Published in final edited form as:

Aphasiology. 2013 ; 27(10-12): 1408–1425. doi:10.1080/02687038.2013.843151.

Effects of Verb Bias and Syntactic Ambiguity on Reading in People with Aphasia

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Abstract

Background: The Lexical Bias Hypothesis (Gahl, 2002) claims that people with aphasia have difficulty understanding sentences when the verb's argument structure bias conflicts with the sentence structure. This hypothesis can account for comprehension deficits that affect simple sentences, but the role of verb bias has not been clearly demonstrated in temporarily ambiguous sentences.

Aims: This study examined how verb bias affects comprehension of temporarily ambiguous and unambiguous sentences using self-paced reading.

Methods & Procedures: People with aphasia and controls read sentences that contained sentential complements (e.g., The talented photographer accepted (that) the fire could not have been prevented.). The main verb was biased to take a direct object (e.g., accepted) or a sentential complement (e.g., admitted). In addition, the sentential complement was either introduced by the complementizer *that* (i.e., unambiguous) or unmarked (i.e., ambiguous).

Results: The people with aphasia's reading times were affected more by verb bias than by the presence of the complementizer, whereas the control group's reading times were more affected by the presence or absence of the complementizer.

Conclusions: The results were generally consistent with the Lexical Bias Hypothesis, and showed that a mismatch between verb bias and sentence structure affected processing of unambiguous and temporarily ambiguous sentences in people with aphasia.

Keywords

Reading comprehension; temporary syntactic ambiguity; aphasia; Lexical Bias Hypothesis

INTRODUCTION

There is a lot of evidence that people with aphasia (PWA) have difficulty understanding sentences that violate the English preference for Subject-Verb-Object (SVO) word order (e.g., Caplan, Waters, DeDe, Michaud, & Reddy, 2007). However, recent evidence suggests that comprehension impairments also affect simple transitive and intransitive sentences (e.g., DeDe, 2013; Gahl, 2002). The Lexical Bias Hypothesis (Gahl, 2002) provides a possible account for why PWA have difficulty understanding both simple and complex sentences. According to this hypothesis, PWA have trouble understanding sentences when the sentence structure conflicts with the lexical biases of the words in the sentence. The purpose of this study was to further examine the extent to which the Lexical Bias Hypothesis accounts for comprehension impairments in PWA.

Lexical biases are determined by statistical regularities within the language. These statistical regularities, which are sometimes called probabilistic cues or constraints, include the frequency of specific structures and lexical items and the contexts in which words commonly occur. There is substantial evidence that these cues influence the computation of sentence structures (i.e., syntactic parsing) in non-brain-damaged populations (e.g., DeDe, 2010; Garnsey, Pearlmutter, Myers, & Lotocky, 1997; MacDonald et al., 1994; Pickering & Van Gompel, 2006; Trueswell & Tanenhaus, 1994),¹ but little is known about how PWA use probabilistic cues.

Investigations of the Lexical Bias Hypothesis have focused on how one cue, verb transitivity bias, affects comprehension of simple active sentences in PWA (DeDe, 2013; Gahl, 2002; Gahl et al., 2003). Verb transitivity bias refers to the likelihood that an optionally transitive verb will occur in either transitive (SVO) or intransitive (SV) sentences. Gahl and colleagues found that PWA made more incorrect plausibility judgments about auditorily presented sentences in which the structure did not match the verb's argument structure preferences (Gahl, 2002; Gahl et al., 2003). In a follow-up study, DeDe (2013) used self-paced reading to investigate whether this type of mismatch affected on-line processing of simple transitive and intransitive sentences. PWA read more slowly and made more comprehension errors when the verb's transitivity bias did not match the sentence structure. This mismatch effect was more robust when a transitively biased verb occurred in an intransitive sentence than when an intransitive verb occurred in a transitive sentence. Taken together, these studies suggest that verb biases affect comprehension of structurally simple sentences in the written and spoken modalities, and that the type of sentence structure matters.

Verb bias is one type of probabilistic cue, but there are a lot of different cues in language. Thus, it is important to understand how different cues interact with one another during sentence comprehension. This issue can be addressed by examining how people process syntactically ambiguous sentences. Syntactically ambiguous sentences contain at least one constituent with more than one possible structural interpretation. For example, consider a sentence such as "*While the parents watched(,) the child sang a song.*" When a comma is inserted after the subordinate verb *watched*, the ambiguous noun phrase *the child* is clearly the subject of a new clause. However, when the comma is omitted, *the child* is temporarily ambiguous because it could also be the object of the subordinate verb, *watched*.

In a self-paced listening study, DeDe (2012) examined how lexical and prosodic cues interact in PWA's on-line comprehension of sentences with early closure ambiguities (e.g., *While the parents watched/danced the child sang a song.*). The lexical cues were verb transitivity bias and plausibility: The subordinate verb was either transitively (*watched*) or intransitively (*danced*) biased. In addition, the noun phrase following the subordinate verb was a plausible object for the transitive verbs but an implausible object for the intransitive verbs (i.e., *watched the child* vs. *danced the child*). Finally, the sentences were produced with and without an "auditory comma" marking the subordinate clause boundary. The PWA were sensitive to the presence of conflicting lexical and prosodic cues in syntactically ambiguous sentences. The PWA also showed relatively long listening times whenever the cues were biased away from the direct object interpretation of the ambiguous noun phrase (*the child*), suggesting that they were sensitive to the relative frequency of SVO structures in

¹Note that this study focuses on syntactic parsing, which plays a critical role in building a mental representation of the sentence and determining who did what to whom. In contrast, the grammar can be considered a description of which structures are grammatical or ungrammatical within a language. To the extent that the grammar is viewed as psychologically real, the parser may use grammatical knowledge as one of the possible sources of information in making parsing decisions (e.g., Fodor, 1989).

