals increased fixations towards the competitor in the sentence offset region. Further analysis also revealed that this difference was mainly due to the incorrect trials. However, in Dickey et al. (2007) end-of-sentence effects were confounded by the fact that the wh-questions under study required question answering, and therefore these fixations might have reflected participants' planning of their answers. However, the sentences in the current study did not require question answering. Therefore, the end-of-sentence effects found in this study did not reflect answer planning. Similarly, Thompson and Choy (in press), found end-of-sentence effects in a study examining eye movements during processing of filler-gap object relative clause structures, in which critical sentences were not presented in the form of questions. Once again, correctly comprehended trials elicited fixations to the trace of moved sentence constituents at the trace site in a manner similar to that of unimpaired listeners. However, incorrectly comprehended trials elicited increased fixations to the competitors (of the trace of moved sentence constituents) at the sentence offset. Collectively, findings across studies suggest that when comprehension fails, processing failure is reflected at sentence end rather than at the site of binding processing or movement processing, indicating that the deficits are not due to an impairment in processing binding or movement per se. Rather, the fact that comprehension failure is reflected at the end of the sentence suggests a deficit in integration since the end-of-sentence is one of the main areas where integration occurs. Specifically, Carpenter and Just (1977) suggest that comprehenders try to resolve any inconsistencies and search for referents that have not been assigned at the end of the sentence.

Impaired lexical integration—that is, a deficit in integrating the already accessed lexical item into a higher-level representation of the whole sentence or utterance—has been suggested as the source of sentence comprehension failure in agrammatic individuals in previous studies. Nakano and Blumstein (2004) found that agrammatic aphasic participants have a deficit in integrating thematic information. In contrast to normal controls, who showed evidence of thematic integration by exhibiting significantly more priming when strong thematic information was available, agrammatic participants did not show a priming effect. These results were interpreted as evidence that individuals with Broca's aphasia have deficits in thematic integration. Swaab, Brown, and Hagoort (1998) also suggested an impairment in lexical integration in a study examining N400 ERP effects when individuals with Broca's aphasia encountered ambiguous words in sentence contexts. Rather than deficits in meaning access, their aphasic participants were delayed in selecting the meaning appropriate to the sentence context. In another study, Swaab, Brown, and Hagoort (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, for example in sentences like "The girl dropped the candy on *the sky*". Finally, lexical integration costs have been shown to influence syntactically complex sentences, such as those with movement dependencies. Measuring ERPs for sentences with various types of movement, Felser, Clahsen, and Munte (2003) found that when syntactic dependencies were more complex, aphasic individuals had more difficulty integrating moved sentential elements.

In conclusion, the present findings indicate that abnormal automatic processing of binding was not the source of comprehension failure for the aphasic participants. Even though the aphasic participants were impaired in their offline comprehension, their automatic processing of binding was intact even on trials in which comprehension failed, thus refuting the claims of a binding deficit as advanced by DDH. The findings from this study also do not provide support for TDH, as results showed that comprehension of binding structures are impaired in addition to movement structures. Furthermore, the results are not in line with slowed-processing accounts, which have been advanced to explain comprehension failure for both pronominal (Pinango & Burkhardt, 2001) and filler-gap structures (Burkhardt et al., 2003; Love et al., 2001). Indeed, the present findings show that although aphasic participants failed to comprehend some of the binding constructions tested, this failed comprehension did not result from delayed processing of binding constructions. In fact, the aphasic participants were able to activate (fixate on) the correct reference for both reflexives and pronouns in a timely manner on both correct and incorrect trials. In addition, although evidence of delayed lexical access was noted in early sentence regions, reactivation of the items via binding processing did not elicit delayed fixation patterns. Finally, the fact that aphasic participants were able to successfully reactivate the antecedent at the site of the reflexive or pronoun even when comprehension failed suggests that they were able to maintain the antecedent in working memory and successfully assign a thematic role. Hence, our results suggest that comprehension failure was not due to a reduced working memory storage capacity.

The crucial difference between correctly comprehended sentences and incorrectly comprehended sentences for the aphasic participants occurred at the sentence offset in the form of increased fixations to the competitor after the correct antecedent had been activated. We suggest that lexical integration deficits may be the source of this processing pattern. Confirmation of this postulate awaits further research. However, regardless of its accuracy, processing deficits underlying sentence comprehension failure are likely general processing deficits, such as a lexical integration deficits, that can affect not only binding, but also structures with syntactic movement.

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APPENDIX

Test stories

1. Some soldiers and farmers were in a house.

   A soldier told the farmer with glasses to shave him/himself in the bathroom.

   And he did.

