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Tracking Passive Sentence Comprehension in Agrammatic Aphasia

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Abstract

People with agrammatic aphasia often experience greater difficulty comprehending passive compared to active sentences. The Trace Deletion Hypothesis (TDH; Grodzinsky, 2000) proposes that aphasic individuals cannot generate accurate syntactic representations of passive sentences and, hence, use an agent-first processing strategy which leads to at-chance performance. We tested this claim using the eyetracking-while-listening paradigm in order to reveal online processing routines. Ten agrammatic aphasic participants and 10 age-matched controls listened to passive and active sentences and performed a sentence-picture matching task (i.e., selecting between two pictures with reversed thematic roles), while their eye movements were monitored. Control participants' performance was at ceiling, whereas accuracy for the aphasic participants was above chance for active sentences and at chance for passive sentences. Further, for the control participants, the eye movement data showed an initial agent-first processing bias, followed by fixation on the correct picture in the vicinity of the verb in both active and passive sentences. However, the aphasic participants showed no evidence of agent-first processing, counter the predictions of the TDH. In addition, in active sentences, they reliably fixated the correct picture only at sentence offset, reflecting slowed processing. During passive sentence processing, fixations were at chance throughout the sentence, but different patterns were noted for correct and incorrect trials. These results are consistent with the proposal that agrammatic sentence comprehension failure involves lexical processing and/or lexical integration deficits.

Keywords

agrammatic aphasia; passive sentences; agent-first strategy; eyetracking; on-line sentence processing

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1. Introduction

People with agrammatic aphasia often have difficulty comprehending sentences with non-canonical word orders, in which the linear order of NPs within a sentence does not match their semantic prominence (e.g., Caplan & Futter, 1986; O'Grady & Lee, 2005; Schwartz, Saffran, Linebarger, & Pate, 1987; Schwartz, Saffran, & Marin, 1980). For instance, aphasic individuals often experience greater difficulty understanding passive sentences, in which the theme precedes the agent (e.g., *The boy was pushed by the girl*) than canonical active sentences (e.g., *The girl pushed the boy*), a pattern that has been found across a variety of languages, including English, Dutch, German, Italian, and Turkish (Bastiaanse & Edwards, 2004; Burchert & De Bleser, 2004; Grodzinsky, Piñango, Zurif, & Draï, 1999; Linebarger, Schwartz, & Saffran, 1983; Luzzatti et al., 2001; Yarbay Duman, Altinok, Özgirgin & Bastiaanse, 2011). They also exhibit impaired ability to understand structures with syntactically-displaced objects, in which the theme of the embedded clause precedes the agent, such as object-relative clauses and clefts (e.g., object cleft: *It was the boy_i that the girl pushed _____i*) (Grodzinsky, 1989; Grodzinsky et al., 1999).

On the basis of these and related findings, some researchers claim that agrammatic aphasia involves impaired representation or processing of syntactic dependencies (Burkhardt, Piñango, & Wong, 2003; Grodzinsky, 1986; 1989; 2000; Mauner, Fromkin, & Cornell, 1993; Zurif, Swinney, Prather, Solomon, & Bushell, 1993). Transformational models of syntax claim that in non-canonical structures such as passives, object-relative clauses, and object clefts, the object is moved from its position following the verb, and a trace (or copy) of this movement is left in the original object position (Chomsky, 1983; 1993; 1995; Marantz, 1995). Evidence from cross-modal lexical priming has supported the view that the process of associating the moved element (the *filler*) with its original position (the *gap*) may be absent or delayed in agrammatic aphasia. Some studies show, for example, that in contrast to individuals with Wernicke's aphasia and healthy controls, people with Broca's aphasia do not show evidence of re-activation of the agent at the gap site in subject-relative clauses (e.g. *The gymnast loved the professor_i from the northwestern city who_i _____i complained about the bad coffee*; Zurif et al., 1993). Other studies show, however, that gap-filling effects do occur but are delayed relative to healthy controls, for example, in *wh*-movement structures such as object-relative clauses (Burkhart et al., 2003; Love, Swinney, & Zurif, 2001).

Other recent studies show a different pattern. That is, using eyetracking-while-listening paradigms individuals with agrammatic (Broca's) aphasia show both successful and timely filler-gap processing in *wh*-structures (Dickey, Choy, & Thompson, 2007; Dickey & Thompson, 2009; Thompson & Choy, 2009; also see Blumstein et al., 1998). For example, Dickey et al. (2007) asked participants to listen to stories such as (1) as they viewed visual arrays of four pictures depicting the two participants in the event (e.g., a boy, a girl), the location of the event (e.g., a school), and an unrelated distractor object (e.g., a door).

1. 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.

