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Reading and Listening in People with Aphasia: Effects of Syntactic Complexity

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Abstract

Purpose—The purpose of this study was to compare on-line effects of syntactic complexity in written and spoken sentence comprehension in people with aphasia and non-brain-damaged adults.

Method—The participants in experiment one were non-brain damaged younger and older adults (n=20 per group). Ten people with aphasia participated in experiment two. In both experiments, the participants read and listened to sentences in self-paced reading and listening tasks. The experimental materials consisted of object cleft sentences (e.g., *It was the girl who the boy hugged*.) and subject cleft sentences (e.g., *It was the boy who hugged the girl.)*.

Results—The predicted effects of syntactic complexity were observed in both experiments one and two: reading and listening times were longer for the verb in sentences with object compared to subject relative clauses. The non-brain-damaged controls showed exaggerated effects of syntactic complexity in reading compared to listening. People with aphasia did not show different modality effects from the non-brain-damaged participants.

Conclusion—Although effects of syntactic complexity were somewhat exaggerated in reading compared to listening, both people with aphasia and non-brain-damaged controls show similar effects in both modalities.

Keywords

Reading comprehension; auditory comprehension; sentence comprehension

Introduction

There is a relatively large body of literature regarding sentence comprehension impairments in people with aphasia, but most of them m m have focused on auditory comprehension (e.g., Caplan Waters, DeDe, Michaud, & Reddy, 2007; Thompson & Choy, 2009). As a result, little is known about reading comprehension disorders in people with aphasia, or about the relationship between auditory and reading comprehension. Reading impairments limit people with aphasia's ability to receive information (e.g., regarding health care decisions) in the written modality. Understanding the relationship between auditory and written sentence comprehension is also important in order to determine whether evaluation and treatment focused on one modality can be expected to generalize to the other.

The purpose of the present study was to directly compare reading and auditory comprehension in people with aphasia. That is, this study investigated whether the structure building operations involved in constructing the mental representations of written and

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spoken sentences can be separately impaired in people with aphasia. Modality-independent sentence comprehension deficits would suggest that the underlying impairment affects central linguistic processes. In contrast, abnormal differences between reading and auditory comprehension would suggest that comprehension impairments at least partly reflect modality-specific operations.

Many studies of sentence comprehension in people with aphasia have focused on syntactic parsing operations, especially those involved in the comprehension of sentences with long distance dependencies. One well-studied contrast is the processing difference between sentences with object- and subject-relative clauses (as in examples 1 and 2).

Complex Sentence: Object-Cleft

(1) It was the girl who the boy hugged on Sunday morning.

Simple Sentence: Subject-Cleft

(2) It was the boy who hugged the girl on Sunday morning.

Sentences with object relative clauses (ex. 1) are more difficult to understand than sentences with subject relative clauses (ex. 2) for both people with aphasia and non-brain-damaged controls. Studies of on-line sentence comprehension have demonstrated that both younger and older non-brain-damaged individuals spend more time processing (reading or listening to) the embedded verb in sentences with object- versus subject-extracted relative clauses (e.g., Caplan et al., 2011; Gibson, Desmet, Grodner, Watson, & Ko, 2005; Gordon, Hendrick, Johnson, & Lee, 2006; Waters & Caplan, 2005). For example, the processing demand associated with the relative clause verb "*hugged*" is greater in sentences like (1) than sentences like (2) (e.g., Waters & Caplan, 2005; Caplan, DeDe, Waters, Michaud, & Tripodis, 2011). Differences in processing time associated with object vs. subject relative clauses reflect the integrity of syntactic parsing abilities, and are referred to as effects of syntactic complexity (also cf. Thompson & Choy, 2009 for discussion).

The underlying difference between object and subject relative clauses can be captured in several ways. For example, the distance between the theme or undergoer of the relative clause verb ("the girl") and the verb itself is greater in (1) than (2) (Gibson, 1998). There are also increased integration costs due to the noun phrase intervening between the head of the relative clause and the position to which it is related. In addition, object relatives violate the canonical Subject-Verb-Object word order of English. Finally, object relative clauses may be more difficult to understand because they occur less frequently than subject relative clauses.

For people with aphasia, the differences between object and subject relative clauses can be observed in both on-line and off-line measures of comprehension. Off-line measures include end of sentence judgments such as accuracy on comprehension questions. Many studies have reported that people with aphasia make more errors about object than subject cleft sentences, as well as other sentence types with non-canonical word order (e.g., Caplan, Baker, & Dehaut, 1985; Caplan & Waters, 2003; Caplan et al., 2007; Dickey & Thompson, 2004; Dickey, Choy, & Thompson, 2007).

A smaller number of studies have investigated how people with aphasia process object and subject cleft sentences using on-line measures. On-line measures provide a way to examine the moment-by-moment processes with which people build a mental representation of a sentence. The advantage of on-line methods is that they provide a more fine-grained measure of the processes involved in sentence comprehension than off-line studies. Studies using the self-paced listening paradigm have reported that people with aphasia, like non-brain-damaged controls, spend more time listening to the verb of object cleft sentences than the verb in subject cleft sentences (e.g., Caplan & Waters, 2003; Caplan et al., 2007). Converging evidence using the visual world paradigm, which uses eye-tracking to examine auditory comprehension, has shown that people with agrammatic aphasia and non-brain-damaged controls show similar on-line processing of sentences containing object relative clauses (e.g., Thompson & Choy, 2009).

To my knowledge, there has only been one on-line study investigating how people with aphasia read sentences containing object- and subject- relative clauses (Sung, 2009). In Sung's self-paced reading study, only one of twenty participants with aphasia performed above chance on both the simple and complex sentences (Complex: *The aide who the nurse directed helped the patient in a very friendly manner.* Simple: *The nurse who was from the clinic directed the aide in a very friendly manner*.). As Sung (2009) pointed out, there was a high error rate and a large amount of variability in the data for both non-brain-damaged controls and people with aphasia. As a result, she reported non-significant effects of syntactic complexity for the control group, and did not use inferential statistics for the people with aphasia. The high error rate likely reflected the fact that the sentence types in Sung (2009) were longer and more complex than the stimuli that have been used in most previous studies (e.g., Caplan et al., 2007). Thus, people with aphasia may show syntactic complexity effects in self-paced reading for other, simpler types of structures that contain object relative clauses (e.g., object and subject clefts).