   A. Did the farmer shave the soldier?

   B. Did the farmer shave himself?

2. A mother and her daughters were in the garden.

   The mother told the daughter with flowers to wash her/herself with soap.

   And she did.

   A. Did the daughter wash the mother?

   B. Did the daughter wash herself?

3. The king and some judges were at the palace.

   The king told the judge in the suit to save him/himself from the mob.

   And he did.

   A. Did the judge save the king?

   B. Did the judge save himself?

4. The president and some officers were in the oval office.

   The president told the officer with the newspaper to accuse him/himself of the alleged crime.

   And he did.

   A. Did the officer accuse the president?

   B. Did the officer accuse himself?

5. Some artists and models were at a party.

   An artist told the model on the sofa to introduce her/herself to the eligible men.

   And she did.

   A. Did the model introduce the artist?

   B. Did the model introduce herself?

6. Some doctors and teachers were at a conference.

   A doctor told the teacher in a wheelchair to present him/himself to the attendees.

   And he did.

   A. Did the teacher present the doctor?

   B. Did the teacher present himself?

7. A general and some scientists were in a meeting.

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The general told the scientist with the computer to seat him/himself at the head of the table.

And he did.

- **A.** Did the scientist seat the general?
- **B.** Did the scientist seat himself?

8. A bellboy and some gangsters were in a hotel.

The bellboy told the gangster with the handcuffs to lock him/himself up in the room.

And he did.

- **A.** Did the gangster lock the bellboy up?
- **B.** Did the gangster lock himself up?

9. Some policemen and journalists were at the anti-war rally.

A policeman told the journalist with the camera to protect him/himself from the protesters.

And he did.

- **A.** Did the journalist protect the policeman?
- **B.** Did the journalist protect himself?

10. Some detectives and reporters were at the police station.

A detective told the reporter with the umbrella to observe him/himself on the videotape.

And he did.

- **A.** Did the reporter observe the detective?
- **B.** Did the reporter observe himself?

11. Some fishermen and gardeners were at the market.

A fisherman told the gardener with strawberries to move him/himself to another stall.

And he did.

- **A.** Did the gardener move the fisherman?
- **B.** Did the gardener move himself?

12. The pope and some monks were at the Vatican.

The pope told the monk with the beads to calm him/himself before the ceremony.

And he did.

- **A.** Did the monk calm the pope?
- **B.** Did the monk calm himself?

13. Some boxers and golfers were at the clubhouse.

A boxer told the golfer in the sweater to scold him/himself for the bad putting.

And he did.

- **A.** Did the golfer scold the boxer?

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B. Did the golfer scold himself?

14. The sheriff and some firemen were at a crime scene.

The sheriff told the fireman with the briefcase to criticise him/himself for his negligence.

And he did.

A. Did the fireman criticise the sheriff?

B. Did the fireman criticise himself?

15. Some dancers and housewives were in the dressing room.

A dancer told the housewife with the basket to dress her/herself in a glittery costume.

And she did.

A. Did the housewife dress the dancer?

B. Did the housewife dress herself?

16. A singer and some tourists were in a hotel room.

The singer told the tourist with the luggage to wake him/himself up in the morning.

And he did.

A. Did the tourist wake the singer up?

B. Did the tourist wake himself up?

17. A bride and some nuns were at church.

The bride told the nun with the white gloves to pray for her/herself at the altar.

And she did.

A. Did the nun pray for the bride?

B. Did the nun pray for herself?

18. A scholar and some athletes were in the library.

The scholar told the athlete with the notebook to blame him/himself for the late book return.

And he did.

A. Did the athlete blame the scholar?

B. Did the athlete blame himself?

19. The queen and some nurses were at the hospital.

The queen told the nurse with the ring to prepare her/herself for the surgery.

And she did.

A. Did the nurse prepare the queen?

B. Did the nurse prepare herself?

20. Some ballerinas and violinists finished a performance.

A ballerina told the violinist with the microphone to compliment her/herself on the performance.

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And she did.

   A. Did the violinist compliment the ballerina?

   B. Did the violinist compliment herself?

21. A gunman and some outlaws were in a saloon.

The gunman told the outlaw with the dagger to turn him/himself in for the crime.

And he did.

   A. Did the outlaw turn the gunman in?

   B. Did the outlaw turn himself in?

22. A catcher and some batters were in the dugout.

The catcher told the batter with the white sneakers to replace him/himself with another player.

And he did.

   A. Did the batter replace the catcher?

   B. Did the batter replace himself?

23. Some gymnasts and skaters were in the Olympic stadium.

A gymnast told the skater with the mittens to videotape her/herself during the games.

And he did.

