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Effects of Word Frequency and Modality on Sentence Comprehension Impairments in People with Aphasia

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Abstract

Purpose—It is well known that people with aphasia have sentence comprehension impairments. The present study investigated whether lexical factors contribute to sentence comprehension impairments in both the auditory and written modalities using on-line measures of sentence processing.

Methods—People with aphasia and non-brain-damaged controls participated in the experiment (n=8 per group). Twenty-one sentence pairs containing high and low frequency words were presented in self-paced listening and reading tasks. The sentences were syntactically simple and differed only in the critical words. The dependent variables were response times for critical segments of the sentence and accuracy on the comprehension questions.

Results—The results showed that word frequency influences performance on measures of sentence comprehension in people with aphasia. The accuracy data on the comprehension questions suggested that people with aphasia have more difficulty understanding sentences containing low frequency words in the written compared to auditory modality. Both group and single case analyses of the response time data also pointed to more difficulty with reading than listening.

Conclusions—The results show that sentence comprehension in people with aphasia is influenced by word frequency and presentation modality.

Introduction

People with aphasia often have trouble understanding spoken and written sentences. Studies of on-line sentence processing in this population have focused on how aphasia affects comprehension of structurally complex sentences in the auditory modality (e.g., Caplan, Waters, DeDe, Michaud, & Reddy, 2007; Grodzinsky, 2000; Thompson & Choy, 2009). Some people with aphasia also have trouble understanding structurally simple sentences (e.g., Caplan, Baker, & Dehaut, 1985). However, little is known about why comprehension impairments would affect structurally simple sentences.

In order to successfully understand sentences, lexical items must be accessed quickly and accurately enough to be integrated into the emerging syntactic and semantic representation of the sentence. For this reason, deficits affecting the speed or accuracy of lexical activation may contribute to sentence comprehension impairments in people with aphasia, even in relatively simple sentences. The present study sought to examine how lexical factors contribute to sentence comprehension impairments in both the auditory and written modalities.

The idea that lexical factors contribute to sentence comprehension impairments in people with aphasia is not new. For example, priming experiments have shown that the level or rate of lexical activation is impaired in people with aphasia (e.g., Del Toro, 2000; Hagoort, 1997; Love, Swinney, Walenski, & Shapiro, 2008; Milberg et al., 1981; Milberg et al., 1995; Prather, Zurif, Swinney, Love, & Brownell, 1997). There is also evidence that people with agrammatic aphasia show delayed or incomplete access to information about word class and are slow to integrate words into sentences (Swaab, Brown, Hagoort, 1997, 1998; ter Keurs et al., 1999, 2002; Thompson & Choy, 2009).

Thompson and Choy (2009) recently described several eye-tracking studies showing similar on-line syntactic processing in people with agrammatism and non-brain-damaged controls. Although there was evidence of delayed lexical access during sentence comprehension, this delay did not affect the overall pattern of results for the complex sentences in the on-line measures. Based on their results, Thompson and Choy (2009) concluded that the people with aphasia built syntactic representations on a similar time course as controls, but had impairments affecting integration of lexical information. In contrast, Love and colleagues (2008) argued that delayed lexical access in people with aphasia does lead to difficulty building syntactic representations. They compared on-line syntactic processing when sentences were presented with normal and slowed speech rates. The people with agrammatism only showed normal patterns of syntactic processing during slowed speech. They concluded that slowed lexical access contributes to sentence comprehension impairments because lexical information is not available when it is needed by the parser.

Word Frequency Effects

Another way to investigate the extent to which lexical deficits contribute to sentence comprehension impairments is by manipulating variables known to make word recognition more difficult. For example, word frequency is a well-studied variable that affects lexical access time. Converging evidence across multiple studies using diverse tasks has established that non-brain-damaged individuals require more time to recognize low frequency words than high frequency words (e.g., Brysbaert, Lange, & Van Wijnendaele, 2000; Ferreira et al., 1996; Gerhand & Barry, 1999; Just et al., 1982; Morrison & Ellis, 1995; Turner, Valentine, & Ellis, 1998).

Word frequency effects have been explained in the context of spreading activation models of lexical access (e.g., Dahan & Magnuson, 2006; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997). For example, connections between sublexical and lexical representations may be stronger in commonly occurring words than in less frequently used words. As a result, high frequency words reach the threshold needed to recognize a word more quickly than low frequency words.

Word frequency effects have been argued to be magnified in individuals who have less stable or weakened lexical representations (Condray, Siegle, Keshavan & Steinhauer, 2010; Perfetti, 2007; Yap, Tse, & Balota, 2009). For example, Yap et al. (2009) use the term *lexical integrity* to describe the strength and quality of representations of words in the mental lexicon. They operationally defined lexical integrity based on knowledge of word forms and meanings, and found larger word frequency effects in individuals with lower levels of lexical integrity. On this view, larger effects of word frequency in people with aphasia might point to lexical impairments, which could lead to difficulty understanding sentences. At this point, it is important to note that the focus of this paper is not on severe lexical impairments, which would lead to gross failures of word recognition. Instead, the focus is on deficits that affect the speed with which words are recognized.

Most studies about word frequency effects in people with aphasia have focused on single word production or comprehension. This literature has reported conflicting results. Some studies have reported absent or even reversed frequency effects in people with aphasia (e.g., Crutch & Warrington, 2005; Hoffman, Jefferies, & Lambon Ralph, 2011; Hoffman, Rogers, & Lambon Ralph, 2011; Jefferies & Lambon Ralph, 2006; Nickels & Howard, 1995; Warrington & Shallice, 1979). Such studies include both production and comprehension tasks, but typically report only accuracy data. Hoffman and colleagues (2011) recently found that individuals with stroke-induced aphasia did not show effects of word frequency in a synonym judgment task. They suggested that people with aphasia have impairments of cognitive control, which lead to reduced word frequency effects. Their argument was that high frequency words are more likely to have multiple meanings or senses than low frequency words, and thus, identifying the correct sense of high frequency words draws heavily on top down processing. They further claimed that impaired cognitive control mechanisms in people with aphasia interfere with the ability to select the correct sense of a word, counteracting any advantages associated with higher frequency of occurrence.

Other studies have reported that people with aphasia show typical effects of word frequency, that is, evidence of more difficulty processing low than high frequency words (e.g., Bose, van Lieshout, & Square, 2007; Gerratt & Jones, 1987; Kittredge, Dell, Verkuilen, & Schwartz, 2008; Nozari, Kittredge, Dell, & Schwartz, 2010; Varley et al., 1999). One study reported both accuracy and reaction time measures from a written lexical decision task (Gerratt & Jones, 1987). They found that both people with aphasia and non-brain-damaged controls took longer to decide whether low versus high frequency items were real words, and that frequency effects were equivalent in the participant groups. In addition, the effect of word frequency on the accuracy data was less robust in both the people with aphasia and controls. These results suggest that people with aphasia are sensitive to word frequency, and that reaction times provide a more sensitive measure of these effects than accuracy.

