

RESEARCH ON SPOKEN LANGUAGE PROCESSING
Progress Report No. 24 (2000)
Indiana University

**Reduced, Citation, and Hyperarticulated Speech in the Laboratory:
Some Acoustic Analyses¹**

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¹ This work was supported by NIH-NIDCD Training Grant DC00012 to Indiana University. We would like to thank Corey Yoquelet for his assistance in the acoustic analysis.

Reduced, Citation, and Hyperarticulated Speech in the Laboratory: Some Acoustic Analyses

Abstract. An acoustic analysis was carried out on a set of sentence stimulus materials varying in speech style (Reduced, Citation, and Hyperarticulated) that was elicited via a technique developed previously in our laboratory by Brink, Wright and Pisoni (1998) and Harnsberger and Pisoni (1999). Sentences recorded from twelve speakers were acoustically analyzed for sentence duration, keyword duration, and F1-F2 vowel space dispersion. The Reduced, Citation, and Hyperarticulated styles varied in terms of articulatory precision, in increasing order. Thus, the styles were predicted to differ significantly in keyword and sentence duration, with longer durations corresponding to more articulatorily precise styles. The styles were also predicted to differ significantly in the extent to which vowels in keywords were centralized, affecting the extent of vowel space dispersion. More disperse spaces were predicted for more articulatorily precise styles. Of the twelve participants, seven produced sentences with either the predicted keyword or sentence duration differences (or both) between all three styles. Eight of the twelve participants also showed the predicted vowel dispersion differences between styles, with greater dispersion corresponding to a larger vowel space. However, for some participants the dispersion differences between the Reduced and Citation styles were quite modest. In addition, all twelve participants produced a Hyperarticulated style that differed in keyword duration, sentence duration, and vowel dispersion from the Reduced and Citation styles, as predicted. Overall, the results demonstrate that it is possible to elicit controlled sentence stimulus materials varying in speech style in a laboratory setting, although the method requires further refinement to elicit these styles more consistently from individual participants.

Introduction

A longstanding problem in studies of speech production and speech perception has concerned the limitations imposed by experimental control and by laboratory settings in the collection of naturalistic speech. Naturalistic, spontaneous speech refers to a speech style commonly employed by talkers and listeners in conversations outside of a laboratory setting. In contrast, the style typically elicited from talkers in a recording session is read speech, sometimes called “lab speech,” which differs in numerous ways from more spontaneous styles. These differences can include the duration of the utterance and its constituent words, pausing, and the degree of centralization in the quality of vowels, to name a few (Byrd, 1994; Picheny, Durlach, & Braida, 1989; Summers, Pisoni, Bernacki, Pedlow, & Stokes, 1988). Unfortunately, much of what we know about speech production, speech perception, and spoken language processing has relied on a narrow range of speech styles, usually read speech. Theoretical models based on such studies may be severely limited in their capacity to generalize to other speech styles and, most importantly, to the speech styles that listeners encounter most frequently outside of a laboratory environment.

The popularity of read speech in studies of speech perception and spoken language processing has been driven by its numerous advantages to researchers. Read speech can be useful in limiting sources of error in the data collection process, or in avoiding particular confounds that might render the results uninterpretable. Control over the quality and structure of the materials also insures that an experiment can be replicated in other laboratories, a key aspect of any experiment. However, the reliance on studies of read speech elicited in the laboratory has meant that perception of variability that exists among speech styles has not been studied in detail. Other types of “nonlinguistic” variability have been shown to affect

speech perception and spoken word recognition, including talker, rate, and stimulus variability (Bradlow, Nygaard, & Pisoni, 1999; Mullennix & Pisoni, 1990; Nygaard, Sommers, & Pisoni, 1995). These studies suggest that listeners encode in long-term memory significant details and properties of speech signals that they encounter, and that these details influence the subsequent perception and recognition of speech. If listeners are sensitive to detailed properties of speech, then variation in those properties due to speech style differences may also play an important role in perceptual processing, one that has thus far been neglected in studies of speech perception and spoken word recognition.

