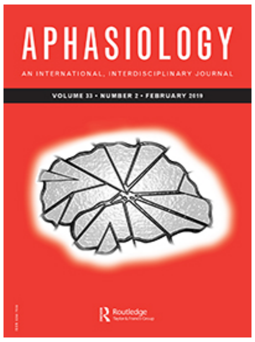

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Error analysis of oral paragraph reading in individuals with aphasia

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ABSTRACT

Background: Acquired reading impairments that commonly occur in individuals with aphasia can significantly impact their quality of life. Few studies have examined errors during oral connected text reading and the relationship of errors to reading comprehension, which is significant since readers rarely encounter reading material presented as single words in everyday situations.

Aims: This preliminary study aimed to characterize the errors made by persons with aphasia during oral paragraph reading relative to neurotypical peers, examine the association between reading error frequency and aphasia severity, oral and silent reading comprehension, and extent of motor speech deficits, and examine the relationship between oral and silent reading comprehension performance of persons with aphasia.

Methods and procedures: Eight persons with aphasia (three with anomic, four with Broca's, one with conduction) and eight age- and education-matched neurotypical participants orally read paragraphs from the Gray Oral Reading Tests, Fifth Edition, and answered associated comprehension questions. The Western Aphasia Battery – Revised, Reading Comprehension Battery for Aphasia – Second Edition, and Apraxia of Speech Rating Scale provided measures of aphasia severity, silent reading comprehension, and extent of motor speech impairment for persons with aphasia. Reading samples were descriptively analyzed for error frequency and type. Two-tailed Spearman's correlations were used to examine the relationship between total error frequency, aphasia severity, oral and silent reading comprehension, and extent of motor speech deficit.

Outcomes and results: Persons with aphasia made significantly more errors relative to participants without aphasia. Of persons with aphasia, individuals with anomic aphasia produced the fewest errors with the least amount of variance relative to persons with Broca's and conduction aphasia. Persons with anomic aphasia made more morphological errors and self-corrections relative to other errors. Persons with Broca's aphasia made a high number of articulation errors, fillers, and self-corrections, while the person with conduction aphasia made more visual-phonological and visual-semantic errors relative to other persons with aphasia. Moderate to strong associations were found between total error frequency, aphasia severity, oral reading comprehension, and extent of motor speech deficit when articulation errors were included in the total error frequency.

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Conclusions: Although preliminary, the results suggest analysis of reading errors and comprehension of oral paragraph reading can provide a more detailed account of reading and language processing deficits of persons with aphasia, and supports the use of oral reading as a measure of speech production impairment. Future research will need to examine a larger sample of participants to appreciate the clinical and theoretical implications.

Introduction

Two million individuals in the United States have aphasia (National Aphasia Association, n.d.), and of this two million, about 68% have reading deficits related to language processing (i.e., central alexia; Brookshire, Wilson, Nadeau, Rothi, & Kendall, 2014). Alexia, or acquired reading impairment, can significantly impact a person with aphasia's quality of life and safety (Knollman-Porter, Wallace, Hux, Brown, & Long, 2015), such as preventing them from being able to return to work, to read for pleasure, or to correctly read the prescription label on their medication. To date, much of the literature examining reading impairments of individuals with aphasia has focused on single word reading abilities (e.g., Brookshire et al., 2014); however, no studies to our knowledge have specifically examined the errors made by persons with aphasia during oral connected text reading and their relationship to comprehension. This is significant given that readers rarely encounter reading material presented as single words in everyday situations and that comprehension of written material is the ultimate goal of reading. Furthermore, evidence from developmental reading suggests that oral connected text reading ability is a good predictor of comprehension (Jenkins, Fuchs, van Den Broek, Espin, & Deno, 2003; Kim, Wagner, & Foster, 2011), and can provide a good framework for conceptualizing this potential relationship in persons with aphasia.

Many reading fluency theories have characterized developmental readers, both skilled and unskilled, and provide a good framework for explaining how oral reading errors in connected text impact reading comprehension. One particular theory, the verbal efficiency account of reading ability (Perfetti, 1985, 1992), builds on the automaticity theory (LaBerge & Samuels, 1974), which posits that an individual has limited attentional resources available for a given cognitive task. The more automatic the individual becomes at a given task, the less attention must be devoted to execute the task. Related to reading, as word recognition becomes more automatic, attention resources once required for word decoding can be devoted to comprehension. The verbal efficiency account of reading, in particular, suggests that quick, automatic word reading reduces the attention load and allows working memory to be utilized for meaning construction. In contrast, less skilled readers have poor word identification skills, which taxes attentional resources and reduces working memory capacity necessary for comprehension (Jenkins et al., 2003). Support for the verbal efficiency theory comes from evidence for the association between reading speed and comprehension, both of single words (e.g., McCormick & Samuels, 1979) and connected text reading tasks (e.g., Fuchs, Fuchs, Hosp, & Jenkins, 2001).

Reading errors of neurotypical adults

Errors that characterize oral reading in neurotypical adults have not garnered much attention by investigators. Early work described reading errors based purely on surface-level observations, with no insight into the underlying linguistic processes (Leu Jr., 1982). For example, Swanson (1937) presented six surface-level error categories that included substitutions, repetitions, omissions, insertions, mispronunciations, and miscellaneous. More recently, errors were described based on linguistic "miscues" made during oral reading. Categories of errors included syntactic (e.g., adding or omitting plural markers), semantic (e.g., replacing a word, such as *cat*, with a word with similar meaning, such as *feline*), and graphically similar (e.g., pronouncing a word such as *bat* as a graphically similar word like *ban*; Leu, 1982). It was also recognized that not all errors interfere equally with reading comprehension and that the context of a passage could compensate for oral reading errors made, aiding in overall understanding (Goodman, 1973). Nonetheless, it is likely persons with aphasia make errors during oral reading that reflect those of neurotypical readers, in addition to errors that reflect their underlying linguistic deficits.