The effect of word frequency on sentence comprehension has not been directly studied in people with aphasia. Shewan and Canter (1971) reported that vocabulary difficulty, which was determined primarily by word frequency, had a significant effect on sentence comprehension in people with aphasia. However, because vocabulary difficulty was one of several manipulated variables, the effects may not reflect word frequency alone. In addition, this study only reported off-line accuracy data, which are not sensitive to on-line structure building operations. Thus, it is not clear whether word frequency has a measurable effect on sentence processing in real time in people with aphasia.

The conflicting findings in the literature may reflect the fact that reaction time is a more sensitive measure than accuracy. In addition, there may be reason to expect differences between word and sentence level processing. Recall that Hoffman and colleagues (2011) argued that impaired cognitive control mechanisms result in reduced word frequency effects in people with aphasia. It is possible that the effect of impaired cognitive control mechanisms is mitigated in sentences compared to single words. The reason is that sentences provide at least some context to facilitate lexical selection, which may compensate for impaired cognitive control. Even in sentences with low cloze probability, syntactic structure narrows the range of possible and likely grammatical classes that can occur in a particular position in a sentence. Thus, people with aphasia may show more reliable word frequency effects in sentences than isolated words.¹

¹ It is also possible that word frequency effects would be smaller in sentences if the critical words were predictable in the sentence context (cf. Van Petten & Kutas, 1990). However, word frequency effects are observed when the high and low frequency words are equally unpredictable in the sentential context (e.g., Juhasz et al., 2006).

Given that reaction times are likely to be sensitive to frequency effects, and given the benefits of sentential context, it is likely that word frequency effects would be observed in online measures of sentence processing. However, there is reason to wonder whether frequency effects would differ in spoken and written sentence comprehension. Most studies of frequency effects for words in simple sentences in non-brain-damaged populations have examined reading comprehension (e.g., Inhoff & Rayner, 1986; Just & Carpenter, 1982, Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006, but cf. Ferreira et al., 1996). In contrast to studies of non-brain-damaged populations, studies of people with aphasia have focused on auditory comprehension. In order to increase the comparability of the present study to the existing literature, this study compared word frequency effects in reading and auditory comprehension. More importantly, comparing frequency effects in the two modalities provides the opportunity to investigate whether impairments affecting lexical access are equivalent in spoken and written sentence comprehension in people with aphasia.

Effects of Modality on Sentence Comprehension

It is possible that general properties of reading and listening would lead to modality-specific effects (cf. Turner, Valentine, & Ellis, 1998). If this were the case, then both non-brain-damaged controls and people with aphasia should show differences between reading and listening comprehension. One factor that might lead to modality-specific effects in both groups is the relative ease of word recognition in reading versus listening. Word boundaries are more clearly demarcated in written than spoken sentences. In addition, readers can look at a word for as long as they choose before moving on to the next. In contrast, speakers determine the rate of auditory sentence presentation, limiting the listeners' ability to regulate how long they have to process each word. If these perceptual features differentially affect auditory and written sentence comprehension, then the relative complexity of the spoken signal suggests that the auditory modality would be more demanding.

On the other hand, reading ability is acquired somewhat later in life and draws on phonological representations developed for auditory language processing. When children learn to read, written language proficiency requires a strong foundation in oral language (e.g., Hogan, Catts, & Little, 2005; Mattingly, 1984; Snow, 1991). Phonological neighborhood density, which refers to the number of words that sound similar to a target item, influences reading comprehension into adulthood (e.g., Yates, Friend, & Ploetz, 2008). These types of findings suggest that reading involves an additional processing step (i.e., mapping orthography onto phonology), and so might be more demanding than listening.

It is also possible that people with aphasia are more sensitive to differences between reading and listening than controls. A small number of studies have examined modality effects in aphasic sentence comprehension, and reported conflicting results. Gardner and colleagues (1975) reported that people with anterior perisylvian lesions performed somewhat better on anomaly detection tasks in the auditory than written modality. People with posterior perisylvian lesions showed the opposite pattern. Gallaher and Canter (1982) compared performance on written and auditory versions of a sentence picture matching task. They showed that people with Broca's aphasia performed significantly better on the auditory than written version of the task, but a follow-up study found no significant differences between the modalities in people with anomic or conduction aphasia (Peach et al., 1988). These studies suggest that at least some individuals with aphasia show modality-specific effects. However, all of these were off-line studies, which are not sensitive to the time course of structure-building operations. Thus, they may over- or under-estimate the extent of modality differences. The present study revisited the issue of modality effects using more sensitive, on-line measures of sentence processing.

There is more than one reason why people with aphasia might show disproportionate modality effects when compared to non-brain-damaged individuals. An individual with aphasia might have impairments in the peripheral processes necessary to support lexical access in one modality, resulting in failures of word recognition in that modality. Such individuals would likely show modality specific effects on untimed word picture matching tasks in addition to sentence level tasks. These types of impairments were not the focus of the present study.

However, even people with aphasia who perform well on untimed word picture matching tasks in both modalities sometimes report difficulty understanding written or spoken sentences. In such cases, aphasia may affect the speed with which the semantic system is accessed from phonological (spoken words) or orthographic (written words) representations. This type of lexical deficit would have little to no effect on word picture matching accuracy, but might interfere with the rapid lexical activation necessary for normal sentence processing. In general, if accessing words is relatively slow in one modality, then variables that influence lexical activation should have a greater effect in the impaired modality. The present study tested these predictions by comparing word frequency effects in spoken and reading sentence comprehension.

The Present Study

The present study had two goals: The first goal was to establish whether people with aphasia show effects of word frequency during on-line processing of simple sentences. Equivalent word frequency effects in the people with aphasia and non-brain-damaged controls would suggest that the lexical retrieval operations associated with word recognition are relatively preserved in this sample of people with aphasia. Exaggerated or absent word frequency effects would point to deficits in word recognition, which could contribute to trouble understanding sentences.

The second goal was to determine whether frequency effects were of the same magnitude in spoken and written sentence comprehension. Processing of written and spoken sentences containing high and low frequency words were compared using two on-line measures of sentence processing, self-paced listening and self-paced reading. In both tasks, sentences are presented in short segments. Participants are required to press a button to request each segment, and the response times are interpreted as a measure of processing demand. The advantage of using self-paced listening and reading is that they have similar dependent measures, so the results can be compared relatively directly. In addition, previous studies have established that people with aphasia can do self-paced tasks and that they produce interpretable results (e.g., Caplan et al., 2007; Sung et al., 2009).