   A. Did the skater videotape the gymnast?

   B. Did the skater videotape herself?

24. Some skiers and hikers were in the mountain during a storm.

The skier told the hiker with the backpack to cover him/himself with a blanket.

And he did.

   A. Did the hiker cover the skier?

   B. Did the hiker cover himself?

25. A florist and some cellists were in a cafe.

The florist told the cellist with the necklace to treat her/herself to a cappuccino.

And she did.

   A. Did the cellist treat the florist?

   B. Did the cellist treat herself?

26. A mailman and some cyclists were on a bicycle trail.

The mailman told the cyclist with goggles to coach him/himself on a mountain.

And he did.

   A. Did the cyclist coach the mailman?

   B. Did the cyclist coach himself?

27. Some surfers and divers were at the beach.

A surfer told the diver with the headphones to rub him/himself with sunscreen.

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And he did.

- **A.** Did the diver rub the surfer?
- **B.** Did the diver rub himself?

28. Some swimmers and wrestlers were at the gym.

A swimmer told the wrestler with the trophy to time him/himself on laps.

And he did.

- **A.** Did the wrestler time the swimmer?
- **B.** Did the wrestler time himself?

29. A hairdresser and some pianists were at the hair salon.

The hairdresser told the pianist in a cardigan to watch her/herself in the mirror.

And she did.

- **A.** Did the pianist watch the hairdresser?
- **B.** Did the pianist watch herself?

30. A bartender and some janitors were at the bar.

The bartender told the janitor with a martini to serve him/himself a pint of beer.

And he did.

- **A.** Did the janitor serve the bartender?
- **B.** Did the janitor serve himself?

31. Some acrobats and magicians were at the circus.

An acrobat told the magician with the handkerchief to transform him/himself into a rabbit.

And he did.

- **A.** Did the magician transform the acrobat?
- **B.** Did the magician transform himself?

32. A jester and some swordsmen were in the courtyard.

The jester told the swordsman in armour to train him/himself with the lance.

And he did.

- **A.** Did the swordsman train the jester?
- **B.** Did the swordsman train himself?

33. A prince and some guards were at the palace.

The prince told the guard with the horn to disguise him/himself as a priest.

And he did.

- **A.** Did the guard disguise the prince?
- **B.** Did the guard disguise himself?

34. A thief and some cops were in an alley.

The thief told the cop in jeans to arrest him/himself for his violent behaviour.

And he did.

A. Did the cop arrest the thief?

B. Did the cop arrest himself?

35. A father and some students were at the book store.

The father told the student at the table to test him/himself on his French.

And he did.

A. Did the student test the father?

B. Did the student test himself?

36. A waiter and some runners were in a cafeteria.

The waiter told the runner with the towel to enter him/himself in the marathon.

And he did.

A. Did the runner enter the waiter?

B. Did the runner enter himself?

37. Some chemists and dentists were at a convention.

A chemist told the dentist with the folder to show him/himself around the booths.

And he did.

A. Did the dentist show the chemist around?

B. Did the dentist show himself around?

38. A pirate and some robbers were on a ship.

The pirate told the robber with the flashlight to hide him/himself with a mask.

And he did.

A. Did the robber hide the pirate?

B. Did the robber hide himself?

39. A butler and some chauffeurs were at a country mansion.

The butler told the chauffeur with the compass to drive him/himself to the city.

And he did.

A. Did the chauffeur drive the butler?

B. Did the chauffeur drive himself?

40. A referee and some linebackers were on the sidelines.

The referee told the linebacker with sunglasses to remove him/himself from the stadium.

And he did.