Ideally, to address the issues of the generalizability of theoretical models to more naturalistic speech and the encoding and use of style-specific detail in spoken word recognition, a method would be needed to elicit different speech styles, particularly more naturalistic ones, while maintaining control over the speech materials elicited. Such a method would constitute a happy compromise between the benefits of experimental control and the benefits of analyzing a more natural, representative sample of speech. Various methods have been developed in prior work to elicit spontaneous speech, including the recording of natural conversation, guided conversations on a particular topic, and narration or map tasks (Hirschberg & Nakatani, 1996; Labov, 1972; Milroy, 1987; Speer, Sokol, & Schafer, 1999; Swerts & Collier, 1992). These methods have proven useful in eliciting specific words, phrases, and discourse units of interest. However, they typically fail to control for phonetic context, and they are often not appropriate for eliciting certain linguistic forms, such as specific sentences.

In our laboratory, we have attempted to develop a method of eliciting different speech styles at the sentence level while controlling for the particular sentence materials used. The range of speech styles we have studied includes a Reduced, or hypoarticulated, style, which should more closely resemble the speech style employed in natural settings than does laboratory read speech. The first version of this method was developed by Brink, Wright, and Pisoni (1998). They attempted to elicit three speaking styles, namely Reduced, or hypoarticulated speech; Citation, or read speech (the style normally used in reading controlled materials in a laboratory setting); and Hyperarticulated speech (i.e., clear speech). Each style was elicited in a separate condition of the experiment. Brink et al. attempted to elicit Reduced speech by having participants read a sentence while engaging in a concurrent processing task, specifically, remembering a digit sequence of five to seven digits that was presented immediately prior to the sentence. After reading the sentence, participants were asked to recall the digit sequence in the same order in which it was presented. The digit span task was considered to be a distractor task, chosen to place the participant under a cognitive load while reading a sentence. The digit span task was chosen as the concurrent task because it was successful in pilot studies in producing the desired speech style while minimizing disfluencies by the participants. Citation speech was elicited by simply having listeners read single sentences presented on a computer screen. Hyperarticulated speech was elicited in an experimental condition similar to the Citation speech condition. Participants were asked to read single sentences presented on a computer screen. During this portion of the experiment, they were prompted in a subset of trials to repeat the sentence “more clearly.” After responding to that prompt, participants were given the same prompt a second time, and the second reading was chosen to represent Hyperarticulated speech. This procedure had been used successfully in an earlier study by Johnson, Flemming, and Wright (1993).

Brink et al. tested this methodology with six participants, all native speakers of English, and evaluated its success in a detailed acoustic analysis. They measured several properties of the sentences, as well as keywords in the sentences, including the duration, f_0 range, absolute RMS energy, energy range, degree of vowel centralization, and degree of vowel dispersion. The results of the acoustic analysis showed that the method was successful in eliciting a Hyperarticulated speech style that was highly distinct from the Citation style, a result that was found for all six talkers. The duration, vowel centralization, and vowel dispersion measures showed the most consistent differences. However, the method failed to elicit significant differences between the Reduced and Citation sentences for five of the

six talkers. Only one participant produced Reduced speech that was acoustically distinguishable from Citation speech using these measures.²

