Speech sound errors associated with aphasia have been attributed to disintegration of both phonologic and motoric processes in different subtypes of aphasia (Pierce, 2001). In nonfluent aphasia (NA), which often co-occurs with apraxia of speech (AOS), motor programming and motor planning difficulties are the typically proposed error generating mechanisms. In contrast, phonemic paraphasia observed in fluent aphasia (FA) is typically thought to be related to inability to retrieve and maintain sequences of phonemes for production. Distortion errors, indicative of motor programming deficiency, predominate in AOS; but also have been reported to a lesser extent in FA, in studies involving word or sentence repetition (McNeil, Robin & Schmidt, 2009; Odell, McNeil, Rosenbek & Hunter 1991; Odell, Bonkowski, & Mello,1995). Associated features of dysfluency and dysprosody have also been reported in AOS (Kent & Rosenbek, 1983). In contrast, undistorted phonemic level errors also occur in both FA and NA subtypes (Blumstien, 1973; Pierce, 2001). This study examines the occurrence of phonemic errors as well as phonetic distortion, dysfluency and dysprosody in speech produced by individuals diagnosed with NA with AOS versus FA with phonemic paraphasia, in comparison with the speech of non-aphasic control speakers. This information is important (1) in order to advance our understanding of AOS, which usually occurs, clinically, in the presence of NA; (2) to further elucidate the role of distortion in FA, wherein speech errors are often described clinically as being fluently produced with little effort or distortion (Seddoh, Robin, Hageman, Moon, & Folkins, 1996); and (3) to help toward differentiating phonological/representational impairments from motorically based aspects of apraxic speech, which may not be mutually exclusive (Ziegler, Aichert & Staiger, 2012).

Methods

Participants were twelve adult male speakers with aphasia (6 with NA; 6 with FA), ranging in age between 40 to 77 years. All had had a left unilateral left hemisphere lesion demonstrated by CT scan. None of the patients were judged clinically to exhibit dysarthria. Patients had undergone standardized aphasia testing using the Boston Diagnostic Aphasia Examination (BDAE) Fluent and nonfluent classification was based on the BDAE Speech Characteristics Profile. See Table 2. Characteristics of speakers with aphasia are provided in Table 1. Speakers with FA were characterized by fluent verbal expression, poor sentence repetition, and good auditory comprehension. All speakers with FA also exhibited fluent phonemic paraphasias in connected speech. Speakers with NA were characterized by nonfluent verbal expression, poor sentence repetition and good auditory comprehension. All speakers with NA also exhibited AOS (i.e., articulatory groping, phonetic distortion, dysprosody and dysfluency, in addition to somewhat variable articulation errors) in connected speech. Additional expressive language analyses also were completed to confirm group inclusion decisions. Six non-aphasic adult males with similar age range served as control speakers.

Stimuli consisted of five polysyllabic words (e.g., "administration") which each participant repeated five times in response to a model provided by the examiner, yielding a total of 450 word productions. Broad phonemic transcriptions of each word were obtained by phonetically trained transcribers using repeated digital play back supported by descriptive spectrography (KayElemetrics CSL Model 4300B), which allowed transcribers to cursor off specific segments and syllables and listen to them individually. No diacritics were employed and distortion errors were excluded.

Transcription reliability (exact agreement) was found to be 82%. Discrepancies were resolved using consensus transcription procedures. Visual analog scaling of judgments of phonetic distortion, dysprosody and dysfluency were independently obtained for each word production using a 20 cm vertical scale by trained SLP graduate student listeners via headphones in a quiet room. Inter-listener reliability ranged from r = .86 to.78 (p < .05). Scaling judgments were averaged across listeners for subsequent analysis. Temporal acoustic measurements were obtained in milliseconds for word, syllable and inter-syllable interval durations (Pulgram, 1970) from waveforms and wide band spectrograms using CSpeech analysis program (Milenkovic, 1997). See Figure 1. Inter-analyst reliability ranged from r = .98 to .78). Various data sets (transcriptional, VAS, acoustic) were evaluated statistically via two-way repeated measures analyses of variance with post hoc means comparisons at alpha level = 0.05.

