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Delayed auditory feedback effects during reading and conversation tasks: Gender differences in fluent adults

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Abstract

Delayed auditory feedback (DAF) impacts the speech fluency of normally fluent males more than that of normally fluent females. Understanding this gender difference may contribute to our understanding of gender differences in the prevalence of developmental stuttering. To characterize this gender difference in fluent people, DAF-induced dysfluency was measured in 20 male and 21 female young adults during oral reading and conversation tasks. Stutter-like dysfluencies (SLDs), articulation errors, interjections, reading errors, and speech rate were measured for both speech tasks as the participant spoke without feedback, with non-delayed feedback, and with DAF presented with 5 delay intervals (14 conditions total). DAF induced SLDs (but not other dysfluencies) more frequently during conversation than reading, and this effect was significantly greater for males than females (*Gender* × *Task* × *Feedback* interaction). Males also produced significantly more reading errors than females. DAF reduced speaking rate significantly more while reading than conversing (*Task* × *Feedback* interaction). DAF significantly decreased the frequency of interjections and increased the frequency of articulation errors; however, no *Gender* effects on these variables were observed. Although significant order effects indicated improved fluency across trials, covariance analysis suggested that order effects could not explain other results.

Educational Objectives: After reading this article, the reader will be able to (1) Discuss developmental stuttering (DS) and gender differences in DS prevalence. (2) Define delayed auditory feedback (DAF). (3) Evaluate the evidence that gender is linked to DAF effects on fluent people. (4) Summarize the results of new research designed to assess sex differences in DAF effects on speech fluency in normally fluent adults. (5) Evaluate the degree to which evidence from the literature indicating that individual differences in attentional control may help us understand gender difference in DAF effects and possibly in DS prevalence as well.

Keywords: Stuttering; Delayed auditory feedback; Altered auditory feedback; Human gender differences; DAF; AAF; PDS; Speech fluency; Attention

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1. Introduction

1.1. Delayed auditory feedback

Delayed auditory feedback (DAF) is typically produced by recording a person's voice and replaying it to the person after a short delay (≤500 ms), usually via headphones. DAF has strong effects on speech fluency, inducing dysfluency in normally fluent people and decreasing or eliminating dysfluency in people with developmental stuttering (DS; thorough reviews of both effects are presented by Bloodstein & Bernstein Ratner, 2008). DAF is only one of the various auditory manipulations that can improve speech fluency in people with DS; other examples are choral reading (Adams & Ramig, 1980; Kiefte & Armson, 2008) and altering the frequency of speech feedback (frequency altered feedback; Hargrave, Kalinowski, Stuart, Armson, & Jones, 1994). However, DAF is the only such stimulus with marked dysfluency-inducing effects in normally fluent individuals. As a group, the effects of these stimuli highlight the strong involvement of auditory processing in the production of fluent speech both in people who stutter and in fluent controls.

Among normally fluent speakers, DAF affects the speech fluency of males more than that of females (Bachrach, 1964; Fukawa, Yoshioka, Ozawa, & Yoshida, 1988; Sutton, Roehrig, & Kramer, 1963). Although studies of developmental changes in the effects of DAF appear rarely in the literature, the results of these studies suggest that the effects of DAF may change developmentally; however, inconsistent results may suggest undiscovered moderating variables. For example, Chase, Sutton, First, and Zubin (1961) described DAF effects increasing with age, whereas Siegel, Fehst, Garber, and Pick (1980) reported the opposite. The latter study also suggested that the DAF delay interval associated with maximum dysfluency induction may vary with age. In searching the DAF literature, we found only one study of the development of gender differences in DAF effects. Timmons and Boudreau (1976) found significant gender differences in DAF effects among children aged 7, 11, and 13 years, but not among those aged 5 or 9 years, suggesting that gender differences in DAF effects may increase with age. The apparent inconsistencies in the 7–11 year range may represent a gender effect that begins small and develops slowly around this age range. This may be consistent with Smith and Zelaznik's (2004) report that speech development tended to plateau in children 7 through 12 years of age, with improvements in speech stability tending to occur before and after, but not during, this age range. A gender difference in DAF effects that begins to develop after 5 years may similarly plateau such that stable effects are not present (or are not easily detected) until around the beginning of adolescence.

1.2. Are DAF effects in fluent people linked to DS?

Developmental stuttering (DS) is characterized by unintended speech dysfluencies. Specifically, people who stutter experience unintended repeated movements (repetitions of speech sounds) and fixed postures; the latter can take the form of prolonged speech sounds or prolonged silences during speech (Teesson, Packman, & Onslow, 2003). Although DS has been widely studied, its etiology remains unknown. The condition begins spontaneously in about 4% of children, and about 75% of these recover spontaneously during childhood. The remaining 25% (1% of the population) continue to stutter throughout adulthood (Andrews, Morris-Yates, Howie, & Martin, 1991; Ardila et al., 1994; DSM-IV, 1994). The prevalence of DS is strongly linked to gender, both among those who recover from childhood stuttering and among those whose stuttering persists into adulthood, with males being more likely than females to experience DS and less likely than females to recover. As a result, the gender difference in DS prevalence increases with age, with the male-to-female ratio growing from about 2:1 in children to about 4:1 to 5:1 in adults (Ambrose, Cox, & Yairi, 1997; Ambrose, Yairi, & Cox, 1993; Drayna, Kilshaw, & Kelly, 1999; Yairi, Ambrose, & Cox, 1996; Yairi, Ambrose, Paden, & Throneburg, 1996).

Gender differences in DS prevalence and recovery are widely accepted, and theories explaining DS must accommodate the existence of gender differences in DS prevalence. However, our knowledge of this gender difference is under-utilized as a means by which to develop theory. For example, the gender difference in DS prevalence may suggest the existence of a factor that is gender-linked in the larger population and which serves to put males at greater risk for DS than females. If we suppose that DS risk is increased in males because, in general, males tend to score higher than females on some unidentified risk factor, then we might expect this factor also to cause gender differences that can be measured in the fluent population. Gender differences in DAF susceptibility among fluent people may constitute evidence of such a factor.