More recently, Harnsberger and Pisoni (1999) extended the work by Brink et al. by testing a variant of the elicitation method for Reduced speech, termed the *calibrated cognitive load method*. Harnsberger and Pisoni calibrated the cognitive load (i.e., the digit span task) to the digit span of individual talkers via an immediate serial recall digit span task administered prior to the speech elicitation task. The cognitive load used by Brink et al. was a fixed load (5 – 7 digits in length), which may have been too easy a concurrent task for some talkers, given that adult digit spans average about 7.7 digits in length (Cavanagh, 1972). The individually calibrated cognitive load proved to be successful in eliciting a Reduced speech style from six of the twelve talkers recorded, a substantial improvement over the method used by Brink et al., though still not ideal. The success of the new method was gauged by a set of perception tests (paired comparison tasks) using phonetically-trained and naïve listeners. The purpose of this study was to evaluate the results of Harnsberger and Pisoni through an acoustic analysis of the sentences produced by talkers in that study. The particular acoustic measures taken were a subset of those used by Brink et al. in an acoustic analysis of their elicited speech materials. The particular subset selected were those that were the most successful in differentiating the three speaking styles elicited from the one talker who produced a consistent Reduced-Citation style contrast.

Methods

Participants

Twelve native speakers of American English (seven females and five males), ranging in age from 18 to 30, participated in this study. Participants received \$15 total for participating in two one-hour sessions. None of the participants reported any history of speech or hearing disorders at the time of testing.

Stimulus Materials

The participants read 34 sentences from the 200 sentences comprising the Speech Perception in Noise (SPIN) set (Kalikow, Stevens, & Elliot, 1977). The SPIN sentences are short sentences, five to eight words in length, ending in a high frequency monosyllabic noun. The 34 SPIN sentences selected for this study are listed in Appendix 1. The recordings took place in a sound-attenuated chamber (IAC Audiometric Testing Room, Model 402) using a head-mounted Shure (SM98) microphone positioned one inch away from the participant's chin. The recordings were digitized at 22.05 kHz (16 bit sampling) using a Tucker-Davis Technologies System II and stored on an IBM-PC 486 computer.

Procedures

The participants were all recorded reading the sentences under three different conditions corresponding to three distinct speech styles: (1) Reduced, (2) Citation, and (3) Hyperarticulated. The elicitation procedure consisted of four tasks carried out over two test sessions. In the first session, participants were administered a simple forward digit span task (see Digit Span Task) and were recorded reading sentences in the Reduced condition. In the second session, which took place within seven days of

² This speaker's Reduced sentences were also perceptually distinguishable from his/her Citation sentences in a pilot Paired Comparison task with three native speakers of English. These native speakers successfully picked the citation sentences as "more carefully pronounced" in reduced-citation sentence pairs, on an average of 89% of test trials. For a detailed description of the Paired Comparison task, see Experiment 2 in Harnsberger and Pisoni's (1999) study.

the first session, participants were recorded reading sentences in the Citation and Hyperarticulation conditions.

Digit Span Task. In the digit span task, participants were presented with a sequence of single digits (0 - 9) on a computer screen inside of the sound-attenuated chamber, and asked to recall the sequence correctly in the order in which it was presented. The participants' responses were digitized and played via headphones to the experimenter, who sat outside of the booth and scored the responses. The responses themselves were not stored to disk as sound files. The length of the digit sequence that was presented started at four, and then increased or decreased via an adaptive staircase algorithm. The algorithm increased the sequence length by one digit for every two sequences at a given length that were successfully recalled by the participant. Whenever the participant responded to a sequence incorrectly, the sequence length was reduced by one digit on the following trial. Over the course of the 25 trials of the task, the sequence length for individual participants increased until the sequence length began eliciting errors. Thus, by the end of the task, participants were “oscillating” between the sequence length that they could consistently recall, and a longer sequence that induced errors. The longest sequence length that was consistently recalled was taken to be the participant's digit span. This value was then used to calibrate the cognitive load in the Reduced condition.

