Introduction

Nonfluent speech pattern is a problem for many individuals with aphasia following stroke. The locus of the perceived nonfluency is not well established, as it may result from word finding difficulties, grammatical problems, motor programming impairments (e.g. apraxia of speech [AOS]), or a combination of the above. Many individuals with nonfluent aphasia (NFA) have intact ability to recognize errors, and are encouraged to do so in order to correct aberrant productions. However, this practice, when habitual, may contribute to or exacerbate the nonfluent output pattern. The present study was spurred by the notion that adults with NFA may over-attend to speech errors, to the detriment of speech fluency and overall communication. We hypothesized that masking the auditory signal in such individuals would result in increased speech fluency, albeit with possible negative effects on speech sound accuracy.

In the past half century, a handful of studies have investigated the effect of auditory masking on verbal output in adults with aphasia, with mixed results. While early studies found improved naming accuracy and faster response times when adults with “motor aphasia” spoke while listening to noise (Birch & Lee, 1955; Birch, 1956), later studies did not find this effect (Weinstein, 1959). Wertz and Porch (1970), finding minimal effect of masking in adults with expressive aphasia but no apraxia, suggested that positive effects of masking on speech may be specific to individuals with apraxia.

More recently, Rogers, Eyraud, Strand, and Storkel (1996) tested the effects of auditory masking on vowel duration of CVC words in three adults with AOS and three control participants, with the hypothesis that masking would result in reduced vowel duration in participants who frequently prolong vowel durations. While no change was observed, Rogers et al. noted that vowel prolongations in AOS may be more prominent in polysyllabic words, with the implication that masking may have an effect for more complex stimuli.

Because of the variant results from previous studies, we began investigating the impact of auditory masking on speech fluency in adults with a broad spectrum of aphasia profiles, including individuals with fluent and nonfluent aphasia and those with and without AOS. The principle objective was to identify individuals with a positive fluency response to masking (e.g. increased speech rate, decreased disfluency duration), as well as non-responders, and determine individual characteristics that differentiate the groups.

Preliminary results identified 4 participants with a positive fluency response to auditory masking of sentence stimuli, with increased rate of speech and/or decreased disfluency duration, as determined by Welch t-test comparisons of masking trials to normal feedback trials. Two additional participants showed no change or an unfavorable response (decreased rate, increased disfluency). These data, while promising, did not account for potential time-dependent effects that might arise due to the observation of repeated measures from the same participant.

The purpose of the present study is to characterize the fluency response to auditory masking in ten adults with aphasia, using a time series methodology to account for non-independence of repeated data points and allow for a more fine-grained characterization of individual response patterns.

Method

To date, data have been analyzed for ten adults (6 female) with speech or language impairments secondary to a single left-hemisphere stroke participated in the study. Participant data are shown in Table 1. Testing included administration of the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2006), a 38-item Motor Speech Examination, and hearing screening. Site of neurological lesion was determined using clinical scans obtained from medical records.

Auditory masking was tested using an ABA′ paradigm, with normal feedback conditions in the A phases and auditory masking in the B phase. The masking stimulus consisted of speech-shaped "pink" noise delivered via foam-tipped earphones at 85 dB SPL. During each phase, participants said 20 sentences from the Harvard sentences list (IEEE), presented in random order.

The effect of masking on speech production was assessed through measurement of speech rate (syllables/sec.), disfluency duration, and speech errors (% syllables with substitution or distortion errors). All coding was completed with *Praat* acoustic analysis software (Boersma & Weenink, 2011), using semi-automated script routines to determine speech rate and TextGrids for manual delineation of speech errors and disfluencies by a graduate student listener.

Participants were identified as positive responders to auditory masking on the basis of syllable rate and disfluency duration time series subjected to a permutation-based analysis. Specifically, the variation of the changes in scores between Phase A and B was obtained by permuting the scores in Phase A. Each permuted A score yielded a new trial A vs. trial B difference, which was then smoothed to reduce the within phase (trial-to-trial) variation. A middle 95% interval was constructed by trimming off the upper and lower 2.5% percentiles. This interval was used as a test for the significant difference of the trials A vs. B.

Results

Six individuals responded to masking with a positive fluency response, defined as increased syllable rate and/or decreased disfluency duration in multiple consecutive permuted masking trials, *outside the 95% confidence intervals*. Six participants had increased syllable rate for at least 11 of 20 permuted masking trials and 5 participants had decreased disfluency duration for at least 8 trials. Individual results showing trials affected for each measure are shown in Table 2.

Four participants were classified as non-responders, including two with a decreased syllable rate for permuted masking trials and no change on disfluency duration (P2, P9), one with no change on either measure (P6), and one with conflicting results (P4; decreased speech rate and disfluency duration). Only two participants (non-responders P4 and P6) showed change for speech errors in permuted trials, with higher speech errors under masking conditions. In addition, participant-specific response patterns were found from the permutation curves, with two responders having immediate and lasting responses (P1, P12) and others showing delayed but lasting positive responses.