The existence of gender differences in the dysfluency-inducing effects of DAF on normally fluent people suggests the existence of a gender-linked factor associated with both auditory processing and speech fluency. The present study was motivated by the possibility that the factors leading to gender differences in DAF susceptibility among fluent people may also cause or contribute to gender differences in the prevalence of DS. As mentioned above, the male-to-female ratio in DS prevalence grows with increasing age, and self-reports of those who have recovered from DS suggest that the increase in male predominance may occur around the age at which gender differences in DAF effects are growing among fluent people (Martyn & Sheehan, 1968; Shearer & Williams, 1965; Timmons & Boudreau, 1976; Wingate, 1964).

1.3. Measurement of gender differences in DAF effects

Although understanding gender differences in DAF effects on normally fluent people may contribute to our understanding of the gender difference in the prevalence of DS, a careful characterization of gender differences in DAF effects is not available in the literature. We therefore sought to clarify this gender difference by presenting DAF to normally fluent men and women. Further, papers reporting gender differences in DAF effects (and most other DAF research as well) are typically based on speech generated via reading tasks. To expand upon this, we also sought to increase our understanding of DAF effects by eliciting more natural speech than that produced while reading aloud.

What follows is a description of an empirical assessment of gender differences in DAF effects among healthy, fluent adults whose fluency was measured during both a reading task and a conversation task. The effects of DAF were assessed via measurement of several dysfluency types including those associated with DS (repeated movements and fixed postures), or “stutter-like dysfluencies” (SLDs). Because we are interested in a possible common cause of gender differences in DS prevalence and DAF effects, the primary hypotheses were simply (a) that DAF-induced dysfluencies would occur more in males than in females and (b) that gender differences in DAF effects would be observed selectively on SLDs. Descriptive goals of the study were (1) to characterize gender differences in DAF effects, (2) to determine whether gender differences in DAF effects are related to the interval by which DAF stimuli are delayed, (3) to determine whether DAF effects vary with speaking task, (4) to determine whether gender differences in DAF effects vary with speaking task, and (5) to examine the effects of DAF on other speech characteristics (speech rate, reading errors, articulation errors, and interjections).

2. Method

2.1. Participants

Participants included 20 male and 21 female non-stuttering undergraduate students ranging in age from 18–25 years ($M = 19.78$, $s = 3.87$). Participants were native English speakers with normal hearing, normal or corrected-to-normal vision, and no history of speech, language, psychiatric, or neurological disorder. Some participants received course credit for participation.

2.2. Materials

Audiological screening and all auditory stimuli were presented through a GSI-61 clinical audiometer (Grason-Stadler). Stimulus delays were implemented using the “long delay” plug-in within *ProTools* software (*v*. 6.2, DigiDesign) running on a Dell personal computer. Speech samples were recorded digitally as WAV files using *ProTools* software. For all reading trials, the reading passage was *The Rainbow Passage* (Fairbanks, 1960), a phonetically balanced passage of English prose (462 syllables, 329 words) printed in 13.5 font Arial typeface on an otherwise blank sheet of white printer paper (8.5″ × 11″). Conversational speech was elicited via a subset of 80 speech prompts. Prompt order was randomized for each participant and a mean of about 50 prompts was used per participant. Examples of speech prompts are, “Can you tell me what you did last weekend?,” “Explain the meaning of the phrase, ‘Don’t judge a book by its cover.’,” “Tell me about your extra-curricular activities,” “Describe a jellyfish to someone who has never seen one,” “Describe the relative locations of the 7 continents,” and “Tell me about the last movie you saw.” Syllable counts were obtained using *Readability Calculations* software (*v*. 5.3, Micro Power and Light).

2.3. Procedure

All procedures were approved by the Institutional Review Board of Tulane University. After providing informed consent, each participant was shown to a sound-attenuated chamber located within a sound-attenuated room. The participant was fitted with foam insert ear phones and a headset microphone. The participant's hearing was then assessed via a pure-tone hearing screening (500, 1000, 2000, 4000, and 8000 Hz tones presented at 25 dB).

Each participant's speech was recorded both while reading and while speaking conversationally in response to speech prompts. For each of these conditions, speech was recorded while the participant heard no feedback, non-delayed feedback, or DAF with one of the following delay intervals: 180 ms, 230 ms, 280 ms, 330 ms, and 380 ms. (Note that the label "no feedback" does not imply that the participant is unable to hear his or her own voice; only that no feedback is presented through the earphones.) Speech was amplified such that stimulus intensity was approximately 90 dB SPL for conversational speech (typically around 65 dB SPL at 3 feet). The headset microphone mentioned above was used to avoid fluctuations in stimulus intensity due to variable mouth-to-microphone distance associated with participant head movement. Although speech intensity was not measured, casual observation of behavior suggested that speech intensity increased when DAF was presented (consistent with previous reports; e.g., Howell, 1990). Because amplification was constant, such increases in speech intensity resulted in concomitant increases in feedback intensity. Participants therefore could not adjust speech intensity so as to increase the presence of the natural speech signal relative to the amplified signal.

Each participant's speech was recorded under 14 separate conditions (2 speech tasks × 7 feedback conditions). Presentation order was randomized for each participant, with the constraint that trials alternated between reading and conversation. Initial task was randomized across participants. No feedback and non-delayed feedback conditions served as controls to provide a baseline for normal speech characteristics. Speech was recorded via a headset microphone and returned to the subject through the foam insert earphones. The delay was produced via the *ProTools* (Digidesign) software package with M-Box, using the "long delay" plug-in set to 100 ms, 150 ms, 200 ms, 250 ms, or 300 ms (the discrepancy between these equipment settings and the delay intervals reported above results from a shortcoming of *ProTools* with M-Box and is discussed below in Section 4.7.2). Conversational prompts were presented until each trial reached a minimum of 3 min (including prompts). After completing a brief survey associated with another study, the participant was debriefed.

