Individuals with aphasia demonstrate a wide range of reading and writing deficits, including impaired letter and word recognition, difficulty repeating words and text, difficulty reading aloud, poor reading comprehension, and spelling impairments (Basso, 2003; Roth & Worthington, 2005). One theory used to explain the nature of reading and writing impairments in aphasia is based on a "modularity assumption," where domain-specific modules make up complex cognitive functions including language processing (Basso, 2003, p. 108). Depending on which modules of this system are impaired due to brain injury, and which modules are functioning, patients with aphasia will have different impairments of their reading and writing skills, often leading to a specific type of dyslexia (Beeson, Maglorire, & Robey, R., 2005; Cherney, 2005; Whitworth, et al., 2005). Damage to the non-lexical route results in "phonological dyslexia" in which case individuals cannot perform grapheme to phoneme conversion and thus must rely on whole word recognition to access meaning. The hallmark of phonological dyslexia is that reading of non-words is significantly more impaired than real word reading. Individuals who suffer from "deep dyslexia" have a disruption not only in the non-lexical route but also in the lexical route, and therefore cannot use whole word recognition to access meaning. Deep dyslexia is characterized by semantic errors, substitution of visually similar words for target words, and difficulty reading function words compared to nouns and verbs (Coltheart et al., 1980, Basso, 2003; Brookshire, 2007).

In contrast to a modular approach to understanding reading disorders, others have hypothesized that reading problems observed in aphasia can be due to a disruption in one or more of the primary neuronal systems, such as semantics, phonology, or vision (Patterson & Lambon Ralph, 1999). If damage occurs to one of these primary systems, a disruption in both reading and non-reading tasks will be observed since all language activities are underpinned by the same systems (Crisp & Lambon Ralph, 2006; Farah, Stowe, & Levinson, 1996; Jefferies, Sage, & Lambon Ralph, 2007; Seidenberg & McClelland, 1989). X

It has more recently been proposed that the various types of dyslexia are not necessarily independent of one another, but rather reflect different degrees of impairment that may be placed along a continuum (Glossar & Friedman, 1990; Crisp & Lambon Ralph, 2006). Crisp and Lambon Ralph (2006) evaluated reading in 12 individuals with aphasia and found considerable overlap of dyslexia symptoms, and further, that most of the symptoms traditionally associated with deep dyslexia were present in all participants. Thus, the authors concluded their findings supported the notion of a continuum of performance. It should be noted that participants were selected based on demonstration of specific symptoms, and individuals with very mild or very severe deficits were excluded. In addition, a large proportion of the errors in the Crisp et al. study used to support their hypothesis were categorized as being visually related words or non-words, or no response. However, lack of specific information about the participants make it difficult to fully interpret this information. For example, no data is provided regarding severity or type of aphasia, or coexistence of apraxia or dysarthria. Therefore, to fully understand the nature of the reading deficits and the relation of reading performance to other language (non-reading tasks), error analysis must be interpreted in the context of overall speech and language skills.

In order to explore the primary systems hypothesis, Crisp et al. (2006) examined performance in their 12 participants (e.g. picture naming, lexical decision, reading on non-words). Findings demonstrated impaired phonology in all cases, lending further support to the primary systems hypothesis. Interestingly, writing was not examined, yet this modality has the potential to provide valuable information regarding systems supporting both reading and writing.

The purpose of the current study is to further examine the concept of a continuum of performance in phonological-deep dyslexia, to further understand the underlying deficits corresponding to performance on the continuum, and to provide an in-depth analysis of error type in relation to concomitant speech and language symptoms.

Methods

Participants

Fourteen individuals with aphasia due to a stroke were recruited from a university clinic to participate in this study. Participants who were not literate in English prior to their stroke were excluded. The sample represents a wide range of severity and types of aphasia. Four individuals had concomitant apraxia of speech. See Table 1 for complete demographic information.