Reduced Condition. The Reduced condition was similar to the Reduced condition described by Brink et al. and consisted of 136 trials, four trials for each of the 34 SPIN sentences, with a 1 s inter-trial interval. The order of the blocks of four trials varied randomly for each participant. Each trial consisted of four parts: initially, participants were presented with a digit sequence, which remained on the screen for 2 s; then, after a 2.5 s interval, a sentence was displayed on the computer screen for the participant to read; next, the participant's response was recorded over a 6 s window; finally, participants were prompted to recall the digit sequence in the correct order. The length of the digit sequence was based on the participant's digit span as measured in the Digit Span Task. The length of the digit sequence in a given trial was either the same as the span score, or plus/minus one digit. For example, if a participant had a span of seven in the digit span task, he/she would be presented with digit sequences ranging in length from six to eight. The same sentence, embedded in the digit span task, was presented four times, with the fourth reading taken as the reduced sentence for subsequent analysis. Before the recording began for the Reduced condition, participants were told that they would be participating in a short-term memory experiment. Participants were instructed to focus on the digit span task in the Reduced condition, in the hope that they would be less careful in monitoring their production of the test sentences.

Citation and Hyperarticulation Conditions. The Citation and Hyperarticulation conditions were identical to those described earlier by Brink et al. In the Citation condition, participants were prompted to read aloud a sentence that appeared on the computer screen. Each sentence was presented once, for a total of 34 trials, with a 1 s ITI. The order in which the sentences were presented was randomized for each participant. The Hyperarticulation condition was similar to the Citation condition, and consisted of two types of trials. The first trial type, the “citation cycle,” was identical to a Citation condition trial. In the second trial type, the “hyperarticulation cycle,” participants were also prompted to read aloud a sentence appearing on the computer screen. After reading this sentence, participants were then prompted to “Please read the sentence more clearly.” After responding, they were asked again to read the sentence more clearly. Thus, for the hyperarticulation cycle, the same sentence was read three times, with the third reading taken to be the example of the “hyperarticulated” reading of the sentence for subsequent analysis. The 34 sentences each appeared in three citation cycles and one hyperarticulation cycle. The program controlling the experiment was designed to insure that the Hyperarticulation condition began with a citation cycle, and that hyperarticulation cycles were separated by at least two citation cycles.

Acoustic Analysis. The recorded sentences were acoustically analyzed for the duration of the sentences as well as three to four keywords. All of the keywords were content words and commonly appeared in one of three positions within the sentences: (1) near the beginning (usually the participant noun), (2) near the middle (usually the main verb) and (3) in the final position (usually the main object of the verb or of a preposition). Duration was measured directly from the waveforms with accompanying wide band spectrograms for reference using Cool Edit 2000 software.

The keywords in each sentence, in all three styles, were also acoustically analyzed for *vowel dispersion*, defined as the average Euclidian distance in Barks of keyword vowels from the center of an individual's vowel space. Vowel formant measures were made from an overlaid LPC-FFT display. The LPC employed 12-16 coefficients (based on the participant) and a 25 ms frame size. The FFT used a 1024-point window. A wide-band spectrogram was used for reference. The formant measures were made at the point of maximal displacement of F1 and F2. The results of the acoustic analyses were used to examine the differences between the Reduced, Citation, and Hyperarticulated styles of individual participants.

Results

Duration Measures

Figures 1 and 2 display the mean keyword and sentence durations for each participant, respectively. Table 1 shows the differences in the duration measures (in seconds) between the Reduced, Citation, and Hyperarticulated styles for individual participants. The difference scores were computed by subtracting the mean duration measure (i.e., the keyword or sentence duration measure) of the “less precise” style from the “more precise” style. Thus, we predicted positive, significant difference scores in all cases. The mean duration measures for each participant were submitted to separate 3 (Style: Reduced, Citation, Hyperarticulated) X 2 (Unit of Analysis: Keyword, Sentence) repeated measures ANOVAs. For every participant, there were significant main effects of Style and Unit of Analysis, as well as a significant Style by Unit of Analysis interaction. Appendix 2 lists the results of the statistical analysis by participant.