2.4. Data handling

Following data collection, conversational speech samples were transcribed and syllable counts were measured using *Readability Calculations* software. Raters blind to subject identity and *Feedback* condition measured speaking time for each trial (excluding prompt-delivery for conversation trials) and the frequencies of the following dysfluency types: repeated movements, audible fixed postures (prolongations), inaudible fixed postures (blocks or hesitations), articulation errors, reading errors, and interjections ("er," "um," "like," etc.). Repeated movements and fixed postures were aggregated into a single measure of stutter-like dysfluencies (SLD). Reading errors were measured only for reading trials, whereas interjections were measured only for conversation trials. For this reason, other speech characteristics (speaking rate, articulation errors, reading errors, and interjections) were not aggregated and were examined in separate analyses. For each trial, all frequencies were transformed to events per 100 syllables (e.g., SLDs/100 syllables).

Speaking Rate was measured by dividing *Number of Syllables Spoken* by *speech duration* using an *overall speaking rate* measure for which SLDs and other speech characteristics did not add to *Number of Syllables Spoken* and participants' pauses and dysfluencies were not excluded from *Speech Duration*. Because *Speaking Rate* may have been impacted by the presence of dysfluencies, effects on *Speaking Rate* were assessed after controlling statistically for the presence of dysfluencies using covariance analysis. Periods of silence during which participants listened to speech prompts were not counted as part of *Speech Duration* during conversational trials.

2.5. Statistical design

2.5.1. Stutter-like dysfluencies (SLDs)

Effects on the dependent variable (DV) *SLD rate* (SLDs/100 syllables) were assessed via a 2 ×2 × 7 mixed analysis of variance (ANOVA) with *Gender* (male, female) entered as a grouping factor and with *Task* (Reading, Conversation), and *Feedback* (None, 0 ms delay, 180 ms delay, 230 ms delay, 280 ms delay, 330 ms delay, and 380 ms delay) entered as repeated-measure factors.

2.5.2. *Other speech characteristics*

Effects on the DV *Articulation Error Rate* (errors/100 syllables) were tested via 2 × 2 × 7 mixed ANOVA identical in design to that used to analyze effects on *SLD Rate*.

Effects on the DVs *Reading Error Rate* and *Interjection rate* were tested via 2 × 7 mixed ANOVA with *Gender* entered as a grouping factor and *Feedback* entered as a repeated-measures factor. With the exception of the absence of the *Task* independent variable (because reading errors exist only when reading), the design was identical to that described for *SLD Rate*.

Effects on the DV *Speaking Rate* were tested via 2 × 2 × 7 mixed ANOVA identical to those used to test effects on *SLD Rate* and *Articulation Error Rate*.

For all analyses, the impact of order effects was assessed by replacing the *Feedback* factor with *Trial*, a repeated-measures factor (with levels 1 through 7) representing the trial on which a speech sample was recorded. Significant *Trial* effects indicate behavioral changes over the course of the experiment due to factors such as fatigue, boredom, adaptation, or practice effects (e.g., those that might result from repeated reading of *The Rainbow Passage*).

When order effects were detected, their impact on observations was assessed using adjusted means obtained through analyses of covariance (ANCOVA) in which repeated-measures variables were recast as grouping variables (because ANOVA cannot accommodate a repeated-measures covariate) and in which *Trial* was included as a covariate.. Although this procedure does not produce valid significance tests, adjusted means were examined to assess the character of results after removing order effects. The procedure is therefore simply descriptive and was used to determine whether results were meaningfully impacted by order effects.

For repeated-measures factors, violations of the sphericity assumption were handled via use of Huynh-Feldt-corrected degrees of freedom. For each analysis, only the highest-order significant effect is characterized using estimated marginal means (*M*) and standard errors (SE). When post hoc tests were used, Type I error rate was controlled using modified Bonferroni methods (Holm, 1979; Larzelere & Mulaik, 1977). All data were analyzed via SPSS 15.0.1.1 (2007). Alpha was set at $\alpha = .05$ for all other tests.

3. Results

3.1. *Reliability of speech characteristic measurements*

Approximately 12% of trials were coded by a second rater. Reliabilities were as follows: $r_{\mathrm{SLD}} = .884$, $r_{\text{articulation errors}} = .793$, $r_{\text{reading errors}} = .703$, $r_{\text{interjections}} = .846$.

3.2. *Efficacy of speech prompts*

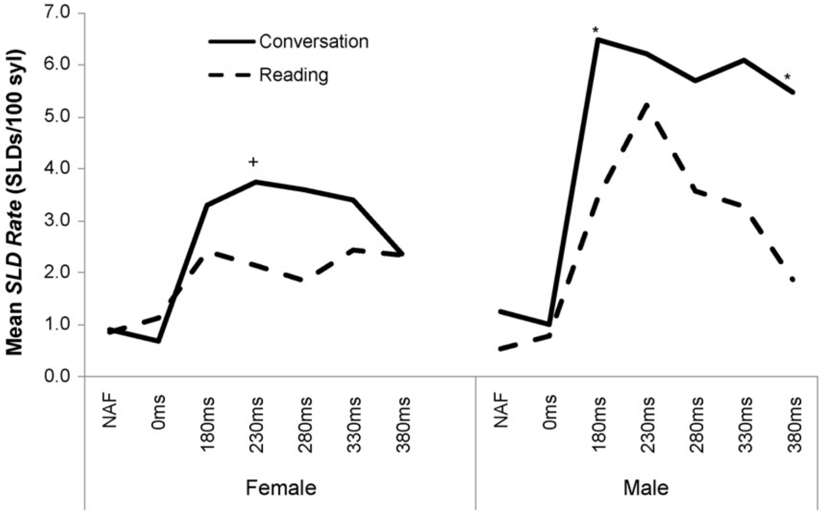
During each 3-min conversational trial, participants responded to a mean of 7.11 speech prompts, with a mean of 32.62 s between prompts. Speech prompts elicited a mean of 381.87 syllables per condition.