Reading errors associated with aphasia and alexia

In contrast to neurotypical reading errors, oral reading errors commonly seen in individuals with aphasia with concomitant central alexia often reflect the individual's underlying linguistic processing deficits (Coslett & Turkeltaub, 2015). Specific issues with reading that are associated with aphasia are similar to those seen with distinct alexia types – semantic, surface, phonological, and deep (Beeson & Insalaco, 1998) – though a predictable relationship between aphasia type and alexia type has not been identified. Semantic alexia rarely accompanies aphasia, but usually co-occurs with certain types of dementia; thus, this subtype will not be discussed in detail.

Surface alexia

Surface alexia, associated with lesion sites in the left temporal or temporal-parietal regions, is commonly seen in fluent types of aphasia, and is characterized by an inability to read words with irregular spellings that cannot be sounded out. Surface alexia has also been well-documented by Woollams and colleagues (2007) to co-occur with semantic dementia, and the presence of surface alexia is a feature used in the diagnosis of the semantic variant of primary progressive aphasia (Gorno-Tempini et al., 2011). For single word oral reading, visual, phonological, and morphological errors are commonly seen in individuals with surface alexia (Coslett & Turkeltaub, 2015). Visual errors, such as *mild* for *slid*, are the result of reading the target word as another word that has similar letters. Although the precise mechanism underlying visual errors is unknown, it is thought that they occur after visual processing has taken place (Coslett & Turkeltaub, 2015). Phonological errors, such as *pat* for *bat*, are the result of reading the target word as another word that sounds similar, usually differing only by one or two phonemes (Coslett & Turkeltaub, 2015). Morphological errors, such as *kid* for *kids*, are the result of omitting morphemes from or adding morphemes to the target word (Coslett & Turkeltaub, 2015).

Phonological alexia
Phonological alexia, associated with general damage to the left hemisphere, is characterized by difficulty reading non-words and/or novel words (Coslett & Turkeltaub, 2015). Visual, phonological, morphological, and regularization errors are commonly seen in phonological alexia (Coslett & Turkeltaub, 2015). Regularization errors, such as *car* for *dar*, involve reading a target non-word as a similar sounding real word (Coslett & Turkeltaub, 2015). The primary difference between surface and phonological alexia is that individuals with phonological alexia often make regularization errors. Regularization errors are usually not seen in surface alexia.

Deep alexia
Deep alexia, associated with extensive left hemisphere lesions, is commonly seen in non-fluent types of aphasia, and is characterized by difficulty reading non-words, and the presence of visual and semantic reading errors (Coslett & Turkeltaub, 2015). Persons with deep alexia also make semantic errors, such as producing synonyms or antonyms for a word (e.g., misreading *blood* as *heart*; Coslett & Turkeltaub, 2015). These semantic errors differentiate deep alexia from phonological and surface alexia. Along with visual and semantic errors, individuals with deep alexia also commonly make phonological and morphological errors in their oral reading (Coslett & Turkeltaub, 2015). It is not clear at this time, however, how each of the alexia subtypes would align with errors produced by persons with aphasia during oral connected text reading.

Connected text oral reading

Webb and Love (1983) characterized oral reading deficits in 35 persons with chronic aphasia and concomitant alexia. The authors of this study did not specify the aphasia or alexia subtype breakdown of their population, so the variability in aphasia subtypes is unknown. Nonetheless, errors were the highest in the reading comprehension tasks, compared to oral reading and picture recognition. Even the participants who had the fewest number of errors during the reading tasks reported they no longer read for pleasure, indicating that reading was laborious and had become less useful after their brain injury. Results revealed that reading ability was correlated to the severity of language impairment present in persons with aphasia.

Oral connected text reading has been incorporated into treatment protocols, such as Multiple Oral Re-reading (MOR; Moyer, 1979) or Oral Reading for Language in Aphasia (ORLA) treatment (Cherney, Merbitz, & Grip, 1986) for persons with aphasia. Both treatments are based on repetitive, multimodality stimulation to elicit a change in oral reading accuracy (Cherney, 2004). ORLA has been shown, generally, to be efficacious for all participants, regardless of type or severity of aphasia, and with ORLA treatment, comprehension improved once accuracy of oral reading improved (Cherney, 2004; Cherney et al., 1986). Several studies have examined the effects of these treatment approaches with results varying depending on the reading measures assessed, number of participants included, style of interventions, and length of intervention (Cherney, 2010a, 2010b; Kim & Russo, 2010; Lacey, Lott, Snider, Sperling & Friedman, 2010).

More recently, Purdy and colleagues (2018) performed a systematic review of 15 articles specific to reading treatment of persons with aphasia, some of which are cited above. They identified four categories of treatment procedures: oral reading treatment (e.g., MOR and ORLA), strategy-based treatment (e.g., covering the words above and below the sentence being read or highlighting key words), cognitive-based treatment (e.g., attention process training-II), and hierarchical treatment. Due to variance in treatment delivery factors and outcome measures of the 15 studies, Purdy and colleagues were unable to make a clear recommendation on a reading treatment protocol for persons with aphasia.

Several studies have also investigated various factors that influence reading in persons with aphasia and concomitant alexia. DeDe (2017) found persons with aphasia were sensitive to lexical variables (e.g., word class, word length, and word frequency) during silent reading. Mitchum, Haendiges, and Berndt (2005) measured reading accuracy in isolation and in connected text and found a positive impact of the contextual effects gained by reading in sentences, rather than lists of single words, for two of five of their participants with aphasia. Jones, Pierce, Mahoney, and Smeach (2007) concluded that reading familiar content improved the comprehension skills of persons with aphasia in their study. Last, Webster, Morris, Howard, and Garraffa (2017) studied the effect of text variables on reading comprehension in two groups of persons with aphasia, one group with reading impairments and one without reading impairments. Their findings determined both groups differed significantly from the age-matched controls in terms of reading time and comprehension accuracy.