English. However, the exact role of verb bias was somewhat unclear because verb transitivity and plausibility were manipulated together.

Taken together, the existing research suggests that PWA are sensitive to verb transitivity bias, and that there is a general preference for SVO structures. These findings are consistent with the Lexical Bias Hypothesis, but it is unclear whether PWA use verb bias in the same way as controls when more than one cue is manipulated. The present study extended the Lexical Bias Hypothesis by asking whether PWA rely on verb bias to a greater extent than another type of cue, namely the syntactic cues communicated by the complementizer *that*. This syntactic cue was chosen because it is a highly reliable cue for non-brain-damaged individuals (e.g., Garnsey et al., 1997).

To address this question, the present study focused on another type of temporarily ambiguous structure, namely the direct object/sentential complement ambiguity. Consider examples (1) and (2):

1. Direct Object Biased Verb:

The talented photographer accepted (that) the fire could not have been prevented.

2. Sentential Complement Biased Verb:

The ticket agent admitted (that) the airplane had been late taking off.

Sentences (1) and (2) both contain sentential complements (underlined). These sentences are unambiguous when the sentential complement is introduced by the complementizer *that*, but temporarily ambiguous when the complementizer is omitted. In the ambiguous condition, the noun phrase following the main verb (e.g., *the fire*) could be interpreted as the direct object of the main verb or the subject of a sentential complement. The embedded verb is the point in the sentence at which the correct interpretation becomes clear, known as disambiguation. When parsing sentences such as (1) and (2), readers who interpret the ambiguous noun phrase as the object of the main verb must do some sort of reanalysis at the embedded verb to identify its subject. Evidence of processing disruptions (e.g., longer reading times) at the disambiguating segment is generally taken as evidence that participants had to reinterpret the ambiguous noun phrase.

Garnsey et al. (1997) manipulated several probabilistic cues to investigate how college age adults parse sentences containing sentential complements, like those in (1) and (2). First was whether the sentence was ambiguous (i.e., presence vs. absence of *that*). Second, the main verbs were biased to take a sentential complement (SC), a direct object (DO), or were not strongly biased to occur in either frame (Equi). For example, verbs such as “*accept*” are more frequently followed by a DO than a SC. In contrast, verbs such as “*admit*” are more frequently followed by a SC than a DO. The equi-biased verbs were not strongly biased to occur in DO- or SC- frames (e.g., *concede*). Thus, in the examples above, the main verb is in its preferred frame in (2) but not (1). Finally, Garnsey et al. manipulated whether the ambiguous noun phrase was a plausible object for the main verb. For example, “*airplane*” is an implausible object for “*admit*,” whereas “*mistake*” is a plausible object.

Both structural ambiguity and verb bias influenced self-paced reading times for college students (Garnsey et al., 1997). First, the presence of the complementizer disambiguated the sentence for controls: Reading times were longer for *that* in unambiguous sentences with DO- compared to SC- biased verbs. However, there were no effects of verb bias, ambiguity, or plausibility at any other point in the unambiguous sentences. Second, plausibility of the ambiguous noun phrase was most important when verb biases were weak. For example,

reading times for the ambiguous noun phrase were longer in ambiguous than unambiguous sentences in sentences with strongly DO- or SC- biased verbs, regardless of plausibility. Third, recovery from ambiguity was relatively easy when the main verb was biased toward the correct interpretation of the sentence. At the point of disambiguation, reading times were longer in ambiguous than unambiguous sentences with DO-bias, but not SC-bias, verbs.

The Present Study

The present study used self-paced reading to investigate how verb bias and structural ambiguity affect on-line sentence comprehension in PWA. The materials were a subset of those used by Garnsey et al (1997), because that study documents that these materials are sensitive to the critical effects in young adults. Only verb bias and structural ambiguity were manipulated because Garnsey et al. (1997) found no effects of plausibility in sentences with strongly biased main verbs.

The Lexical Bias Hypothesis does not generate clear predictions regarding how PWA will use the complementizer, or how ambiguity and verb bias will interact during sentence processing. However, the presence of the complementizer is arguably the strongest cue that the sentence contains a sentential complement. Thus, the key question is whether PWA will show effects of verb bias in both ambiguous and unambiguous sentences.

If PWA use all types of lexical cues, then they might show normal ambiguity effects. A study by Dickey, Milman, and Thompson (2008) suggests that people with agrammatic aphasia will be sensitive to the presence of the complementizer. In their study, people with agrammatic aphasia made speeded grammaticality judgments about sentences with sentential complements. Although the agrammatic individuals made more errors than the controls overall, the results suggested that comprehension of complementizers was relatively intact. This type of finding suggests that PWA and controls will show similar ambiguity effects.