It is important to note that modality differences could arise due to normal differences in written and auditory sentence comprehension. Thus, non-brain-damaged controls may also show modality effects. As reviewed above, there is reason to predict that either reading or listening is the “easier” modality. However, if aphasia has modality-specific effects on lexical processing, then people with aphasia may show larger modality effects than the control group.

Method

Participants

Eight people with aphasia (mean = 49 years) and 8 age-matched controls (mean = 50 years) participated. All participants passed a hearing screen at 500, 1000, 2000, and 4000 Hz using a criterion of 40 dB in the better ear. All participants reported normal or corrected-to-normal vision and denied visual impairments (e.g., cataracts). The non-brain-damaged controls

denied any history of neurological disease, speech language disorder, or reading impairment. All control participants scored at least 28 out of 30 on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975).

The people with aphasia were at least 6 months post-onset of aphasia and were diagnosed with aphasia by a licensed speech language pathologist. They completed an extensive test battery to describe their speech, language, and cognitive abilities. Background information about the people with aphasia is presented in Table 1.

To be included in the study, the participants with aphasia were required to have documented speech-language impairments and single word comprehension within normal limits. The long form of the Boston Naming Test (BNT) (Kaplan, Goodglass, & Weintraub, 2001) was administered to document the presence of anomia, which is a symptom of all aphasia types. All of the participants performed two standard deviations below the mean for age-matched controls. The Peabody Picture Vocabulary Test (PPVT, 4th Edition, Form A) (Dunn & Dunn, 2007) was administered as a measure of the participants' auditory word comprehension. This test, which is normed on non-brain-damaged participants aged 2 through 99 years of age, requires participants to identify which of four pictures matches an auditorily presented word. All participants with aphasia performed within two standard deviations of the mean for age-matched controls on the PPVT. The results of the BNT and PPVT are presented in Table 1.

Two measures of lexical processing were used to ensure that neither gross impairment in lexical access, nor significant peripheral impairments (visual or auditory analysis) were responsible for observed differences in sentence comprehension. Participants completed the auditory and written versions of the lexical decision and word picture matching tasks on the Psycholinguistic Assessment of Language (PAL) (Caplan, 1992). The materials in these tasks are matched for variables such as word length and frequency. Table 2 presents proportion correct data for these tasks for each participant. All participants performed above chance on all four PAL sub-tests. Chi-square analysis showed that none of the participants' performances consistently differed in the written and spoken modalities.

The short form of the Boston Diagnostic Aphasia Exam (Goodglass, Kaplan, & Barresi, 2000) was administered to permit syndrome classification and to provide general information about the participant's auditory comprehension, reading comprehension, oral reading ability, and repetition ability. Results are presented in Table 3.

Additional testing was used to identify participants with symptoms of agrammatism. Identifying people with agrammatism is potentially of interest because this subgroup of people with aphasia has been reported to show distinct patterns of sentence comprehension ability, specifically on sentences containing non-canonical word order (e.g., Grodzinsky, 2000; Thompson & Choy, 2009). At present, no particular claims have been made regarding whether or not people with agrammatism show distinct effects of word frequency during sentence comprehension. Including these measures provides the opportunity to examine the data relative to the presence of agrammatic symptoms in the people with aphasia. The Northwestern Naming Battery-Final (Thompson & Weintraub, unpublished) was administered in order to calculate the verb:noun ratio for naming accuracy. This test includes 16 nouns and 16 verbs, which were matched for frequency. The Sentence Comprehension and Sentence Production Priming subtests of the Northwestern Assessment of Verbs and Sentences (Thompson, unpublished) were administered to measure comprehension and production of canonical (e.g., actives, subject relatives) and non-canonical (e.g., passives, object relatives) sentence types. The ratios of non-canonical: canonical sentences that were correctly understood and produced were also calculated.

Ratios of less than one are consistent with a diagnosis of agrammatism. The results are in Table 4.

Stimuli

The stimuli were 21 sentence pairs that contained high and low frequency words (see examples 1 and 2). They were a subset of those developed by Juhasz, Liversedge, White, and Rayner (2006). These stimuli were also used by Rayner et al. (2006) in a reading study with non-brain-damaged younger and older adults. Frequency was originally measured using the CELEX database (Juhasz et al., 2006). The high frequency words had an average occurrence of 143 words per million and the low frequency words had an average occurrence of 1.35 words per million. The frequency of the critical words also differed in the 131 million item HAL database, which is based on usenet newsgroups in 1995 (78331 vs. 1733 occurrences, $t(39)=5.7$, $p<.001$) (Balota et al., 2007; Lund & Burgess, 1996). Note that one of the items (camouflage) did not occur in this database. The critical words also differed in the SUBTLEX database, which is based on subtitles from American English movies (68.5 vs. 2.0 occurrences, $t(40)=4.1$, $p<.001$) (Brysbaert & New, 2009). This suggests that the difference in word frequency holds across spoken and written language. Not surprisingly, the items also differed with respect to age of acquisition and familiarity (t 's > 3.8). Thus, it is possible that one of these lexical features contributes to any effects that are observed in the dataset. However, for the purposes of this paper, the critical point is that these items differ with respect to word frequency.

1. Ralph / rested / in / the village / before he started / on his trip. (High Freq)
2. Ralph / rested / in / the hammock / before he started / on his trip. (Low Freq)
3. Did Ralph rest before his trip?

Juhasz and colleagues matched the items with respect to number of letters and lack of predictability of critical words in the sentence context. In order to use these materials in the auditory modality, word pairs in the present study were also matched for number of syllables and spoken length, which was estimated by the number of phonemes in the word (all F 's > 1.3). Items were also matched for neighborhood density, which refers to the number of competitors that differ from the target by one sound or letter. The average phonological neighborhood density was greater than orthographic (.74 vs. .51), but the difference was not significant, $F(1, 40)=2.1$, $p=.12$. Critically, there were no frequency effects on neighborhood density within modality and no interactions with modality (F 's < 1). Items were also matched with respect to orthographic and phonological neighborhood frequency (F 's < 1.8). Finally, the biphone frequency of high and low frequency words did not differ (F 's < 1.2). These procedures resulted in elimination of some items from the original Juhasz et al. stimulus set.

Tasks

Performance was compared on self-paced listening and self-paced reading, two tasks that permit a narrow comparison due to similar dependent measures (reading vs. listening time) and presentation style.