Assessment

A variety of subtests from the Psycholinguistic Assessment of Language Processing in Aphasia (PALPA, Kay et al., 1992) were used to assess the possible overlap of dyslexic symptoms and to determine the underlying basis of all language symptoms. Specific subtests used for assessment can be found in Table 2. All participants were tested individually over two, 2-hour sessions.

Results

Table 3 presents results, ordered from most impaired to least impaired. All participants demonstrated symptoms of phonological dyslexia in that oral reading of words was always more accurate than reading non-words. However, there was no clear imageability or grammatical class effect, and the number of semantic errors produced was negligible.

Further analysis of errors showed a qualitative difference among participants (see Table 4). The majority of errors were visual word or non-word errors, or no response. Individuals with nonfluent aphasia (e.g. Broca's) and coexisting apraxia of speech often made single phoneme substitutions or deletions that resulted in real word (night-right; grow-go) or non-word (piano-miano; radio-redo). These errors were quite different from the visual errors that were produced by individuals with fluent aphasia (e.g. conduction or Wernicke's). These individuals produced visually-related non-words that were distant from the target in terms of number of phoneme substitutions (audience- adinos) as well as unrelated non-words (squirrel-raddle), and may have had syllable additions (swing-sisiril).

To explore the underlying basis of performance, semantic, phonologic and orthographic skills were analyzed. Most patients showed strong semantic skills in at least one modality (Table 5). In most cases, performance was better in the auditory modality compared to the written modality, indicating they were more likely to have accessed the word meaning through the phonological form than the orthographic form. A similar pattern was seen on phonological tasks (Table 6). Although there was a wide range of performance, all participants did better with the auditory modality compared to the written. In addition, all participants repeated real words better than non-words, indicating meaning supported the ability to retrieve the phonologic form of the words.

Variable patterns of performance were also seen on writing tasks (Table 7). In some cases, difficulty was noted primarily with lexical retrieval, while others demonstrated problems with retrieval of the orthographic form as well. Error analysis showed some participants attempted to spell by regular grapheme to phoneme conversion (castle- kassall), while others retained some of the orthographic form (castle- casle).

Additional detailed analysis will be provided and the theoretical and clinical implications of these findings will be discussed.

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Table 1. Participant demographic information, including age, education (ED), time post stroke (TPO), Western Aphasia Battery Aphasia Quotient (AQ), type of aphasia, and presence (Y) or absence (N) of apraxia of speech.

	GE	JJ	PH	LC	EK	AW	MB	BC	JM	MM	ML	AM	JC	RS
Age (years)	56	53	60	57	70	67	64	66	64	65	50	67	62	59
ED (years)	12	12	12	16	12	16	12	12	16	18	16	12	12	16
TPO (years)	18	17	1	2	4	1	4	1	8	6	2	5	7	3
AQ	53.3	44.5	50.9	59.4	85.9	85.6		32		86.5	71.9	79.3	45.1	48.6
Aphasia type	Broca	Broca	Broca	Broca	Broca	conduct	Wern	Wern	anomic	anomic	Trans-motor	anomic	Wern	Wern
Apraxia	Y	N	Y	Y	Y	N	N	N	N	N	N	N	N	N

Table 2. Subtests from the Psycholinguistic Assessment of Language Processing in Aphasia used for testing.

Assessments to explore the phonological-deep continuum

- 8 (oral reading non-words by syllable)
- 30 (syllable length)
- 31 (frequency/imageability)
- 32 (grammatical class)
- 35 (regular/exception)
- 36 (oral reading non-words by syllable)

Assessments to explore the possible bases of a continuum

Semantic Impairments

- 47 (spoken word to picture match)
- 48 (written word to picture match)
- 49 (auditory synonym judgment)
- 50 (written synonym judgment)
- 53A (picture naming)

Phonological Impairments

- 8 (repetition non-words by syllable)
- 15 (Rhyme judgment auditory and written)
- 22 (sound out letter)
- 23 (matching letter sound to printed letter match)
- 53D (repetition of words)

Orthographic Impairments

- 39 (letter length spelling)
- 44 (spelling regularity)
- 53B (written naming)
- 53 E (spelling picture names to dictation)

Table 3. Assessment to explore the continuum of phonologic-deep dyslexia (Least number correct to greatest number correct).