There is also reason to expect that PWA will have trouble processing syntactic cues from function words such as *that*. Several early studies demonstrated that PWA process function words differently than non-brain-damaged controls (e.g., Friederici, 1985; Grossman, Carey, Zurif, & Diller, 1986; Rosenberg, Zurif, Brownell, Garrett, & Bradley, 1985; Swinney, Zurif, & Cutler, 1980). For example, Rosenberg et al. (1985) asked people with aphasia to cross out target letters in written passages. Both healthy controls and people with Wernicke's aphasia missed more target letters when they occurred in closed-class words (e.g., "t" in "*but*" vs. "*bat*"). In contrast, people with agrammatic Broca's aphasia showed no difference in error rates for open- and closed-class words. A more recent series of studies reported that people with Broca's aphasia showed delayed or reduced electrophysiological responses to grammatical class when compared to healthy controls (ter Keurs, Brown & Hagoort, 2002; ter Keurs, Brown, Hagoort & Stegeman, 1999, also cf. Park, McNeil, & Doyle, 2002). However, these studies did not distinguish complementizers from other types of function words. This is important because Dickey et al. (2008) suggested that people with aphasia's responses may differ depending on the type of function word.

Predictions

Garnsey et al.'s (1997) results suggest that the critical measure is reading times for the disambiguating region of the temporarily ambiguous sentences. For healthy controls, reading times for this part of the sentence were predicted to be relatively long in ambiguous sentences with DO-biased verbs compared to the other conditions. For PWA, the Lexical Bias Hypothesis clearly predicts longer reading times for this segment in ambiguous sentences with DO- versus SC-biased verbs. If PWA have difficulty processing the

complementizer, then they may also read the disambiguating region more slowly in unambiguous sentences with DO- compared to SC- biased verbs. An alternative hypothesis is that PWA are as sensitive to the presence of the complementizer as controls, in which case the two groups would likely show the same basic pattern of reading times for the disambiguating segment.

Finally, reading times for the complementizer (*that*) and ambiguous noun phrase (*the fire/the airplane*) may be informative with respect to identifying when PWA and controls first show sensitivity to the manipulations of ambiguity and verb bias.

METHOD

Participants

The University of Arizona Institutional Review Board for human subjects' protection approved this study. Ten PWA (mean age= 49 years) and ten non-brain-damaged controls (mean age= 50 years) participated.² One person with aphasia (P09) was omitted because her reading times were greater than 3 standard deviations above the mean for all other participants in all conditions. All participants were native English speakers and reported p or corrected-to-p vision. Non-brain-damaged participants reported no history of speech language disorders, reading impairments, or diseases affecting the central nervous system. They scored at least 28 out of 30 points on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975).

A speech language pathologist diagnosed participants with aphasia based on an extensive testing battery. Previous studies investigating the Lexical Bias Hypothesis (e.g., DeDe, 2013; Gahl, 2002; Gahl et al., 2003) have not reported significant differences in sentence comprehension as a function of aphasia type. For this reason, participants with aphasia were included if they demonstrated adequate reading and auditory comprehension at the lexical level (to minimize the contribution of profound deficits in word-level-comprehension). The PWA performed within two standard deviations from the mean for age-matched controls on the Peabody Picture Vocabulary Test, which tests single word comprehension in the auditory modality (PPVT, 4th Edition, Form A) (Dunn & Dunn, 2007). Written word comprehension was assessed with the Lexical Decision and Word Picture Matching subtests on the Psycholinguistic Assessment of Language (PAL) (Caplan, 1992). All participants achieved at least 88% on the PAL Written Word Picture Matching subtest, showing that they did not have significant impairments in written word processing. Confrontation naming was assessed with the Boston Naming Test (BNT) (Kaplan, Goodglass, & Weintraub, 2001). All of the PWA performed two standard deviations below the mean for age- and education-matched controls (Tombaugh & Hubley, 1997). Finally, proportion correct on comprehension questions about written transitive and intransitive sentences provided a measure of reading comprehension. For examples, see sentences 3 and 4 in Table 4. On this measure, all of the PWA scored above chance on the binomial distribution. Results of these tests and additional background information are presented in Table 1.

All participants with aphasia except P10 completed the short form of the Boston Diagnostic Aphasia Exam (Goodglass, Kaplan, & Barresi, 2000; See Table 2). P10 earned an Aphasia Quotient of 94.8 on the Western Aphasia Battery, which is above the typical cut off for aphasia. He was included in the study because he presented with anomia on the BNT (see above) and in conversational speech. He also performed more poorly than controls on the Northwestern Naming Battery and on non-canonical sentences on the Sentence Production

²These participants were also reported in DeDe (2013).

Priming subtest of the Northwestern Assessment of Verbs and Sentences (see below). Taken together, the data suggest that he had very mild aphasia.

The Northwestern Naming Battery was used to assess naming of verbs and nouns (Thompson, Lukic, King, Mesulam, & Weintraub, 2012). Comprehension and production of sentences with non-canonical and canonical word order were assessed with the Sentence Comprehension and Sentence Production Priming subtests of the Northwestern Assessment of Verbs and Sentences (Cho-Reyes & Thompson, 2012). These tests can be used to identify individuals with agrammatic symptoms, which is potentially of interest because this subgroup has been reported to show distinct patterns of sentence comprehension ability on some types of structures (e.g., Grodzinsky, 2000; Thompson & Choy, 2009). Ratios less than 1 are consistent with a diagnosis of agrammatic comprehension or production.