Self-Paced Listening—Self-paced listening is a task that measures on-line auditory sentence processing. Sentences are broken into short segments and participants press a button to request each segment. A female speaker of American English recorded the sentences as 16-bit sound files sampled at 44.1 kHz in a sound-attenuated booth (Boersma & Weenink, 2011). Sentences were recorded and broken into segments using Praat software. Segmentation boundaries were defined by low energy points in visually displayed acoustic spectra and investigator judgments of the acoustic signal. Segment boundaries are depicted

by slashes in examples 1 and 2. The waveforms were then entered into E-prime (Schneider, Eschman, & Zuccolotto, 2002) for use in the experiment.

Participants listened to the sentences over high-quality noise attenuating headphones at comfortable listening levels. During the experiment, participants saw a “Ready?” prompt, and pressed a button to indicate when they were ready to hear the sentence. An E-prime button box interfaced with a computer recorded the reaction time to request each segment. All sentences were followed by a yes/no comprehension question, which was presented auditorily and visually to reduce memory demands (see example 3). Participants responded to the comprehension questions by pressing a button on the E-prime button box, which recorded accuracy of the response.

Self-paced reading—The sentences were presented using the same segmentation as for self-paced listening. Each trial began with a series of dashes (–) marking the length and position of the words in the sentence. The participants pressed a button to reveal each segment. When they pressed the button, the previously revealed segment reverted to dashes and the next segment was revealed. The button box collected the same data as described for self-paced listening.

Procedures

The sentence pairs were tested in both tasks. The stimuli were divided into 2 lists so that the members of the sentence pairs were separated. They were combined with fillers with various structures so that the experimental sentences comprised less than 25% of the items in any list. All participants completed all four lists (2 lists, 2 modalities) in separate testing sessions, which were at least 7 days apart to minimize practice effects. The order of list and task presentation was counterbalanced across participants. All lists began with 10 practice items to familiarize participants with the procedure. There was a break half-way through the experiment.

Results

Data analyses were directed at testing two research questions. First, are word frequency effects equivalent in people with aphasia and non-brain damaged controls? Second, are frequency effects equivalent in the spoken and written modalities? The independent variables were the word frequency (high vs. low frequency), modality (listening vs. reading times), and group (people with aphasia vs. non-brain-damaged controls). The dependent variables were proportion correct on the comprehension questions and the on-line measures of sentence comprehension, reading and listening times.

Yes-No Comprehension Questions

Table 5 presents the accuracy data. The accuracy data were analyzed in mixed 2 (word frequency) x 2 (group) x 2 (modality) ANOVAs. Significant interactions were inspected using Tukey post-hoc tests with a Bonferroni correction for multiple comparisons. Contrast effects and 95% confidence intervals for significant effects are reported using the methods for mixed designs described by Masson and Loftus (2003), which are commonly used in studies of sentence comprehension (e.g., DeDe, 2010; Federenko, Gibson, & Rohde, 2006; Van Dyke & Lewis, 2003). The contrast effects represent the difference between conditions, and the confidence interval indicates the estimated range of values within which the true population parameter (i.e., the difference between conditions) is likely to fall in 95% of cases. The confidence intervals are calculated using a pooled mean square error term and the sample size, and thus provide an index of the variability within the sample.

The people with aphasia answered fewer questions accurately than the controls, $F(1,14)=25.20$, $p<.001$. There was a significant effect of modality, $F(1, 14)=5.06$, $p<.04$, which was modified by an interaction with group, $F(1,14)=11.75$, $p=.004$. The people with aphasia made more errors than controls in both modalities (reading: $t(7)=7.77$, $p<.001$, contrast effect = .16, 95% Confidence Interval = $\pm .03$, listening: $t(7)=2.93$, $p=.04$, contrast effect = .06, 95% Confidence Interval = $\pm .03$, Bonferroni-corrected $\alpha = .013$). The people with aphasia also made more errors on the reading than listening task, $t(7)=4.01$, $p=.006$, contrast effect = .09, 95% Confidence Interval = $\pm .03$. The age-matched controls did not show a significant effect of modality, $t<1$.

The effect of modality was also modified by an interaction with word frequency, $F(1,14)=11.73$, $p=.004$. For sentences in the low frequency condition, the participants answered more questions correctly when listening than reading, $t(7)=4.61$, $p=.002$, contrast effect = .07, 95% Confidence Interval = $\pm .03$ (Bonferroni-corrected $\alpha = .013$). Proportion correct for high frequency items did not differ in reading and listening ($t<1$).

Inspection of the group means in each condition suggested that the two-way interactions described above were primarily driven by people with aphasia in the reading task. However, the three way interaction was not significant, $F(1,14)=3.27$, $p=.09$.

Response times

The measures of on-line sentence processing were the reading and listening times for the high and low frequency words. Items associated with incorrect responses on the comprehension questions were omitted from the response time analyses. Three segments were analyzed. Response times were compared for the high and low frequency words to determine whether there was a significant effect of word frequency. In addition, the words immediately preceding and following the high and low frequency words were analyzed to determine whether the effects were localized to the critical segment. These are referred to as positions N-1 and N+1 (where N is the critical word).

Response times that were less than 50 or greater than 5000 milliseconds were removed. 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 less than 1% of the data.

In order to compare reading and listening times, the self-paced response times must be controlled for spoken segment duration in listening and number of letters in reading. Typically, response times are reported as ms per character for reading and ms per segment for listening. However, in this study, it was critical that reading and listening times be on the same scale. For this reason, an alternative approach, which has been used to control for effects of word frequency (Ferreira & Clifton, 1986), was used to equate the self-paced response times in reading and listening. Raw response times were regressed against length (i.e. segment duration or number of letters), and the residuals of these analyses were used in ANOVAs. It is important to note that this procedure results in negative reading and listening times when the observed response times are faster than would be predicted on the basis of the word length.

Given that clinical populations often show greater response variance than non-brain-damaged controls, the data were inspected to ensure that the assumption of homogeneity of variance was met. The criterion was that the ratios of the largest to smallest variance not exceed 10 (Tabachnick & Fidell, 2001). The ratios for the omnibus ANOVA, ranged from 23 to 26 for the residual response times for each of the three segments. However, when the data were separated by modality, the ratios ranged from 1.5 to 6.2. For this reason, the

reading and listening data were analyzed in separate 2 (word frequency) by 2 (group) mixed ANOVAs. Significant interactions were examined using Tukey post-hoc tests with a Bonferroni correction and contrast effects and 95% confidence intervals were computed following Masson and Loftus (2003). Results are presented in the order that the words occur in the sentences.

Segment N–1—Segment N–1 directly preceded the critical word and was identical in the high and low frequency sentences. There were no significant effects of group or word frequency in the listening or reading time data (all F 's < 1.23). This demonstrates that the response times did not differ prior to critical words in the high and low frequency conditions.