3.3. *Effects on SLD Rate*

Significant *Gender* differences were observed in the relationship between *Task* and *Feedback* effects, as evidenced by a significant *Gender* × *Task* × *Feedback* interaction; $F_{3.31,129.14} = 2.36, p = .047$ (see Table 1, Fig. 1). Significant *Task* effects were observed only for males listening to 180 ms ($p < .0001$) and 380 ms ($p < .0001$) DAF. Because task effects on females were not observed for any levels of *Feedback*, females' data were analyzed alone to determine whether *Feedback* effects varied with *Task*. A significant *Task* × *Feedback* interaction was observed for females, $F_{6,120} = 6.28$, $p < .0001$. To facilitate interpretation, we will mention that the largest *Task* effect for females occurred with the 230 ms delay interval ($p = .034$). The *Gender* × *Task* × *Feedback* interaction superseded the following significant lower-order effects: *Task* main effect, $F_{1,39} = 15.84, p = .0003$; *Feedback* main effect, $F_{1.43,55.36} = 12.44, p = .0002$; *Task* × *Feedback* interaction, $F_{3.31,129.14} = 3.93, p = .008$.

Table 1
Estimated marginal means (*M*) and standard errors (SE) depicting the *Gender* × *Task* × *Feedback* interaction effect on SLD Rate (SLDs/100 syllables). NAF = No auditory feedback presented.

	Female				Male			
	Conversation		Reading		Conversation		Reading	
Feedback	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
NAF	0.91	0.18	0.87	0.13	1.26	0.19	0.54	0.13
0 ms	0.68	0.16	1.13	0.23	1.01	0.16	0.79	0.24
180 ms	3.32	1.28	2.41	0.85	6.50	1.31	3.46	0.87
230 ms	3.76	1.41	2.13	1.43	6.23	1.45	5.23	1.46
280 ms	3.60	1.30	1.86	1.16	5.70	1.33	3.58	1.19
330 ms	3.41	1.40	2.43	1.12	6.11	1.44	3.28	1.15
380 ms	2.36	1.24	2.34	0.60	5.47	1.27	1.87	0.61



* $p = < .0001$; significant post- hoc
\+ $p =$ .0342; n/s

Fig. 1. The effect of DAF on stutter-like fluency rate (SLDs/100 syllables). The plot shows *Gender* differences in *Task*-dependent *Feedback* effects, as evidenced by a significant *Gender* × *Task* × *Feedback* interaction. SLD = Stutter-like dysfluency.

This *Gender* × *Task* × *Feedback* interaction could potentially have been driven simply by the contrast between no delay and DAF. To determine whether delay *interval* was a factor (rather than the mere presence of delay), the analysis was run a second time, but with *Feedback* replaced by the 5-level variable *Interval* (180 ms, 230 ms, 280 ms, 330 ms, and 380 ms). In this analysis, the *Gender* × *Task* × *Interval* interaction was statistically significant ($F_{2.55,107.439} = 3.39$, $p = .024$) and was larger in magnitude ($\eta^2 = .08$) than the *Gender* × *Task* × *Feedback* effect of the original analysis ($\eta^2 = .06$).

No significant order effects were detected ($p > .05$ for *Trial* main effect and for all interactions involving *Trial*).

3.4. Effects on Speaking Rate

Speaking rate was faster during reading than conversation conditions, and this difference varied significantly with *Feedback*, such that DAF effects were larger during reading than during conversation, as evidenced by a significant *Task* × *Feedback* interaction, $F_{5.76,207.27} = 5.77$, $p < .0001$ (see Table 2 and Fig. 2). *Speaking rate* was significantly reduced by presentation of DAF across all delay intervals for both conditions. When participants were reading, this effect was slightly but significantly diminished at 380 ms DAF (versus 180 ms, $p = .002$, and 230 ms, $p = .002$).

Table 2
Estimated marginal means (*M*) and standard errors (SE) depicting the *Task* × *Feedback* interaction effect on speech rate (syllables/second). NAF = No auditory feedback presented.

	Conversation		Reading	
Feedback	*M*	SE	*M*	SE
NAF	3.14	0.12	4.62	0.09
0 ms	3.13	0.10	4.73	0.08
180 ms	2.65	0.08	3.73	0.10
230 ms	2.59	0.08	3.78	0.11
280 ms	2.59	0.07	3.89	0.10
330 ms	2.63	0.08	4.00	0.09
380 ms	2.65	0.06	4.04	0.10

This *Task* × *Feedback* interaction superseded the following significant main effects: *Task*, $F_{1,36} = 313.68$, $p < .0001$; *Feedback*, $F_{4.47,160.76} = 49.70$, $p < .0001$.

When order effects were assessed, a significant *Task* × *Trial* interaction was detected, $F_{6,216} = 5.121$, $p < .0001$. Simple interaction tests indicated order effects for the reading task ($F_{1,36} = 313.68$, $p < .0001$), with *speaking rate* increasing significantly after the first two trials then stabilizing. For the conversation task, no significant order effects were observed and means were not suggestive of order effects (*M*s = 2.62, 2.80, 2.83, 2.75, 2.88, 2.81, and 2.69 syl/sec). *Trial* was therefore added to the model as a covariate for reading trials.

In addition to order effects, the presence of dysfluencies in speech can cause artifactual decreases in measured *speaking rate* because dysfluencies add to the time needed to complete an utterance. The relatively high *SLD Rate* during conversation could therefore cause an apparent slowing of speech during conversation. To control for decreases in *Speech Rate* caused by dysfluencies, the number of SLDs observed in a trial was added to the statistical model as a second covariate. Fig. 2 includes both unadjusted means (heavy curves) and adjusted means (light curves) for each condition.

