Feedback and feedforward control in apraxia of speech: Noise masking effects on fricative production.

The present study tested two hypotheses about apraxia of speech (AOS), framed in the DIVA model (Guenther, Ghosh, & Tourville, 2006). The DIVA model assumes that speech targets are regions in auditory space, and combines two mechanisms to reach those targets: feedback control and feedforward control. The Feedforward System Deficit (FF) hypothesis states that feedforward control is impaired in AOS, with consequently a greater reliance on feedback control (Jacks, 2008; Maas, Mailend, & Guenther, 2013). The Feedback System Deficit (FB) hypothesis states that feedback control is impaired in AOS; for example, self-generated auditory feedback may be disruptive (cf. Ballard & Robin, 2007).

We tested these hypotheses by measuring acoustic fricative contrast in normal listening and noise masking conditions. The rationale is that noise masking effectively eliminates the self-generated auditory feedback signal, thus forcing a greater reliance on feedforward control. For unimpaired speakers, we predict a reduction in acoustic contrast, given evidence that speakers monitor and use auditory feedback on-line (e.g., Tourville, Reilly, & Guenther, 2008), though this reduction is expected to be small given the robust feedforward commands presumably available to unimpaired speakers (e.g., Perkell, 2012).

For speakers with AOS, the FF hypothesis predicts greater reduction of contrast with masking in AOS patients than in controls, because removal of auditory feedback will reveal the impaired feedforward commands. The FB hypothesis predicts increased contrast with feedback masking, because removal of interfering auditory feedback enables intact feedforward commands to produce adequate contrasts.

Methods

Participants

Participants included five speakers with AOS and varying degrees of aphasia and eight age-matched control speakers (Table 1).

Group	Age	Sex	Hand
CON (N=8)	67 (5)	2F,6M	7R,1L
AOS (N=5)	63 (7)	2F,3M	5R

Materials & Procedures

Targets were sibilants /s, ʃ/ in CVC words (*seat, sheet, sock, shock*) in the carrier phrase "a____again". Participants produced phrases in random order within each of 16 alternating normal and masking blocks. Masking involved speech-shaped noise presented over headphones at 95 dB-SPL (Perkell et al., 2007) throughout production of the phrase. A sound level meter was used to maintain comparable loudness between conditions.

Design & Analysis

The primary dependent measure was acoustic contrast (based on perceptually acceptable tokens; n≥11 out of 16 trials for all participants), defined as the ratio (s/ʃ) of spectral means (first spectral moment) obtained from a 20-msec window at fricative midpoint (cf. Nittrouer, Studdert-Kennedy, & McGowan, 1989; Perkell et al., 2007) using an automated script in PRAAT (Boersma & Weenink, 2010). Contrast data were analyzed with 2 (Group) x 2 (Condition) x 2 (Vowel) ANOVAs. Overall error rate, fricative duration and spectral means were also analyzed, with separate 2 (Group) x 2 (Condition) x 2 (Fricative) x 2 (Vowel) ANOVAs.

Results

Group data are presented in Figure 1 (Duration), Figure 2 (Spectral Mean) and Figure 3 (Contrast).

Error Rate
The AOS group made more errors than controls, $F(1,11)=11.55$, $p=0.0060$ (CON: 0.7%, AOS: 16.9%). There was also a main effect of Fricative, $F(1,11)=7.27$, $p=0.0208$ (/s/ targets: 9.1% vs. /ʃ/ targets: 4.8%), and a Group x Fricative interaction, $F(1,11)=5.68$, $p=0.0363$, indicating that the fricative difference was larger in the AOS group (/s/: 21.9% vs. /ʃ/: 11.9%) than in the control group (/s/: 1.0% vs. /ʃ/: 0.3%). There were no effects involving Condition, nor were any other effects significant ($Fs < 1.65$, $ps > 0.23$).