Critical Segment—Response times for the high and low frequency words differed in reading and listening. Figure 1 presents the residual response times by group and condition.

In the *auditory comprehension* task, the main effects of group and word frequency were non-significant ($F = 1.01$). However, there was a significant interaction between group and word frequency, $F(1,14) = 17.74$, $p = .008$. Both groups listened to low frequency words for numerically longer than high frequency words. This difference was significant in the people with aphasia, $t(7) = 3.36$, $p = .005$, contrast effect = 67.13, 95% Confidence Interval = ± 41.29 ms (Bonferroni-corrected $\alpha = .013$), but not in the control group, $t(7) = 2.59$, $p = .06$.²

In the *reading comprehension* task, response times were numerically longer for low compared to high frequency words. However, the effect of word frequency only reached the level of a trend, $F(1,14) = 3.32$, $p = .08$. There were no other significant effects (all F 's < 1). This result likely resulted from the high degree of variability in the aphasic group's reading times.

Segment N+1—Segment N+1 directly followed the critical word and was identical in all conditions. There were no significant effects for this position in the sentence (all F 's < 1.26).

Individual Analyses of Response Times

An important question is how many individual participants with aphasia showed greater effects of word frequency than controls in one or both modalities. This is especially relevant given the high degree of variability in the reading time data for participants with aphasia. This question was addressed using the Revised Standardized Difference Test (RSDT; Crawford & Garthwaite, 2005). Here, the RSDT was used to compute the probability that an individual with aphasia's response time difference between two conditions (e.g., response time data for high and low frequency words in the reading task) was greater than what would be expected on the basis of the control group's mean and standard deviations in both conditions. The results are presented in Figure 2.

In the *listening* task, seven of eight participants with aphasia showed a trend towards longer response times for low versus high frequency words. Three participants (P2, P3, and P8) showed significantly greater word frequency effects than would be expected based on the control data. P1 showed a trend towards a reverse frequency effect.

In the *reading* task, seven of the eight participants with aphasia showed significantly greater effects of word frequency than would be expected on the basis of the control data. Four of

²Note that analyses of a larger group of controls showed significant word frequency effects, which did not differ as a function of modality (DeDe, in preparation).

these participants showed frequency effects that were in the expected direction (P2, P4, P6, and P8). Three of the participants with aphasia showed reverse frequency effects, that is, longer response time for high versus low frequency words (P1, P3, and P7).

Post Hoc Analyses—The data were inspected to determine whether there was evidence of a relationship between certain individual characteristics and specific patterns of word frequency effects. There was no hint that aphasia type, agrammatic characteristics, severity, or age was associated with particular effects of frequency or modality. For example, P3, P4, and P8 all performed significantly better on the lexical decision task in the auditory than written modality (see Table 2). P1, P2, P5, and P8 all showed symptoms consistent with agrammatism on the Northwestern measures (see Table 4). However, none of these groupings revealed a consistent pattern of results in the response time data.

Discussion

This experiment addressed two issues: (1) whether people with aphasia and non-brain-damaged controls show equivalent effects of word frequency in on-line measures of sentence comprehension and (2) whether the effects of word frequency are similar in listening and reading. In general, the results suggested that people with aphasia are sensitive to word frequency during on-line sentence comprehension. However, the effect of word frequency was not equivalent in people with aphasia and controls. For example, analyses of the listening time data showed that, as a group, the people with aphasia showed larger effects of word frequency than the controls. Also, in contrast to the control group, people with aphasia showed somewhat different word frequency effects in reading and listening. The people with aphasia appeared to show larger frequency effects in reading than listening, and some individuals with aphasia showed a reverse frequency effect.

Effects of Word Frequency

These results confirm that response times are more sensitive to effects of word frequency than accuracy measures. As in previous studies using word repetition and lexical decision tasks, accuracy on the comprehension questions did not reveal consistent effects of word frequency. However, for the response time data, seven of the eight participants with aphasia showed a frequency effect of at least 75 ms on one of the two tasks. In some cases, these were reverse frequency effects, which will be discussed separately. Here, the critical points are that most of the participants with aphasia were sensitive to the difference between high and low frequency words, and that the effects of word frequency were not equivalent in the people with aphasia and the control group.

The finding that people with aphasia and non-brain-damaged controls do not show equivalent effects of word frequency suggests that lexical representations are weakened by aphasia (cf. Condray et al., 2010; Perfetti, 2007; Yap et al., 2009). Yap et al. (2009) suggested that people with relatively weak lexical representations would show larger word frequency effects. In the context of aphasia, weakened connections between phonological and semantic representations might introduce more noise into the operations involved in lexical access, resulting in delayed or inaccurate word recognition (cf., Dell et al., 1997). Low frequency words might be particularly vulnerable because they have weaker sublexical and lexical networks than high frequency words (cf., Dahan & Magnuson, 2006).

These word level deficits may affect the speed with which lexical items are accessed and integrated into syntactic representations, and are likely to contribute to comprehension impairments. This interpretation is borne out by the accuracy data, since the people with aphasia made more errors than controls in both modalities, even though the sentences were syntactically simple. It is worth noting here that all of the people with aphasia scored within

the normal range on a test of receptive single-word vocabulary, suggesting that gross failures of lexical access cannot account for the results.

The results of the present study are consistent with previous research showing lexical impairments during on-line sentence comprehension in people with aphasia (e.g., Love et al., 2008; Thompson & Choy, 2009). Recall that Thompson and Choy (2009) did not find evidence that delayed lexical access affected on-line sentence processing. However, they did not explicitly manipulate features of the lexical items. The present experiment extends their work by suggesting that variables such as word frequency affect lexical access time during on-line sentence processing. It is possible that slowed word recognition means that lexical information is not available when needed by the parser (e.g., Love et al., 2008). However, these data suggest that the extent to which slowed lexical access affects on-line syntactic processing may depend on features of the lexical items in the sentences.

One lingering question involves the presence of reverse frequency effects in people with aphasia. A small number of studies have reported reverse frequency effects in this population (Hoffman et al., 2011; Marshall, Pring, Chiat, & Robson, 2001). Both Marshall et al (2001) and Hoffman, Rogers, and Lambon Ralph (2011) suggested that certain people with aphasia have an easier time accessing words that are more semantically distinct, which they argued is often the case for low frequency words (also cf. Hoffman et al., 2011). Further research is needed to clarify the types of participants and tasks that are most susceptible to reversal of the frequency effect. In the context of the current study, it is important to note that only one participant with aphasia (P1) showed reverse frequency effects in both reading and listening. The other three participants (P3, P5, P7) showed normal frequency effects in the auditory sentence comprehension task. For this reason, the most conservative approach is to focus on the magnitude of the processing time difference for high and low frequency words rather than the direction. Further research is required to determine whether reverse frequency effects are stable and what they mean for the mental lexicon.