As a second assessment of the effect of dysfluencies on overall speech rate, dysfluency durations were measured in a randomly selected subset of participants (about one third of the total sample; $n_{male} = n_{\text{female}} = 7$) and these durations were subtracted from *speech duration* for each condition. The attenuated *speech duration* measure was used to recompute *speaking rate* and these measures were analyzed as were the original *speaking rate* data. The pattern of results observed was essentially identical to that observed in the original analysis and in the covariance analysis; *speaking rate* was faster during Reading than Conversation conditions, and this difference varied significantly with *Feedback*, such that DAF reduced *speaking rate* during Reading but not Conversation conditions, $F_{6,72} = 8.34$, $p < .0001$.

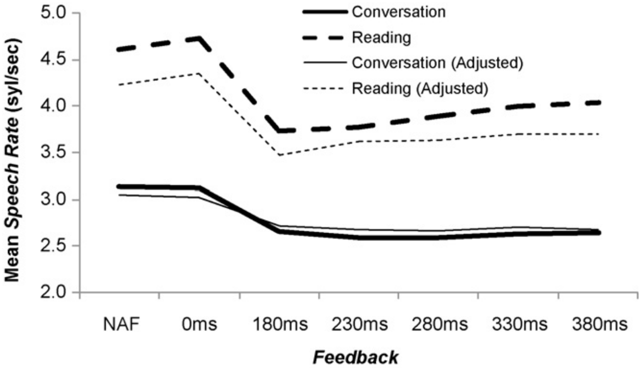


Fig. 2. The effect of DAF on speaking rate (syllables/second). The plot shows *Task*-dependency of *Feedback* effects, as evidenced by a significant *Task* × *Feedback* interaction. Heavy lines indicate observed data; lighter lines indicate means obtained via covariance analysis following adjustment for order effects and dysfluency frequency.

Table 3
Estimated marginal means (M) and standard errors (SE) depicting the effect of Feedback on interjection rate (interjections/100 syllables) and on articulation error rate (errors/100 syllables). NAF = No auditory feedback presented.

	Interjections		Articulation errors		
Feedback	M	SE	M	M_{adj}	SE
NAF	3.18	0.34	0.07	0.05	0.02
0 ms	3.36	0.32	0.07	0.05	0.02
180 ms	2.62	0.29	0.47	0.45	0.10
230 ms	2.62	0.29	0.43	0.41	0.06
280 ms	2.75	0.33	0.47	0.45	0.08
330 ms	2.76	0.25	0.44	0.42	0.09
380 ms	2.58	0.30	0.46	0.43	0.09

In sum, statistical and methodological controls suggest that the *Task* × *Feedback* interactive effect on *speaking rate* is not an artifact caused by order effects or by the increased frequency of dysfluencies in the conversation conditions than in the reading conditions.

3.5. Effects on interjection rate

Interjections were significantly associated with *Feedback*, $F_{4.75,185.19} = 2.91$, $p = .016$ (see Table 3). Post hoc testing indicated a significant difference in *interjection rate* between the 180 ms DAF condition and both non-delayed feedback conditions ($p = .002$).

No significant order effects were detected ($p > .05$ for *Trial* main effect and for all interactions involving *Trial*).

3.6. Effects on articulation error rate

Articulation error rate was significantly higher during the reading task ($M = .29$, SE = .05) than during the conversation task ($M = .39$, SE = .06), $F_{1,39} = 6.43$, $p = .015$. *Articulation error rate* was also significantly associated with *Feedback*, $F_{3.87,150.81} = 12.64$, $p < .0001$ (see Table 3). Specifically, articulation errors were significantly more frequent in DAF conditions than in conditions without DAF ($p < .0002$ for all significant comparisons). No significant differences were observed between the two non-delayed conditions or among the five DAF conditions.

When order effects were assessed, a significant *Trial* × *Order* interaction was detected, $F_{4.26,166.17} = 2.68$, $p = .030$. Simple interaction tests indicated order effects for the Conversation task ($F_{4.441,173.206} = 3.456$, $p = .007$) including significant decreases in *Articulation Error Rate* after the first two trials (Ms = 0.61, 0.51, 0.28, 0.30, 0.41, 0.33, and 0.31 errors/100 syl). For the Reading task, no significant order effects were observed ($p = .117$) and means were not suggestive of order effects, although a slight non-significant increase in articulation error rate was observed in the final trial (Ms = 0.25, 0.35, 0.27, 0.21, 0.26, 0.26, and 0.46 errors/100 syl). This interaction superseded a significant *Task* main effect, $F_{1,39} = 6.428$, $p = .015$.

When *Trial* was added to the statistical model as a covariate, adjustment of *Articulation error rate* for the conversation condition was lost in rounding error ($M = .39$ errors/sec) and was minor for the reading task ($M = .25$). Adjusted means associated with the *Feedback* effect were minor also, and are shown in Table 3.

3.7. Effects on reading error rate

Males ($M = .47$, SE = .08) made significantly more reading errors than did females ($M = .10$, SE = .08), $F_{1,39} = 10.96$, $p = .002$. No significant effects of *Feedback* were observed ($p > .05$ for the *Feedback* main effect and for all interactions involving *Feedback*).

When order effects were assessed, a significant *Trial* main effect was detected ($F_{4.41,172.02} = 3.54$, $p = .006$), with *reading errors* dropping significantly after the first two trials. Adjustment of means increased *reading error rate* slightly (by about .08) but did not impact the gender difference reported above (because net adjustment of means was identical for both groups owing to the repeated-measures nature of *Trial*).

4. Discussion

In the present study we examined the effects of gender, speaking task, and delay interval on the dysfluency-inducing effects of DAF. In this section we will discuss the following contributions of this research: (1) characterization of DAF effects during conversation, (2) demonstration that DAF induced more frequent dysfluencies during conversation than during oral reading, (3) replication of previous observations of higher rates of DAF-induced dysfluency in men than in women, (4) demonstration that between-task differences in DAF effects are larger for males than females, and (5) demonstration that gender and task associations with DAF effects impacted stutter-like dysfluencies (SLDs) but not other dysfluencies (ODs).