There is a fair amount of debate regarding why people with aphasia have difficulty understanding sentences with object relative clauses (e.g., processing vs. representational theories, cf. Caplan et al., 2007; Grodzinsky, 2000; Thompson & Choy, 2009). This debate was not the focus of the present study. Instead, the present study focused on whether sentence comprehension impairments in people with aphasia affect written and spoken language in similar ways. Sentences with long distance dependencies (e.g., subject and object clefts) provide a good test case for this question because all of the studies described above focused on comprehension of object and subject relatives in the auditory modality. Although some authors have focused on people with agrammatism (e.g., Grodzinsky, 2000; Thompson & Choy, 2009), others have investigated effects of syntactic complexity in mixed groups of people with aphasia (Caplan & Waters, 2003; Caplan et al., 2007; Dickey et al., 2011; Sung, 2009; Sung et al., 2009). As a result, it is possible to compare the results of the present study to previously published papers on auditory sentence processing.

There is some evidence that modality influences how non-brain-damaged controls process sentences with long distance dependencies. Caplan et al. (2011) and Waters and Caplan (2005) both investigated effects of syntactic complexity in older and younger adults. Both studies found the expected effects of syntactic complexity in both age groups. However, the effect of syntactic complexity was greater in older than younger adults in Caplan et al.'s (2011) self-paced reading study but not in Waters and Caplan's (2005) self-paced listening study. These results suggest that modality and age might interact with syntactic complexity, but the two studies included slightly different sentences and different groups of participants. It is an open question whether modality differences would be observed within a single study.

There have been no direct comparisons of on-line reading and listening comprehension for sentences with long distance dependencies (using either on-line or off-line measures). However, a small number of studies have directly compared reading and auditory comprehension in people with aphasia. Gardner and colleagues (1975) compared people with aphasia's performance on anomaly detection tasks in the two modalities. People with anterior perisylvian lesions made fewer errors in the auditory modality, whereas people with posterior perisylvian lesions made fewer errors in the written modality. In addition, two studies have compared accuracy on written and auditory versions of a sentence-picture-matching task using simple active sentences (e.g., *The birds are attacking the cats*) (Gallaher & Canter, 1982; Peach, Canter, & Gallaher, 1988). Gallaher and Canter (1982) showed that people with Broca's aphasia had more difficulty with the auditory than written version of the task, but a follow-up study showed no significant effects of modality for people with anomic and conduction aphasia (Peach et al., 1988). These studies suggest that at least some individuals with aphasia show modality-specific effects on comprehension accuracy. However, none of these studies focused on whether effects of syntactic complexity differed in the two modalities. In addition, they were all off-line studies, suggesting that they might not have been sensitive enough to detect differences in processing spoken and written sentences.

Only one study has used on-line methods to directly compare written and auditory sentence comprehension in a mixed group of people with aphasia (DeDe, 2012). This study compared effects of word frequency in simple sentences using self-paced listening and reading tasks. Non-brain-damaged controls showed typical word frequency effects, which are longer response times for low compared to high frequency words. In the auditory modality, the people with aphasia showed larger effects of word frequency than the controls. There was a lot of variability in the reading times for the people with aphasia. Some of the participants with aphasia showed exaggerated word frequency effects, whereas others showed reverse frequency effects (i.e., longer response times to high than low frequency words). For the present study, the critical point is that lexical access seemed to be less stable in the written than auditory modality.

DeDe (2012) described several reasons why word frequency effects might differ in the auditory and written modalities. For example, reading may be more vulnerable than listening because reading ability typically requires explicit instruction and emerges later than auditory language processing. In addition, reading experience (both before and after a stroke) or lesion location might affect lexical access. However, differences in lexical access when reading and listening to sentences do not necessarily mean that all sentence-level processes would be expected to show modality differences. In particular, the structure building operations involved in constructing the mental representation of a sentence may not differ across modalities. These processing algorithms may engage more central processes, and therefore not show differences as a function of modality.

The purpose of the present study was to (1) examine on-line reading comprehension of object and subject clefts in people with aphasia and (2) determine whether on-line comprehension of these sentences types is similar in the written and auditory modalities. Previous studies of sentence comprehension in non-brain-damaged controls and people with aphasia generate the prediction that both reading and listening times would be longer in the verb in object vs. subject cleft sentences. Regarding modality, DeDe's (2012) results suggest that the effects of syntactic complexity would differ in reading and listening. This would be consistent with the claim that comprehension impairments at least partly reflect modality-specific impairments. However, it is also possible that syntactic processing does not show modality differences, which would be consistent with the claim that the underlying impairment affects central linguistic processes.

Before investigating modality effects in people with aphasia, it is important to determine whether non-brain-damaged populations show the same pattern of results on spoken and written sentences. As noted above, previous studies suggest that syntactic complexity effects in reading and listening differ as a function of age (Caplan et al., 2011; Waters & Caplan, 2005). For this reason, experiment one compared written and auditory sentence comprehension in non-brain-damaged older and younger adults. The purpose of this experiment was to provide a point of comparison for experiment two, which investigated modality effects in people with aphasia. If the non-brain-damaged controls show differences as a function of modality, then the question becomes whether people with aphasia show similar effects of modality.

Experiment One: Non-brain-damaged Younger and Older Adults

Participants

Older (65–80 years, 6 males) and younger (18–30 years, 2 males) adults participated in this experiment (n=20 per group). All participants were native speakers of English with no history of language or learning disabilities. All participants reported that they had normal or corrected-to-normal vision. All 20 of the older adults and 15 of the younger adults were White. Three of the younger adults self-identified as Hispanic, and two self-identified as Asian. Two of the older adults completed high school, three completed some college, four earned their bachelor's degree, and 11 held a graduate or professional degree. Of the younger adults, two had completed high school, 12 had completed some college, 4 had earned their bachelor’s degree, and two were working toward a graduate degree.

All of the older adults denied a history of dementia or other neurological disease and scored at least 27 out of 30 on the Mini Mental State Exam (Folstein et al, 1975). The older adults’ hearing was screened hearing using pure-tone audiometry; only participants with normal hearing in the speech frequency range for their age were included (Morrell et al., 1996). The older adults had higher education levels than the younger adults, meaning that any evidence of age-related declines is not due to greater education in the younger adults. As expected, the older adults outperformed the younger adults on a vocabulary measure, the Wechsler Adult Intelligence Scale-Revised (WAIS) vocabulary subtest (Wechsler, 1981). Younger adults earned higher scores than older adults on a working memory task (subtract 2 span). Table 1 presents descriptive data about the participants.

Experimental Materials

The stimuli were 24 pairs of complex (object-cleft) and simple (subject-cleft) sentences such as (1) and (2) (repeated below as (3) and (4)). The simple sentences contained subject-relative clauses and canonical word order for English. The complex sentences contained object-relative clauses and non-canonical word order for English. Each experimental item was followed by a comprehension question such as “Did the girl hug the boy?” The questions for the experimental items required the participants to correctly assign the thematic roles in the sentences.

(3) **Object Cleft**: It was / the girl / who / the boy / hugged / on Sunday morning.