Following each story, *wh*-questions were presented (e.g. *Who_i did the boy kiss _____i that day at school?*) as their eye movements were tracked. Aphasic participants performed significantly more poorly on the behavioral task than control participants, however they, like healthy control listeners, showed evidence of online gap-filling by looking at the picture depicting the filler (e.g., *girl*) at the gap site (cf. Sussman & Sedivy, 2003). Dickey and

Thompson (2009) found similar patterns for object-relative structures. Interestingly, in both studies gap-filling effects were found for both correctly and incorrectly comprehended sentences; however, when participants responded incorrectly, they often looked at the incorrect picture at sentence end. These findings suggest that poor comprehension of non-canonical sentences seen in agrammatic aphasia is not due to impaired or delayed syntactic processing; rather they suggest that this results from impaired lexical integration, that is, difficulty incorporating the successfully activated filler into the semantic representation of the sentence. This hypothesis is also potentially compatible with the finding that aphasic participants show delayed gap-filling effects in cross-modal priming (Burkhardt et al., 2003; Love et al., 2001). Because gap-filling is mediated by lexical processing, which is delayed in agrammatic aphasia (e.g., Choy, 2010; Choy & Thompson, 2010; Prather, Zurif, Love, & Brownell, 1997; Thompson & Choy, 2009; Yee, Blumstein, & Sedivy, 2008), delayed gap-filling could derive from slowed lexical processing, rather than slowed syntactic processing (cf. Love, Swinney, Walenski, & Zurif, 2008).

Less clear-cut findings, however, have emerged from studies investigating passive sentence structures. According to transformational theories of syntax, these structures involve NP-movement, e.g. in a sentence such as *The boy_i was pushed ____i by the girl*, the theme NP (*the boy*) moves from the post-verbal position to the subject position. However, studies using cross-modal priming have shown that for young normal listeners NP-movement is processed differently from *wh*-movement. Rather than gap-filling effects showing up at the gap site, these effects emerge downstream from the gap, if at all. For example, one of the few studies of passive sentence processing found gap-filling effects 1000ms downstream from the verb (Osterhout & Swinney, 1993). Similar effects have been found in studies examining unaccusative structures, which are hypothesized to involve NP-movement (e.g., *The leaf_i fell ____i*) (Burzio, 1986). Using cross-modal lexical priming, Burkhardt et al. (2003) and Friedmann, Taranto, Shapiro, and Swinney (2008) found gap-filling effects for unaccusatives, but downstream (650–750ms) from the verb, with no priming effects at the gap site. In an eyetracking study, Dickey and Thompson (2009) also failed to find evidence of gap-filling for either unimpaired or agrammatic aphasic listeners for NP-movement sentences. That is, there was no significant increase in looks to the filler object at the gap site or downstream from it. However, these results may have been related to the methodology used in the study. The passive items from Dickey and Thompson (2009) involved both NP- and *wh*-movement (e.g. *Point to who_i was tickled ____i by the bride at the mall*), adding additional complexity to the task.

As Fodor (1993) discusses, there are multiple possible explanations for the fact that passive sentences are processed differently than *wh*-structures. First, the two structures may have different types of syntactic representations, as suggested by Head-Driven Phrase Structure Grammar (HPSG; Sag, Wasow, & Binder, 2003). On this theory *wh*-structures contain gaps (as in transformational theories), however, passive structures are derived via a lexical rule that alters the argument structure of the verb. If this is correct, it could potentially account for the observed processing differences. However, as Fodor points out, it is also possible that the two structures have similar syntactic representations, but are simply processed differently.

The present study investigates online processing of passive sentences in agrammatic aphasic and age-matched control participants using an eyetracking-while-listening paradigm coupled with a sentence-picture matching task (after Stromswold, Eisenband, Norland, & Ratzan, 2002; cf. Hanne, Sekerina, Vasisht, Burchert, & De Bleser, 2011). Stromswold et al. presented healthy adults and children with auditory active or passive sentences (e.g., *The girl was pushing the boy* or *The girl was pushed by the boy*) and images with reversed thematic roles (e.g., a girl pushing a boy; a boy pushing a girl) with instructions to point to

the picture that corresponded with the sentence as their eye movements were monitored. Results showed that, for the passive constructions, adults fixated the correct picture after hearing the verb (i.e., at the gap site, prior to the *by*-phrase), however, the children did not do this until after hearing the entire sentence. These data indicate that adult listeners, but not children, are able to parse and interpret passive sentences as they unfold in real time. More generally, the results show that this paradigm provides detailed information about the processing routines used when people interpret passive and active sentences.