Results

Results indicated that both FA and NA groups produced significantly more phonemic errors than the control speakers, and the FA group produced significantly more total errors than the NA group (p < .05). The NA group produced more consonant than vowel errors. The FA group produced more vowel errors than consonant errors with significantly more vowel substitutions predominating (p < .05). See Figure 2. Consistency of phonemic errors by location within words was significantly greater in the NA than in the FA group; and was greater in the NA than in the control group (p < .05), which did not differ from the FA group. Consistency of error type at a given location was significantly greater than the control group for both the NA and FA groups (p < .05), which did not differ from each other.

Distortion, dysfluency and dysprosody were significantly greater for both NA and FA than for control speakers (p<.05). While somewhat greater in the NA than FA group, they did not differ significantly between aphasia groups. Temporal acoustic analyses revealed that the NA group was significantly slower than controls on word, syllable, and interval durations, but the FA group was significantly slower than controls only on syllable duration (p < .05). See Figure 2. Controls speakers demonstrated a significant trend toward systematic decrease of duration across trials that was absent in both aphasia subgroups. See Figure 3. Durational variability was significantly greater than normal in the FA group for all measures, whereas the NA group exhibited significantly greater variability for word and interval durations (p < .05). The FA group's syllable durations were significantly more variable than those of both NA and controls, who did not differ from each other. See Figure 4.

Discussion

Both groups of speakers with aphasia exhibited high levels of phonemic errors as well as statistically significant levels of distortion on this complex polysyllabic repetition task. The findings are consistent with earlier studies (Odell, McNeil, Rosenbek & Hunter 1991; Odell, Bonkowski, & Mello,1995), lending additional support to the notion that features suggestive of AOS do occur in speakers with FA. The results also extend prior findings based on relatively pure AOS to speakers with AOS in the presence of NA. For the speakers with NA, distortion comprised the greatest degree of impairment while phonemic errors, albeit abnormal, were relatively less impaired. For speakers with FA, however, highly variable phonemic errors were more prevalent. Acoustic findings support the presence of motor programming/planning deficits in both groups of speakers with aphasia. Greater durational variability at the level of the syllable in the speakers with FA may reflect their reduced phonemic consistency by error location, probably due to decreased representational stability. The findings suggest that given a sufficiently difficult task, as presently employed, subgroups of speakers with aphasia may exhibit both phonological and motor planning/programming difficulties, although to differing degrees. Phonological/representational and motor planning/programming interpretations of the findings will be evaluated in light of recent neural modeling of speech production (Hicock, 2012; van der Merwe, 2009).

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Table 1. Characteristics of 12 Speakers with Aphasia.

Group	Subject	Age	Education	MPO	Percentile*	Etiology
Nonfluent	1	40	6	7	80	cva
Nonfluent	2	54	8	7	80	cva
Nonfluent	3	57	12	2	80	cva
Nonfluent	4	67	8	25	90	cva
Nonfluent	5	66	16	34	80	cva
Nonfluent	6	42	12	240	60	ohi
Fluent	1	62	8	22	80	cva
Fluent	2	56	5	16	60	cva
Fluent	3	62	12	5	60	cva
Fluent	4	61	12	10	60	cva
Fluent	5	67	8	23	60	cva
Fluent	6	67	18	20	80	cva

*BDAE overall percentiles; ohi = open head injury

Table 2. BDAE Speech characteristics profiles for 12 speakers with aphasia.