(4) **Subject Cleft**: It was / the boy / who / hugged / the girl / on Sunday morning.

Each sentence pair contained the same lexical items. The critical comparison was the relative clause verbs in object and subject relatives. All of the critical noun phrases were animate and high frequency. T-tests showed that frequency of the agents (e.g., boy) and patients (e.g., girl) did not differ ($p=.33$). Words in critical positions did not differ with respect to number of syllables, number of phonemes, orthographic neighborhood density or frequency, phonological neighborhood density or frequency, and biphone probability (all t’s < 1.1).

Experimental Tasks

The experimental tasks were self-paced reading and self-paced listening. The advantage of using these tasks are that (1) the dependent variables are comparable (listening vs. reading times) and (2) previous studies have shown that both tasks are sensitive to effects of syntactic complexity. Segmentation of the sentences was identical in both tasks, as shown by the slashes in examples 3 and 4.

Self-Paced Listening—A female speaker of American English trained in phonetics and phonology recorded the sentences in a sound-attenuated booth using Praat (Boersma & Weenink, 2011). Sentences were recorded as 16-bit sound files sampled at 44.1 kHz. Sentences were broken into segments using Praat (Boersma & Weenink, 2011). Segmentation was determined by areas with low signal amplitude at the end of words, as identified through visual and auditory inspection, and the breaking point that maximized the intelligibility of each segment. The waveforms were then entered into E-prime (Psychology Software Tools, Inc.) for use in the experiment. At the beginning of each trial in the experiment, participants saw the prompt “Ready?” and then paced through each segment of the sentence by pressing a button on an E-prime button box. The stimuli were played over high-quality earphones at comfortable listening levels. The button box collected reaction times for each button press and accuracy for the comprehension questions.

Self-Paced Reading—This task is the visual analog of self-paced listening. Sentences were presented phrase by phrase on a computer screen, using E-prime experimental software. Sentences were initially represented as a series of dashes corresponding to the length of each word in the sentence (Just & Carpenter, 1982). Participants paced their way through each sentence by pressing a button on a button box to reveal each successive phrase. At the first key press, the dashes corresponding to the words in the first phrase disappeared and were replaced by the actual words. When a participant pressed the key again, the first phrase was replaced by dashes, and the second phrase appeared. As in self-paced listening, the button box recorded reaction time for each button press and accuracy for the comprehension questions.

Procedures

The same materials were used in self-paced listening and self-paced reading. The experimental stimuli were divided into two lists so that the members of each sentence pair were assigned to different lists (i.e., the object and subject cleft version of any given pair were in different lists). Each list contained an equal number of object and subject cleft sentences. The experimental stimuli were combined with fillers so that critical sentences comprised about 21% of the items in each list. Inclusion of fillers is critical in order to ensure that participants do not develop an expectation for any given sentence type. The filler sentences were made up of items from other, unrelated experiments. The fillers included active transitive and intransitive sentences (n=56), temporarily ambiguous sentences with sentential complements (n=16), and unambiguous sentences with sentential complements (n=16). Examples are given in Table 2. The full set of fillers is available from the author upon request.

Participants completed both lists in both tasks in four separate testing sessions, which were at least 7 days apart. There were 10 practice sentences and an optional break halfway through each list. The order of list and task presentation was counterbalanced across participants.

Results

Comprehension Questions—Average proportion correct is in Table 3. The data were analyzed in 2 (sentence type: Subject vs. Object Cleft) by 2 (modality: reading vs. listening) analyses of variance (ANOVA) by participants (F1) and items (F2). There were main effects of group, $F1(1,38)=9.1$, $p=.005$, $F2(1, 23)=51.43$, $p<.0001$, partial $\eta^2 = .19$ and sentence type, $F1(1,38)=36.9$, $p<.0001$, $F2(1,23)=3.83$, $p=.06$, partial $\eta^2 = .49$. These main effects were qualified by the interaction between sentence type and group, F1(1,38)=5.28, p=.03, F2(1, 23)=8.7, p=.01, partial $\eta^2 = .12$. Tukey tests suggested that the effect of sentence type was greater in the older than younger adults (collapsing across modality).

There were no significant effects of modality. However, the interaction of sentence type and modality reached the level of a trend, F1(1,38)=2.7, p=.11, F2(1, 23)=3.2, p=.09, partial $\eta^2 = .07$. The three-way interaction of sentence type, modality, and group was significant by items but not participants, F1(1,38)=3.1, p=.09, F2(1, 23)=5.5, p=.03, partial $\eta^2 = .08$. Inspection of the means showed that the effects of sentence type were numerically greater in the older than younger adults (in both modalities).

Reading and Listening Times—Response times that were less than 50 or greater than 5000 milliseconds were removed. Outliers greater or less than three 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 5% of the data.

Reading and listening times for critical segments were derived from reaction times to control for effects of spoken segment duration and number of letters. Reaction times are frequently reported as milliseconds per letter in self-paced reading and milliseconds per segment in self-paced listening. However, comparing results of the two tasks requires that reading and listening times be on a similar scale. For this reason, a regression approach was used to control for length in both modalities. Raw reaction times for each participant were regressed against length (i.e., segment duration or number of letters), and the residuals of these analyses were used in the statistical analyses. Note that residual reaction times are sometimes negative if the predicted reading or listening times (based on word length) are longer than actual processing times.

The data were first analyzed in 4 (session:1 – 4) by 2 (group: older vs. younger) by 2 (sentence type: object vs. subject cleft) by 3 (segment: NP1, NP2, Verb) ANOVAs. There was a significant main effect of session due to participants responding more quickly across the four sessions (i.e., reading and listening times were faster). However, the effect of session did not interact with any other variable (all F's < 1), and so the data were collapsed across session for all subsequent analyses.

The data were then analyzed in 2 (group: older vs. younger) by 2 (sentence type: object vs. subject cleft) by 2 (modality: reading vs. listening) by 3 (segment: NP1, NP2, Verb) mixed ANOVAs, where group was the between participants variable. Figure 1 presents mean residual reaction times for each segment by group and condition. Only highest order significant effects are discussed. Significant interactions were explored using Tukey post-hoc tests with a criterion of $p<.05$.

There was a main effect of sentence type, F1(1,38)=30.0, p<.0001, F2(1,23)=53.0, p<.0001, partial $\eta^2 = .44$ and an interaction between sentence type and segment, F1(2,76)=35.2, p<.0001, F2(2,46)=77.1, p<.0001, partial $\eta^2 = .48$. The three-way interaction between sentence type, segment, and modality was also significant, F1(2,76)=6.0, p=.004, F2(2,46)=18.0, p<.0001, partial $\eta^2 = .14$. Tukey tests showed that there were no significant effects of modality or syntactic complexity for the first or second noun phrase. As predicted, reading and listening times for the verb were longer in object than subject cleft sentences. Reading times were longer than listening times for the verb in object clefts but not subject clefts. Reading and listening times did not differ for the first or second noun phrase.