Impact of apraxia of speech

Although most everyday reading is silent for meaning, reading aloud is advantageous for examining breakdowns in linguistic processing of persons with aphasia during reading, and can help reveal factors that contribute to comprehension deficits. However, concomitant motor speech disorders may contribute to difficulties observed during oral reading compared to silent reading. As apraxia of speech commonly co-occurs with non-fluent subtypes of aphasia, it is likely that these persons will produce articulation errors, fillers, repetitions, and self-corrections, among others, in addition to linguistic errors. Supported by the verbal efficiency account of reading (Perfetti, 1985, 1992), these additional speech production errors made during oral reading may significantly impact comprehension compared to reading comprehension during silent reading, by requiring additional attentional resources and limiting working memory capacity. The results of the current study are discussed with these potential limitations in mind.

Research questions and hypotheses

This preliminary study aimed to characterize the errors made during oral paragraph reading, and examined the association between oral paragraph reading errors and reading comprehension in persons with varying subtypes of aphasia compared to age- and education-matched neurotypical peers. The data discussed here are part of a larger study examining factors that contribute to oral connected text reading deficits. The specific research questions and hypotheses were as follows:

(1) How does the frequency and types of oral paragraph reading errors of individuals with aphasia compare to participants without aphasia? It was hypothesized that

persons with aphasia would make errors of greater frequency compared to participants without aphasia, with the errors reflecting those of neurotypical readers and linguistic deficits that underlie aphasia or speech production errors observed in concomitant apraxia of speech.

(2) What is the relationship between the frequency of errors during oral paragraph reading and overall aphasia severity, oral and silent reading comprehension, and extent of motor speech deficits in persons with aphasia? Because aphasia is a central disorder and reading is a modality of language, it was hypothesized that error frequency during oral reading would be strongly associated with aphasia severity. As such, more errors would be indicative of more severe aphasia. Guided by the verbal efficiency account of reading ability (Perfetti, 1985, 1992), it was hypothesized that a higher frequency of errors would be associated with lower oral and silent reading comprehension skills and greater extent of motor speech deficit.

(3) What is the relationship between oral and silent reading comprehension in persons with aphasia? It was hypothesized that oral and silent reading comprehension would be strongly, positively associated. Higher scores on oral reading comprehension would be associated with higher scores on silent reading comprehension.

Methods

Participants

A convenience sample of three persons with anomic aphasia, four persons with Broca's aphasia, and one person with conduction aphasia participated in this study, age: M = 59.00, SD = 11.77; education level in years: M = 14.56, SD = 4.74. Additionally, eight age- and education-matched neurotypical peers, age: M = 60.00, SD = 11.91; education level in years: M = 14.33, SD = 2.06, also participated. Although a convenience sample was used, general inclusion and exclusion criteria were followed. Persons with aphasia had aphasia determined by the Western Aphasia Battery – Revised (WAB-R; Kertesz, 2006); were 6 months or greater post-onset, M = 41, SD = 47.62 months, native English speakers, between 30 and 80 years old; had the ability to read aloud; and were able to provide either written or verbal informed consent.

The WAB-R Aphasia Quotient was used to determine aphasia severity, M = 77.78, SD = 11.00. The Matrix Reasoning subtest of the Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV), M = 14, SD = 4.74, was used to provide a test of inductive reasoning, selected because it requires less verbal and cultural dependence (Dugbartey et al., 1999) than other tests, such as Raven's Progressive Matrices Test (Raven, 1976). Silent reading comprehension was measured using the Reading Comprehension Battery for Aphasia – Second Edition (RCBA-2), M = 88.67, SD = 9.73 (LaPointe & Horner, 1998), and apraxia of speech was assessed using the Apraxia of Speech Rating Scale (ASRS), M = 1.56, SD = 1.59 (Strand, Duffy, Clark, & Josephs, 2014). Of note, the individual with conduction aphasia was left-handed prior to their stroke.

Participants without aphasia were also native English speakers, between 30 and 80 years old, with cognitive skills within normal limits as determined by the Matrix Reasoning subtest of the WAIS-IV (Wechsler, 2008) and the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975). They had the ability to read aloud and provide informed consent, self-reported normal or corrected-to-normal vision, and no speech-language, reading, or neurological/cognitive disorders.

Participants in both groups were excluded if they had a history of dementia or other neurological conditions (e.g., Parkinson's disease), alcohol abuse, psychiatric disorder and/or traumatic brain injury, history of communication disorder or reading disability prior to stroke, or visual acuity deficits that were unable to be corrected. All participants in both groups self-reported normal hearing abilities, and passed a vision screening using the McDowell Vision Screening Test (McDowell & McDowell, 1998). The McDowell Vision Screening Test was adapted for use with the current study's participant sample (designed for very young children with severe disabilities), and selected because it is designed to detect abnormalities in distance and near-point acuity, ocular alignment and motility, color perception, and ocular function.

No significant differences between the group of individuals with aphasia and the control group emerged for age, $U = 28.50$, $p = .71$, education level, $U = 30.00$, $p = .82$, and scores on the WAIS-IV matrix reasoning subtest, $U = 14.50$, $p = .07$. Table 1 shows the detailed demographic and assessment information for both participant groups. Participants were compensated for their participation and gave signed informed consent for study inclusion. Approval for this study was obtained from the Institutional Review Board at the University of South Alabama.

Materials

Table 2 presents the number of words and sentences, font size, and entry points by grade level, according to the Gray Oral Reading Tests – Fifth Edition (GORT-5) Examiner's Manual, for the first eight GORT-5 paragraphs used as stimuli. Additionally, each paragraph had a mixture of factual (e.g., "With whom did the child ask to play?") and inferential (e.g., "Where do you think 'here' is in the story?") open-ended comprehension questions that were asked and answered orally immediately after the reading of each paragraph. The ratios of factual to inferential questions per paragraph are also displayed in Table 2.