Stimuli

The stimuli were a subset of those used in Garnsey et al. (1997). Examples were given in (1) and (2) and are repeated below as (3) and (4).

3. Direct Object Biased Verb:

The talented photographer/ accepted/ (that)/ the fire/ could not/ have been/ prevented.

4. Sentential Complement Biased Verb:

The ticket agent / admitted/(that)/ the airplane/ had been/ late/ taking off.

5. Example Comprehension Question: Did the photographer accept something?

There were a total of 64 experimental sentences, divided into four conditions. All of the experimental sentences contained sentential complements. The main verb was either biased to take a direct object ($n=16$) or a sentential complement ($n=16$). Each sentence occurred both with and without the complementizer *that*. Recall that Garnsey et al. (1997) reported that plausibility did not affect reading times for the critical segments (i.e. the ambiguous noun phrase and disambiguation) when the main verb was strongly DO- or SC- biased. Given that the focus of this study was on verb bias and ambiguity, and to minimize the number of experimental conditions, plausibility was not manipulated in this study. For this reason, the noun phrase that followed the main verb was always implausible as a direct object. The fact that the noun phrase was implausible for sentences with both DO- and SC-biased verbs, together with the results of Garnsey et al.'s (1997) study, means that differences in reading times likely reflect verb bias rather than plausibility. The full set of materials can be found in Appendix B of Garnsey et al. (1997).

Garnsey et al. (1997) presents a detailed description of the procedures involved in norming the stimuli. Verb bias and plausibility norms were obtained through a series of pilot studies. To obtain verb biases, Garnsey et al. asked college-age students to complete sentence fragments (e.g., Debbie remembered...). Verbs were classified as DO-biased if they were used in DO-contexts at least twice as often as SC-contexts. SC-biased verbs were used twice as often in SC-contexts as DO-contexts. Plausibility norms were obtained from college age students, who rated sentences such as "*The talented photographer accepted the fire*" on a 7-point scale (7= plausible). Plausibility ratings for the subset of items used in the present study did not significantly differ due to sentence type, $t(30)=1.14$, $p=.26$ (DO: mean = 2.9, range 1.9-4.24; SC: mean=2.6, range 1.74-3.87). Both the verbs and nouns were matched for length across the two lists (t 's = 1.1, p 's = .29). The critical verbs were also matched for

frequency, $t(30)=1.37$, $p=.18$. The frequency of the subset of nouns used in this study differed for sentences with SC- and DO-biased verbs, $t(30)=2.6$, $p=.01$.

Task

Self-paced reading was used to measure on-line written sentence processing. The sentences were broken into segments as indicated in examples (3) and (4). At the beginning of each trial, a “Ready?” prompt appeared on the screen. Next, a series of dashes (–) marking the length and position of the words in the sentence appeared on the screen. The participant pressed a button to reveal the first segment of the sentence. On each successive button press, the visible segment reverted to dashes and the next segment appeared. A yes/no comprehension question followed each sentence (see example 5). The questions were designed to ensure that the participants were reading for comprehension, and targeted information presented in the main clause or the sentential complement. Comprehension questions were presented auditorily and visually to reduce memory demands. Participants indicated a “Yes” or “No” response by pressing buttons on a button box. Button presses were made on an E-prime button box interfaced with a computer (Psychology Software Tools, Pittsburgh, PA). The button box recorded reaction times to request each segment and accuracy of comprehension question response.

Procedures

The stimuli were divided into 2 lists so unambiguous (*that* included) and ambiguous (*that* omitted) versions of the same sentences were separated. Each list contained an equal number of sentences with sentential complement and direct object biased verbs. There were a total of 112 sentences in each list (32 experimental stimuli and 80 fillers), so the experimental items comprised less than 30% of the items in the list. It is critical to include fillers so that participants do not develop an expectation for any given sentence type. The fillers consisted of items from other, unrelated experiments, and included active transitive and intransitive sentences ($n=56$), and object and subject cleft sentences ($n=24$). Examples are given in Table 4. The full set of materials, including fillers, is available from the author upon request. Presentation order was pseudo-randomized, with the constraint that no more than two sentences of the same type occurred in succession. Each list was preceded by ten practice items, and contained a break at the halfway point.

All participants completed both lists in separate testing sessions, which were at least 7 days apart. Order of list presentation was counterbalanced across participants. Each session, participants completed one experimental list and tests from the battery described above. Participants were offered breaks between each task. Testing sessions lasted approximately 1½ hour.

RESULTS

The independent variables were group (PWA vs. controls), ambiguity (*that* included vs. omitted), and verb bias (sentential complement (SC) vs. direct object (DO) biased). The dependent variables were proportion correct on the comprehension questions and reading times for critical segments. The data were analyzed in mixed analyses of variance (ANOVA) by participants (F1) and items (F2). Significant effects were explored using Tukey post-hoc tests using a criterion of $p<.05$. Trends were operationalized as p -values greater than .05 but less than .10. Only effects that were significant in the participants or items analysis are presented.