A. Did the linebacker remove the referee?

B. Did the linebacker remove himself?

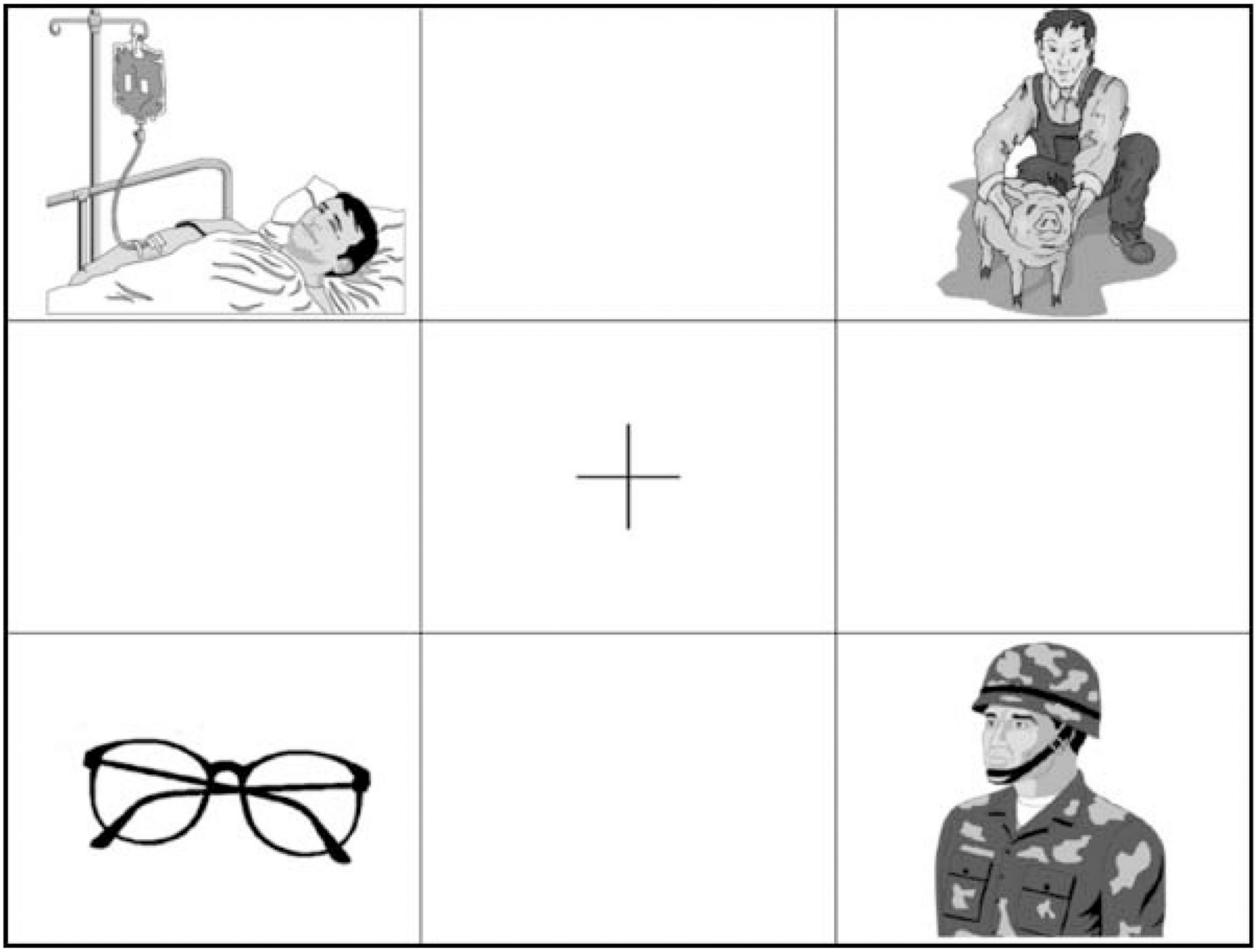

Figure 1.
Sample visual picture panel. In the reflexive condition (e.g., *The soldier told the farmer with glasses to shave himself in the bathroom*), the *farmer* is the target and *soldier* is the competitor. For the pronoun condition (e.g., *The soldier told the farmer with glasses to shave him in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