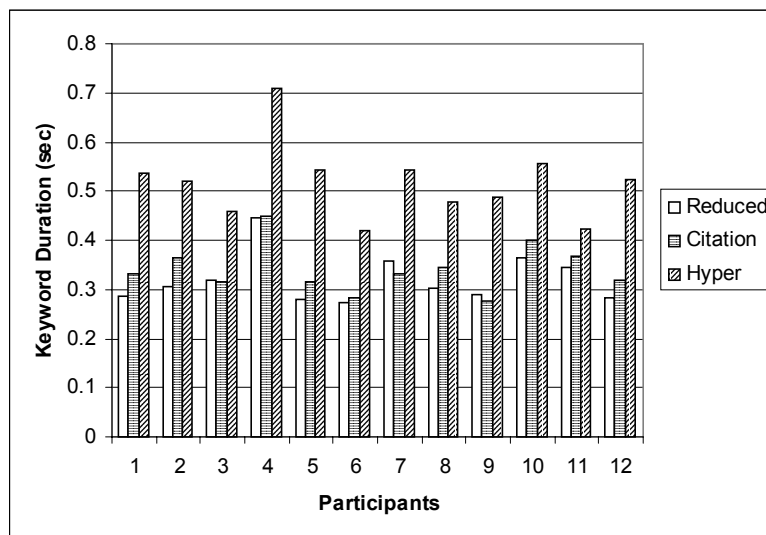


Figure 1. Mean keyword durations of each style for each participant.

Post hoc analyses (Tukey t-tests) showed that seven participants produced positive, significant differences between the Reduced and Citation styles in whole sentences, while only one participant produced positive differences between the two styles in keyword duration. Both the sentences and keywords read in the Hyperarticulated style differed significantly from those read in the Reduced and Citation styles for every participant, as predicted. The differences in duration between the sentences read in the Hyperarticulated style and those in the Reduced and Citation styles were much greater in magnitude than the differences in duration between the Reduced and Citation styles. Overall, seven out of twelve participants differentiated the three styles by manipulating some aspect of the temporal properties of the sentence.

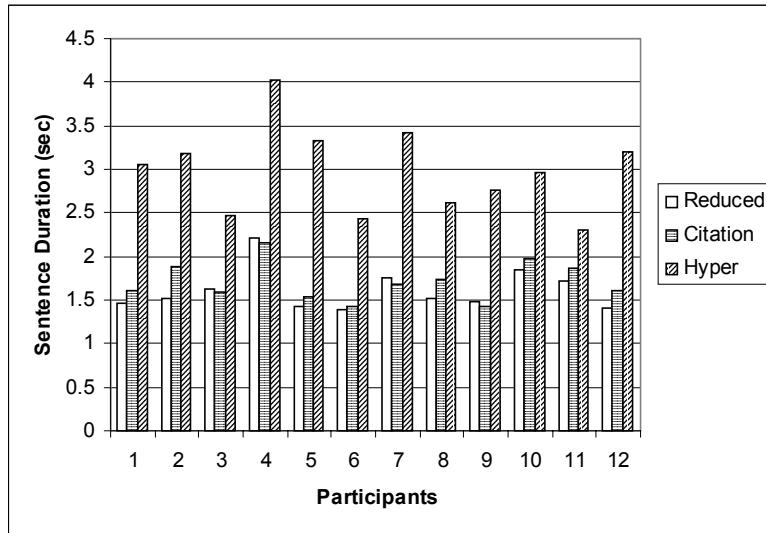


Figure 2. Mean sentence durations of each style for each participant.