Yes-No Comprehension Questions

Table 5 presents the accuracy data for each individual with aphasia and each group. PWA made more errors than controls, $F(1,17)=29.8$, $p<.0001$, $F(1,30)=227.8$, $p<.0001$, $\eta^2=.55$. The main effect of ambiguity, and the interaction between ambiguity and group, were significant by participants [ambiguity: $F(1,17)=5.95$, $p=.03$, $F(1,30)=2.82$, $p=.10$, $\eta^2=.01$; ambiguity $\times$ group: $F(1,17)=4.32$, $p=.053$, $F(1,30)=2.82$, $p=.10$, $\eta^2=.01$]. Inspection of the means suggested that there were more errors about sentences in the ambiguous condition, and that the difference was greater in PWA than non-brain-damaged controls.

Reading times

Overview—The measure of on-line sentence processing was the reading time for the critical segments: the point of disambiguation, the ambiguous noun phrase, and the complementizer *that*.

Items associated with incorrect responses on the comprehension questions were omitted from the analyses. Raw response times were log transformed and trimmed to improve the fit of the data to a p distribution. Given the variability in the response time data, extreme values were identified based on visual inspection of a p probability plot of each participant's data. In addition, outliers greater or less than two standard deviations from the mean for each participant in each condition were replaced with the value of the upper or lower limits for that condition. These procedures affected 4% of the data.

Critical segments in the sentences containing SC- and DO- biased verbs differed in length. The variance associated with length was controlled by regressing raw reading times against the number of letters in the segment, separately for each participant (Ferreira & Clifton, 1986). In addition, the frequency of the ambiguous noun phrase was included in the regressions for the analysis of that phrase because frequency differed as a function of sentence type (see methods section).³ The residuals of the regression analyses were used in the ANOVAs. This procedure results in negative reading times when the observed reading times are faster than the predicted reading times.

Variance ratios were calculated to determine whether the assumption of homogeneity of variance was met. The maximum variance ratio for the omnibus ANOVA was 28.6, which exceeds Tabachnick and Fidell's (2001) criterion of 10. Separating the analyses by segment resulted in a variance range of 4.8-13.2. Separate ANOVAs by segment and group had a variance range of 1.2-7.6. Thus, residual reading times were analyzed in repeated 2 (ambiguity) by 2 (verb bias) ANOVAs separately for each segment and group. For the PWA, 4 items were dropped from the F2 analysis because fewer than 2 of the PWA answered the associated comprehension questions correctly.

Results are presented in the order that the words occur in the sentences. Figure 1 presents reading times for each condition and group.

Complementizer (that)—Reading times for the complementizer in unambiguous sentences were analyzed in a one-way ANOVA with verb bias as the independent variable. The PWA showed no significant effects of verb bias ($F < 1$, *DO*: -7.0 ms, *SC*: 10.7 ms). In contrast, the control group read *that* more quickly after SC- compared to DO- biased verbs,

³Another set of analyses was run to control for the plausibility of the noun as a direct object for the main verb. This was accomplished by including the plausibility ratings in the regression analyses. The pattern of significance for the PWA and controls was identical to the results reported here.

though the effect was only significant in the analyses by participants, $F(1, 9)=7.86$, $p=.02$, $F(1,31)=1.72$, $p=.20$, $\eta^2=.49$ (DO : 48.3 ms, SC : -53.0 ms).

Ambiguous Noun Phrase (The fire/ The airplane)—For PWA, the interaction of ambiguity and verb bias was marginally significant by participants, $F(1, 8)=5.32$, $p=.05$, $F(1,26)=2.21$, $p=.20$, $\eta^2=.13$. Reading times were longer for ambiguous than unambiguous sentences in the DO -bias condition, but did not differ in the SC -bias condition.

For the non-brain-damaged controls, there was a significant effect of ambiguity, $F(1,9)=7.49$, $p=.02$, $F(1,30)=5.54$, $p=.03$, $\eta^2=.27$. Reading times were longer in ambiguous than unambiguous sentences. There were no other significant effects (all F 's < 2.7 , all p 's $> .13$).

Disambiguation (Could not/ Had been)—PWA read more slowly in sentences with DO - than SC -bias verbs, $F(1,9)=66.25$, $p<.001$, $F(1,26)=8.76$, $p<.01$, $\eta^2=.44$.

Non-brain-damaged controls read the disambiguating region more slowly in ambiguous than unambiguous sentences, but the effect was only significant by participants, $F(1,9)=9.88$, $p=.01$, $F(1,30)=3.47$, $p=.07$, $\eta^2=.07$. There were no other significant effects (all F 's < 2.4 , all p 's $> .15$).

Interim Summary—The results point to an interesting difference between the control group and the PWA. The control group's reading times seem to be most affected by the presence or absence of the complementizer. In contrast, the PWA's reading times seemed to be most affected by verb bias. To explore this finding, individual cases were analyzed to determine whether the effects of ambiguity and verb bias differed in PWA and controls.

Analyses of Individual Case Data (PWA Only)

Individual reading times at the disambiguating segment were analyzed to test the hypothesis that verb bias influenced reading times to a greater extent in PWA than controls. The disambiguating segment was chosen because it was the critical segment (cf. Garnsey et al., 1997). The Bayesian Standardized Difference Test (BSDT) compares an individual's responses in two conditions, such as the effects of verb bias and ambiguity, to the same difference in the control group (Crawford, Garthwaite, & Wood, 2010). Significant results means that the difference in the single case is greater than would be expected based on the normative group.