Procedures

For all participants without aphasia and for five participants with aphasia, screenings, standardized testing, and oral paragraph reading with comprehension questions (in that order) occurred within just one session. For two participants with aphasia, two sessions were needed, and for one participant with aphasia, three sessions were required. Experimental sessions occurred approximately a week apart. Individuals that required more than one session were those with Broca's aphasia and concomitant speech production deficits. The 16 developmentally sequenced reading passages of the GORT-5 (Wiederholt & Bryant, 2012) were used to elicit oral reading samples and comprehension scores. The paragraphs were presented in the order of difficulty. Participants answered the five corresponding comprehension questions after each paragraph. Since the 16 paragraphs progress with increasing difficulty, participants read as many paragraphs as possible without reaching a point of fatigue, as judged by the participant and research personnel. This decision was ultimately up to the participant, although to reduce effects of fatigue, research personnel encouraged participants to break or stop

Table 1. Demographic and assessment information for all participants.

Participant	Age	Gender	Ed Level (yrs)	WAIS-IV MR[a]	Handedness	Months Post-Onset	WAB-R AQ[b]	ASRS[c]	RCBA-2[d]	Aphasia Subtype
Persons with Aphasia										
P1	54	F	12	14	R	119	60.4	2	79	Broca's
P3	71	M	16	12	R	11	63.8	3	72	Broca's
P4	56	F	16	14	R	127	86.3	0	75	Anomic
P5	69	M	17	5	R	17	79.8	3	88	Broca's
P6	53	F	12	15	R	20	65.7	4	74	Broca's
P7	68	M	16	19	L	6	83.3	0	96	Conduction
P8	35	M	16	21	R	39	92.5	0	97	Anomic
P9	55	F	12	10	R	6	91.1	0	92	Anomic
Participant	Age	Gender	Ed Level (yrs)	WAIS-IV MR[a]	MMSE[e]					
Controls										
C1	57	M	17	20	35					
C3	56	F	12	12	33					
C4	73	F	16	17	28					
C5	54	F	12	16	32					
C6	35	F	16	24	35					
C7	68	F	15	18	35					
C8	54	F	12	20	34					
C9	70	M	16	20	35					

[a]WAIS-IV MR = Wechsler Adult Intelligence Scale, 4th Edition, Matrix Reasoning subtest (max score 26); [b]WAB-R = Western Aphasia Battery – Revised (max score 100); [c]ASRS = Apraxia of Speech Rating Scale (0 indicates features of apraxia are not present, 4 indicates features of apraxia are nearly always evident and marked in severity); [d]RCBA-2 = Reading Comprehension Battery for Aphasia – 2nd Edition (max score 100); [e]MMSE = Mini Mental State Examination.

Table 2. GORT-5 paragraph information.

Paragraph #	# of Words*	# of Sentences*	Font Size**	Entry Points by Grade*	Comprehension Questions Factual/ Inferential*
1	17	5	16.5	1st–3rd	4/1
2	41	5	16.5	4th–5th	4/1
3	52	7	16.5	N/A	5/0
4	81	9	13.5	6th–9th	5/0
5	106	7	13.5	10th–11th	2/3
6	100	9	13.5	12th <	5/0
7	106	6	13.5	N/A	5/0
8	129	7	11.5	N/A	5/0

Font style for all paragraphs is Arial; *information obtained from the GORT-5 Examiner's Manual; **calculated by the authors.

when the participant had been reading for approximately two hours. For all participants, regardless of the number of testing sessions, comprehension questions for the GORT-5 paragraphs that were read were completed in the same session. Participants without aphasia, as well as individuals with anomic and conduction aphasia, read all 16 paragraphs of the GORT-5. However, individuals with Broca's aphasia read only eight paragraphs. Therefore, for comparison, only paragraphs 1–8 were examined for oral reading errors and comprehension, as all participants read these paragraphs.

Error coding and data preparation

Oral readings of the GORT-5 paragraphs were audio and video recorded for later transcription and analysis. Samples were orthographically transcribed. For orally read words that could not conform to orthographic spelling, International Phonetic Alphabet symbols were used. Error codes were retrieved from Cherney (2004), Leff and Starrfelt (2014), and the GORT-5 Examiner's Manual (Wiederholt & Bryant, 2012). For the purposes of this study, the following errors are considered to be common during the oral reading of neurotypical readers (Wiederholt & Bryant, 2012): self-corrections, whole word additions, whole word repetitions, whole word omissions, and reversals. The following errors are considered to be typical during the oral reading of persons with aphasia (Cherney, 2004; Leff & Starrfelt, 2014): neologisms, visual, semantic, visual-semantic, morphological, phonological, visual-phonological, fillers, articulation errors, and unrelated function words. Errors classified as being consistent with neurotypical readers were produced by persons with aphasia during this study, and likewise (though rarely), errors classified as being common for persons with aphasia were produced by persons without aphasia. A detailed description of the error codes can be found in Appendix 1. Each errored production was assigned one error code, apart from special cases involving semantic and/or morphological errors that were also produced with articulatory error. In these cases, errors were assigned both a semantic (or morphological) code and an articulation code.

Trained research assistants transcribed each oral paragraph reading sample. Inter- and intra-rater reliability was completed for transcription and error coding for one participant with aphasia and one control participant. Percent agreement was used as the measure of reliability. For transcription of the participant with aphasia's reading sample, intra-rater reliability was 96.26% and inter-rater reliability was 92.5%. For error coding of the participant with aphasia's reading sample, intra-rater reliability was 95% and inter-rater reliability was 97%. Intra-rater reliability for the transcription of the participant without aphasia's reading sample was 99%, and inter-rater reliability was 98.46%. Intra-rater reliability was 99% for error coding of the participant without aphasia's reading sample, and inter-rater reliability was 95%. Because the percent agreement was greater than 90% for all comparisons, the transcriptions and error codes of the first rater were utilized for data analyses. A consensus was reached between two raters on answers to the comprehension questions.