		JJ	BC	JC	GE	RS	PH	LC	EK	AW	MB	ML	JM	AM	MM
Total possible = 298	**Total correct**	**0**	**0**	**10**	**18**	**20**	**40**	**105**	**160**	**183**	**238**	**240**	**260**	**270**	**294**
	Max score														
PALPA #8 Reading nonwords	**30**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**6**	**21**	**2**	**15**	**22**	**27**
1 syllable	10	0	0	0	0	0	0	0	0	3	7	0	7	8	9
2 syllable	10	0	0	0	0	0	0	0	0	2	6	1	5	6	9
3 syllable	10	0	0	0	0	0	0	0	0	1	8	1	3	8	9
PALPA #30 Oral reading	**24**	**0**	**0**	**4**	**18**	**5**	**8**	**10**	**18**	**19**	**24**	**24**	**24**	**23**	**24**
1 syllable word	8	0	0	2	8	4	3	5	6	8	8	8	8	8	8
2 syllable word	8	0	0	1	5	1	4	3	7	5	8	8	8	8	8
3 syllable word	8	0	0	1	5	0	1	2	5	6	8	8	8	7	8
PALPA # 31 Imageabilty X Frequency	**80**	**0**	**0**	**6**	**0**	**9**	**14**	**29**	**50**	**58**	**70**	**77**	**80**	**78**	**80**
HIHF	20	0	0	2	0	3	7	14	17	18	18	20	20	20	20
HILF	20	0	0	2	0	3	7	8	16	17	19	19	20	20	20
LIHF	20	0	0	1	0	1	0	3	10	11	18	19	20	19	20
LILF	20	0	0	1	0	2	0	4	7	12	15	19	20	19	20

PALPA #32 Grammatical Class Reading	**80**	**0**	**0**	**0**	**0**	**0**	**9**	**24**	**50**	**55**	**72**	**78**	**79**	**77**	**80**
Nouns	20	0	0	0	0	0	1	11	12	13	18	20	20	18	20
Verbs	20	0	0	0	0	0	3	5	12	15	19	19	20	20	20
Adjectives	20	0	0	0	0	0	4	8	15	13	18	20	20	19	20
Functors	20	0	0	0	0	0	1	0	11	14	17	19	19	20	20
PALPA #35 Regular/ exception word reading	**60**	**0**	**0**	**0**	**0**	**0**	**9**	**42**	**42**	**43**	**43**	**59**	**60**	**54**	**60**
Regular spelling	30	0	0	0	0	0	5	21	22	20	25	30	30	27	30
Exception spelling	30	0	0	0	0	0	4	21	20	23	18	29	30	27	30
PALPA#36 Nonword reading	**24**	**0**	**0**	**0**	**0**	**6**	**0**	**0**	**5**	**2**	**8**	**0**	**6**	**16**	**23**
3 letter	6	0	0	0	0	5	0	0	1	0	2	0	1	3	6
4 letter	6	0	0	0	0	1	0	0	2	0	2	0	3	6	6
5 letter	6	0	0	0	0	0	0	0	2	2	3	0	2	3	5
6 letter	6	0	0	0	0	0	0	0	0	0	1	0	0	4	6

Table 4. Error analysis for all errors on real-word oral reading (PALPA 30, 31, 32, 35) (Greatest number of errors to fewest number of errors).

	BC	JJ	JC	RS	GE	PH	LC	EK	AW	MB	AM	ML	JM	MM
Total # errors	244	244	235	217	181	158	152	86	73	36	11	6	1	0
Type of error														
Semantic				2			1	2						
Visually related real word				6	2	12	1	10	5	8	6	6	1	
Derivational					1			1			1			
Unrelated real word			1	5	2	3	8	2	5		2			
Visually related nonword			4	41	2	19	32	33	38	25	2			
Visually unrelated nonword			50	21		26		22	22	3				
No response	244	244	180	142	174	98	110	16	3					

Table 5: Semantic assessment (least number correct to greatest number correct).