The main effects of ambiguity and verb bias were estimated using difference scores. The main effect of ambiguity was calculated by subtracting reading times in the unambiguous (*that* included) condition from the ambiguous (*that* omitted) condition, collapsing across verb bias. The main effect of verb bias was calculated by subtracting reading times in the SC -bias condition from the DO -bias condition, collapsing across the unambiguous and ambiguous conditions.

Figure 2 presents the difference scores for each individual with aphasia and average difference scores for the non-brain-damaged controls. Inspection of the difference scores for the non-brain-damaged controls suggested that the effect of ambiguity was somewhat larger than the effect of verb bias, but the difference was not significant, $t(9)=.32$, $p=.75$.

Seven of the nine PWA showed a larger effect of verb bias than complementizer. Four of these participants (P02, P03, P06, & P10) showed a significantly greater difference than would be expected based on the control group. This pattern of results is consistent with the claim that verb bias had a greater effect on the PWA than the control group.

The two remaining participants (P04, P08) showed the same general pattern as the control group: a larger effect of ambiguity than verb bias. P04 (but not P08) showed a significantly greater difference between the two effects than the control group did. This participant also had negative difference scores for both effects, indicating that his reading times were longer in the unambiguous than ambiguous condition, and in sentences with SC- than DO-bias verbs. Inspection of P04's raw data revealed that his reading times for sentences containing DO-bias verbs showed the expected pattern: they were longer for ambiguous than unambiguous sentences. The opposite pattern was observed in sentences with SC-bias verbs. Reading times were longer in the unambiguous than ambiguous condition. Although this pattern is somewhat surprising, it suggests that both ambiguity and verb bias influenced his reading times.

The data were also inspected to determine whether there were clear patterns of performance related to aphasia type. Consider participants P2, P5, and P8, all of whom have non-fluent aphasia and symptoms consistent with agrammatism. Both P2 and P5 showed a greater effect of verb bias than ambiguity, as would be expected if people with agrammatism have difficulty with closed-class words. However, P8 (mixed non-fluent) showed a larger effect of ambiguity than verb bias. In addition, some individuals with fluent aphasia (e.g., P3 and P10) showed greater effects of verb bias than controls. Thus, it is not clear that sensitivity to the complementizer *that* varies systematically as a function of aphasia type.

Items with Incorrect Responses on Comprehension Questions (PWA Only)

The high error rate (see Table 5) raises the question of how PWA read sentences when they answered the comprehension questions incorrectly. To address this question, reading times for items with incorrectly answered questions were analyzed using the same methods as described for the analysis of correctly answered questions. Two participants (P06 and P07) were excluded because they did not have enough incorrectly answered items in each condition after data trimming. Item analyses were not conducted because the analysis would have been limited to items that at least one participant with aphasia answered incorrectly.

Complementizer (That) and Ambiguous Noun Phrase (The fire/ The airplane)—

There were no significant effects of ambiguity or verb bias condition (all F 's < 2.3 , p 's $> .18$).

Disambiguation (Could not/ Had been)—Reading times were significantly longer for sentences with DO-biased verbs than SC-biased verbs, $F(1,6)=17.68$, $p=.01$, $\eta^2=.22$.

DISCUSSION

The present study investigated how verb bias and temporary syntactic ambiguity affect sentence comprehension in PWA. Consistent with the Lexical Bias Hypothesis, the primary determinant of processing difficulty for this group of PWA appeared to be verb bias. This interpretation was supported by the analyses of both correctly and incorrectly answered items. In addition, analysis of the individual cases indicated that the effects of verb bias were greater than the effects of ambiguity for seven of the nine participants with aphasia.

In contrast, the results indicated that ambiguity was the primary determinant of processing difficulty for controls. Recall that Garnsey et al.'s (1997) college aged adults showed ambiguity effects for sentences with DO, but not SC, biased verbs. In the present study, effects of ambiguity were observed in sentences with both DO- and SC-biased verbs. However, it is unclear whether Garnsey et al. would have found a significant interaction between verb bias and ambiguity because they did not directly compare reading times for sentences with DO- and SC- biased verbs. It is also possible that this interaction was not

significant in the present study due to the small sample size. Regardless, the difference between Garnsey et al. (1997) and the present study does not change the overall pattern of results: The effect of ambiguity was significant in the control group, but not the PWA. In contrast, the effect of verb bias was significant in the PWA, but not the controls.

The results are consistent with those reported by DeDe (2013) in that the effects of verb bias were greater in PWA than controls. The previous study showed that a mismatch between verb bias and sentence structure disrupted processing in syntactically simple sentences. The current work shows that such a mismatch also affects processing of temporarily ambiguous sentences. It also clarifies the results reported in DeDe (2012) by showing that verb bias affects ambiguity resolution when plausibility is held constant.