Results

Prior to analyses, the data were tested using the Shapiro–Wilk test of normality. Non-normal distributions were evident for error frequency across all categories for persons with aphasia (total errors, neurotypical errors, errors characteristic of aphasia; all $p < .02$). Control participants showed non-normal distributions for neurotypical errors only ($p = .001$). For these reasons, in addition to the relatively small and heterogeneous sample, non-parametric tests were used to examine comparisons of error frequency between groups and the associations among variables of interest. Normal distributions were present for comprehension for both groups (both $p > .24$), so parametric tests were used to examine comprehension across the two groups.

Frequency and errors types

Table 3 summarizes the error frequency of each paragraph and the total error frequency for all participants for paragraphs 1–8 of the GORT-5, and Table 4 summarizes the error

Table 3. Error frequency and comprehension scores for paragraphs 1–8 of the GORT-5.

	Total Errors								Comprehension Questions Correct out of 5									
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	Total Errors (of 2034 words)	[a]Comprehension Questions % Correct
Controls																		
C1	0	0	0	2	1	0	3	1	2	4	5	5	4	5	4	4	7	82.5
C3	0	1	1	1	0	2	4	2	3	4	4	4	5	4	2	2	11	70
C4	0	1	0	1	4	2	0	6	5	4	4	2	4	2	1	1	14	57.5
C5	1	1	0	0	0	2	5	7	5	3	4	3	5	4	3	1	16	70
C6	0	1	0	1	0	1	0	0	3	5	5	5	4	4	3	3	3	80
C7	0	0	0	0	1	1	0	2	5	5	5	4	4	4	4	3	4	85
C9	0	0	0	0	0	1	1	1	2	5	5	5	4	4	3	3	3	77.5
C10	2	0	0	2	4	4	3	8	4	5	4	4	4	4	4	3	23	80
Anomic																		
P4	1	4	3	10	6	13	12	14	2	3	4	2	2	3	1	1	63	45
P8	2	6	5	13	11	16	24	26	3	5	5	4	3	3	3	2	103	70
P9	0	3	1	6	11	12	7	17	2	3	4	5	4	2	2	3	57	62.5
Broca's																		
P1	0	3	2	10	6	17	26	30	2	2	1	1	0	0	0	0	94	15
P3	12	32	45	64	99	83	137	175	0	3	4	4	1	2	3	1	647	45
P5	5	28	28	88	123	104	165	184	0	1	4	3	4	2	3	2	725	47.5
P6	30	77	72	117	168	202	194	226	1	1	0	2	0	0	1	1	1086	15
Conduction																		
P7	1	2	4	21	27	18	35	39	2	4	2	4	4	4	2	4	174	65

[a]Comprehension Questions % Correct is based on 40 questions.

Table 4. Descriptive statistics for specific error categories of each participant with aphasia and control group.

	Controls	Anomic			Broca's				Conduction
	M (SD)	P4	P8	P9	P1	P3	P5	P6	P7
Errors Typical of Persons with Aphasia									
Neologisms	–	–	–	1	6	10	18	7	14
Visual	0.11 (0.33)	–	–	–	2	6	4	1	–
Semantic	0.67 (0.71)	4	6	9	4	28	26	13	12
Visual-Semantic	1.11 (1.5)	1	3	2	10	14	16	9	16
Morphological	0.44 (0.73)	13	19	4	19	26	24	42	5
Phonological	–	–	1	–	2	9	2	–	1
Visual-Phonological	–	3	2	2	6	13	21	2	19
Fillers	4 (3.5)	–	10	–	–	133	143	201	–
[a]Articulation	1.44(1.13)	2	5	–	–	146	60	361	3
Unrelated Function Words	1.89 (1.96)	–	–	–	2	30	7	7	–
Neurotypical Errors									
Self-Corrections	0.22 (0.44)	22	47	25	34	86	233	358	49
Whole Word Additions	0.22 (0.44)	11	3	6	1	37	52	6	2
Whole Word Repetitions	0.11 (0.33)	–	7	3	8	47	97	17	22
Whole Word Omissions	–	6	–	5	–	61	22	62	4
Reversals	0.11 (0.33)	1	–	–	–	1	–	–	–

– denotes that the error type was not produced; [a]Articulation errors were coded when either distorted additions, substitutions, or pure distortion errors were made, otherwise speech sound errors were considered phonological.

frequency in specific error categories. Compared to persons with aphasia, participants without aphasia, $M = 10.13$, $SD = 7.22$, made significantly fewer total errors than persons with aphasia, $M = 365.00$, $SD = 397.00$, $U = 0.00$, $p = .001$. Within the group of persons with aphasia, there was considerable variability as shown in Table 3. Individuals with anomic aphasia produced, on average, 74.33 errors, $SD = 25.01$, while individuals with

Broca's aphasia produced 638.00 errors on average, but with a much higher variance, *SD* = 410.00. P1, with Broca's aphasia, only made 94 errors performing with much higher accuracy than the other individuals with Broca's aphasia.

Across the eight paragraphs, participants without aphasia either remained about the same (C6, C9) or increased slightly in error frequency (C10 from two to eight errors). C1 and C3 made fewer errors in paragraph 8 than paragraph 7. Persons with aphasia generally made more errors during reading as the paragraphs became more difficult. P3, P5, and P6 with Broca's aphasia made larger increases in error frequency across the paragraphs compared to other persons with aphasia.