The three-way interaction of sentence type, segment, and group was significant by items but not participants, F1(2,76)=1.87, p=.16, F2(2,46)=8.9, p=.001, partial $\eta^2 = .05$. The four-way interaction (sentence type×segment×group×modality) showed the same pattern, $F1(2,76)=1.9$, $p=.16$, $F2(2,46)=5.0$, $p=.01$, partial $\eta^2 = .05$. Greater effects of syntactic complexity in older than younger adults would be interesting both with respect to changes in sentence comprehension associated with normal aging and expected patterns of performance for people with aphasia. For this reason, difference scores were computed for the three segments (noun phrase 1, noun phrase 2, and the verb) in object and subject cleft sentences. T-tests were used to determine whether the effect of group was significant for each difference score, separately for the listening and reading time data. The only significant effect of group was in the listening times for the verb, $t(38)=2.04$, $p=.05$. No other contrasts, including reading times for the verb, differed as a function of group (all t's ≤ 1.7, all p's ≥ .10).

Summary of Experiment One

The results replicated previous studies showing longer reading and listening times for the relative clause verb in object cleft compared to subject cleft sentences. Effects of modality were observed at the verb: Reading times were longer than listening times for the verb in complex, but not simple, sentences. This finding suggests that the effects of syntactic complexity observed in written and auditory sentence processing are fundamentally similar, but somewhat exaggerated in reading. There was also weak evidence that the effects of syntactic complexity in the auditory modality were greater in older than younger adults.

The critical points are that non-brain-damaged controls showed effects of syntactic complexity in both modalities, and that the effects were somewhat larger in reading than listening. Thus, people with aphasia were predicted to show differences as a function of modality. Experiment two investigated whether people with aphasia showed effects of syntactic complexity in both modalities, and whether the effects of modality differed from those observed in the non-brain-damaged populations. If the effects of modality observed in people with aphasia are similar to modality effects observed in controls, then sentence comprehension impairments probably affect central linguistic processes. If people with aphasia show significantly different modality effects than would be expected based on the control data, then sentence comprehension impairments likely affect modality-specific operations.

Experiment Two: People with Aphasia

Participants

Ten people with aphasia (mean age= 52.4 years) participated in the study[1]. All were native English speakers with normal or corrected-to-normal vision and denied significant visual impairments (e.g., cataracts). They were at least 6 months post-onset of aphasia due to left hemisphere brain damage. Table 3 presents demographic information and results of some background testing.

All people with aphasia completed a battery of background tests to characterize their language disorders. On the Boston Naming Test (BNT), all participants except P10 performed at least two standard deviations below the mean for age-matched controls (Kaplan, Goodglass, & Weintraub, 2001). All of the participants with aphasia performed within two standard deviations of the mean for age-matched controls on the Peabody Picture Vocabulary Test (PPVT, 4th Edition, Form A) (Dunn & Dunn, 2007), demonstrating single word comprehension within normal limits.

[1]Data from a subset of these participants (P1–P8) were reported in DeDe (2012).

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Participants completed spoken and written versions of the lexical decision and word picture matching tasks on the Psycholinguistic Assessment of Language to ensure that they did not have gross impairments in lexical access or significant peripheral impairments (visual or auditory analysis) (PAL; Caplan, 1992). The results are presented in Table 5. Chi-square analysis showed that the participants' performance did not consistently differ across modalities. P3, P4, and P8 all performed significantly better on the auditory than written lexical decision task. However, none of the participants with aphasia showed a significant difference between written and auditory processing on both the word picture matching and lexical decision tasks, suggesting that lexical processing did not differ systematically in the two modalities. All participants performed above chance on all four PAL sub-tests.

All participants except P10 completed the short form of the Boston Diagnostic Aphasia Exam (Goodglass, Kaplan, & Barresi, 2000) (see Table 6). P10 completed the Western Aphasia Battery, and earned an Aphasia Quotient (AQ) of 94.8. Although this AQ is above the typical cut off for someone with aphasia, he was included because he exhibited anomia in conversational speech and reported significant difficulty in reading comprehension.

Additional testing was used to identify participants with symptoms of agrammatism, which is potentially of interest because this subgroup has been reported to show distinct patterns of comprehension impairment on sentences containing object relative clauses (e.g., Grodzinsky, 2000). The Northwestern Naming Battery-Final was administered to calculate the verb: noun ratio (Thompson, Lukic, King, Mesulam, & Weintraub, 2012). The ratios of non-canonical: canonical sentences that were correctly comprehended and produced were calculated based on the Sentence Comprehension and Sentence Production Priming subtests of the Northwestern Assessment of Verbs and Sentences (Cho-Reyes & Thompson, 2012). Ratios less than 1 are consistent with a diagnosis of agrammatism. Results are presented in Table 7.

Tasks, Materials, and Procedures

The materials, tasks, and procedures were identical to those described for Experiment 1. The only difference was that the people with aphasia completed additional testing to characterize their language disorder.

Results

Comprehension Questions—Individual and group data for proportion correct are presented in Table 3. The data were analyzed using signed rank tests because of the relatively small sample size. Effect sizes were calculated using the methods described for Wilcoxon Signed Rank tests by Corder and Foreman (2009). There were effects of syntactic complexity: People with aphasia made more errors following sentences with object than subject cleft in both modalities (auditory: S=19, p=.02, ES=.69, written: S=20.5, p=.03, ES=.66). There were no effects of modality: Proportion correct for the listening and reading tasks did not differ in either sentence type (all S's ≤ 11, all p's ≥ .21).

Reading and Listening Times—Data were trimmed using the same methods as described in experiment one, except that extreme values were identified based on visual inspection of a normal probability plot of each participant's data (because of variability in the data, see below). These procedures affected 7% of the data. Unlike experiment one, the data were analyzed using non-parametric statistics due to the sample size and because inspection of the variances indicated that the data violated the assumption of homogeneity of variance. The variance ratios ranged from 1.8 to 19.0 for the listening task and 1.7 to 20.7 for the reading task.[2]

To determine whether there were practice effects, data from each session (collapsed across sentence type and modality) were compared using Friedman tests, separately for the three critical segments. There were no significant effects of session on the reaction time data (also see footnote 2), so the data were collapsed across session in the subsequent analyses.