Subject	Citation - Reduced		Hyperarticulated - Reduced		Hyperarticulated - Citation	
	Key	Sentence	Key	Sentence	Key	Sentence
1	0.046	0.154**	0.253**	1.587**	0.207**	1.433**
2	0.059*	0.359**	0.215**	1.662**	0.156**	1.303**
3	-0.004	-0.037	0.140**	0.844**	0.144**	0.881**
4	0.003	-0.047	0.261**	1.816**	0.258**	1.863**
5	0.034	0.115*	0.262**	1.895**	0.228**	1.78**
6	0.009	0.041	0.147**	1.047**	0.138**	1.006**
7	-0.026	-0.085	0.184**	1.666**	0.21**	1.751**
8	0.040	0.205**	0.173**	1.089**	0.133**	0.884**
9	-0.012	-0.050	0.197**	1.284**	0.209**	1.334**
10	0.033	0.116*	0.191**	1.115**	0.158**	0.999**
11	0.025	0.133**	0.078**	0.577**	0.053*	0.444**
12	0.034	0.191**	0.239**	1.774**	0.205**	1.583**

Table 1. Mean differences between the “more precise” and “less precise” styles for the duration measures (in seconds). “Key” denotes keyword.

* $p < .05$, ** $p < .01$

Vowel Dispersion

Figure 3 shows the differences in vowel dispersion for each individual participant between the three styles, with greater dispersion corresponding to a larger vowel space. Reduced, Citation, and Hyperarticulated (Hyper) styles were predicted to differ in increasing order in degree of vowel dispersion. An example of vowel spaces differing in degree of dispersion appears in Figure 4, which shows Participant 2's vowel spaces computed from the keyword vowels in each style. Figure 4 demonstrates that, as participants articulate in speaking styles that increase in articulatory precision (i.e., from Reduced to Hyperarticulated, in order of increasing precision), the corresponding vowel spaces expand.

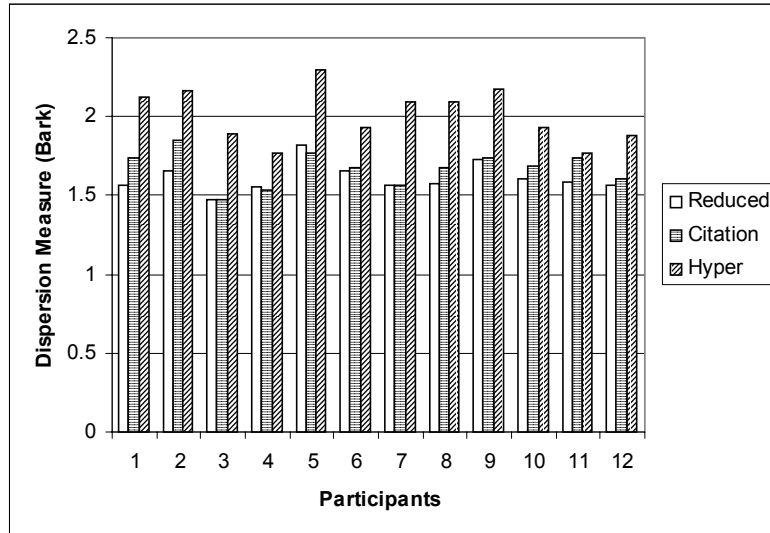


Figure 3. Vowel dispersion measures of each style for each participant.

All twelve participants produced a Hyperarticulated style that differed in vowel dispersion from the Reduced and Citation styles, as predicted. Four participants failed to produce a Reduced style that differed in vowel dispersion from the Citation style in the predicted manner. Eight of the twelve participants showed some degree of vowel dispersion differences in the predicted manner between all three styles. However, for most participants, the differences in vowel dispersion between the Reduced and Citation style were much more modest than those involving the Hyperarticulated style. A statistical analysis of the individual results was not possible given that, for each participant, only one vowel dispersion score could be computed for each style.

Discussion

The goal of this study was to evaluate in an acoustic analysis the success of the calibrated cognitive load method in eliciting three distinct speech styles. The acoustic analysis showed that the revised procedure was successful in eliciting Reduced speech from a majority of the talkers, although large individual differences remain. With a fixed cognitive load, only one of six participants produced reliable differences between the Reduced and Citation styles based on an extensive acoustic analysis of their utterances (Brink et al., 1998). Thus, the results reported by Harnsberger and Pisoni (1999) together with the results of the present study suggest that individually calibrating the cognitive load for the individual participant results in a more consistent elicitation procedure for a Reduced style of speech.