Effects of Modality

The control participants did not show any consistent effects of modality, suggesting that there are not general differences in how frequency affects written and auditory lexical access. In contrast, the group with aphasia did appear to show somewhat different results in the two modalities. In the listening task, seven of the eight participants with aphasia showed at least a trend in the direction of normal frequency effects. However, only 3 people with aphasia showed larger word frequency effects than controls based on Crawford and Garthwaite's (2005) test. There was much more variability in the reading time data. First, seven of the eight aphasic participants showed larger frequency effects than the controls using the RSDT (Crawford & Garthwaite, 2005). As discussed above, three of the participants showed reverse frequency effects in the reading task. Thus, it seems that the frequency effects are more variable, and of larger magnitude, in reading than listening.

This leads to the question of why the frequency effects were more variable in reading than listening. The results of this study suggest that reading does not benefit from the fact that word boundaries are more distinct in the visual modality, or from the fact that readers have more control over lexical presentation rate than listeners. Thus, even though reading is a perceptually less challenging task than listening, lexical access seems to be more stable in the auditory modality in people with aphasia.

Weakened lexical representations might account for the increased variability in word frequency effects in the written modality (cf. Yap et al., 2009). Written word recognition involves mapping orthography onto both semantic and phonological representations. Thus,

damage to the connections between orthography and phonology, orthography and semantics, and phonology and semantics might all affect written word recognition. That is, increased noise throughout the lexical network might disproportionately affect reading. In general, these data suggest that the possible advantages conferred by reading (reduced presentation rate and a less demanding perceptual task) do not facilitate comprehension of written sentences.

Previous studies have suggested that some groups of people with aphasia perform better on reading or listening tasks. As a group, the people with aphasia were more accurate on the auditory comprehension task than the reading comprehension task. Consistent with the results reported by Gallaher and Canter (1982), the participants with Broca's aphasia performed more accurately on the auditory comprehension task. However, one of the three participants with anomic aphasia and one of the two participants with mixed non-fluent aphasia showed similar differences between auditory and written sentence comprehension, which were of at least the same magnitude. In addition, one of the participants with Broca's aphasia (P2) showed larger frequency effects than controls in both reading and listening tasks, while the other (P5) showed minimal frequency effects in either modality. Taken together, these data suggest that the people with Broca's aphasia did not show a distinct pattern of results relative to the other individuals with aphasia. Thus, it is not clear that there are distinct effects of modality or word frequency for certain subsets of people with aphasia. Future studies, particularly with a larger sample of people with aphasia, are needed to fully explore these issues. Replication of these effects is especially important given the relatively small sample size and the variability of the response time data (as indexed by the size of the confidence intervals).

Clinical Implications

In summary, the present study showed that people with aphasia are sensitive to effects of word frequency during on-line sentence comprehension. Thus, people with aphasia who perform well on word picture matching tasks may have trouble processing sentences that contain low frequency words, even if they do not show effects of frequency in word-level tasks. This finding suggests that clinicians should consider including items with relatively low frequency words when evaluating and treating sentence-level comprehension deficits. This suggestion is consistent with the principles of the Complexity Account of Treatment Efficacy (e.g., Thompson, Shapiro, Kiran, & Sobecks, 2003). The results also showed that reading comprehension may be more challenging than listening, suggesting that written and auditory sentence comprehension should be evaluated separately in people with aphasia.

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References

- Balota DA, Yap MJ, Cortese MJ, Hutchison KA, Kessler B, Loftis B, Neely JH, Nelson DL, Simpson GB, Treiman R. The English Lexicon Project. *Behavior Research Methods*. 2007; 39:445–459.
- Boersma, P.; Weenink, D. Praat: doing phonetics by computer [Computer program]. 2011. Version 5.2.21, retrieved from <http://www.praat.org/>
- Bose A, van Lieshout P, Square PA. Word frequency and bigram frequency effects on linguistic processing and speech motor performance in individuals with aphasia and normal speakers. *Journal of Neurolinguistics*. 2007; 20:65–88.

- Brysbaert M, New B. Moving beyond Kucera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods*. 2009; 41:977–990.
- Caplan, D. *Language: Structure, processing, and disorders*. Cambridge, MA: MIT Press; 1992.
- Caplan D, Baker C, Dehaut F. Syntactic determinants of sentence comprehension in aphasia. *Cognition*. 1985; 21:117–175. [PubMed: 2419022]
- Caplan D, Waters G, DeDe G, Michaud J, Reddy A. A study of syntactic processing in aphasia I: Behavioral (psycholinguistic) aspects. *Brain and Language*. 2007; 101:103–150.
- Condray R, Siegle GJ, Keshavan MS, Steinhauer SR. Effects of word frequency on semantic memory in schizophrenia: Electrophysiological evidence for a deficit in linguistic access. *International Journal of Psychophysiology*. 2010; 75(2):141–156.
- Crawford J, Garthwaite PH. Testing for suspected impairments and dissociations in neuropsychology: Evaluation of alternatives using monte carlo simulations and revised tests for dissociations. *Neuropsychology*. 2005; 19(3):318–331.
- Crutch SJ, Warrington EK. Abstract and concrete concepts have structurally different representational frameworks. *Brain*. 2005; 128:615–627.
- DeDe G. Utilization of Prosodic Information in Syntactic Ambiguity Resolution. *Journal of Psycholinguistic Research*. 2010; 39:345–374.
- Dell GS, Schwartz MF, Martin N, Saffran EM, Gagnon DA. Lexical access in aphasic and nonaphasic speakers. *Psychological Review*. 1997; 104(4):801–838. [PubMed: 9337631]
- Del Toro JF. An examination of automatic versus strategic priming effects in Broca's aphasia. *Aphasiology*. 2000; 14(9):924–947.
- Dunn, LM.; Dunn, LM. *Peabody Picture Vocabulary Task*. 3. American Guidance Service; Circle Pines, MN: 2007.
- Fedorenko E, Gibson E, Rohde D. The nature of working memory capacity in sentence comprehension: Evidence against domain-specific working memory resources. *Journal of Memory and Language*. 2006; 54(4):541–553.
- Ferreira F, Clifton C. The independence of syntactic processing. *Journal of Memory and Language*. 1986; 25:348–368.
- Ferreira F, Henderson JM, Anes MD, Weeks PA Jr, McFarlane DK. Effects of lexical frequency and syntactic complexity in spoken language comprehension: Evidence from the auditory moving windows technique. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1996; 22:555–568.
- Folstein MF, Folstein SE, McHugh PR. Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*. 1975; 12:189–198.
- Gallagher AJ, Canter GJ. Reading and listening comprehension in Broca's aphasia: Lexical versus syntactical errors. *Brain and Language*. 1982; 17:183–192.
- Gardner H, Denes G, Zurif E. Critical reading at the sentence level in aphasia. *Cortex*. 1975; 11:60–72.
- Gerhand S, Barry C. Age-of-acquisition and frequency effects in speeded word naming. *Cognition*. 1999; 73(2):B27–B36.
- Gerratt B, Jones D. Aphasic performance on a lexical decision task: multiple meanings and word frequency. *Brain and Language*. 1987; 30(1):106–115.
- Goodglass, H.; Kaplan, E.; Barresi, B. *Boston Diagnostic Aphasia Examination*. 3. New York: Lippincott, Williams & Wilkins; 2000.
- Grodzinsky Y. The neurology of syntax: Language use without Broca's area. *Behavioral and Brain Sciences*. 2000; 23:1–71. [PubMed: 11303337]
- Haarmann HJ, Just MA, Carpenter PA. Aphasic sentence comprehension as a resource deficit: A computational approach. *Brain and Language*. 1997; 59:76–120.
- Hagoort P. Semantic priming in Broca's aphasia at a short SOA: No support for an automatic access deficit. *Brain and Language*. 1997; 56:287–300.
- Hoffman P, Jefferies E, Lambon Ralph MA. Remembering “zeal” but not “thing”: Reverse frequency effects as a consequence of deregulated semantic processing. *Neuropsychologia*. 2011; 49:580–584.