Fricative Duration
The AOS group produced longer fricatives than controls, $F(1,11)=12.11$, $p=0.0052$. Fricatives were longer in the Noise condition than in the Normal condition for both groups (Condition: $F[1,11]=4.98$, $p=0.0474$), with no Group x Condition interaction ($F[1,11]=1.54$, $p=0.2401$). There was also a Vowel effect, $F(1,11)=28.65$, $p=0.0002$, indicating that fricatives were shorter when followed by /a/ than by /i/. A Fricative x Condition interaction, $F(1,11)=10.06$, $p=0.0089$, indicated that the fricative lengthening effect in noise was significant for /ʃ/ but not for /s/. No other effects were significant ($Fs<1.15$, $ps>0.30$, except Fricative x Vowel: $F[1,11]=2.65$, $p=0.1321$, and Group x Fricative x Condition interaction, $F(1,11)=3.29$, $p=0.0972$).

Spectral Mean
Given several interactions involving Vowel (including a fourway interaction indicating a difference between *seat* and *sock* for the AOS group only in the Normal condition; see Figure 2), separate analyses were run for /a/ (*sock*, *shock*) and /i/ (*seat*, *sheet*).

For /a/, the ANOVA revealed a main effect of Fricative, $F(1,11)=109.82$, $p<0.0001$, reflecting the expected difference in spectral means between /s/ (5369 Hz) and /ʃ/ (3751 Hz). There was a significant effect of Condition, $F(1,11)=7.06$, $p=0.0223$, which indicated that spectral mean was higher in the Noise condition (4681 Hz) than in the Normal condition (4438 Hz). No other effects were significant ($Fs<1.68$, $ps>0.20$, except Group x Fricative: $F(1,11)=2.02$, $p=0.1831$; and Group x Condition x Fricative, $F(1,11)=4.12$, $p=0.0674$, suggestive of a trend for a condition effect for /s/ in the AOS group only).

The pattern was essentially the same for /i/, with main effects of Fricative, $F(1,11)=67.80$, $p<0.0001$ (/s/: 5739 Hz; /ʃ/: 3933 Hz) and Condition, $F(1,11)=12.04$, $p=0.0052$ (Noise: 4937 Hz; Normal: 4735 Hz). No other effects approached significance ($Fs<1$, n.s., except Group x Condition, $F[1,11]=2.65$, $p=0.1321$).

Acoustic Contrast
There were no main effects of Group, Condition, or Vowel ($Fs<1$, except Vowel: $F[1,11]=2.34$, $p=0.1545$), but there was a significant Group x Vowel interaction, $F(1,11)=5.30$, $p=0.0418$, and a significant Group x Condition x Vowel interaction, $F(1,11)=5.06$, $p=0.0460$, reflecting a smaller contrast for AOS than for controls for /a/ in the Normal condition only.

Discussion

As expected, speakers with AOS made more errors and had longer fricative durations than control speakers. For spectral means, the results indicated that both groups differentiated /s/ and /ʃ/ with higher spectral mean for /s/ than for /ʃ/. Interestingly, both groups demonstrated higher spectral means under masking conditions for both fricatives. This pattern may suggest that when auditory feedback is not available, speakers may adopt a more anterior tongue position in an attempt to obtain more robust somatosensory feedback to control speech movements (cf. Ghosh et al., 2010; Perkell et al., 2007). The finding of longer fricative durations in the masking condition is consistent with this interpretation.

With respect to contrast, there were no effects of noise masking in either group. The absence of an effect of masking in the control group is contrary to previous research with fricatives (cf. Perkell et al., 2007), and may suggest that older speakers (as in the present study) have more robust feedforward commands and are thus less susceptible to absence of auditory feedback than younger speakers (as in previous studies). The absence of masking effects for older control speakers has been reported previously for acoustic vowel contrast (Maas et al., 2013).

For the AOS group, it is possible that the absence of a group-level masking effect is due to different response patterns among individual participants. Inspection of individual participants revealed that some participants demonstrated a greater reduction in contrast (consistent with the FF hypothesis), whereas others demonstrated an increased contrast under masking conditions (consistent with the FB hypothesis). Thus, these patterns may have canceled each other out in the group-level analyses. Individual patient data will be available at the time of the conference to explore possible subtypes of speech motor planning impairments.

Figure 1. Fricative duration by condition and target. Error bars represent standard error.