Discussion

The present study confirms and extends previous analyses showing positive fluency responses in adults with aphasia and/or AOS, using a permutation-based analysis to identify time-dependent patterns in syllable rate and disfluency duration. Six participants responded with increased syllable rate and/or decreased disfluency duration, while four additional participants either had no response or reduced speech rate under masking conditions.

The use of the permutation analysis allowed us to determine the likelihood of a response based on only 20 masking trials. In particular, two participants had an evident change in fluency measures from the first masking trial, while the remaining four responded within 8 to 13 trials. In all responders, fluency changes were sustained throughout the 20 masking trials.

While the present study was focused on identifying temporary changes in fluency, the participant-specific patterns have potential implications for implementing masking in a long-term training paradigm. Specifically, the permutation analysis identified the *onset* of a likely response, but it might also be used to identify adaptation to masking, in which continued exposure to masking noise no longer has a fluency benefit. Through continued investigation of individual responses to masking, we hope to optimize the dose of masking stimulation and develop treatment leading to lasting speech fluency improvement in adults with aphasia and AOS.

Table 1. Participant data

	Partici-pant	Age	Sex	Time Post Onset	WAB Aphasia Quotient	Aphasia Type	Apraxia Severity
Responders	P1	47;5	M	0;5	98	Anomic	Mild
	P3	51;9	F	7;6	88	Anomic	None
	P7	59;5	F	1;2	69	Broca's	Mod
	P8	73;4	M	4;9	30	Broca's	Mild
	P11	66;8	F	0;5	60.5	Broca's	Mod
	P12	66;6	F	2;3	75.7	Broca's	Severe
Non-responders	P2	52;8	F	1;3	96	Anomic	None
	P4	64;1	M	0;2	86	Anomic	None
	P6	50;1	M	4;10	96	Conduction	Mod
	P9	27;8	F	1;6	82.1	Anomic	None

WAB: Western Aphasia Battery (Kertesz, 2006)

Table 2. Individual responses to masking

	Partici-pant	Change in disfluency duration (sec.)	Change in speech rate (sylls/sec.)	Change in syllables with errors (%)
Responders	P1	-0.24$^{1-20}$	0.52$^{1-17}$	0.5%$^{n/a}$
	P3	-0.73$^{12-20}$	0.50$^{6-20}$	-2.4%$^{n/a}$
	P7	-4.34$^{7-20}$	0.17$^{9-20}$	2.6%$^{n/a}$
	P8	-0.11$^{n/a}$	0.43$^{13-20}$	-0.6%$^{n/a}$
	P11	-4.23$^{7-20}$	0.12$^{8-20}$	-3.0%$^{n/a}$
	P12	-2.76$^{2-20}$	0.58$^{1-20}$	-2.1%$^{n/a}$
Non-responders	P2	-0.02$^{n/a}$	-0.41$^{9-20}$	1.3%$^{12-16}$
	P4	-0.26$^{4-13}$	-0.08$^{14-20}$	16.4%$^{1-20}$
	P6	0.68$^{n/a}$	-0.007$^{n/a}$	12.7%$^{13-17}$
	P9	0.04$^{n/a}$	-0.19$^{9-16}$	0.4%$^{n/a}$

Note. Values in cells represent mean change between the masking and baseline phases, with negative values indicating lower measures in the masking compared to baseline. Values in superscript represent the masking trial numbers for which change was significant.

References

Birch, H. G. (1956). Experimental investigations in expressive aphasia. *New York State Journal of Medicine, 56*(24), 3849-3852.

Birch, H. G., & Lee, J. S. (1955). Cortical inhibition in expressive aphasia. *Archives of Neurology & Psychiatry*, *74*(5), 514.

Boersma, Paul & Weenink, David (2011). Praat: doing phonetics by computer [Computer program]. Version 5.3, retrieved 15 October 2011 from http://www.praat.org/.

IEEE Subcommittee on Subjective Measurements (1969). IEEE Recommended Practices for Speech Quality Measurements. *IEEE Transactions on Audio and Electroacoustics, 17*, 227-246.

Kertesz, A. (2006). *Western Aphasia Battery- Revised*. San Antonio, TX: Pearson.

Rogers, M., Eyraud, R., Strand, E., & Storkel, H. (1996). The effects of noise masking on vowel duration in three patients with apraxia of speech and a concomitant aphasia. *Clinical Aphasiology*, *24*, 83-96.

Weinstein, S. (1959). Experimental analysis of an attempt to improve speech in cases of expressive aphasia. *Neurology, 9*, 632-635.

Wertz, R., & Porch, B. (1970). Effects of masking noise on the verbal performance of adult aphasics. *Cortex, 6*(4), 399-409.