Recently, Hanne et al. (2011) used this paradigm to investigate canonical and non-canonical sentence comprehension in German agrammatic aphasic listeners and healthy controls. As their eye movements were tracked, participants listened to canonical active (subject-verb-object) and non-canonical active (object-verb-subject) German sentences and performed a sentence-picture matching task. As expected, the aphasic participants performed better than chance on canonical sentences but at chance on non-canonical sentences. The eye movement data showed that aphasic listeners had qualitatively similar looking patterns relative to controls on sentences that they interpreted correctly. However, aphasic participants' eye movement patterns diverged from that of controls on trials when they responded incorrectly. Hanne and colleagues interpreted these results as evidence that chance performance on non-canonical sentences stems from different processing routines in correct and incorrect trials, rather than guessing (counter one of the major claims of the Trace Deletion Hypothesis (TDH); Grodzinsky, 1986; 1989; 2000).

The present study tests whether the processing claims of the TDH are borne out for English agrammatic listeners. The TDH proposes that aphasic individuals fail to represent traces of movement, which assign thematic roles to moved noun phrases (NPs). Therefore, in agrammatic aphasia moved NPs cannot be assigned thematic roles through the syntax. In passive sentences (e.g., *The boy was pushed by the girl*), the first noun phrase (NP1: e.g., *the boy*) is assigned the role of agent through a linear, agent-first processing heuristic (cf. Caplan & Futer, 1986), while the second noun phrase (NP2: e.g., *the girl*) is assigned a second agent role by the *by*-phrase, which leads to guessing and chance-level comprehension. It is unclear precisely how this hypothesis translates into predictions for incremental processing. One possibility is that agrammatic listeners exhibit a bias to interpret NP1 as an agent, as has been previously been observed for healthy adult listeners (Kamide, Scheepers, & Altmann, 2003; Knoeferle, Crocker, Scheepers, & Pickering, 2005, although cf. Stromswold et al., 2002). However, unlike controls, aphasic listeners may be unable to revise their initial interpretation of NP1 on the basis of syntactic structure (presumably because traces are deleted). If this were the case, we would expect to see initial looks to the picture in which NP1 is agent, followed by at-chance looks to both pictures at the *by*-phrase, when NP2 is also assigned the agent role. Another possibility is that the agent-first strategy applies only after the syntactic structure is generated. If this were correct, we would expect to see initial at-chance looks to both pictures (as NP1 is not assigned a semantic role by the grammar), followed by increased looks to the correct picture at the *by*-phrase, as NP2 is assigned the agent role. At sentence offset, the default linear strategy would assign the agent role to NP1 as well, resulting in at-chance looks to both pictures. In the present study, we test whether either possible incarnation of the processing predictions of the TDH is borne out.

We also test the alternative hypothesis that impaired sentence comprehension in agrammatic aphasia is due to a deficit in lexical processing and/or lexical integration. This hypothesis predicts that aphasic listeners should fail to exhibit agent-first processing at any point in the sentence. As mentioned above, previous research suggests that an agent-first processing bias is part of intact linguistic processing: healthy listeners tend to immediately interpret NP1 as an agent unless there are disambiguating morphological cues, e.g. case marking in German

(Kamide et al., 2003; Knoeflerle, 2007; Knoeflerle et al., 2005). Such a bias requires the rapid use of a robust statistical generalization (NP1 = agent) in order to facilitate integration. If agrammatic aphasia involves impaired processing and/or integration of lexical representations, as has been previously suggested (Choy, 2010; Choy & Thompson, 2010; Love et al., 2008; Milberg, Blumstein, Katz, Gershberg, & Brown, 1995; Myers & Blumstein, 2005; Prather et al., 1997; Thompson & Choy, 2009; Yee et al., 2008), then we would expect to see *no* agent-first bias in aphasic participants. In addition, if poor comprehension of passives results from frequent lexical integration failure, rather than guessing, we would expect to see evidence of distinct processing routines when lexical integration succeeds relative to when it fails, i.e. different patterns of fixations on correct and incorrect trials (cf. Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Thompson & Choy, 2009).

In addition, we looked for indirect evidence of successful gap-filling in control and aphasic patients in the passive condition. It is important to note that the sentence-picture matching task is not a direct test of gap-filling, as it requires both syntactic processing (i.e., the syntactic association of the filler with the gap) and lexical-semantic integration (i.e., the integration of the filler into the meaning of the sentence). However, we can infer that gap-filling (or an alternative process of building passive syntactic representations) has occurred if the participant reliably fixates the correct picture soon after the gap site (the verb). We expected to see evidence of successful gap-filling and lexical integration in control participants, as in Stromswold et al. (2002). However, we predicted that the aphasic participants would not fixate the correct picture at the gap site, reflecting impaired lexical integration.