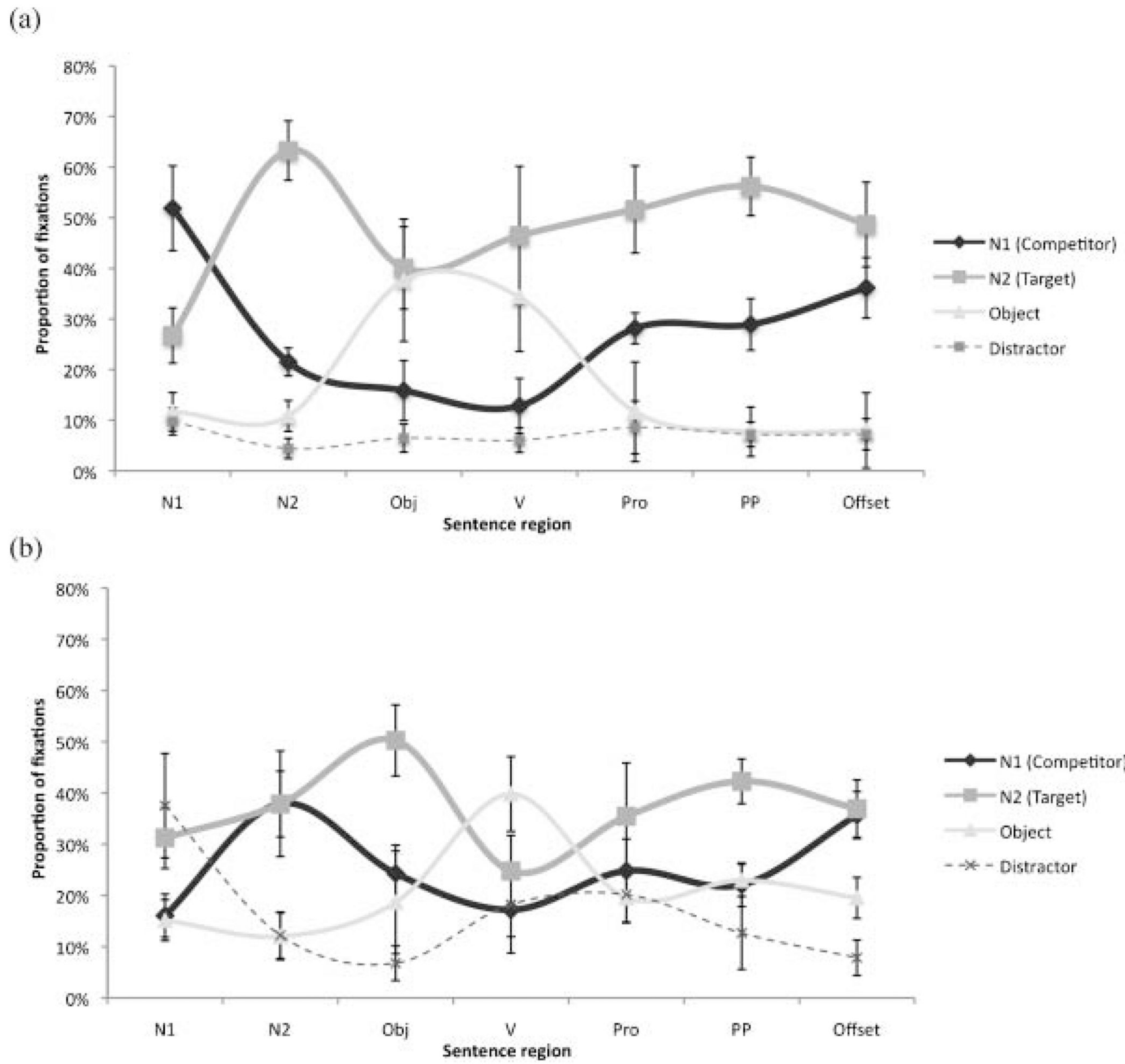

Figure 2.

Proportion of fixations to target, competitor, object, and distractor items displayed in the visual panels across sentence regions in the reflexive condition for control participants (a) and aphasic participants (b). The lines in the graph have been smoothed and error bars, which represent standard errors (*SE*s), have been inserted.