While a success rate of seven out of twelve participants represents a marked improvement over the results reported by Brink et al., the time and effort required by this procedure to elicit the style differences for just 34 different sentences necessitate changes in the experimental procedure to reduce the range of individual differences. First of all, the cognitive load could be increased to one or two digits more than the participant's individual digit span, to insure that the task is sufficiently demanding for the listener as they produce the sentences. A heavier cognitive load may, unfortunately, also have the effect of eliciting more disfluencies. A digit span task with a heavier cognitive load may also prove to be so difficult a task that participants may ignore the span task and simply read the sentence.

Secondly, an adaptive algorithm could be employed throughout the elicitation of Reduced sentences. Currently, a fixed range of loads is used in the elicitation procedure that has been calibrated to the individual participant in an immediate serial recall digit span task (the calibration task). However, due to changes in attention or fatigue, a participant's "effective" digit span could change over the course of the elicitation procedure and, thus, could be higher or lower than that measured in the calibration task. One way to address this possibility would be to adjust the cognitive load adaptively over the course of the elicitation procedure, increasing the load when participants continue to perform well (i.e., recall the digit sequence correctly), and decreasing the load when participants fail to correctly recall a sequence in order.

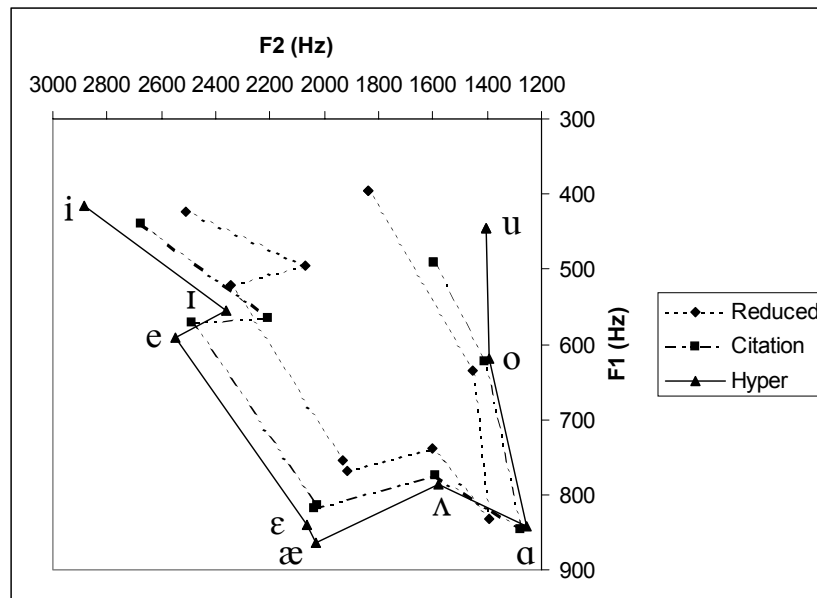


Figure 4. The vowel spaces of participant 2 for keyword vowels in Reduced, Citation, and Hyperarticulated (Hyper) styles.

Finally, the success of the present elicitation procedure, as determined by the acoustic analysis, may be underestimated by the particular measures taken. Our analysis employed the subset of measures used by Brink et al. that were most successful in differentiating the three styles for the single participant who reliably produced them. Brink et al. measured overall sentence energy, word energy, sentence energy range, word energy range, and the pitch range of the sentence as well as sentence and word duration and vowel dispersion. It is possible that, for the stimulus materials measured in this study, additional measures such as those used by Brink et al. would have revealed other acoustic differences between the three speaking styles for listeners.