Finally, we investigated the time course in which aphasic and control participants reach a final interpretation of passive and active sentences. Recall the findings of Stromswold et al. (2002) that healthy adults identify and correctly interpret passives upon hearing the verb, whereas children only do so at sentence end, suggesting slowed and/or alternative mechanisms for processing passives. The present study tests whether aphasic participants interpret passive and active sentences online, as healthy participants do, or whether they parse and interpret them only at sentence end. Hanne et al. (2011) found evidence of slowed processing of canonical active sentences in agrammatic aphasia; while controls fixated the correct picture immediately after hearing the verb, aphasic listeners did not do so until sentence offset. In addition, in a recent event-related potential (ERP) study, agrammatic listeners, in contrast to healthy controls and individuals with right-hemisphere lesions, showed no online sensitivity to sentence-picture mismatches in passive sentences and delayed sensitivity in active sentences, although they performed above chance in both conditions in an offline behavioral task (Wassenaar & Hagoort, 2007). On the basis of these findings, one might predict that agrammatic participants will parse and interpret passive and actives more slowly than controls, as reflected by at-chance looks to both pictures until sentence end. This would be consistent with a range of studies implicating slowed lexical and/or syntactic processing in agrammatic aphasia (e.g., Burkhardt et al., 2003; Choy, 2010; Hanne et al., 2011; Love et al., 2001; 2008; Prather et al., 1997; Thompson & Choy, 2009; Yee et al., 2008).

2. Method

2.1 Participants

All participants were native English speakers and had normal hearing and vision, and all participants were right-handed, with the exception of one aphasic participant (A2) who was premorbidly left-handed. There were 10 age- and education-matched healthy control participants (4 males) with a mean age of 58.6 (range = 49–77) and no history of

neurological, psychiatric, speech, language, or learning impairments. The aphasic participants were 10 individuals (7 males) with a mean age of 54.6 (range = 36–74). Demographic and language testing data for the aphasic participants are presented in Table 1.1 These participants presented with Broca's aphasia with agrammatism secondary to a single left-hemisphere stroke and were at least six months post-onset. Administration of the *Western Aphasia Battery* (WAB; Kertesz, 2006) indicated mild to moderate severity (mean Aphasia Quotient = 76.0, $SD = 6.0$, range = 66.3–83.2), with fluency scores of 4 or 5 and relatively spared auditory comprehension (Comprehension subtest scores ranged from 7.1 to 10) and object naming (Naming subtest scores ranged from 7.9 to 9.0). In narrative speech, all participants evinced nonfluent output with short utterances (mean MLU = 6.17) and frequent grammatical errors (mean percentage of grammatical sentences: 45.6%). Testing of sentence comprehension ability using the *Northwestern Assessment of Verbs and Sentences* (NAVS; Thompson, experimental version) showed superior performance for canonical sentences (i.e., actives, subject *wh*-questions, and subject-relative clauses) compared to non-canonical constructions (i.e., passives, object *wh*-questions, and object-relative clauses), tested using a sentence-picture matching paradigm with semantically reversible sentences and two-argument, transitive verbs.¹ Pre-testing also showed that all participants were able to read single words.

2.2 Apparatus

An Applied Science Laboratories model D6 eyetracker was employed. The D6 eyetracker consists of a pan/tilt camera and a control unit, sampling at a rate of 60 Hz. Accuracy is within 1 degree, while precision is within half of 1 degree. A chinrest was used to prevent head movements. The visual stimuli were presented on a 19" computer monitor, using Superlab 4 (Cedrus). The auditory stimuli were presented using speakers placed next to the monitor.

2.3 Eyetracking Materials

Forty two-argument verbs were selected (see Appendix).² Frequency data obtained from the Celex database (Baayen et al., 1993) indicated that these verbs occur frequently, with a mean log lemma frequency per million of 1.76 ($SD = .55$). For each verb, active and passive sentences were created (see Table 2). In addition, using each verb, subject cleft (SC) and object cleft (OC) sentences were developed and were included as filler items. All sentences were recorded digitally by a male native English speaker. The sentences had a mean length of 1845 ms ($SD = 249$ ms), with a speech rate of 4.11 syllables per second, which is within the range of normal speech production (e.g., Love et al., 2008; Radeau, Morais, Mousty, & Bertelson, 2000; van Heuven & van Zanten, 2005).

The sentences were organized into two stimulus lists that each included a total of 80 trials, consisting of 20 trials of each sentence type. The first half of each list included all verbs (one sentence per verb); in the second half, each verb was repeated within a different type of sentence structure. Active sentences became OC constructions, or vice versa, whereas passive and SC constructions were exchanged. Thus, each half of the experiment included an equal number of canonical and non-canonical constructions, and each verb appeared in both the active and passive experimental conditions across the two stimulus lists. The gender of the agent was counterbalanced across conditions and stimulus lists. To prevent the gender of the agent from being predictable when a verb was repeated in the second half of the experiment, the agent remained the same on 50% of the trials. In order to prevent the

¹A narrative sample was not obtained for participant 8; NAVS testing data was not obtained for participant 9.