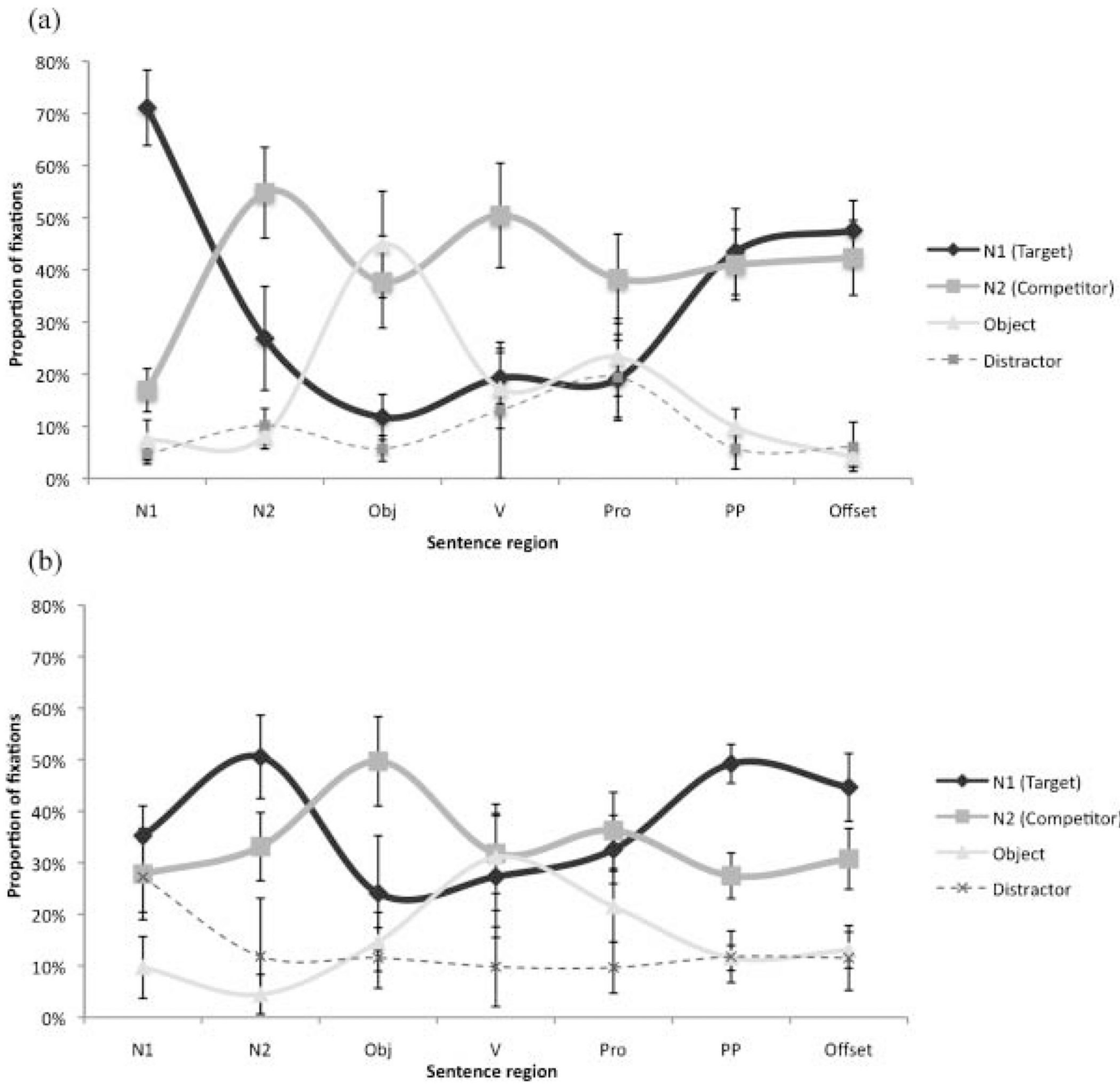

Figure 3.
Proportion of fixations to target, competitor, object, and distractor items displayed in the visual panels across sentence regions in the pronoun condition for control participants (a) and aphasic participants (b). The lines in the graph have been smoothed and error bars, which represent standard errors (*SE*s), have been inserted.

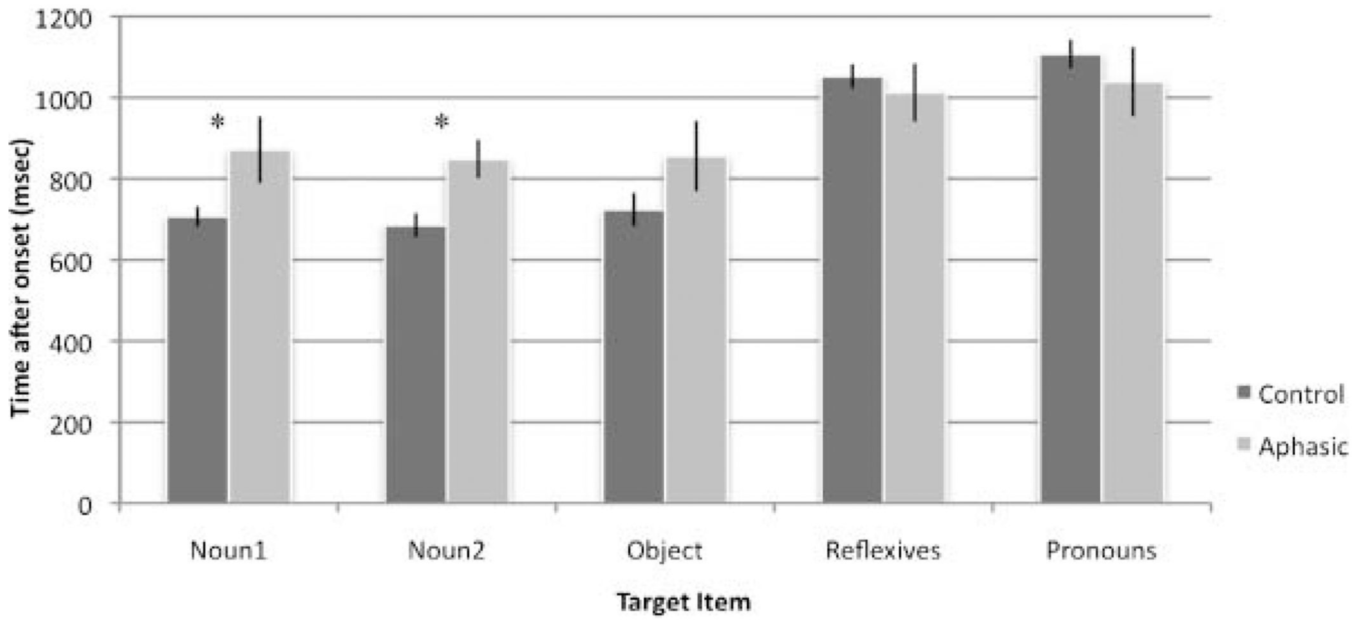

Figure 4.
Time to fixation for nouns and pronominals for control and aphasic participants. * = significant differences between groups.