Summary and Conclusions

In this study, a set of sentences produced in three speech styles by a novel elicitation procedure developed by Brink et al. (1998) and Harnsberger and Pisoni (1999) were acoustically analyzed. In the analysis, the duration and vowel formant frequencies of keywords were measured, as well as the duration of the entire sentence. The results were used to determine the efficacy of the elicitation method. The acoustic analysis showed that six of the twelve participants differentiated the Reduced and Citation styles in both duration and vowel formant frequency. All twelve participants differentiated the Hyperarticulated style from the Reduced and Citation styles. The limited success of the elicitation procedure suggests that further refinement of the procedure is required. Several variants of the elicitation procedure were suggested, including the use of a heavier cognitive load and/or an adaptive load in the elicitation of Reduced sentences. In addition, the limitations of the acoustic analysis were discussed, and greater range of measures was suggested.

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Appendix 1: Stimulus Sentences (keywords underlined)

The farmer harvested his crop.
 His boss made him work like a slave.
 He caught the fish in his net.
 Close the window to stop the draft.
 The beer drinkers raised their mugs.
 I made the phone call from a booth.
 The cut on his knee formed a scab.
 The railroad train ran off the track.
 They drank a whole bottle of gin.
 The airplane dropped a bomb.
 I gave her a kiss and a hug.
 The soup was served in a bowl.
 The cookies were kept in a jar.
 How did your car get that dent?
 The baby slept in his crib.
 The cop wore a bullet-proof vest.
 No one was injured in the crash.
 The hockey player scored a goal.
 How long can you hold your breath?
 At breakfast he drank some juice.
 The king wore a golden crown.
 He got drunk in the local bar.
 The doctor prescribed the drug.
 The landlord raised the rent.
 Playing checkers can be fun.
 Throw out all this useless junk.
 Her entry should win first prize.
 The stale bread was covered with mold.
 I ate a piece of chocolate fudge.
 The story had a clever plot.
 He's employed by a large firm.
 The mouse was caught in the trap.
 I've got a cold and a sore throat.

Appendix 2: Statistical tests of individual participant results

Participant	Style	Unit of Analysis	Interaction
1	F(1, 31) = 5082.37, p < .0001	F(2, 64) = 635, p < .0001	F(2, 62) = 342.65, p < .0001
2	F(1, 30) = 7398.76, p < .0001	F(2, 60) = 745.2, p < .0001	F(2, 60) = 447.25, p < .0001
3	F(1, 30) = 8942.34, p < .0001	F(2, 66) = 438.19, p < .0001	F(2, 60) = 225.12, p < .0001
4	F(1, 32) = 8106.39, p < .0001	F(2, 64) = 773.4, p < .0001	F(2, 64) = 437.91, p < .0001
5	F(1, 31) = 5500.4, p < .0001	F(2, 66) = 909.39, p < .0001	F(2, 62) = 531.17, p < .0001
6	F(1, 32) = 5557.58, p < .0001	F(2, 66) = 421.69, p < .0001	F(2, 64) = 240.77, p < .0001
7	F(1, 31) = 6709.39, p < .0001	F(2, 64) = 772.32, p < .0001	F(2, 62) = 484.74, p < .0001
8	F(1, 27) = 6640.62, p < .0001	F(2, 66) = 417.87, p < .0001	F(2, 54) = 222.9, p < .0001
9	F(1, 23) = 4877.07, p < .0001	F(2, 64) = 557.29, p < .0001	F(2, 46) = 297.67, p < .0001
10	F(1, 29) = 6003.42, p < .0001	F(2, 66) = 315.57, p < .0001	F(2, 58) = 161.03, p < .0001
11	F(1, 26) = 8646.99, p < .0001	F(2, 52) = 134.32, p < .0001	F(2, 52) = 79.18, p < .0001
12	F(1, 20) = 3459.85, p < .0001	F(2, 51) = 509.1, p < .0001	F(2, 40) = 299.21, p < .0001

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