²The verb "hug" was included in the experiment, but was omitted from the analyses because participants from both groups did not consistently select the intended picture, regardless of the condition.

suffixes *-ed* and *-ing* from being associated with non-canonical and canonical constructions, respectively, half of the filler items in both the SC and OC constructions took the form of the present participle.

For each verb, two line drawings were created (see Figure 1 for examples). One drawing depicted an agent performing an action on a theme/patient (e.g., a boy shaving a man), while the second drawing depicted reversed agent and theme/patient roles (e.g., a man shaving a boy). The location of the drawing corresponding to the target sentence was counterbalanced across trials. All picture stimuli were judged by five healthy young volunteers to be clear and unambiguous depictions of the target sentences.

2.4 Procedure

Prior to the eyetracking portion of the experiment, all participants were familiarized with the picture stimuli. For each verb, the two relevant drawings depicting that action were displayed on a computer screen along with the corresponding printed verb for 5 seconds. Participants were asked to read each verb silently, view each set of drawings and indicate to the examiner any action words (or pictures) that they did not understand. None of the participants expressed any difficulty understanding either the words or pictures.

Following the verb and picture familiarization procedure, participants were provided with instructions about the experiment: that they would hear a sentence and see two pictures on each trial, and use a mouse to click on the picture that matched the sentence. Following this, the experiment was begun. In a dimly-lit room, participants' eyes were positioned 55 cm from the stimulus display and eyetracker calibration was established. On each trial, a fixation cross appeared for 3 seconds and when it disappeared, two pictures appeared on the screen. Five hundred milliseconds later, the auditory sentence began. The pictures disappeared when the participant used the mouse to click on one of the pictures, advancing the experiment to the next trial. After a block of 10 trials participants were given a break, following which the eyetracker was recalibrated.

2.5 Data Analysis

Five time regions of interest were identified for each critical sentence (see Table 2). These regions were: (1) Sentence Onset (beginning of the sentence to onset of the first noun (N1)) (2) N1 (onset of N1 to onset of the verb) (3) Verb (onset of the verb to offset of the verb) (4) Post-Verb (offset of the verb to onset of the second noun (N2)) and (5) Sentence Offset (onset of N2 to the end of the trial). To control for the delay associated with the programming and execution of eye movements (see Altmann & Kamide, 2004), each time window began and ended 200ms later than the associated linguistic stimulus.

The proportion of fixations on the target and distractor pictures in each time region was computed, and for each participant average fixation proportions were calculated for each sentence condition. In order to be considered a fixation, participants' eyes were required to remain in the same position for 100ms (six consecutive samples; cf. Dickey & Thompson, 2009). Within each sentence region, we then computed a target advantage score by subtracting the average fixation proportion for the distractor picture from the average fixation proportion for the target picture. Within each sentence region, the target advantage scores were submitted to a one-sample *t* test with a comparison value of 0, which is equal to chance performance.

The crucial regions of interest in the present study were Regions 2, 3–4, and 5. If participants used an agent-first strategy, we expected this to show up as soon as they heard N1 (i.e., Region 2). An agent-first strategy would be reflected by a positive target advantage in the active condition (where this strategy is ultimately successful) and a negative target

advantage in the passive condition (where it is not). On the basis of Stromswold et al. (2002), we expected a positive target advantage to emerge in both conditions immediately at or after the verb (i.e., Regions 3 & 4) for the healthy participants, reflecting rapid lexical integration and in the passive condition, gap-filling. If aphasic participants were also able to perform these operations quickly and accurately, we would expect the same pattern of fixations. However, if agrammatic aphasia were associated with impaired lexical integration processes, as we hypothesized, we would expect to see a delayed (i.e., in Region 5) or even absent emergence of a positive target advantage.

3. Results

3.1 Behavioral Accuracy

The age-matched control participants demonstrated good ability to comprehend both the active and passive sentences, with a mean accuracy rate (proportion of correct responses) of .99 ($SE = .01$) in the active condition and 1.0 in the passive condition. Conversely, the agrammatic participants showed reduced accuracy for both sentence types (active sentence accuracy rate = .74 ($SE = .05$); passive sentence accuracy rate = .60 ($SE = .06$)).⁴ Performance was significantly greater than chance in the active ($t(8) = 5.42, p < .001$), but not the passive, condition ($t(8) = 1.87, p = .10$) and performance was significantly different in the two conditions, with passive sentence comprehension poorer than active sentence comprehension ($t(8) = 2.82, p < .05$).