4.1. DAF effects during conversation

Auditory feedback is typically manipulated while participants are reading or engaging in scripted speech. The effects of altered auditory feedback on the fluency of spontaneous, unscripted speech have received correspondingly little attention in the literature. Typical DAF studies therefore have lower external validity than studies requiring unscripted speech. The absence of studies investigating DAF effects during conversational speech was acknowledged in a recent review by Lincoln, Packman, and Onslow (2006), and we have been similarly unable to find published studies demonstrating the effects of DAF on conversational speech. The present study contributes new information regarding the character of DAF effects on relatively natural speech.

The present finding that DAF induces significantly greater dysfluency during conversation than during reading demonstrates the importance of studying DAF effects on unscripted speech and suggests that studies including only reading or scripted speech may underestimate DAF effects. Future studies may therefore benefit from the inclusion of unscripted speech conditions.

4.2. Gender differences in DAF effects

The higher rate of dysfluencies in men than in women is consistent with the literature summarized in the introduction. However, the relationship between DAF delay interval and dysfluency induction varied with participant gender. For the standard reading condition, this difference can be viewed most easily by comparing the dashed curves in the two plots shown in Fig. 1. In the right half of Fig. 1, note that males exhibited the expected parabolic-arch pattern; dysfluency rate increased with increasing delay interval until the rate peaked at 230 ms delay, then decreased with increasing delay interval for delays >230 ms. In contrast, the left half of the figure shows relatively small and stable DAF effects for females. Replication of this finding is needed, as other investigators' descriptions of gender differences in the delay-interval-dependence of DAF effects are not available in the literature.

4.3. Gender differences in DAF effects are task-dependent

For the standard reading task, a parabolic relationship between delay interval and dysfluency rate was observed only in males. During unscripted conversation, this pattern was observed only in females (Fig. 1, left plot, solid line). In contrast, males exhibited greatest dysfluency with a 180 ms delay interval during unscripted conversation, and dysfluency rates tended to decrease gradually with increasing delay intervals.

Dysfluency occurred with greater frequency when participants spoke extemporaneously than while reading. That the increase is simply a by-product of the increased speech rate relative to reading seems unlikely because (a) the effect was observed only for SLDs, and (b) we did not observe corresponding interactive effects on speech rate. The dramatically different task demands associated with reading and conversation may suggest that DAF effects are mediated by factors such as cognitive demands or automaticity. This and other task effects must be interpreted in light of the fact that a single passage was used for all reading conditions, a limitation discussed in more detail in Section 4.7.1 below.

4.4. Moderation of DAF effects by gender and task is SLD-specific

One interesting feature of the present results is that moderation of DAF effects by gender and task was observed for SLD rate but not for the rates at which participants produced articulation errors, reading errors, interjections, or speech itself. The narrow focus of these interactive effects on SLDs alone is consistent with the notion that fully understanding gender differences in DAF effects among normally fluent people may improve our understanding of gender differences in DS risk. Exploring the possibility of a link between gender differences among fluent people and gender differences in stuttering prevalence may be warranted in future research.

4.5. Order effects

Order effects were observed such that articulation errors decreased across conversation trials whereas across reading trials speaking rate increased and reading errors decreased. Each of these effects can be construed as improvement in fluency across trials, with speech improving early (after the first two trials) and stabilizing later (trials 3–7). These data do not indicate clearly whether the changes are associated with general carryover effects (e.g., boredom, fatigue, practice, or relaxation) or with specific carryover effects involving adaptation to DAF. We controlled for order effects in two ways. First, to allow interpretation of DAF effects, we randomized the order of feedback conditions across trials. Second, we examined the impact of order effects via examination of adjusted means generated using covariance analyses. For each effect, these adjusted means indicated patterns of results nearly identical to those indicated by unadjusted means and did not provide evidence that any of the effects reported above were artifacts of carryover.

The consistency in the pattern of these order effects (stabilization after the first two trials) suggests that studies of DAF effects on fluent individuals might benefit from inclusion of at least two practice trials (or perhaps 4 min of practice speech) prior to data collection. Alternatively, if experimental designs do not allow practice trials, we recommend the use of statistical procedures such as those used above to test for order effects and, if present, to evaluate their impact.

4.6. A candidate explanation for variation in DAF effects

The results of the present study support the existence of gender differences in DAF effects on the speech of fluent adults. That this gender difference was observed for the dysfluency types that are associated with DS but not for other speech characteristics affected by DAF is consistent with a link between gender differences in DS and DAF susceptibilities (in fluent adults). However, these relationships do not suggest specific factors that might drive individual differences.

The effect of DAF, a purely aural stimulus, on speech fluency suggests that auditory processing systems play some role in the production of fluent speech. The term “auditory processing” likely describes features associated with DAF effects, but the term is expansive and also likely encompasses processes that are not related to DAF effects. Preferable would be to identify a narrower facet of auditory processing that is associated with both gender and speech fluency, and which might reasonably explain individual differences in DAF effects. The literature described below suggests that auditory attentional control may be worth considering as a factor explaining gender differences in DAF susceptibility (among normally fluent individuals) as well as risk for DS.