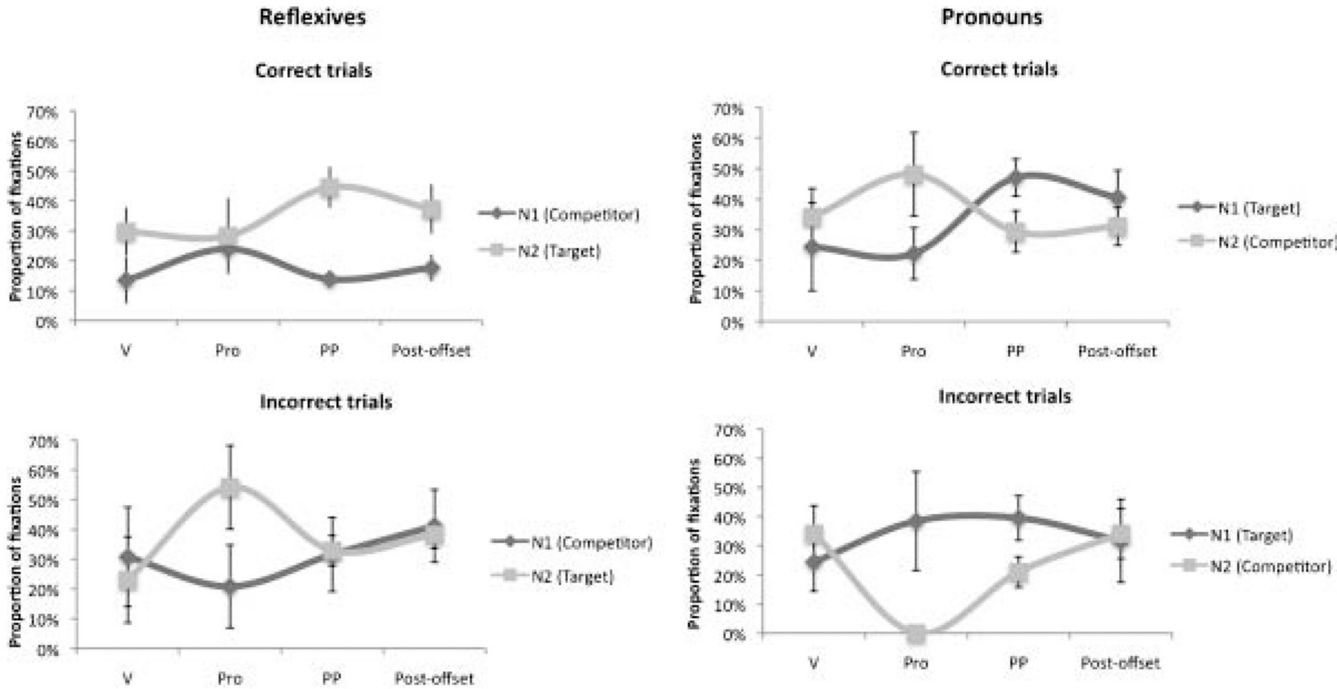

Figure 5.