Reading and listening times for the group of participants with aphasia are presented in Figure 2. Signed rank tests were used to compare response times for object and subject cleft sentences in both modalities, and effect sizes were calculated following methods described by Corder and Foreman (2009). As in experiment one, response times for the two sentence types did not differ for the first or second noun phrase, in either modality (all $S \leq 8.5$, all p's $\geq .38$). Both reading and listening times were longer for the verb in object- compared to subject -cleft sentences (*reading*: S=20.5, p=.04, ES=.66; *listening*: S=21.5, p=.03, ES=.69). Thus, people with aphasia showed the expected pattern of longer response times for the most demanding segment (the verb) in more demanding sentences.

Analysis of Individual Data: Analysis of individual cases was used to determine whether people with aphasia showed larger effects of syntactic complexity than controls, and whether there were differences as a function of modality. Group analyses were not used because experiment one suggested that there might be differences between younger and older adults. The younger adults' data from experiment one were used as the reference group for participants P4, P7, and P8 because they were relatively young (under age 40). The older adults' data were used as the reference group for the other participants with aphasia. The individual data were analyzed using the Bayesian Unstandardized Difference Test, which can be used to compare an individual's response times in two different conditions (e.g., listening times for the verb in object vs. subject clefts) to the magnitude of the same difference in a reference sample (BUDT; Crawford, Garthwaite, & Wood, 2010). This method reveals whether an individual with aphasia shows a larger or smaller effect of syntactic complexity than would be expected based on non-brain-damaged controls. The BUDT was used instead of the standardized version because both tasks were on the same scale. Individual response times for the people with aphasia are presented in Figure 3.

Effects of Syntactic Complexity: To examine effects of syntactic complexity, response times for the verb were compared in object and subject relatives, separately for listening and reading. Based on a criterion of p<.05, only P9 showed a significantly greater effect of syntactic complexity than would be expected based on the non-brain-damaged adults' data (in both listening and reading).

Effects of Modality: The BUDT was also used to determine whether people with aphasia showed different modality effects than those observed in the control group. Difference scores were computed by subtracting response times for subject cleft sentences from response times for object cleft sentences. The difference scores for reading and listening times were then compared to the analogous difference scores for the appropriate control group. Using a criterion of p<.05, P6 was the only individual with aphasia who significantly differed from the normative sample. Inspection of the data in Figure 3 indicates that the primary difference was that the modality effect was reversed. Unlike the control group, P6 showed a larger syntactic complexity effect in the listening task than the reading task. In addition, P10 showed a marginal effect (p=.08) due to larger effects of syntactic complexity in reading compared to listening.[3]

[2]Inspection of the individual data suggested that the variance was due to very long response times for P9. In fact, when P9 was removed, the data met the assumption of homogeneity of variance. The data were analyzed using ANOVAs but omitting P9, and the same pattern of results was obtained as is reported here (for analyses with and without session in the model). Here, non-parametric statistics are reported to maximize the sample size and allow P9 to be included in the individual analyses.

General Discussion

The present study had two goals: to examine on-line reading in people with aphasia, and to determine whether sentence comprehension impairments in people with aphasia are modality independent. Regarding the first goal, the people with aphasia showed the expected effects of syntactic complexity (i.e., longer response times for the verb in object compared to subject relative clauses) in both listening and reading. This result validates the use of self-paced reading in people with aphasia by showing that the predicted effects of syntactic complexity are observed with this task in this population.

Before turning to the comparison of auditory and written sentence comprehension in people with aphasia, it is important to consider the effects of modality in the non-brain-damaged controls. Experiment one showed that non-brain-damaged controls evince the same basic patterns of response times in the auditory and written modalities. However, the effects of syntactic complexity were larger in reading than listening. As noted in the introduction, listening may exert fewer processing demands because it is a more natural and over-practiced skill than reading. The results of this study suggest that the possible benefits of written sentence processing (e.g., ability to inspect each word for as long as desired) do not facilitate comprehension of sentences containing object relative clauses.

It is unclear whether modality also has a significant effect on lexical access in non-brain-damaged populations. DeDe (2012) did not directly address this question, though inspection of the data in that study point to a non-significant trend towards larger frequency effects in reading than listening for the control group. In addition, Turner and colleagues (1998) reported significant effects of word frequency for written but not auditory lexical decision in college students. Thus, non-brain-damaged populations may show modality effects in both lexical and syntactic processing.

Given the results of experiment one, the question is whether people with aphasia show different effects of modality than non-brain-damaged adults. Like the controls, people with aphasia showed similar patterns of syntactic complexity in the written and spoken modalities. Unfortunately, variability in the data precluded direct comparison of reading and listening times for the people with aphasia. The analyses of individual data indicated that only two of the ten people with aphasia showed different modality effects than the non-brain-damaged controls. One of these participants (P6) showed greater complexity effects in listening than reading and the other (P10) showed marginally greater effects in reading. These analyses suggest that sentence comprehension impairments in people with aphasia do not systematically affect one modality to a greater extent than the other. This is consistent with the view that sentence comprehension impairments affect central linguistic, rather than modality-specific, operations.

These results differ from DeDe (2012), which showed a greater modality effect in people with aphasia than controls. In that study, people with aphasia showed larger effects of word frequency than non-brain-damaged controls. The effects of word frequency were more variable in the written than spoken sentences, pointing to modality differences in lexical access. In the present study, the people with aphasia's reading and listening times also showed a lot of variance. However, the range of variance ratios was roughly equivalent across the two modalities. Instead, the large variance ratios likely reflect relatively long

[3]An anonymous reviewer noted that both P6 and P10 were classified as having anomic aphasia, raising the possibility that people with anomic aphasia show greater modality effects than controls (or individuals with non-fluent aphasia). To test this hypothesis, Wilcoxon Signed Rank Tests were used to examine the effect of modality on the difference scores from the five participants classified as anomic (P3, P6, P7, P8, P9, P10). Data from participants classified as having non-fluent aphasia were analyzed in the same way. The effect of modality was not significant in either of the groups, S's ≤1.1, p's ≥ .27, likely due to the small sample sizes.

response times for P9 in both tasks (see Figure 3). Thus, in contrast to word frequency, reading comprehension of sentences with long distance dependencies (i.e. object relatives) does not seem to be more variable than auditory comprehension. In addition, DeDe (2012) reported that seven of the eight participants with aphasia showed significantly different word frequency effects than would be expected based on the control data. In the present study, only one participant showed significantly different modality effects than expected based on the control data. The lack of significant differences from the control group is a null effect, and so should be interpreted somewhat cautiously. Nonetheless, the fact that another study using the same methods (DeDe, 2012) identified significant differences from the control group strengthens the present results.