3.2 Eyetracking

The average target picture advantage scores for each participant group are presented in Figure 2, by sentence condition. In the active sentence condition, age-matched controls did not show a significant preference for one picture over the other in the earliest sentence regions (Regions 1 and 2). A significant target advantage appeared at the verb (Region 3; $t(9) = 3.96, p < .01$) and was maintained through Regions 4 and 5 ($t(9) = 4.96, p < .01$ and $t(9) = 10.41, p < .001$, respectively). In the passive condition, these participants showed at-chance looks to both pictures in Region 1, followed by a negative target advantage starting at N1, i.e., in Regions 2 and 3 ($t(9) = -4.04, p < .01$ and $t(9) = -3.34, p < .01$, respectively). A positive target advantage emerged in Region 4, the Post-Verb region ($t(9) = 6.36, p < .001$) and continued through Region 5 ($t(9) = 13.43, p < .001$). Taken together, these results suggest that the control participants had an agent-first processing bias which was evident in Regions 2 and 3 in the passive condition. There was also a trend in this direction in Region 2 of the active condition, though it did not reach significance until Region 3, where it could also be interpreted as an immediate effect of the verb. Upon hearing the verb, healthy listeners were able to quickly fixate the correct picture, with positive target advantages appearing in Region 3 in the active condition and Region 4 in the passive condition.

The aphasic listeners showed different patterns for both active and passive sentences. In the active sentence condition, they showed at-chance looking patterns until a positive target advantage emerged in Region 5, following mention of the theme ($t(9) = 3.13, p < .05$). In the passive sentence condition, they looked equally often to both pictures throughout the sentence. This suggests first that aphasic participants, unlike controls, did not show an agent-first processing bias. Second, they were slower than controls to fixate the correct picture in the active condition. Finally, they did not show evidence of timely gap-filling and lexical integration at any point in the passive sentences; instead, they exhibited at-chance looks throughout the sentence, consistent with their behavioral performance.

⁴One aphasic participant (A4) did not make any errors within either critical condition.

3.3 Fixations as a Function of Behavioral Accuracy

In order to examine aphasic participants' fixations as a function of behavioral accuracy, we calculated separate target advantage scores for correct and incorrect trials (see Figure 3). For active sentences, a significant target advantage again emerged in Region 5 for correct trials ($t(8) = 6.45, p < .001$). This pattern was similar to, although stronger than, that seen when we examined correct and incorrect trials together. Conversely, for incorrect trials, a significant negative target advantage was seen in Region 5 ($t(7) = -4.66, p < .01$). This suggests that participants did not reach their final interpretations of active sentences until they had heard N2.

In the passive sentence condition, a significant target advantage was seen in Region 5 for correct trials, which was not seen when we examined the data for both correct and incorrect trials together ($t(8) = 6.36, p < .001$). For incorrect trials, a significant negative target advantage emerged in Region 4 ($t(7) = -3.18, p < .05$) and was maintained during Region 5 ($t(7) = -4.56, p < .01$).³ That is, the aphasic participants began to preferentially fixate the incorrect picture during the region that followed the verb, coinciding with their incorrect sentence interpretation. These eye-gaze patterns are consistent with (at least) two possible interpretations. First, aphasic listeners may be unable to parse and interpret passive structures, simply guessing as the sentence nears completion, as predicted by the TDH. Alternatively, they may attempt to parse sentences as passive, but with varying success. We think the second explanation is more likely, for reasons we will discuss below.

4. Discussion

In the present study, we examined eye movement patterns while aphasic and age-matched control participants listened to active and passive sentences. Presented with two pictures with reversed thematic roles, participants were asked to click on the picture that corresponded with the sentence. Whereas control participants performed almost perfectly in both conditions, aphasic participants made consistent errors in both conditions, performing above chance on active sentences and at chance on passive sentences, consistent with previous behavioral studies (see review in Grodzinsky et al., 1999; although cf. Berndt, Mitchum, & Haendiges, 1996).

Eye movement data revealed that healthy control and aphasic participants processed the sentences differently starting from the first noun. Control participants exhibited an agent-first processing bias that emerged immediately upon hearing N1 in the passive condition (Regions 2 and 3), as reflected by initial looks to the picture in which N1 was the agent. There was also a non-significant trend in this direction in the active condition in Region 2 that reached significance in Region 3. This finding is consistent with previous eyetracking studies (Kamide et al., 2003; Knoeferle et al., 2005), as well as some theories of normal sentence processing (e.g. Bever, 1970; Townsend & Bever, 2001). In contrast, aphasic participants showed no online evidence of an agent-first bias at any point in the sentence, counter the predictions of some previous accounts of sentence comprehension in aphasia, including the TDH (Grodzinsky, 1986; 1989; 2000; cf. Caplan & Futter, 1986;). We also saw no evidence of double-agent interpretations, which are also predicted by the TDH. Instead, at-chance looks were noted to both pictures throughout the sentence. These results are consistent with the behavioral findings of Beretta and Munn (1998) suggesting that aphasic listeners do not assign passive sentences two-agent interpretations.