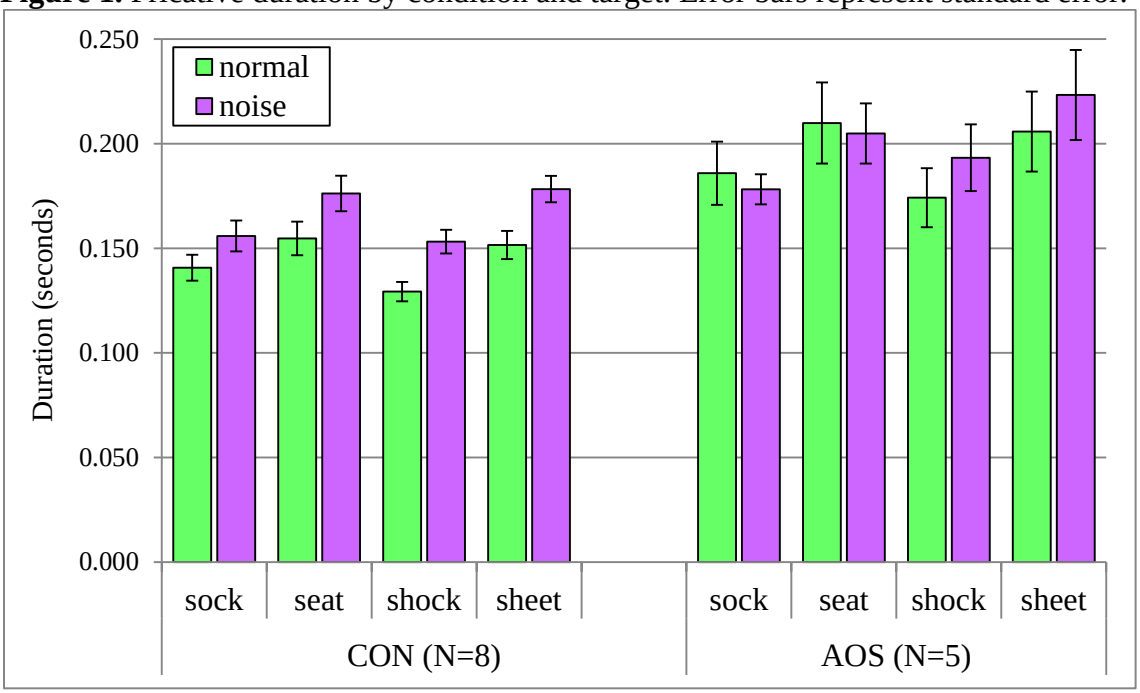


Figure 2. Spectral mean by condition and target. Error bars represent standard error.