Taken together, the results of DeDe (2012) and the present study suggest that people with aphasia show different modality effects from non-brain-damaged controls in lexical, but not syntactic, processing. This difference may reflect the fact that lexical processing depends on peripheral processes to a greater extent than syntactic processing. Both lexical and syntactic processes draw on a combination of bottom up and top down influences (e.g., Gibson, 2006). For syntactic parsing, the top-down information includes syntactic and semantic expectations set up by the preceding context. As a very simple example, given the determiner "*The*," top-down information would predict that the next lexical item would be a noun. Predictions based on the top-down representation of the sentence are validated based on the bottom-up information (i.e., the actual lexical items). In the case of lexical access, the bottom-up cue is the visual or auditory signal, whereas the top down information is the sentence context (e.g., the noun *ball* would be relatively easy to access given the phrase *The girl threw the* …). Therefore, modality effects on lexical access may reflect differences in accessing the semantic system from the auditory and visual signals. People with aphasia may not show greater modality effects in syntactic parsing because sentence-level operations do not directly draw on the peripheral signal in the same way as lexical processes. Importantly, this interpretation is consistent with the view that sentence comprehension impairments in aphasia affect modality-general, rather than modality-specific, linguistic operations.

The present study also differed from previous studies comparing off-line auditory and written sentence comprehension. First, Gallaher et al. (1982) suggested that people with Broca's aphasia performed more accurately on a sentence picture-matching task in the auditory compared to written modality. However, they tested comprehension of simple active sentences, in which the foils were primarily semantic rather than syntactic. Their results are not inconsistent with the results of the present study because they focused on lexical processes whereas the present study focused on syntactic processes. Indeed, DeDe (2012) found that the people with aphasia generally showed larger effects of word frequency than controls. Inspection of the participants with aphasia's reading and listening times (reported in DeDe, 2012) reveals that the frequency effect was larger in reading than listening for 3 of the 4 participants with Broca's or mixed non-fluent aphasia (P2, P4, P5, and P8).

A second difference relates to modality differences in individuals with fluent aphasias. Peach et al. (1988) did not find a difference between reading and listening for people with conduction or anomic aphasia in a study using the same methods and materials as Gallaher et al. (1982). In the present study, inspection of data from individuals with anomic aphasia (Figure 3) is suggestive of a numeric trend towards relatively large effects of modality. This trend, together with the fact that people with conduction and anomic aphasia types showed differences between reading and listening in DeDe (2012), may reflect the use of more sensitive (on-line) methodologies.

The purpose of the present study was to compare auditory and reading comprehension in a mixed group of people with aphasia. Some researchers have argued that individuals with agrammatism or Broca's aphasia show distinct patterns of comprehension for syntactically complex sentences (e.g., Grodzinsky, 2000; Thompson & Choy, 2009). To my knowledge, these authors have not suggested that there would be modality differences in reading and listening for individuals with any aphasia type. In fact, Thompson and colleagues' "Treatment of Underlying Forms" involves oral reading of visually presented words and sentences, and results in generalization to comprehension of auditorily presented sentences (e.g., Thompson, Choy, Holland, & Cole, 2010). Although the present study did not explicitly vary aphasia type, inspection of the individual data suggests that people with non-fluent aphasia do not show large modality differences in syntactic processing. Further, the magnitude of the modality effects was within the range that would be expected based on control data. However, future research may address this question more directly by comparing reading and auditory comprehension in people with different aphasia types.

This paper does not address the extent to which lesion location influences modality effects. The analysis above would not predict modality differences in syntactic processes as a function of lesion location (also cf. Caplan, 2004). On the other hand, lesions affecting peripheral processes (such as visual or auditory word recognition) would be expected to cause modality-specific impairments. Further research is needed to address the extent to which specific lesion locations affect lexical processing (e.g., word frequency effects). Future studies might also investigate whether modality effects differ when reading or listening to paragraphs rather than sentences.

From a clinical perspective, this study demonstrates that people with aphasia show effects of syntactic complexity in both reading and listening. The fact that syntactic complexity effects were exaggerated in the written modality suggests that reading tasks may be more complex than listening tasks, even if performance on clinical tests (such as sentence picture matching) are equivalent. For this reason, and following from the principles of the Complexity Account of Treatment Efficacy (e.g., Thompson, Shapiro, Kiran, & Sobecks, 2003), treatment efforts may be best directed at written language processing. Finally, this finding indicates that studies of on-line written and auditory language processing in people with aphasia can be interpreted as a coherent body of literature, rather than needing to treat reading comprehension studies as different from auditory comprehension studies.

In conclusion, this study showed that the structure building operations involved in understanding sentences with relative clauses are fundamentally similar in reading and writing. In addition, sentence comprehension impairments in aphasia appear to be modality-general. Although there may be greater effects of syntactic complexity in reading than listening, the effects of modality are not exaggerated in people with aphasia compared to non-brain-damaged controls. Instead, abnormal modality effects in people with aphasia are more likely to be observed in lexical than syntactic processing (DeDe, 2012).

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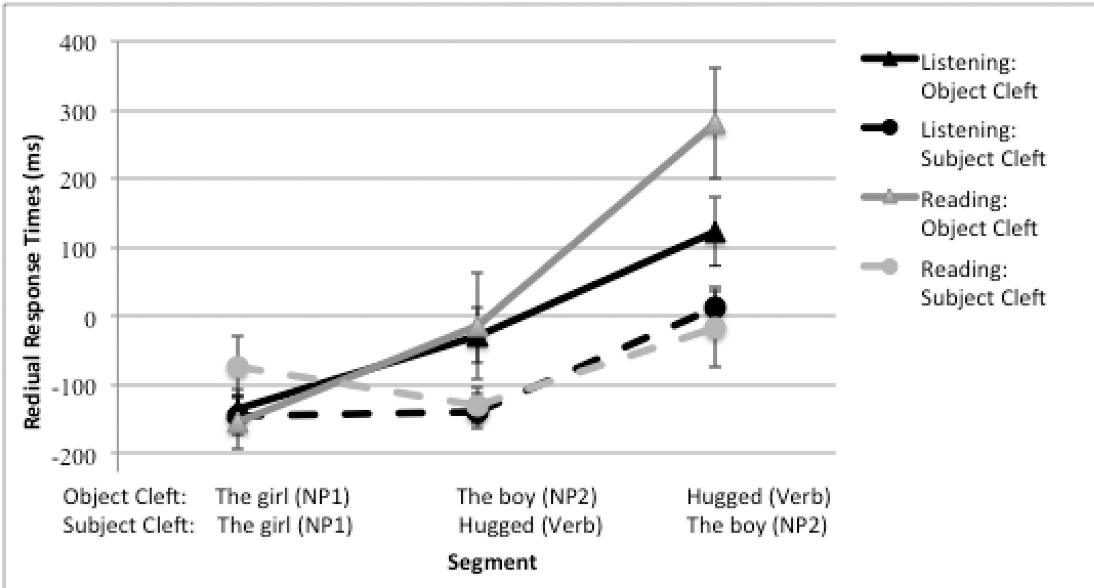
Panel A: Older Adults