³The behavioral accuracy data for one aphasic participant (A9) were lost due to experimenter error.

The present results raise the question of why aphasic participants did not exhibit an agent-first bias, even though it is characteristic of normal sentence processing. One possibility is that the agent-first bias is absent in agrammatic aphasia because of reduced automatic lexical activation, which has been demonstrated in previous studies (Milberg et al., 1995; Myers & Blumstein, 2005; Yee et al., 2008). The results of Myers and Blumstein (2005) are particularly relevant to the present study. They report that both normal controls and Broca's aphasic individuals exhibit associative semantic priming (e.g., *ball* is processed faster after the associated verb *bounce* than after the unrelated verb *learn*) in a range of environments (single-word priming, sentences, and ungrammatical sentences). Controls also exhibit priming in all environments on the basis of thematic role processing: *ball* is processed more quickly following verbs that could select it as an object (e.g., *move*) than verbs that do not (e.g., *learn*). However, aphasic individuals only show this kind of priming in a subset of environments (single-word priming and sentences). Myers and Blumstein interpret these findings as evidence for reduced lexical activation in aphasia, in particular of the lexical-semantic generalizations that underlie thematic role assignment. One such generalization is that sentence subjects tend to be agents. If aphasic listeners do not activate lexical generalizations of this sort while processing sentences, it could account for the absence of an agent-first bias in the present study. A second possibility is that aphasic individuals do activate and use this generalization, but they do so more slowly than healthy controls – too slowly for its effects to appear online under normal conditions. Slow emergence of an agent-first bias could result from slowed lexical activation (Choy, 2010; Choy & Thompson, 2010; Love et al., 2008; Prather et al., 1997; Thompson & Choy, 2009; Yee et al., 2008) and/or lexical integration (Choy, 2010; Thompson & Choy, 2009). The predictions of these two hypotheses could be tested in future research. The delayed lexical processing hypothesis predicts that agrammatic listeners would exhibit an agent-first bias given sufficient time to do so, e.g. if the linguistic stimuli were produced with a slower speech rate and/or pauses between words. In contrast, the reduced activation hypothesis predicts that an agent-first strategy would never emerge for aphasic listeners.

After an initial agent-first bias, age-matched control participants fixated the correct picture upon or immediately after hearing the verb in both conditions. These results are consistent with the findings of Stromswold et al. (2002) and Hanne et al. (2011), indicating that unimpaired adult participants are capable of quickly using morpho-syntactic cues (i.e., verb morphology) to parse and interpret passive and active sentences. We can thus conclude that both gap-filling (or a comparable syntactic process) and lexical integration occur rapidly in healthy control participants.

The aphasic listeners showed markedly different eye movement patterns from the controls in both conditions. In the passive condition, the agrammatic participants did not show a significant target advantage in any sentence region, in line with their at-chance behavioral performance. In contrast with some previous eyetracking studies (Dickey et al., 2007; Thompson & Choy, 2009), we saw no evidence of online gap-filling. This was not surprising, given that in the present study eye movements reflected not only gap-filling, but also lexical integration. One possible explanation of the aphasic participants' eye movement data is that they are unable to generate accurate syntactic representations of passive sentences and resort to guessing, as claimed by the TDH. However, the analysis of fixations by behavioral performance suggests a more nuanced account. We found that when participants chose the correct picture, a positive target advantage emerged only at the end of the sentence (Region 5). However, when they chose the incorrect picture, a negative target advantage emerged immediately following the verb (Region 4). It is thus likely that two different processing mechanisms underlie correct and incorrect interpretations of passive sentences (cf. Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011; Thompson & Choy, 2009). Specifically, we hypothesize that successful

lexical integration, which results in correct “non-canonical” interpretations of passive sentences (NP1 = theme), is generally *slower* than unsuccessful lexical integration, which leads to incorrect “canonical” responses (NP1 = agent). This account is consistent with the results of a recent eyetracking study of passive syntactic production in agrammatic aphasia (Cho & Thompson, 2010). In this study, participants heard and then repeated passive “prime” sentences and were then presented with a two-participant scene (e.g., a woman poking a man) and asked to produce a sentence with the same structure as the prime. Cho and Thompson reported that participants were slower to plan correct passive responses (e.g., *The man is poked by the woman*) than incorrect active responses (e.g., *The woman is poking the man*), as reflected by longer speech-onset latencies and gazes to the first participant (N1) in passive responses. This suggests that aphasic listeners generate canonical sentence structures more quickly than non-canonical ones, even when the non-canonical structure is correct. This is consistent with our hypothesis that the relatively early negative target advantage on incorrect trials reflects a fast but erroneous “canonical” interpretation of the sentence, whereas the late positive target advantage in correct trials reflects the slow but successful construction of a non-canonical passive representation.