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

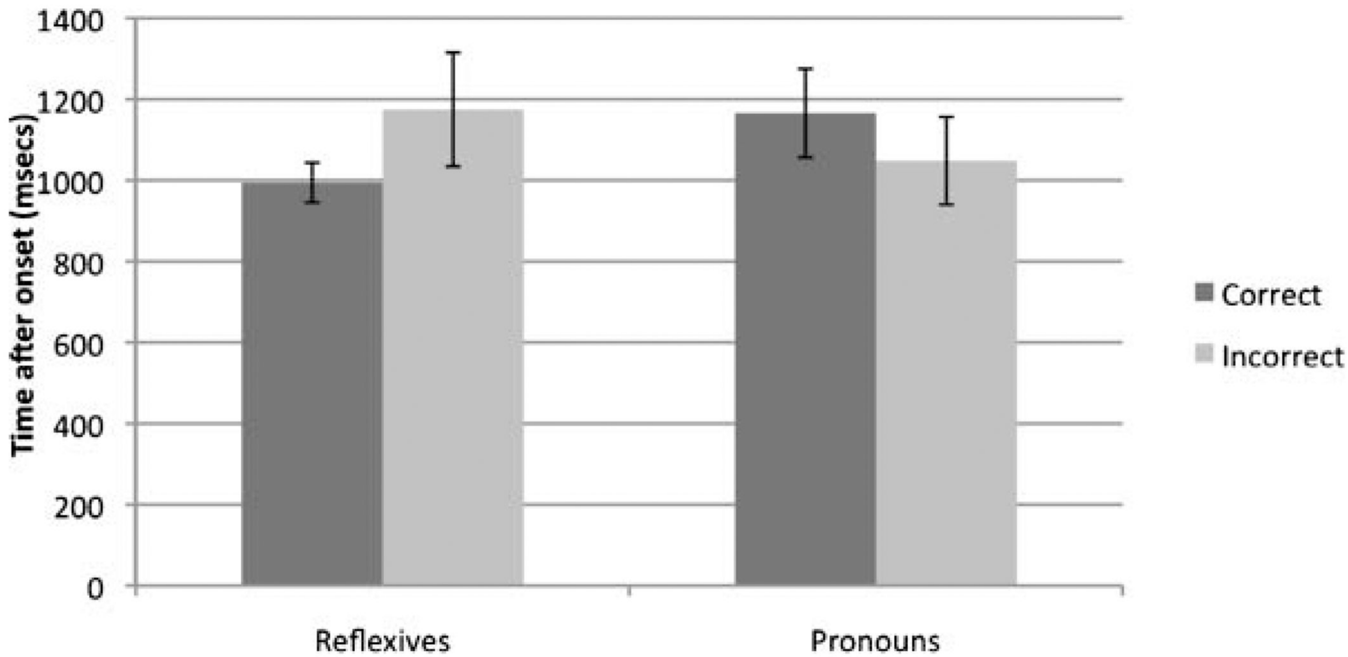

Figure 6.
Time to fixation for reflexives and pronouns for aphasic participants in correct and incorrect trials.

TABLE 1

Demographic data, all participants

Participant	Age (years)	Gender	Education	Years post-onset
A1	35	M	18	1.65
A2	36	M	18	2.33
A3	48	M	20	3.24
A4	57	M	16	3.03
A5	60	M	14	4.04
A6	56	M	18	14.01
A7	54	M	16	1.89
A8	50	F	12	8.25
X′ (SD)	50.03 (9.37)		16.5 (2.1)	4.8 (4.2)
C1	40	F	18	n/a
C2	44	F	17	n/a
C3	56	F	18	n/a
C4	37	F	19	n/a
C5	34	M	22	n/a
C6	49	M	22	n/a
C7	42	F	16	n/a
C8	76	M	12	n/a
X′ (SD)	47.83 (13.55)		18.5 (3.3)	

A = aphasic participant; C = control participant; M = male; F = female.

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TABLE 2

Language profile, aphasic participants

Participant	WAB AQ	WAB Fluency	WAB Comprehension	WAB Repetition	WAB Naming	NAVS SCT Actives	NAVS SCT Passives	NAVS SCT Object Relatives
A1	64.5	4	8.6	5.6	7.1	100%	20%	60%
A2	74.4	5	8.6	7.2	8.4	80%	20%	20%
A3	86.4	6	9.4	9.8	9.0	100%	100%	60%
A4	66.8	2	8.5	9.4	7.5	100%	60%	80%
A5	62.0	4	8.3	5.0	6.3	40%	55%	50%
A6	78.6	6	9	6.6	8.7	80%	65%	40%
A7	75.6	5	8.4	9.4	7.0	100%	60%	100%
A8	64.1	2	8	6.6	5.8	55%	66%	40%
X′ (SD)	71.6 (8.6)	4.3	8.6 (0.6)	7.5 (1.9)	7.5 (1.1)	79% (22%)	56% (26%)	54% (26%)

Western Aphasia Battery (WAB) and Sentence comprehension scores from Northwestern Assessment of Verbs and Sentences (NAVS) or the NU Sentence Comprehension Test. Comprehension on actives, passives, and object relatives were tested with the Sentence Comprehension Test (SCT) of the Northwestern Assessment of Verbs and Sentences (NAVS).

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TABLE 3

Sentence region segments used to examine eye movements during the unfolding of critical sentences

	Noun 1		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	…

TABLE 4

Individual aphasic performance on the comprehension probes

Participant	Reflexives	Pronouns
A1	55%	55%
A2	40%	50%
A3	95%	95%
A4	85%	60%
A5	60%	65%
A6	50%	60%
A7	75%	75%
A8	50%	60%
X′ (SD)	63.8 (19.2)	65.0 (14.1)