Panel B: Younger Adults

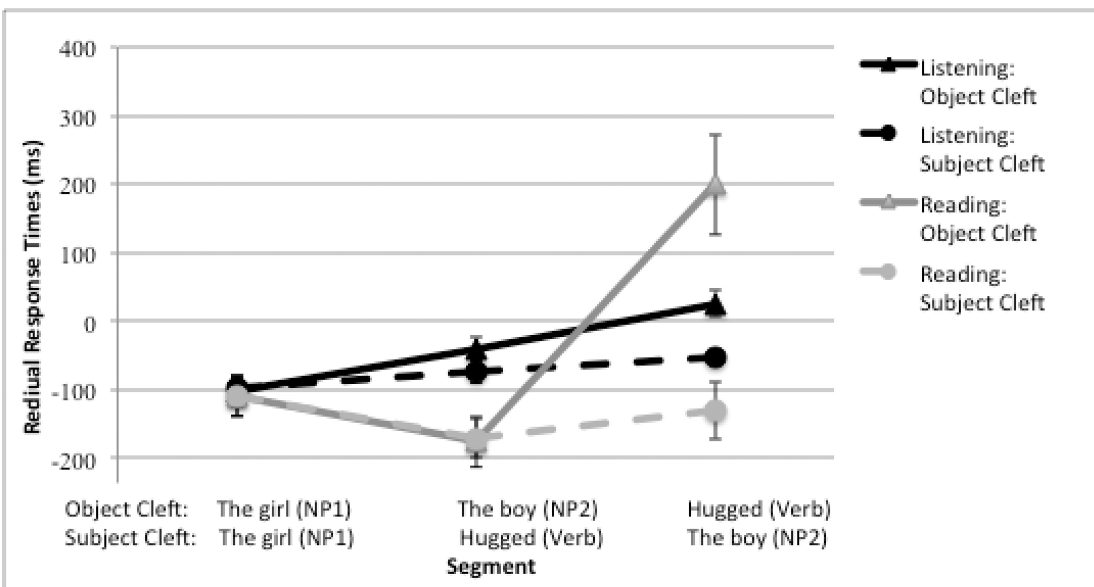


Figure 1.
Mean Reading and Listening Times for Older and Younger Adults. Error bars show standard errors.

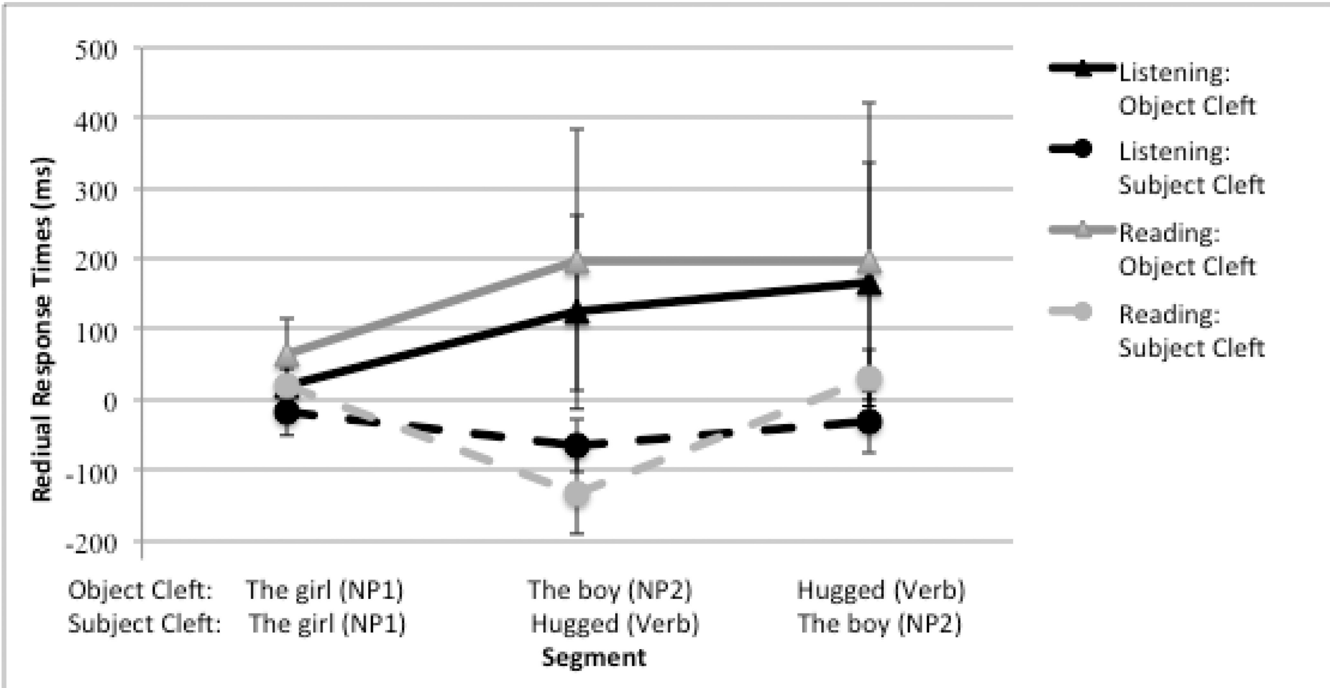


Figure 2.
Listening and Reading Times for People with Aphasia. Error bars show standard errors.