The PWA did not show p effects of ambiguity. Contrary to controls, PWA's reading times in the disambiguating region were affected by verb bias in both unambiguous and ambiguous sentences. In addition, the control group's reading times for the complementizer were affected by verb bias, but PWA did not show sensitivity to ambiguity until the ambiguous noun phrase. The interaction between verb bias and ambiguity could partly reflect the implausibility of the ambiguous noun phrase as the object of the main verb. However, plausibility cannot fully account for the interaction because the ambiguous noun phrase was an implausible object in both verb bias conditions. Thus, the PWA showed sensitivity to the presence of the complementizer at a later point in the sentence than controls, but prior to the point of disambiguation. Finally, PWA made more comprehension errors about ambiguous than unambiguous sentences, meaning that the effect of ambiguity resurfaced at the end of the sentence.

Taken together, the data suggest that PWA were sensitive to both verb bias and the structural cue provided by the complementizer. However, PWA relied on verb bias to a greater extent during on-line sentence processing even though the presence of the complementizer is the more reliable cue. It is possible that the complementizer seemed like the less reliable cue for PWA due to slowed processing of closed-class words (cf., ter Keurs et al., 2002, 1999). Thus, PWA may not rank verb bias more highly than all other types of probabilistic cues. Further research is needed to explain how PWA use different types of cues during sentence processing.

Relying on less reliable cues may lead to greater processing disruptions during sentence comprehension, even when canonical word order is maintained. In addition, PWA might have more trouble resolving the conflict between competing probabilistic cues or show greater processing disruptions when verb biases are violated (cf. DeDe, 2012; 2013). These types of changes in how PWA use probabilistic cues may at least partly account for sentence comprehension deficits, particularly because ambiguous sentences are relatively difficult to understand (cf., Kemtes & Kemper, 1997). Recall from DeDe (2013) that the reliance on verb transitivity bias extends even to simple active transitive and intransitive sentences, meaning that these changes could account for why comprehension impairments affect a wide variety of sentence types.

One question is whether the results of the present study can be generalized to the auditory modality. One reason for this concern is that some of the participants in this study performed differently on measures of reading and listening comprehension in the background testing (see tables 1, 2, & 3). However, the differences in reading and listening comprehension are likely attributable to the fact that the comprehension measures used different types of structures and tasks in the two modalities (e.g., sentence completion vs. picture matching). Furthermore, previous studies comparing auditory and written sentence comprehension suggest that the results can be extended to auditory comprehension. DeDe (2012) found that

PWA's lexical access was more variable in the written than the spoken modality, but DeDe (in press) found similar effects of syntactic complexity in both PWA and controls in both modalities. DeDe (in press) suggested that lexical access is more susceptible to effects of modality because it relies on peripheral processes to a greater extent than central, sentence-level processes. Lexical features such as verb bias are likely to be stored in the semantic system, which is widely viewed as a multimodal system (e.g., Lambon Ralph & Patterson, 2005). Thus, the effects reported in the present study can likely be generalized to auditory language comprehension.

Another question is how to interpret the high error rates for the PWA. First, the accuracy data demonstrate that comprehension impairments affect sentences with canonical word order. It is well known that PWA have more difficulty understanding sentences with two propositions (cf., Caplan, Baker, & Dehaut, 1985), which was true of all of the critical stimuli in the present study. Thus, the low comprehension rate may partly reflect the sentence length. In addition, sentences with sentential complements are more complex than the direct object reading of the sentences. Both the high error rates and the relatively small number of participants mean that the results should be interpreted somewhat cautiously. However, this concern is mitigated by the fact that all of the analyses converged on the same conclusion, which is that PWA relied on verb bias to a greater extent than the presence of the complementizer.

Finally, people with different aphasia types in this study did not show a consistent pattern of sensitivity to the presence or absence of the complementizer *that*. These results are not necessarily inconsistent with previous studies, which focused on individuals with specific aphasia types. The apparent differences likely reflect both the participants included in the studies and the nature of the tasks. For example, the present results are consistent with ter Keurs and colleagues' finding that people with Broca's aphasia show delayed processing of function words. The finding of delayed effects across aphasia types in this study is not inconsistent with their results because they only tested people with Broca's aphasia. Other studies (e.g., Dickey et al., 2004; Rosenberg et al., 1985) used end of sentence measures, which are not sensitive to on-line sentence processing operations.

In summary, the present study both supports and extends the Lexical Bias Hypothesis. Even the presence of a disambiguating complementizer was not sufficient to overcome the effect of a mismatch between verb bias and sentence structure in this group of PWA. Finally, this study adds to the growing body of literature suggesting that deviations from lexical biases play an important role in comprehension deficits in PWA.

Acknowledgments

This work was supported in part by an American Speech Hearing Foundation New Investigators Grant and NIDCD grant DC010808. I would like to thank the research participants and their families and the students who helped with data collection. I would also like to thank Audrey Holland and Janet Nicol for helpful comments on a previous draft of this manuscript.

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Figure 1. Residual Reading Times (controlled for segment length) for Critical Segments. Error bars show standard errors.

Note. Difference scores for the effect of verb bias = DO-bias minus SC-bias. Difference scores for the effect of ambiguity = Reading times in the ambiguous condition minus the unambiguous condition.

Figure 2.
Difference Scores for the Disambiguating Segment in People with Aphasia.