Auditory attentional control describes the ability of an organism to enhance or reduce the salience of select features of the auditory environment relative to other features. Such control can take the form of attentional facilitation (enhancing the salience of, or focusing on, a feature) or attentional inhibition (reducing the salience of, or ignoring, a feature). In any complex auditory environment including a signal surrounded by noise, auditory attentional control facilitates separation of the two and appropriate interaction with the signal. In natural environments the signal and noise components are sufficiently distinct to allow separation of the two without excessively taxing auditory attentional control systems. Similarly, during normal speech, a speaking person’s voice is separated from surrounding environmental noise with minimal effort. However, the presentation of DAF may present special challenges to this system, in that the speaker’s voice and the DAF signal are virtually identical in all respects other than timing, and may therefore both be treated as signal (or noise). DAF could therefore impact speech fluency because some part of the speech production system responds to the DAF signal as it would normally respond to the natural speech signal, thereby creating sequence-inappropriate actions resulting in dysfluencies. Conversely, the DAF signal may constitute reiteration of a signal that is normally under-utilized by people who stutter, thereby reducing dysfluency in this group.

The availability of dual speech signals is typically avoided during DAF presentation by minimizing the availability of the unaltered speech signal via occlusion of the speaking person’s ears with headphones. However, even if the ear is effectively isolated from air pressure variation (sound waves), a “bone-conducted” speech signal is still transmitted from the larynx to the inner ear through bones and other body tissues. A strong auditory attentional control system could allow an individual to enhance the salience of a non-delayed bone-conducted signal (or to reduce that of the DAF signal) sufficiently to maintain fluent speech. Conversely, individuals with poor auditory attentional control might be unable to separate the dual stimuli, leaving speech production systems vulnerable to disruption by a speech signal that is inappropriately time-locked to ongoing speech production. Although attentional control seems a reasonable cause of gender differences in DAF effects, it is so far only speculation. However, the speculation is consistent with published reports of associations among attentional control, gender, DAF effects, and DS.

Various investigators have reported gender differences in auditory attention (Anderson & Hugdahl, 1987; Bush, Korchin, Beall, & Kiritz, 1974; Dolu et al., 2004; Halley, 1975; Munro & Govier, 1993). That attention and DS are related is not a new suggestion; early explanations of DS (Johnson & Knott, 1936; Knott & Johnson, 1936) included attention to (unaltered) speech feedback as an important factor in fluency maintenance among people with DS. More recent observations that people who stutter were less dysfluent when distracted (Arends, Povel, & Kolk, 1988; Schwenk, Conture, & Walden, 2007), performed worse than controls in a dual-task finger-tapping paradigm (Webster, 1990), and showed less auditory sensitivity than controls in a backward-masking task (Howell, Davis, & Williams, 2006) all are consistent with attention as a factor in speech production among DS and as a factor differentiating people who stutter from normally fluent controls. Finally, the existence of a relationship between attention and DAF effects also is not a new suggestion. Others have suggested that attention is an important factor in the effects of DAF on both people who stutter (van Riper, 1970) and fluent individuals (Mostofsky, Schill, & Noyes, 1969). However, empirical tests of an association between DAF effects and auditory attention are rare. In the only relevant empirical study to date, DAF effects on fluent adults and children were reduced during a selective attention task (Zelniker, 1971).

Data from studies of the neural bases of attention suggest that one’s own speech may enjoy special treatment by attentional systems in the brain. In general, attentional control is thought to occur when behavioral goals influence neural activity in sensory and perceptual regions of the brain (see Yantis, 2008, for a review). Functional imaging studies suggest that the representation of “behavioral goals” is widely distributed across the frontal and parietal lobes (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Coull, Frackowiak, & Frith, 1998; Hopfinger, Buonocore, & Mangun, 2000; Loose, Kaufmann, Auer, & Lange, 2003; Madden et al., 1997; Nebel et al., 2005; Rees, Frackowiak, & Frith, 1997) and serves to adjust the sensitivity of primary and secondary sensory neurons to goal-relevant stimuli (Reynolds, Chelazzi, & Desimone, 1999). Some data suggest that modulation of auditory processing occurs automatically during normal speech. Specifically, several studies have showed that auditory cortex responds less strongly to unaltered self-produced speech than to other sounds, including DAF (Chen et al., 2008; Curio, Neuloh, Numminen, Jousmaki, & Hari, 2000; Ford et al., 2001; Heinks-Maldonado, Nagarajan, & Houde, 2006; Houde, Nagarajan, Sekihara, & Merzenich, 2002; Numminen & Curio, 1999; Numminen, Salmelin, & Hari, 1999). These findings suggest that attentional inhibition of unaltered speech is the norm, and that DAF may impact speech because speech salience is (unnaturally) enhanced by disruption of the normal temporal relationship between speech production and speech feedback. Alternatively, attenuation of neural responses to self-produced speech may interfere with attentional control because such attenuation may act in competition with attempts at sensitization of auditory systems by attentional control processes (i.e., attentional facilitation).

These theories and observations do not constitute a demonstration that gender differences in DAF effects can be explained by gender differences in attention. However, the confluence of associations with attention do suggest that we might benefit from future empirical assessments of attentional control as a candidate explanation of gender differences in DAF effects, and perhaps of gender differences in DS prevalence as well. We have found no overt suggestion in the literature that gender differences in the domains of DAF and DS share a common origin, and we have found no research that can be construed as direct support for such a linkage. The existence of gender differences in the two domains may be entirely coincidental; however, the associations described above are interesting and suggest that further study of the role of attention in the production of fluent speech may be warranted.

4.7. Limitations of the present study

4.7.1. Only one reading passage was used

We chose to use *The Rainbow Passage* as the sole reading passage in order to maintain consistency across feedback conditions. However, repeated reading of the passage could have impacted measurement of between-task differences.

Consistent with this possibility, we saw order effects suggestive of learning or practice (reading errors decreased and speaking rate increased across trials). And we saw these effects for reading but not conversation conditions, which is consistent with practice effects associated with re-reading the passage. Examination of adjusted means suggested that these effects existed independent of order effects; however, statistical control does not eliminate concerns about practice effects. Using a variety of reading passages (matched for syntactic complexity, word length, etc.) may be warranted in future research. Whether order effects are caused by re-reading the passage or by other factors (e.g., early nervousness or later boredom) should be explored in future research.