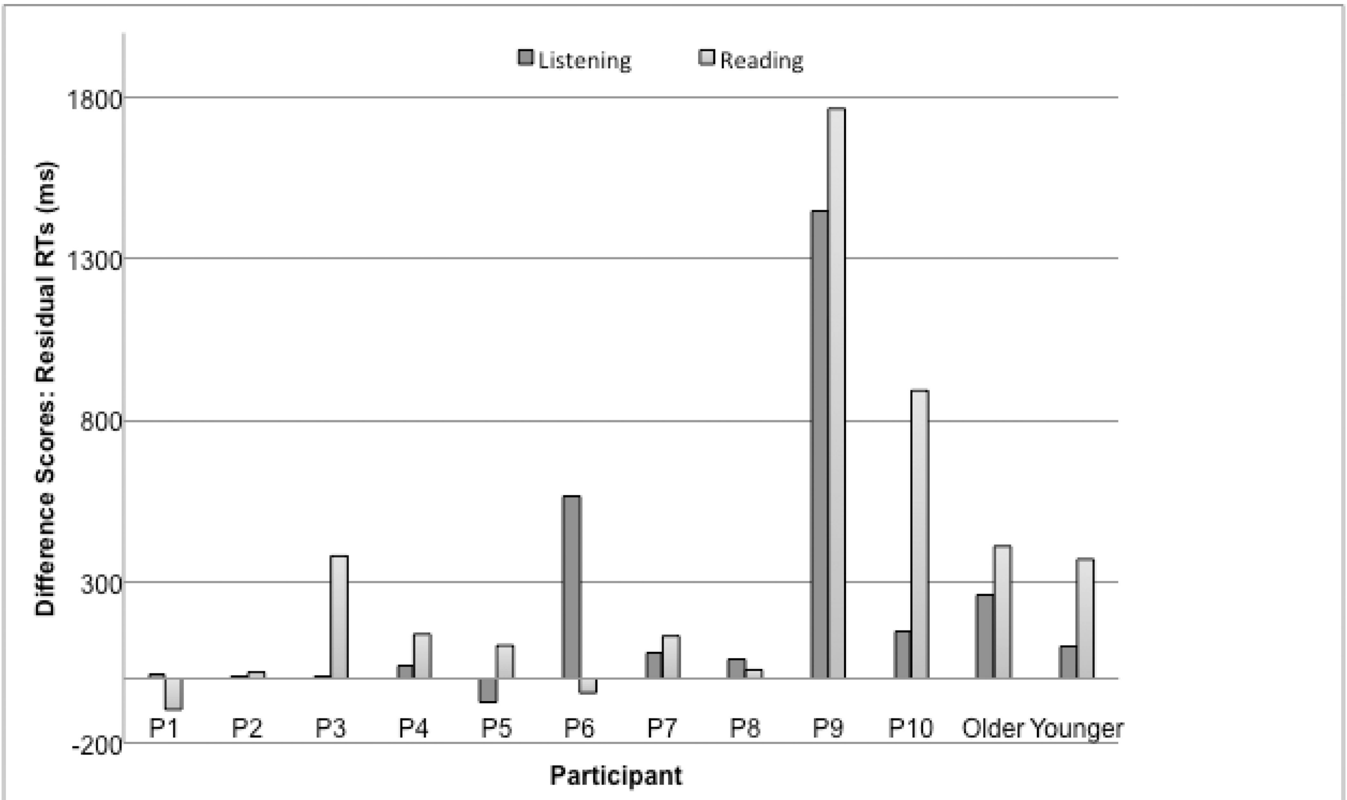


Figure 3.

Individual response times for people with aphasia. Values are difference scores (RTs for object cleft-subject cleft sentences). Group data for older and younger adults are also presented.

Table 1

Descriptive Statistics for Older and Younger Adults

Group	Age*	Edu*	WAIS Vocab*	Sub 2 Span*
Older	69.4 (5.3)	17.9 (2.6)	61.6 (4.5)	4.5 (.74)
Younger	21.8 (3.8)	14.2 (1.6)	52.3 (6.4)	5.6 (.73)

* $p < .05$

Table 2

Examples of Filler Sentences

Filler Type	Examples
Ambiguous sentences with sentential complements (SC)	The factory owner suspected the cash would probably not last long.
Unambiguous SC sentences	The trained referees warned that the game would probably go into overtime.
Transitive Sentences	The choir will sing the song during the festival next Saturday in the park.
Intransitive Sentences	The boy studied before his math test on Tuesday.

Table 3

Older, younger, and aphasic participants' proportion accurate responses on comprehension questions. Values given for group data are mean (standard deviation).

	Listening		Reading	
	Object Cleft	**Subject Cleft**	**Object Cleft**	**Subject Cleft**
Group Data				
Older	0.88 (.09)	0.94 (.08)	0.85 (.12)	0.94 (.06)
Younger	0.92 (.06)	0.96 (.05)	0.91 (.09)	0.94 (.06)
Aphasic	0.67 (.12)	0.74 (.13)	0.64 (.10)	0.72 (.10)
Individuals with Aphasia				
P1	0.63	0.75	0.71	0.63
P2	0.67	0.75	0.67	0.71
P3	0.83	0.75	0.63	0.71
P4	0.67	0.75	0.63	0.67
P5	0.54	0.50	0.63	0.67
P6	0.58	0.71	0.63	0.67
P7	0.71	0.79	0.54	0.79
P8	0.58	0.58	0.58	0.63
P9	0.58	0.83	0.54	0.79
P10	0.92	1.00	0.88	0.96

Table 4

Participant Demographic and Test Performance Data

	Age	Gender	Years Edu	Ethnicity/Race	Aphasia Type	Etiology	BNT*	PPVT**
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 non-fluent ***	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 non-fluent ***	CVA	1	70
P9	64	F	15	White	Anomic	CVA	14	94
P10	50	M	18	White	Borderline Anomic	CVA	54	113

* Max score = 60. All except P10 are 2 SD below the mean for age-matched controls.

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

*** Both participants with mixed non-fluent aphasia had lower auditory comprehension scores on the 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.

Table 5

Performance on PAL Lexical Decision and Word Picture Matching Subtests

	Lexical Decision			Word Picture Matching	
	Auditory		Written	Auditory	Written
P1	.80		.85	.97	1.0
P2	.79		.70	.97	.97
P3	.98	*	.88	.94	1.0
P4	.85	*	.63	.91	.94
P5	.89		.78	1.0	1.0
P6	.95		1.0	1.0	1.0
P7	.96		1.0	1.0	1.0
P8	.81	*	.73	.94	.88
P9	.98		.95	.97	1.0
P10	1.0		1.0	1.0	1.0

$p < .05$

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Table 6

Boston Diagnostic Aphasia Exam (Short Form)*

	Auditory Comprehension			Repetition		Oral Reading (/15)	Reading Comprehension	
	Word (/16)	Commands (/10)	Comp Idea (/6)	Word (/5)	Sent (/2)		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
P9	15	7	6	3	1	14	4	4

*P10 completed the Western Aphasia Battery, AQ = 94.8.

Table 7

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

	Naming Battery			Assessment of Verbs and Sentences					
				Comprehension			Production		
	Noun	Verb	Verb: Noun	Canonical	Non-Canon	Non-Can: Canon	Canonical	Non-Canon	Non-Can: Canon
P1	10	8	0.80	13	11	0.85	0	0	N/A
P2	5	0	0.00	14	13	0.93	0	0	N/A
P3	15	7	0.47	8	10	1.25	10	7	0.70
P4	6	4	0.67	10	10	1.00	0	0	N/A
P5	11	9	0.82	8	7	0.88	1	0	0.00
P6	16	16	1.00	13	7	0.54	10	2	0.20
P7	16	16	1.00	15	11	0.73	15	10	0.67
P8	6	3	0.50	12	10	0.83	0	0	N/A
P9	12	15	1.25	12	5	0.42	13	10	0.77
P10	16	16	1.00	15	15	1.00	15	14	0.93