- Hoffman P, Rogers TT, Lambon Ralph MA. Semantic diversity accounts for the “missing” word frequency effect in stroke aphasia: Insights using a novel method to quantify contextual variability in meaning. *Journal of Cognitive Neuroscience*. 2011; 23:2432–2446. [PubMed: 21254804]
- Hogan T, Catts H, Little TD. The relationship between phonological awareness and reading: Implications for the assessment of phonological awareness. *Language Speech and Hearing Service in Schools*. 2005; 36(4):285–293.
- Inhoff AW, Rayner K. Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception & Psychophysics*. 1986:431–439.
- Jefferies E, Lambon Ralph MA. Semantic impairment in stroke aphasia vs. semantic dementia: A case-series comparison. *Brain*. 2006; 129:2132–2147. [PubMed: 16815878]
- Juhasz BJ, Liversedge SP, White SJ, Rayner K. Binocular coordination of the eyes during reading: Word frequency and case alternation affect fixation duration but not binocular disparity. *Quarterly Journal of Experimental Psychology*. 2006; 59 (9):1614–1641.
- Just MA, Carpenter PA, Wooley JD. Paradigms and Processes in Reading Comprehension. *Journal of Experimental Psychology: General*. 1982; 111(2):228–238.
- Kaplan, E.; Goodglass, H.; Weintraub, S. *Boston Naming Test*. Baltimore: Lippincott, Williams & Wilkins; 2001.
- Kittredge AK, Dell GS, Verkuilen J, Schwartz MF. Where is the effect of frequency in word production? Insights from aphasic picture-naming errors. *Cognitive Neuropsychology*. 2008; 25(4):463–492. [PubMed: 18704797]
- Lund K, Burgess C. Producing high-dimensional semantic spaces from lexical co-occurrence. *Behavior Research Methods, Instruments & Computers*. 1996; 28:203–208.
- Marshall J, Pring T, Chiat S, Robson J. When ottoman is easier than chair: An inverse frequency effect in jargon aphasia. *Cortex*. 2001; 37(1):33–53. [PubMed: 11292160]
- Mattingly, IG. Reading, linguistic awareness and language acquisition. In: Downing, J.; Valtin, R., editors. *Linguistic awareness and learning to read*. Springer-Verlag; New York: 1984. 1984. p. 9-25.
- Milberg W, Blumstein SE. Lexical decision and aphasia: Evidence for semantic processing. *Brain and Language*. 1981; 31:138–150.
- Milberg W, Blumstein SE, Dworetzky B. Phonological processing and lexical access in aphasia. *Brain and Language*. 1988; 34(2):279–293.
- Milberg W, Blumstein SE, Katz D, Gerschberg F, Brown T. Semantic facilitation effects of time and expectancy. *Journal of Cognitive Neuroscience*. 1995; 7:33–50.
- Morrison CM, Ellis AW. Real age of acquisition effects in word naming and lexical decision. *British Journal of Psychology*. 2000; 91:167–180. [PubMed: 10832512]
- Nickels L, Howard D. Aphasic naming: What matters? *Neuropsychologia*. 1995; 33(10):1281–1303. [PubMed: 8552229]
- Nozari N, Kittredge AK, Dell GS, Schwartz MF. Naming and repetition in aphasia: Steps, routes, and frequency effects. *Journal of Memory and Language*. 2010; 63(4):541–559.
- Peach RK, Gallaher AJ, Canter GJ. Comprehension of sentence structure in anomic and conduction aphasia. *Brain and Language*. 1988; 35:119–137.
- Perfetti CA. Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading*. 2007; 11(4):357–383.
- Prather P, Zurif EB, Swinney D, Love T, Brownell H. Speed of lexical activation in non-fluent Broca’s aphasia and fluent Wernicke’s aphasia. *Brain and Language*. 1997; 59:391–411. [PubMed: 9299070]
- Rayner K, Reichle E, Stroud M, Williams C, Pollatsek A. The effect of word frequency, word predictability, and font difficulty on the eye movements of young and older readers. *Psychology and Aging*. 2006; 21:448–465. [PubMed: 16953709]
- Schneider, W.; Eschman, A.; Zuccolotto, A. *E-Prime Experimental Software*. Pittsburgh: Psychology Software Tools Inc; 2002.
- Shewan CM, Canter GL. Effects of vocabulary, syntax, and length on auditory comprehension in aphasic patients. *Cortex*. 1971; 7:209–226. [PubMed: 5160470]