For neurotypical reading errors, persons with aphasia, *M* = 167.00, *SD* = 170.99, made significantly more compared to participants without aphasia, *M* = .63, *SD* = 1.06, *U* = 0.00, *p* = .001. The group of persons without aphasia produced no whole word omissions or reversals, and few errors in the other neurotypical error categories – self-corrections, *M* = 0.25, *SD* = 0.46, whole word additions, *M* = 0.25, *SD* = 0.46, and repetitions, *M* = 0.13, *SD* = 0.35. Persons with aphasia made fewer neurotypical errors, *M* = 167.00, *SD* = 170.99, on average compared to errors characteristic of aphasia, *M* = 198.00, *SD* = 234.33, though not statistically significant, *Z* = −.14, *p* = .89. It is important to note, however, the significant variability in the sample. Self-corrections, *M* = 190.00, *SD* = 122.80, were made with the most frequency, followed by whole word repetition, *M* = 45.00, *SD* = 32.65, whole word omission, *M* = 36.00, *SD* = 26.53, and whole word addition errors, *M* = 26.00, *SD* = 19.05. Only two reversals were made, one by P3 who has Broca's aphasia and one by P4 who has anomic aphasia. P5, *n* = 233, and P6, *n* = 358, both with Broca's aphasia and concomitant apraxia of speech, made the most self-corrections. P5 produced more whole word addition, *n* = 52, and repetition, *n* = 97, errors compared to all other persons with aphasia, while P3, *n* = 61, and P6, *n* = 62, produced more whole word omission errors.

For reading errors characteristic of persons with aphasia, although infrequent, participants without aphasia made visual, *M* = .12, *SD* = .35, semantic, *M* = .63, *SD* = .74, visual-semantic, *M* = .88, *SD* = .83, and morphological, *M* = .50, *SD* = .76, errors. They made no neologisms, phonological, or visual-phonological errors, but infrequently produced fillers, *M* = 4.25, *SD* = 3.65, articulation errors, *M* = 1.50, *SD* = 1.20, and unrelated function words, *M* = 1.63, *SD* = 1.92. Persons with aphasia, *M* = 198.00, *SD* = 234.33, produced significantly more errors characteristic of aphasia compared to the group of participants without aphasia, *M* = 9.50, *SD* = 6.50, *U* = 1.00, *p* = .001. Persons with aphasia produced more articulation errors, *M* = 128.00, *SD* = 127.42, and fillers, *M* = 108.00, *SD* = 83.66, than all other errors types characteristic of aphasia, although it is important to note the large standard deviations. P3, P5, and P6, who all have Broca's aphasia and concomitant apraxia of speech, produced most of these errors compared to the other persons with aphasia. Visual, *M* = 3.00, *SD* = 2.26, and phonological, *M* = 3.00, *SD* = 3.00, errors were produced with the least frequency for the overall group. However, P3 who has Broca's aphasia, produced the most errors in these categories, visual: *n* = 6; phonological: *n* = 9, in additional to semantic errors, *n* = 28, and unrelated function words, *n* = 30, compared to all other persons with aphasia. P5 with Broca's aphasia and P7 with conduction aphasia produced visual-semantic errors (both P5 and P7: *n* = 16), visual-phonological errors (P5: *n* = 21; P7: *n* = 19), and neologisms (P5: *n* = 18; P7: *n* = 14) with the most frequency compared to the other individuals with aphasia.

Comprehension

Table 3 summarizes the comprehension scores for all participants for each paragraph 1–8 and the total comprehension score of the GORT-5. Compared to the 19;0–23;11-year-old GORT-5 normative group, the participants without aphasia in the current study scored in the fiftieth percentile (mean scaled score of 10), which is interpreted as "average". Compared to persons with aphasia, participants without aphasia, $M = 75.31$, $SD = 9.01$, scored significantly better on the GORT-5 reading comprehension questions, $M = 45.63$, $SD = 21.16$, $t(14) = -3.65$, $p = .003$. P8 (70%) and P9 (62.5%), who both have anomic aphasia, scored similarly to the individual with conduction aphasia (65%). All of these individuals answered the comprehension questions with higher accuracy compared to the other persons with aphasia. P1 and P6, both who have Broca's aphasia, scored with the lowest accuracy, 15%. P4 with anomic aphasia scored the same as P3 with Broca's aphasia (45%). The group of persons with Broca's aphasia was divided on the performance of reading comprehension accuracy with P1 and P6 both scoring with 15% accuracy, and P3 and P5 scoring with 45% and 47.5% accuracy, respectively.

As shown in Table 3, two trends emerged in the comprehension scores across the eight paragraphs. The first was increased accuracy across the first four paragraphs, then decreasing accuracy for the remaining four. This trend was observed for many participants with and without aphasia (i.e., C1, C3, C6, C9, C10, P4, P8, P9, P3, P5). The second trend showed better performance for the less difficult paragraphs with systematic decline in performance as the paragraphs became more difficult. Participants without aphasia, C4, C5, and C7 demonstrated this trend, along with P1 with Broca's aphasia.

Associations among variables

For persons with aphasia only, a two-tailed Spearman's correlation was used to examine the relationship between total error frequency, aphasia severity (WAB-R aphasia quotient), oral and silent reading comprehension (GORT-5 total number of comprehension questions correct and RCBA-2 overall score, respectively), and extent of motor speech deficit (ASRS overall score). Bonferroni correction was used to account for multiple comparisons. Table 5 summarizes the results. Moderate to strong associations were found between all variables with the exception of silent reading comprehension, measured by the RCBA-2 and total errors produced during oral reading. Negative associations were found between total error frequency and oral and silent reading comprehension scores, and aphasia severity, indicating greater error frequency during oral reading is associated with poorer reading comprehension and aphasia severity. Positive associations were found between aphasia severity,

Table 5. Spearman correlation results.