While listening to active sentences, aphasic listeners exhibited a delayed pattern of fixations relative to controls, with a target picture advantage occurring only in the sentence-final region. This is consistent with several studies suggesting that agrammatic aphasia is associated with slowed lexical and/or syntactic processing (Burkhart et al., 2003; Choy, 2010; Choy & Thompson, 2010; Hanne et al., 2011; Love et al., 2001; 2008; Prather et al., 1997; Thompson & Choy, 2009; Wassenaar & Hagoort, 2007; Yee et al., 2008). However, it is not possible using a sentence-picture matching task to pinpoint the source of the delay because this task requires both syntactic and lexical-semantic processing. Nevertheless, this finding coupled with those of previous eyetracking studies (e.g., Choy, 2010; Choy & Thompson, 2010; Dickey et al., 2007; Dickey & Thompson, 2009; Thompson & Choy, 2009; Yee et al., 2008) is compatible with a slowed lexical access and/or lexical integration account of sentence comprehension deficits.

To conclude, the present study contributes to our understanding of how aphasic listeners process sentences online, with the results consistent with the hypothesis that impaired lexical processing is involved in comprehension deficits. It also raises many questions for future research, in particular how to more precisely pinpoint the processing mechanisms involved when aphasic listeners interpret passive sentences correctly and incorrectly.

Highlights

- > We used eyetracking to study passive sentence comprehension in agrammatic aphasia.
- > Aphasic and control participants performed a sentence-picture matching task.
- > Controls exhibited agent-first processing; aphasic participants did not.
- > Controls reached correct interpretations at the verb; aphasic participants did not.
- > Impaired passive comprehension in aphasia may stem from lexical processing and/or lexical integration deficits.

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Appendix

Verb Stimuli

Items	
Bury	Pinch
Call	Poke
Capture	Pull
Carry	Punch
Chase	Roll
Clean	Save
Cover	Scold
Distract	Serve
Dry	Shave
Examine	Shove
Follow	Tackle
Grab	Tickle
Greet	Touch
Help	Visit
Kick	Wash
Kiss	Watch
Lift	Weigh
Paint	Wrap
Pat	Squeeze
Pay

Figure 1.
Example of picture stimuli from a critical trial. The verb used with these pictures was *shave*.

Figure 2. Mean target advantage for each group (age-matched control, aphasic), by condition (active, passive) and sentence region. Asterisks denote a significant positive or negative target advantage, i.e., tendency to fixate the correct (positive) or incorrect (negative) picture.

Figure 3. Mean target advantage for aphasic participants, by behavioral accuracy (correct, incorrect), condition (active, passive), and sentence region. Asterisks denote a significant positive or negative target advantage, i.e., tendency to fixate the correct (positive) or incorrect (negative) picture.

Table 1

Demographic and Language Testing Data for Aphasic Participants

Participant	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Age	36	61	48	74	53	57	38	53	63	62
Gender	M	M	F	F	M	M	M	M	M	F
Education (Years)	16	19	17	14	20	18	16	12	16	19
Years Post-Onset	3	19	3	4	8	1	0.6	4	6	6
Western Aphasia Battery										
Fluency	4	4	5	4	5	4	5	5	4	4
Comprehension	7.4	9.5	9	9.2	10	7.1	9.7	8.6	9.5	7.9
Repetition	6.3	5	9	9	9.6	7.8	8.1	6.4	9.4	8.2
Naming	7.9	8.5	8.4	8.5	9	6.3	8.5	8.1	9	8.1
Aphasia Quotient	69.2	69.9	80.8	79.3	83.2	66.3	80.6	74.1	81.8	74.4
Sentence Comprehension (Percent Correct)										
Canonical	64	90	67	100	77	64	62	74	na	87
Non-canonical	51	59	39	84	64	42	54	53	na	39
MLU (Words)	2.29	4.65	2.26	7.0	9.56	7.26	7.27	na	7.97	7.26
Grammatical Sentences (Percentage)	29	23	17	75	75	75	57	na	47	12

Table 2

Sentence Regions

	Region 1 (Sentence Onset)	Region 2 (NI)	Region 3 (Verb)	Region 4 (Post-Verb)	Region 5 (Sentence Offset)
Active Condition	The	man was	shaving	the	boy.
Passive Condition	The	man was	shaved	by the	boy.