- Snow C. The theoretical basis for relationships between language and literacy development. *Journal of Research in Childhood Education*. 1991; 6(1):5–10.
- Sung J, McNeil M, Pratt S, Dickey MW, Hula W, Szuminsky N, Doyle P. Verbal working memory and its relationship to sentence-level reading and listening comprehension in persons with aphasia. *Aphasiology*. 2009; 23(7–8):1040–1052.
- Swaab T, Brown C, Hagoort P. Spoken sentence comprehension in aphasia: Event-related potential evidence for a lexical integration deficit. *Journal of Cognitive Neuroscience*. 1997; 9:39–66. [PubMed: 23968179]
- Swaab T, Brown C, Hagoort P. Understanding ambiguous words in sentence contexts: Electrophysiological evidence for delayed contextual selection in Broca's aphasia. *Neuropsychologia*. 1998; 36:737–761. [PubMed: 9751439]
- Swinney D, Zurif E, Prather P, Love T. Neurological distribution of processing resources underlying language comprehension. *Journal of Cognitive Neuroscience*. 1996; 8:174–184. [PubMed: 23971422]
- Tabachnik, B.; Fidell, L. *Using Multivariate Statistics*. Allyn & Bacon; 2001.
- ter Keurs M, Brown C, Hagoort H, Stegeman D. Electrophysiological manifestations of open- and closed-class words in patients with Broca's aphasia with agrammatic comprehension: An event-related brain potential study. *Brain*. 1999; 122:839–854.
- ter Keurs M, Brown C, Hagoort H. Lexical processing of vocabulary class in patients with Broca's aphasia: An event-related brain potential study on agrammatic comprehension. *Neuropsychologia*. 2002; 40:1547–1561.
- Thompson, CK. *Northwestern Assessment of Verbs and Sentences-Final*. (unpublished)
- Thompson CK, Choy JJ. Pronominal resolution and gap filling in agrammatic aphasia: evidence from eye movements. *Journal of Psycholinguistic Research*. 2009; 38:255–283.
- Thompson, C.; Weintraub, S. *Northwestern Naming Battery*. (unpublished experimental version)
- Turner JE, Valentine T, Ellis AW. Contrasting effects of age of acquisition and word frequency on auditory and visual lexical decision. *Memory & Cognition*. 1998; 26(6):1282–1291. [PubMed: 9847551]
- Van Dyke JA, Lewis RL. Distinguishing effects of structure and decay on attachment and repair: a cue-based parsing account of recovery from misanalyzed ambiguities. *Journal of Memory and Language*. 2003; 49:285–316.
- Van Petten C, Kutas M. Interactions between sentence context and word frequency in event-related brain potentials. *Memory & Cognition*. 1990; 18(4):380–393.
- Varley R, Whiteside S, Luff H. Apraxia of speech as a disruption of word-level schemata: Some durational evidence. *Journal of Medical Speech-Language Pathology*. 1999; 7(2):127–132.
- Warrington EK, Shallice T. Semantic access dyslexia. *Brain*. 1979; 102(March):43–63.
- Yap MJ, Tse CS, Balota DA. Individual differences in the joint effects of semantic priming and word frequency revealed by RT distributional analyses: The role of lexical integrity. *Journal of Memory and Language*. 2009; 61:303–325.
- Yates M, Friend J, Ploetz DM. The effect of phonological neighborhood density on eye movements during reading. *Cognition*. 2008; 107:685–692. [PubMed: 17826758]

Figure 1.
Response Times for High and Low Frequency Words.
Error bars indicate standard error.

Figure 2.
Frequency Effect in Response Time for Individual Participants with Aphasia
* $p < .05$ (RSDT; Crawford & Garthwaite, 2005)

Table 1

Participant Demographic and Test Performance Data

Age	Gender	Years of Education	Ethnicity/ Race	Aphasia Type	Etiology	Boston Naming Test (max=60)	Peabody Picture Vocab Test [*]
P1 65	M	16	White	Conduction	CVA	3	91
P2 65	M	12	Hispanic	Broca	CVA	4	99
P3 70	M	16	White	Anomic	CVA	41	98
P4 31	M	12	Hispanic	Mixed	Gunshot Wound	7	77
P5 54	F	12	White	Broca	CVA	20	80
P6 55	F	14	White	Anomic	CVA	46	91
P7 38	M	14	Hispanic	Anomic	CVA	51	96
P8 32	M	12	Native American	Mixed	CVA	1	70

* Standard Score, all within 2 SD of mean for age-matched controls

Table 2

Performance on PAL Lexical Decision and Word Picture Matching Subtests

	<u>Lexical Decision</u>		<u>Word Picture Matching</u>	
	Auditory	Written	Auditory	Written
P1	.80	.85	0.97	1.00
P2	.79	.70	0.97	0.97
P3	.98*	.88	0.94	1.00
P4	.85*	.63	0.91	0.94
P5	.89	.78	1.00	1.00
P6	.95	1.0	1.00	1.00
P7	.96	1.0	1.00	1.00
P8	.81*	.73	0.94	0.88

*
p<.05 (χ^2)

Table 3

Boston Diagnostic Aphasia Exam (Short Form)

Word (/16)	Auditory Comprehension		Repetition		Oral Reading (/15)		Reading Comprehension	
	Commands (/10)	Comp Idea (/6)	Word (/5)	Sent (/2)	Word Picture Match (/4)	Sent & Para (/4)	Word Picture Match (/4)	Sent & Para (/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

Accuracy by Stimulus Type and Relevant Ratios on the Northwestern Naming Battery and Northwestern Assessment of Verbs and Sentences

Table 4

Assessment of Verbs and Sentences									
Naming Battery			Comprehension			Production			
Noun	Verb	Verb: Noun	Canonical	Non-Canon	Non-Can: Canon	Canonical	Non-Canon	Non-Can: Canon	
P1	3	1	0.33	13	0.85	0	0	0.00	
P2	3	0	0.00	14	0.93	0	0	0.00	
P3	15	7	0.47	8	1.25	10	7	1.43	
P4	5	4	0.80	10	1.00	0	0	0.00	
P5	10	9	0.90	8	0.88	1	0	0.00	
P6	16	16	1.00	13	0.54	10	2	0.20	
P7	15	16	1.07	15	0.73	15	10	0.67	
P8	4	1	0.25	12	0.83	0	0	0.00	

Table 5

Proportion Correct on Comprehension Questions for Individual Participants with Aphasia and Participant Groups. The group data are presented as mean(standard deviation).

Participants with Aphasia	Self-paced listening		Self-paced reading	
	High Freq	Low Freq	High Freq	Low Freq
P1	0.71	0.76	0.82	0.64
P2	0.67	0.81	0.59	0.64
P3	1.00	0.92	0.77	0.77
P4	0.81	0.95	0.77	0.64
P5	0.76	0.76	0.68	0.64
P6	0.90	0.90	1.00	0.91
P7	0.95	1.00	1.00	0.82
P8	0.75	0.85	0.68	0.68
Group Data				
Participants with Aphasia	0.82 (.12)	0.87 (.09)	0.79 (.15)	0.73 (.09)
Controls	0.90 (.12)	0.91 (.22)	0.93 (.16)	0.92 (.18)