	BDAE Speech Characteristics Scale							
Aphasia Groups	**Articulatory Agility**	**Phrase Length**	**Grammatical Form**	**Melodic Line**	**Paraphasias**	**Word Finding**	**Sentence Repetition**	**Auditory Comprehension**
Fluent S1	**6**	**6**	**6**	**6**	**2**	**4**	**0**	**3.5**
Fluent S2	**5**	**5**	**5**	**5**	**3**	**3**	**1**	**3**
Fluent S3	**5**	**5**	**5**	**5**	**3**	**3**	**0**	**3**
Fluent S4	**6**	**6**	**6**	**6**	**3**	**3**	**1**	**2.5**
Fluent S5	**5**	**5**	**5**	**5**	**3**	**3**	**1**	**3**
Fluent S6	**5**	**6**	**6**	**5**	**3**	**3**	**0**	**5.5**
Nonfluent S7	**3**	**2**	**3**	**2**	**NR****	**6**	**2**	**3.5**
Nonfluent S8	**3**	**4**	**3**	**3**	**4**	**7**	**4**	**6**
Nonfluent S9	**2**	**2**	**2**	**2**	**NR****	**6**	**1**	**3**
Nonfluent S10	**3**	**2**	**3**	**2**	**NR****	**6**	**2**	**3.5**
Nonfluent S11	**2**	**2**	**3**	**2**	**NR****	**5**	**2**	**3.5**
Nonfluent S12	**3**	**3**	**1**	**3**	**NR****	**6**	**2**	**6**

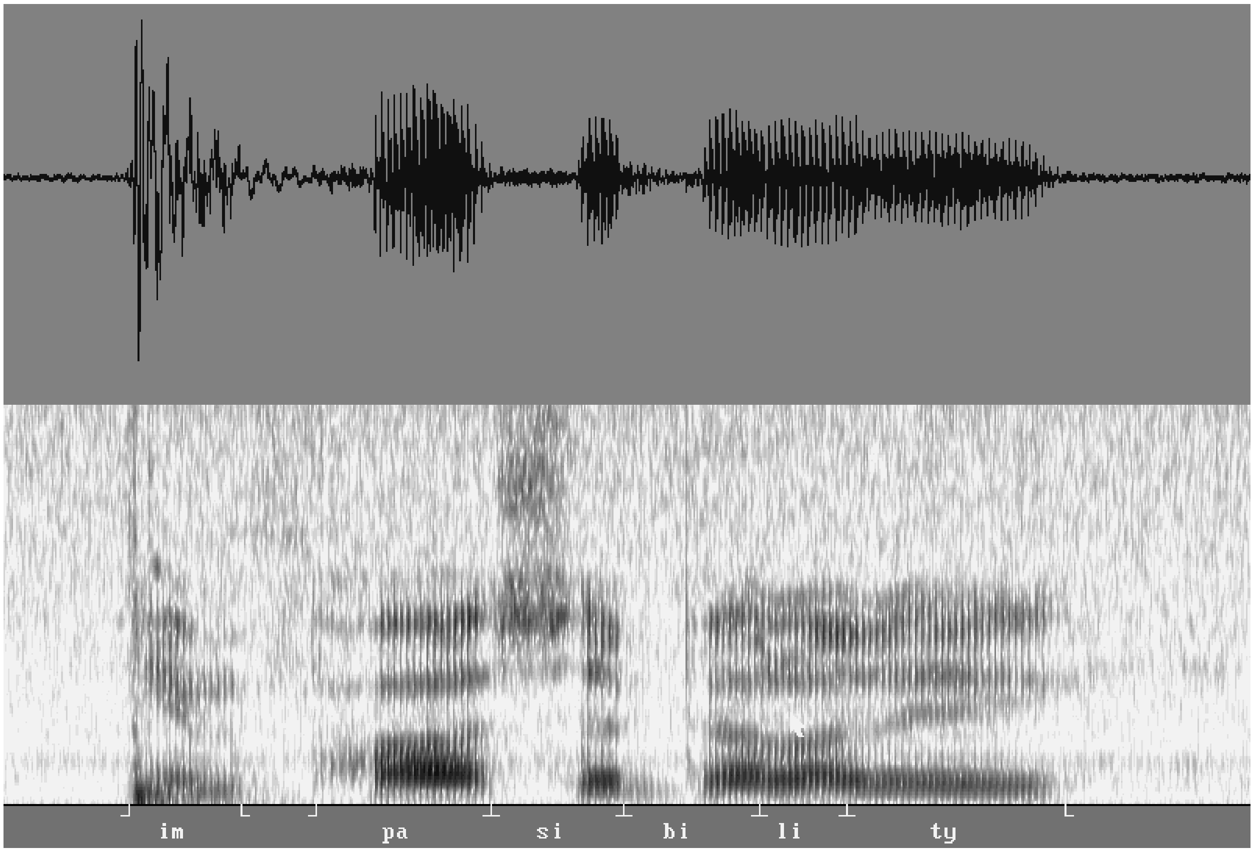
**NR = not rated when phrase length < 4 words