4.7.2. Very short delay intervals were not included

Very short delays (<100 ms) can induce fluency in people who stutter, but show little or no effect on the speech of normally fluent adults (e.g., Stuart, Kalinowski, Rastatter, & Lynch, 2002). We therefore targeted intervals of 100–300 ms. We later learned that actual delay intervals were longer than those requested via instrument settings, presumably due to 80 ms computer processing time unknown to the manufacturer. The delay intervals described throughout in this paper (180 ms, 230 ms, 280 ms, 330 ms, and 380 ms) are accurate and include the processing lag. E.g., the duration of the 380 ms delay condition was the result of an equipment setting of 300 ms and a delay lag of 80 ms.

In the end, although intervals <180 ms were not included, the presentation of longer intervals afforded the unexpected discovery that the 380 ms delay produced a relatively large and significant between-task difference for males and a very small and non-significant between-task difference for females. In fact, in the 380 ms condition males produced the largest and females produced the smallest between-task differences observed in the study. The explanation for this gender difference in task effect may be associated with the disparate cognitive demands of the two speech tasks.

One striking difference between reading and conversation is the necessity for the speaking person to organize the semantic content of speech. Whereas awareness of semantic content is not strictly necessary during reading, a conversing speaker must monitor semantic content in order to produce coherent speech. The literature on event-related potentials (ERP) includes reports of significant gender differences in neural responses to language tasks (Daltrozzo, Wioland, & Kotchoubey, 2007; Wirth et al., 2007). Specifically, gender differences were reported in the a component of the ERP signal associated with semantic processing (the N400). Such a gender difference is consistent with the existence of gender differences in semantic processing. The N400 component is so-named because it occurs around 400 ms after the presentation of a stimulus. Perhaps the present observation of a relatively large gender difference in task effect with the 380 ms delay interval is linked to gender differences in semantic processes that are time-locked to speech production itself.

Studies of associations between cognition and DAF effects are relatively rare. However, an explanation related to semantic components of language may appeal to naïve normally fluent experimental participants, who routinely suggest cognitive causes of dysfluencies in statements such as, "...because I couldn't think about what I was saying while I was hearing what I just said." Although participants may not have insight into the real causes of their dysfluencies, the ERP data described may suggest cause for examination of gender differences in semantic processing as a factor in long-interval DAF effects.

4.7.3. Speech rate and dysfluency rate may be interdependent

Because dysfluency durations were not recorded for the majority of the sample, speaking rate was computed as *Overall speaking rate*, for which the presence of dysfluencies can artificially reduce measurements of speaking rate. Because the *Overall speaking rate* measure was used rather than *Articulatory rate*, the presence of dysfluencies might have artificially decreased measurements of speech rate. Conversely, any deviation from an individual's normal speech rate may impact motor control so as to cause disruption in habitual motor behavior such as speech. In the present results, the slowing of speech caused by DAF presentation could have itself increased the rate of dysfluencies, independent of any direct effects of DAF on fluency.

4.8. Conclusion

The present study was motivated by the theory that factors contributing to gender differences in DAF susceptibility may also contribute to the gender difference in the prevalence of DS. Given this motivation, the most interesting result was the observation of gender differences in DAF effects on SLDs but not on other speech fluency measures. This can not be construed as a demonstration that DS risk and DAF susceptibility are driven by a common gender-linked factor, but the result is consistent with the theoretical motivation and encourages further inquiry.

Another goal of the study was to characterize DAF effects during conversation in normally fluent people. Because the results reported here suggest that DAF effects vary with speaking task, investigators might consider including conversation conditions in future studies of DAF effects. However, this is the first study to suggest such task dependence and the finding requires replication as well as investigation among people who stutter.

To avoid overstating the suggestion that there is a relationship between DAF effects and DS, we note the following: although SLDs were measured, they were just that, stutter-*like* dysfluencies. These can not be construed as a true model for DS, in that there are clear differences between DAF-induced dysfluencies and the dysfluencies observed in people who stutter as a result of DS. For example, whereas dysfluencies associated with DS tend to be linguistically constrained (e.g., occurring at the beginnings of phrases or utterances), DAF-induced dysfluencies may not. Although we did not measure the distribution of dysfluencies within a speech sample, casual observation suggested that the SLDs observed here were distributed throughout phrases and utterances. Similarly, speech during DAF presentation was different than that of a person who stutters, in that increased SLDs were accompanied by other atypical speech characteristics. For example, due to increased frequency of articulation errors and to an overall slowing of speech, the fluent portions of speech produced by participants during DAF often seemed much less natural than the fluent portions of speech produced by people who stutter. Although the pattern of results observed was consistent with a possible link between DAF effects on fluent adults and DS, research including people who stutter or who have recovered from DS will be needed in order to support any conclusion that a real relationship exists.

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CONTINUING EDUCATION

Delayed auditory feedback effects during reading and conversation tasks: Gender differences in fluent adults

QUESTIONS

1. Which is proposed in this paper as a theoretical risk factor for developmental stuttering?
   (a) Attention
   (b) Sensory integration
   (c) Asymmetry in the brain
   (d) History of psychiatric disorder
2. Delayed auditory feedback
   (a) is a stimlus known to exacerbate the symptoms of stuttering.
   (b) impacts normally fluent females more than normally fluent males.
   (c) has similar effects on people who stutter and on normally fluent people.
   (d) can cause normally fluent people to become dysfluent.
3. Which of the following was not reported in the results?
   (a) Gender differences in DAF effects were observed.
   (b) People spoke faster while reading than during conversation.
   (c) DAF effects tended to increase over the course of an individual’s participation in the study.
   (d) DAF impacted all measures of speech fluency.
4. About what percent of the population experiences developmental stuttering at some point in life?
   (a) 1%
   (b) 5%

   (c) 10%
   (d) 20%

5. Among children who stutter, approximately what percent never recover and continue to stutter into adulthood?
   (a) 5%
   (b) 10%
   (c) 20%
   (d) 50%

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