	Total Errors (without articulation errors)	GORT-5 Comprehension	WAB-R AQ	RCBA-2
GORT-5 Comprehension	−.77*(−.07)			
WAB-R AQ	−.45(−.10)	.80		
RCBA-2	−.33(−.31)	.84	.69	
ASRS	.71*(.06)	−.70*	−.74	−.69

*Correlation is significant at the 0.05 level (2-tailed) after Bonferroni correction oral reading comprehension scores, and silent reading comprehension scores, indicating less severe aphasia is associated with better oral and silent reading comprehension abilities. Extent of motor speech impairment measured by the ASRS was negatively associated with oral and silent reading comprehension and aphasia severity but positively associated with error frequency during oral reading. These results indicate that persons with more severe speech production deficits produce oral reading errors with greater frequency, and tend to have more severe aphasia and poorer oral and silent reading comprehension scores.

Because articulation errors accounted for a large portion of the error frequency (9.27%), a second Spearman correlation was conducted to examine the relationship between total error frequency excluding articulation errors, aphasia severity (WAB-R aphasia quotient), oral and silent reading comprehension (GORT-5 and RCBA-2, respectively), and extent of motor speech deficit (ASRS). These results are also shown in Table 5. The results revealed weak associations between total error frequency excluding articulation errors and aphasia severity, oral and silent reading comprehension, and extent of motor speech impairment. These results, compared to the correlation results above, suggest that articulation errors made during oral reading appear to account for much of the associations among the variables.

Discussion

This preliminary study characterized the errors made during oral paragraph reading, and examined the association between oral paragraph reading errors and reading comprehension in individuals with varying subtypes of aphasia compared to age- and education-matched neurotypical peers. Although the study findings contribute to the growing body of literature related to reading difficulties of persons with aphasia and neurotypical older adult reading, the small sample size and potentially confounding variables, such as the heterogeneity of the sample and concomitant motor speech deficits, limits the impact of the findings. It is important to interpret the results with caution until they are replicated.

Error frequency and types

The participants without aphasia made errors across all error categories. Although emerging evidence documents eye movements during reading in neurotypical aging adults (e.g., Rayner, Yang, Castelhano, & Liversedge, 2011), this finding fills a gap in the neurotypical older adult reading literature, as no studies have coded the errors of older adults orally reading paragraphs to our knowledge. Further, these findings build on current word retrieval evidence indicating an age-related decline in naming accuracy, particularly at the semantic level (e.g., Verhaegen & Poncelet, 2013). These age-related cognitive changes might lead to errors during oral reading as seen in the current study; however, intact text memory, vocabulary, and word knowledge preserved in neurotypical aging adults support high levels of comprehension (Gordon, Lowder, & Hoedemaker, 2016).

Persons with aphasia made errors often seen in word retrieval and single-word reading. The error types largely conformed to expectations regarding documented language profiles of the subtypes. Consistent with naming errors observed in persons with anomic aphasia (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997), persons with anomic aphasia in the current study made periodic semantic and morphological errors during reading. In contrast, persons with Broca's aphasia were variable in the error types made across participants. P1 appears to be reading with characteristics consistent with phonological alexia, namely, few errors made in oral reading suggest access to an intact lexicon, especially for high-frequency words (Coslett & Turkeltaub, 2015), but difficulty integrating words that are read is leading to poor reading comprehension. However, the other persons with Broca's aphasia produced errors of similar type, more morphological errors and unrelated function words, consistent with the characteristic grammatical difficulties of non-fluent types of aphasia (Maher, 2017). In addition, the production of semantic errors suggests that their reading is consistent with that of a deep alexia subtype (Coslett & Turkeltaub, 2015). This is consistent with the finding that deep alexia more often occurs in persons with Broca's or global aphasia, rather than fluent aphasia (Coslett & Turkeltaub, 2015). Notable is the similar performance of persons with Broca's aphasia, P1 and P6, for reading comprehension, but considerably different performance for error frequency. P6's performance is consistent with our hypotheses – higher error frequency resulted in poorer comprehension; however, P1 is an exception. The implications of this finding is that word identification alone may not be a good predictor of reading comprehension, as indicated in the verbal efficiency account of reading ability. Some individuals may have intact direct access to the orthographic lexicon, yielding few errors in oral reading, but lack access to the lexical-semantic system to assign meaning to words that are accurately identified.

Association between error frequency and other variables

Although there are reading-specific processes (e.g., visual analysis, grapheme-to-phoneme conversion), many of the language processes that occur during reading are shared with components of spoken language (i.e., lexical-semantic, morphosyntactic processing; Kay, Lesser, & Coltheart, 1996). Thus, it makes sense that performance during reading would reflect aphasia severity or overall language processing ability, to some extent. The association of error frequency when including speech production errors and aphasia severity supports this assertion, along with the Webb and Love (1983) study, which found the relationship between reading deficits and overall language severity to be strong. Further, intervention studies (ORLA; Cherney et al., 1986) that embed connected text reading in their protocols have demonstrated generalization to overall language processing abilities (e.g., WAB-R aphasia quotient scores; Cherney, 2010a, 2010b), suggesting processes that are engaged during reading are shared with overall language processing abilities, as indicated by the current study's finding. Of note, however, is the lack of association when articulation errors are removed from the total error frequency. This finding suggests that articulation errors observed in oral reading may be an indicator of overall impairment, both of language and speech production. Individuals who make articulation errors with high frequency are more likely to have a more significant aphasia, as is the case in the current study sample. Persons who made the most articulation errors also scored the lowest on the WAB-R. Considering the current study's small sample size, when you remove the articulation errors from the frequency count, there may not be sufficient errors remaining to establish an association with aphasia severity.

One significant finding is the differential contribution of articulation errors in the total error frequency to oral reading comprehension. The results support the verbal efficiency account of reading ability (Perfetti, 1985, 1992). When word identification and production is laborious – in this case particularly for persons with speech production deficits – comprehension suffers. As defined by the verbal efficiency account of reading ability, it can be inferred that persons who make a significant amount of articulation errors must rely to a greater extent on attention and working memory processes during oral reading, thus leaving fewer resources available to process and integrate what has been read. However, when the articulation errors are controlled for, the association diminishes, suggesting the linguistic errors produced are not contributing significantly to comprehension difficulty. Further, when examining error frequency and comprehension accuracy across the paragraphs, the verbal efficiency account is not well supported, as only few participants demonstrated a systematic increase in error frequency and a decrease in the accuracy of comprehension questions with increase in task complexity.