Table 1

Participant Demographic and Test Performance Data

Age	Gender	Years Edu	Ethnicity/ Race	Aphasia Type	Etiology	BNT ^a	PPVT ^b	PAL Lexical Decision	PAL Word Picture Match	Simple Trans & Intrans Sentences ^d	
P1	65	M	16	White	Conduction	CVA	3	91	.85	1.0	0.93
P2	65	M	12	Hispanic	Broca	CVA	4	99	.70	0.97	0.75
P3	70	M	16	White	Anomic	CVA	41	98	.88	1.0	0.88
P4	31	M	12	Hispanic	Mixed Nonfluent ^c	Gunshot Wound	7	77	.63	0.94	0.75
P5	54	F	12	White	Broca	CVA	20	80	.78	1.0	0.65
P6	55	F	14	White	Anomic	CVA	46	91	1.0	1.0	0.90
P7	38	M	14	Hispanic	Anomic	CVA	51	96	1.0	1.0	0.85
P8	32	M	12	Native American	Mixed Nonfluent ^c	CVA	1	70	.73	0.88	0.70
P10	50	M	18	White	Borderline Anomic	CVA	54	113	1.0	1.0	0.90

Note. BNT = Boston Naming Test; PPVT = Peabody Picture Vocabulary Test; PAL = Psycholinguistic Assessment of Language; CVA = Cerebral Vascular Accident.

^aMax score = 60;

^bStandard Score, all within 2 SD of mean for age-matched controls;

^cP4 & P8 had lower auditory comprehension scores on the Boston Diagnostic Aphasia Exam (BDAE) than would be expected of individuals with Broca's aphasia (see Table 5). In all other respects, they matched the profile of individuals with Broca's aphasia;

^dMax score=40.

Table 2Boston Diagnostic Aphasia Exam (Short Form)^a

	<u>Auditory Comprehension</u>			<u>Repetition</u>		<u>Oral Reading</u> (/15)	<u>Reading Comprehension</u>	
	<u>Word</u> (/16)	<u>Commands</u> (/10)	<u>Comp Idea</u> (/6)	<u>Word</u> (/5)	<u>Sent</u> (/2)		<u>Word Picture Match</u> (/4)	<u>Sent & Para</u> (/4)
P1	14	7	2	2	0	1	2	4
P2	16	7	6	3	0	1	3	3
P3	13	4	3	3	0	15	3	4
P4	9	6	2	3	0	0	3	0
P5	11	6	4	3	0	9	3	1
P6	16	8	5	4	0	12	4	3
P7	15	9	4	4	1	15	4	4
P8	11	5	2	2	0	0	2	2

^aP10 completed the Western Aphasia Battery (WAB), Aphasia Quotient = 94.8. WAB Scores: content- 10/10, fluency- 9/10, comprehension-10/10, repetition- 9/10, and naming- 9.4/10.

Table 3

Proportion Correct and Ratios Comparing Performance on Stimulus Types on the Northwestern Naming Battery and Northwestern Assessment of Verbs and Sentences (NAVS)

	Northwestern Naming Battery			NAVS Comprehension			NAVS Production		
	Noun ^a	Verb ^a	Verb: Noun ^b	Canonical ^c	Non-Canon ^c	Non-Can: Canon ^b	Canonical	Non-Canon	Non-Can: Canon ^b
P1	0.63	0.50	0.80	0.87	0.73	0.85	0.00	0.00	N/A
P2	0.31	0.00	0.00	0.93	0.87	0.93	0.00	0.00	N/A
P3	0.94	0.44	0.47	0.53	0.67	1.25	0.67	0.47	0.70
P4	0.38	0.25	0.67	0.67	0.67	1.00	0.00	0.00	N/A
P5	0.69	0.56	0.82	0.53	0.47	0.88	0.07	0.00	0.00
P6	1.00	1.00	1.00	0.87	0.47	0.54	0.67	0.13	0.20
P7	1.00	1.00	1.00	1.00	0.73	0.73	1.00	0.67	0.67
P8	0.38	0.19	0.50	0.80	0.67	0.83	0.00	0.00	N/A
P10	1.00	.94	.94	1.00	1.00	1.00	1.00	0.93	0.93

^aMax = 16;

^bRatios < 1 are consistent with agrammatism;

^cMax=15

Table 4

Examples of Filler Sentences

Filler Type	Examples
1. Object Cleft	It was the girl who the boy hugged on Sunday morning.
2. Subject Cleft	It was the boy who hugged the girl on Sunday morning.
3. Transitive Sentences	The choir will sing the song during the festival next Saturday in the park.
4. Intransitive Sentences	The boy studied before his math test on Tuesday.

Table 5

Proportion Correct by Condition. Group data are shown as mean (standard deviation).

	DO-Bias Verbs		SC-Bias Verbs	
	Ambiguous	Unambiguous	Ambiguous	Unambiguous
Group Data				
Controls	.94 (.07)	.97 (.04)	.96 (.06)	.95 (.06)
PWA	.58 (.24)	.66 (.21)	.60 (.23)	.67 (.06)
Individual Data				
P01	0.38	0.56	0.31	0.63
P02	0.38	0.44	0.50	0.56
P03	0.38	0.75	0.81	0.75
P04	0.44	0.75	0.44	0.44
P05	0.44	0.50	0.44	0.44
P06	0.94	0.81	0.69	0.88
P07	0.94	0.94	0.94	0.88
P08	0.56	0.31	0.44	0.69
P10	0.75	0.88	0.88	0.81

Note. DO = Direct Object; SC = Sentential Complement; PWA = People with Aphasia.