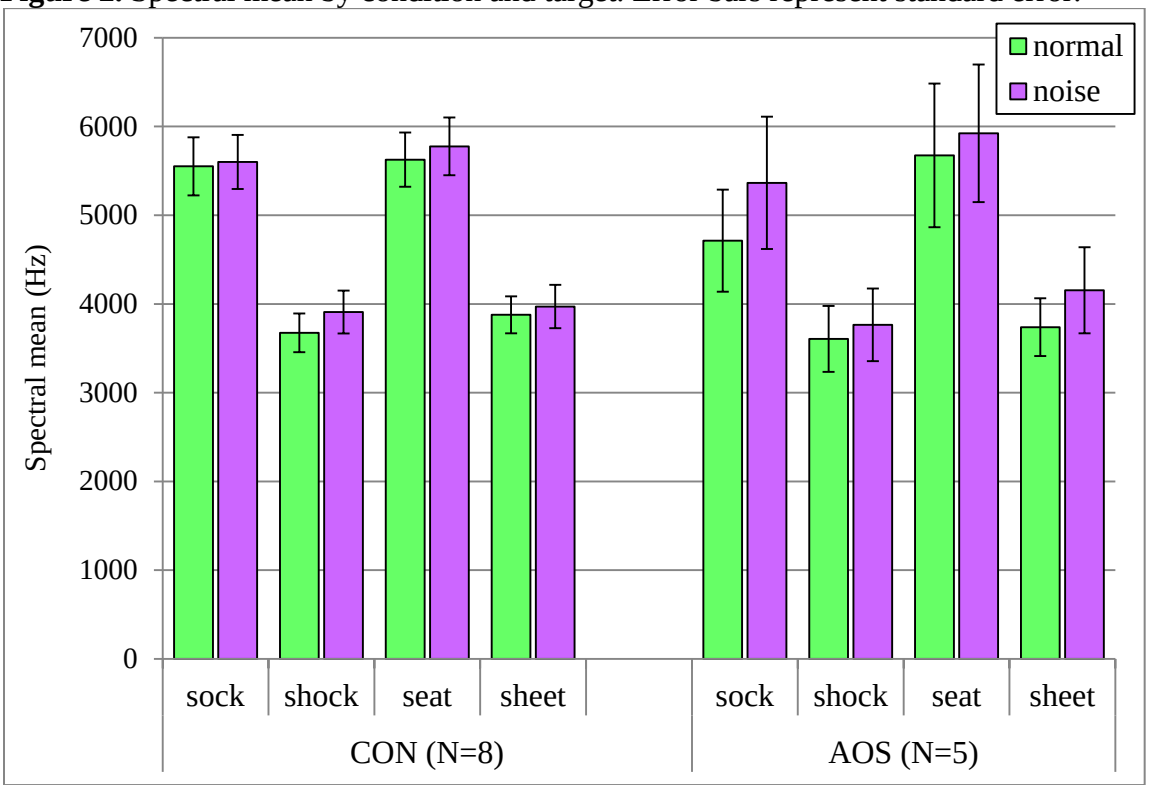
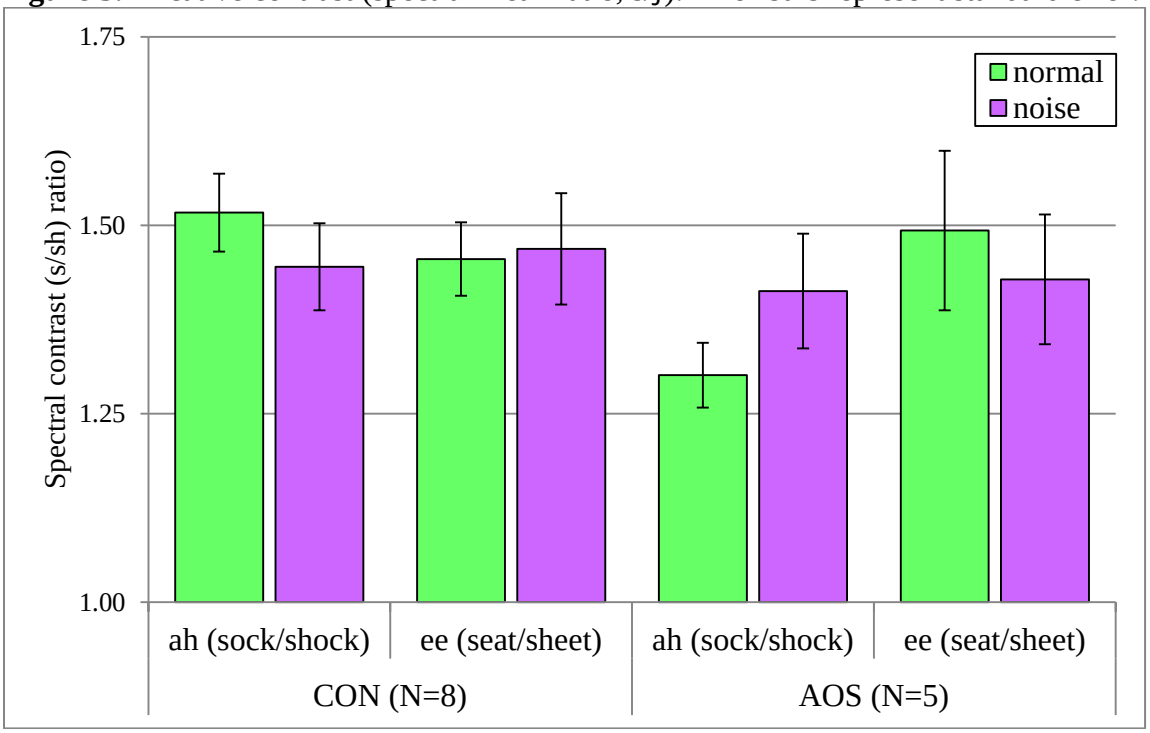


Figure 3. Fricative contrast (spectral mean ratio, s/ʃ). Error bars represent standard error.



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