Table 3. Mean and standard deviations of scaling judgments of subphonemic distortion, dyprosody and dysfluency.*

Speaker Group	Distortion	Dysprosody	Dysfluency
Controls	4.66 (3.46)	3.42 (2.84)	4.2 (1.11)
Fluent Aphasia	17.46 (7.81)	9.38 (5.58)	8.50 (5.95)
Nonfluent Aphasia	20.21 (10.53)	12.07 (4.96)	9.07 (5.18)

*for each variable, scaling was accomplished by a different pair of judges.

Figure 1. Digital waveform (top) and spectrogram (bottom). Transcription and duration markers are placed below the spectrogram.



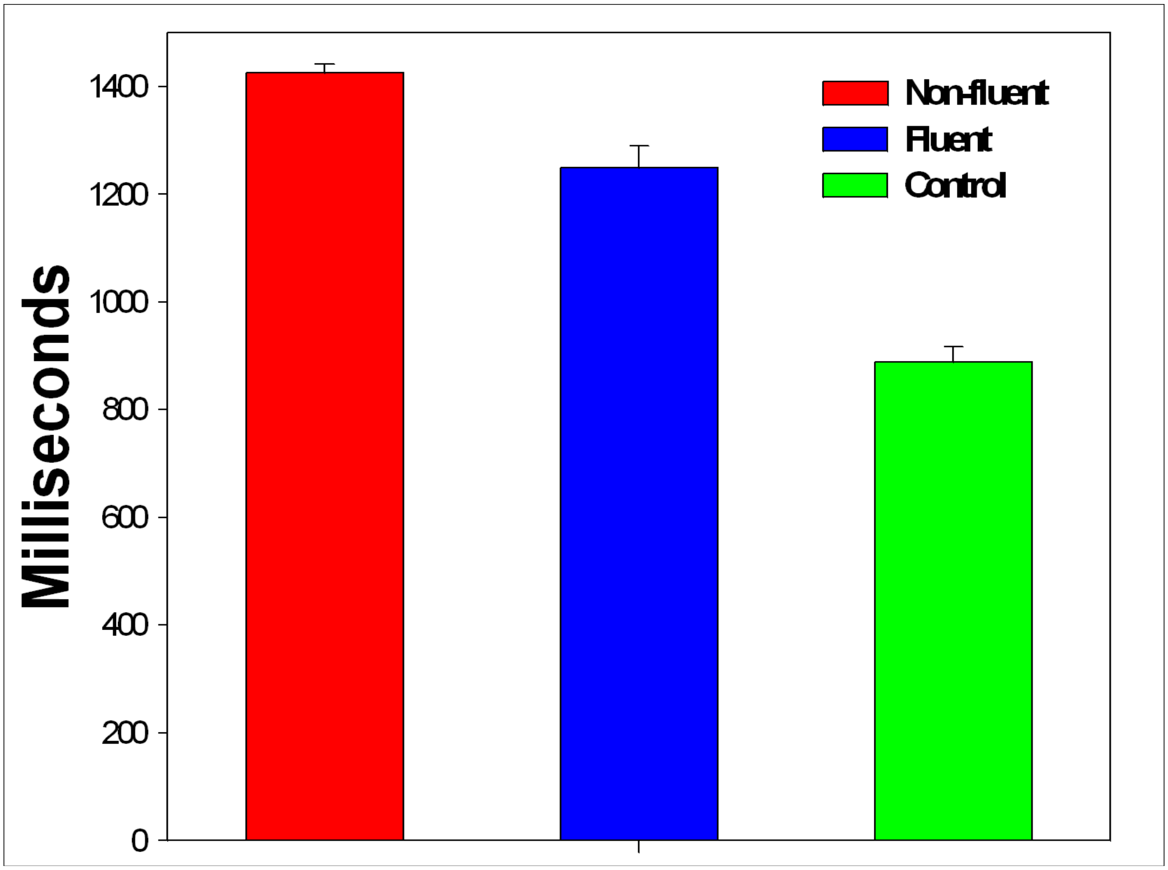


Figure 2. Word durations with standard error bars for three speaker groups.

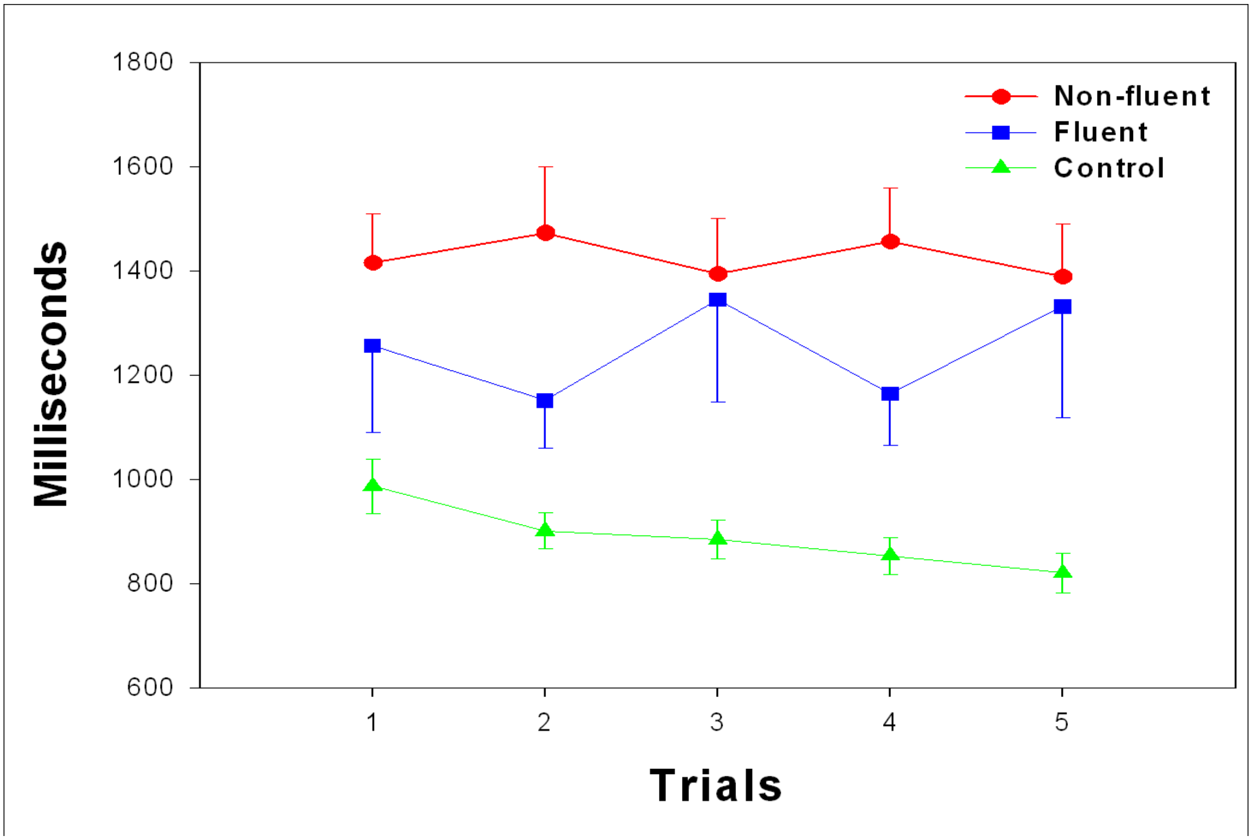


Figure 3. Trials x word repetition interaction showing decreasing linear trend for the control speakers that was not present in the speakers with aphasia.