		RS	MB	JJ	BC	JC	AM	PH	GE	EK	AW	MM	LC	JM	ML
Total Possible = 240		120	131	137	148	173	181	206	208	212	216	218	221	230	231
	Max score														
PALPA # 47 Spoken word to picture matching	40	32	26	32	37	37	37	40	36	40	39	37	40	36	40
PALPA #48 Written word to picture matching	40	26	23	34	29	37	36	40	38	40	38	38	40	39	40
PALPA # 49 Auditory synonym judgment	60	44	45	38	42	52	39	56	51	47	51	55	57	60	57
High imageability	30	24	25	16	26	28	20	29	28	27	28	30	30	30	29
Low imageability	30	20	20	22	16	24	19	27	23	20	23	25	27	30	28
PALPA # 50 Written synonym judgment	60	18	26	33	40	47	34	54	48	49	50	51	58	58	60
High imageability	30	11	14	15	21	28	19	28	28	28	26	28	30	30	30
Low imageability	30	7	12	18	19	19	15	26	20	21	24	23	28	30	30
PALPA #53A Spoken picture naming	40	0	11	0	0	0	35	16	35	36	38	37	26	37	34

Table 6. Phonologic assessment (least number correct to greatest number correct).

		JJ	BC	RS	GE	AM	LC	JC	PH	MB	EK	ML	AW	MM	JM
Total Possible = 268	268 Maximum score	91	92	121	159	160	165	173	175	178	189	211	213	224	246
PALPA #15 Auditory rhyme judgment	60	44	41	38	53	46	58	57	55	56	53	58	56	56	58
PALPA # 15 Written rhyme judgment	60	0	32	4	34	33	36	33	40	29	43	53	44	47	56
PALPA #22 Letter sounding	52	0	5	15	0	18	0	27	32	19	12	18	31	28	37
Upper case	26	0	4	15	0	12	0	12	18	14	6	11	17	14	18
Lower case	26	0	1	0	0	6	0	15	14	5	6	7	14	14	19
PALPA #23 Spoken letter sound-written matching	26	0	14	12	16	2	24	17	24	21	25	13	24	23	25
PALPA #8 Nonword repetition	30	14	0	17	16	21	16	12	6	17	20	29	18	30	30
1 syllable	10	4	0	4	6	8	6	4	1	5	3	10	7	10	10
2 syllable	10	6	0	6	6	9	4	7	3	5	9	9	2	10	10
3 syllable	10	4	0	7	4	4	6	1	2	7	8	10	9	10	10
PALPA #53D Repetition of words	40	33	0	39	40	40	31	27	18	36	36	40	40	40	40

Table 7. Orthographic assessment (least percent correct to greatest percent correct).

		JJ	BC	RS	LC	JM	MB	JC	PH	GE	EK	AM	ML	AW	MM
Total Possible = 144	Percent Maximum number	0	0	1%	5%	8%	30%	34%	58%	70%	72%	71%	88%	91%	92%
PALPA #39 Letter length spelling	24	0	0	0	5	10	18	13	18	20	16	22	22	22	24
3 letter	6	0	0	0	1	6	3	4	6	6	6	6	5	5	6
4 letter	6	0	0	0	3	4	6	6	6	5	4	6	6	6	6
5 letter	6	0	0	0	1	0	6	2	3	5	3	5	6	6	6
6 letter	6	0	0	0	0	0	3	1	3	4	3	5	5	5	6
PALPA #44 Spelling words to dictation regularity	40	0	0	1	0	0	10	NA	NA	24	23	33	32	36	40
Regular	20	0	0	0	0	0	7	NA	NA	16	12	17	17	19	20
Exception	20	0	0	1	0	0	3	NA	NA	8	11	16	15	17	20
PALPA #53B Written picture naming	40	0	0	0	0	0	0	2	20	30	33	23	34	36	29
PALPA #53E Spelling picture names to dictation	40	0	0	0	2	2	15	20	22	27	32	24	39	37	40