Association between silent and oral reading comprehension

Consistent with our hypothesis, a strong association between oral reading comprehension and silent reading comprehension performance emerged. Although the current study was interested in oral reading to provide a means for error coding, this finding is encouraging. When a comprehension component is incorporated into the reading task, and therefore minimizing the likelihood of "fake" reading, both oral and silent reading are likely measuring similar underlying reading mechanisms in persons with aphasia. This finding is also supported by developmental reading studies indicating there is no difference in comprehension scores across silent and oral reading tasks when reading ability is controlled for (e.g., McCallum, Sharp, Bell, & George, 2004).

Study limitations

As this is a preliminary study, there are several limitations to note. The small and heterogeneous sample significantly limits our ability to draw strong conclusions from the results. Additionally, other potential confounds such as the presence of apraxia of speech in the non-fluent participants is significant. Concomitant motor speech disorders may contribute to difficulties observed during oral reading compared to silent reading, although the current data do not support this, as individuals with more severe apraxia of speech also performed poorly on the silent reading measure. We attempted to account for apraxia of speech severity by using the ASRS and a silent reading measure (the RCBA-2); however, the small sample size limited our ability to account for this confound statistically.

The use of the GORT-5 is also a limitation. The GORT-5 is normed for children and adults up to age 23, but not for aging adults or disordered populations. Thus, use of the paragraphs and comprehension questions as stimuli for the primary outcome measure of the current study may not be the most appropriate. To mitigate this, the authors did not implement the GORT-5 scoring procedures. In addition, a limited number of reading passages were used, as data was presented for the first eight paragraphs only. Last, many additional factors such as cognitive load, attention and working memory ability, hearing acuity, or demographic factors, such as everyday reading exposure or reading experience, likely have a role in performance, both for persons with aphasia and participants without aphasia. All of these factors may help explain reading performance, particularly the variability of comprehension scores in the current study's sample. Although measures of these additional factors were not included as part of the current experimental protocol, they will be considered for future research. Despite these limitations, the current study demonstrates the feasibility of such a protocol and gives insight into potential implications.

Future directions

The opportunities for studying reading in persons with aphasia are vast, and can take several potential directions. First, acquiring a larger sample of both older neurotypical individuals and persons with aphasia is required so the results can be interpreted in the context of a broader population. Second, the authors seek to examine additional measures of reading, such as single word reading ability, reading rate and fluency, and to examine how these measures are related to reading comprehension. It is also of interest to examine how well these oral reading measures are related to specific linguistic processes, such as lexical-semantic or syntactic processing skills.

Summary and conclusions

Acquired reading impairments that commonly co-occur in individuals with aphasia can significantly impact their quality of life. Few studies have examined errors during oral connected text reading and the relationship of errors to reading comprehension, which is significant given that readers rarely encounter reading material presented as single words in everyday situations. This preliminary study aimed to characterize the errors made by persons with aphasia during oral paragraph reading relative to neurotypical peers, to examine the association between reading error frequency and aphasia severity, oral and silent reading comprehension, and extent of motor speech deficits, and to examine the relationship between oral and silent reading comprehension performance of persons with aphasia. Error frequency and types produced for orally read paragraphs were largely consistent with the documented language and speech production profiles of persons with aphasia and various subtypes; however, with one specific exception, in which one individual with Broca's aphasia made few errors during reading but had very poor reading comprehension. Overall, though, the results were consistent with the verbal efficiency account of reading ability (Perfetti, 1985, 1992), oral reading error frequency was associated with oral reading comprehension scores. Although preliminary, the results suggest analysis of reading errors and comprehension of oral paragraph reading can provide a more detailed account of reading and language processing deficits of persons with aphasia, and supports the use of oral reading as a measure of speech production impairment. Future research will need to examine a larger sample of participants to appreciate the clinical and theoretical implications.

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Appendix 1. Errors Present in Oral Paragraph Reading

Error Type	Definition	Example
Errors Characteristic of Persons with Aphasia		
Neologism*	A newly coined word	*Floogata* for *elephant*
Visual*	Deletion, addition, and/or substitution of one or more graphemes	*Range* for *manage*
Semantic*	Misreading a word as a semantically similar word	*Heart* for *blood*
Visual-Semantic*	Combination of visual and semantic errors	*Audience* for *auditorium*
Morphological*	Deletion, addition, or substitution of a grammatical morpheme	*Kid* for *kids*
Phonological*	Deletion, addition, or substitution of one or more phonemes	*Which* for *quick*
Visual-Phonological	Combination of visual and phonological errors	*Cat* for *bat*
Fillers	Words or short phrases inserted into the reading	*Uh, um, hold on, ok I got it*
Articulation	Words that were judged to be misarticulated due to Apraxia of Speech (AOS)	*Kah-bah* for *cowboy*
Unrelated Function Words	Words that were not related to the target function word in any way	*The* for *and*
Neurotypical Errors		
Self-Correction**	Substitutions that are immediately corrected	*I go – went* for *I went*
Additions**	Whole words added into the passage	*I think went* for *I went*
Repetitions	Whole words repeated during reading	*I guess, I guess so…*
Omissions**	Whole words omitted from the passage	*I going* for *I am going*
Reversals**	Words or letters that are transposed	*No* for *on*

Notes: *Retrieved from Cherney (2004) and/or Leff and Starrfelt (2014); **Retrieved from the *GORT-5* Examiner's Manual (Wiederholt & Bryant, 2012); Unmarked error categories were added and defined by the authors.