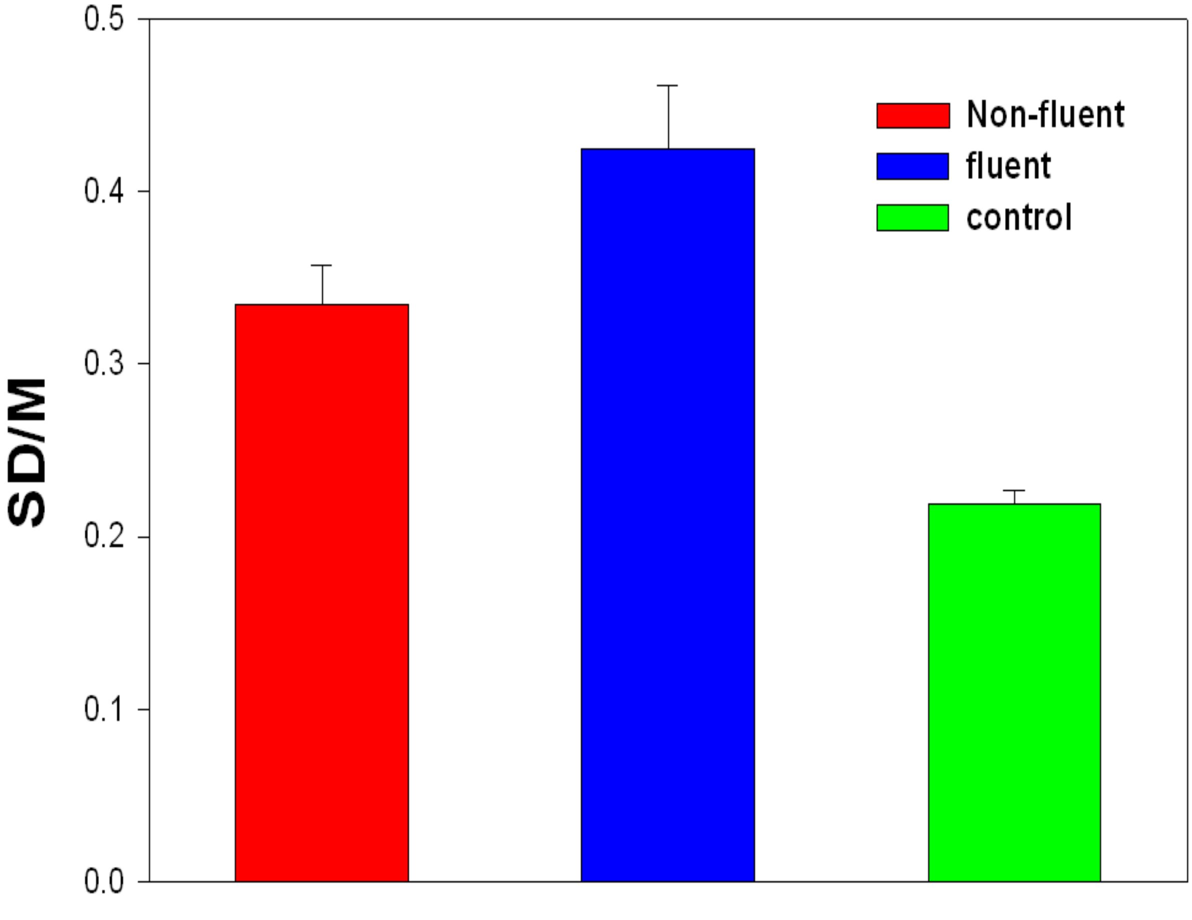


Figure 4. Coefficients of variation for syllable duration in three speaker groups.