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PERCEPTION OF TERMINAL FALL CONTOURS IN SPEECH PRODUCED BY DEAF PERSONS

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Eight deaf children produced each of nine sentences. F_0 measures were obtained at several locations within each utterance (starting F_0, peak F_0, peak F_0 in the final syllable, and final F_0). The relative timing of each F_0 measure (ms from onset of the utterance) was also determined. In addition, several difference measures were derived. Listeners experienced with the speech of the deaf were asked to judge whether they heard a terminal fall, rise, or a flat final intonation contour in each utterance. A multiple linear regression analysis was used to determine if any combination of the acoustic measures could predict listeners' responses. The only variable that made a significant contribution to the regression function was the temporal interval between the terminal peak F_0 and the final F_0. That is, the more slowly the contour fell the more likely listeners were to perceive the contour as flat, regardless of the amount (in Hz or percentage F_0) by which it fell. The regression equation accounted for a statistically significant but not large proportion of the total variance. This suggests that other variables, not measured in this study, play an important role in the perception of utterance final intonation contours in the speech of the deaf.

KEY WORDS: hearing impaired, speech perception, intonation contours, speech production

The role of fundamental frequency (F_0) in the perception of speech produced by hearing talkers has received considerable attention in the literature. For example, studies have shown that variations in F_0 may be used by the listener to decide if an utterance is a statement or a question (Hadding-Koch & Studdert-Kennedy, 1964; Majewski & Blasdell, 1969; Studdert-Kennedy & Hadding-Koch, 1973). A falling terminal F_0 contour can be used by listeners to discern major syntactic boundaries (Streeter, 1978). Moreover, the perception of a stressed syllable is determined to a large degree by an increase in F_0 (Fry, 1955; Rubin-Spitz, McGarr, & Youdelman, 1986). The general approach used in these studies has been to carefully control (e.g., synthesize) and/or quantify the test stimuli with respect to those parameters believed important to the perception of intonation and/or stress. Listeners' responses are then analyzed on a token-by-token basis with reference to the presence or absence of particular acoustic cues. This systematic approach to understanding the acoustic correlates of perceptual phenomena is well-established in the literature on the perception of speech produced by hearing talkers.

The role of fundamental frequency in the perception of speech produced by deaf persons has not been as well studied. Although a few experiments have examined the acoustic correlates of perceived syllabic stress produced by these talkers (e.g., Leder et al., 1986; McGarr & Harris, 1983), similar systematic research has not been conducted on the role of F_0 in the perception of intonation contours. Research in this area has instead focused mainly on (a) objective measurement studies of changes in F_0 as the talker attempts to produce different intonational contours, (b) descriptive studies concerned with the perceived prosodic character of speech produced by deaf persons, and (c) correlational studies that examine the effects of F_0 contours on overall speech intelligibility.

Objective measurement studies have shown that deaf talkers produce insufficient variations in fundamental frequency particularly in their production of declarative versus interrogative utterances (Sorenson, 1974; Sussman & Hernandez, 1979). Some studies have also reported the tendency for deaf talkers to use increases in intensity rather than pitch to mark rising intonation (Phillips, Remillard, Bess, & Pronvost, 1968). Unfortunately, none of these studies measured the perception of the utterances they analyzed acoustically.

Descriptive studies indicate that persons with congenital profound hearing loss produce speech in which the voice quality is "monotonous" and "devoid of melody" (Hudgins & Numbers, 1942; Voelker, 1935). Some studies report that deaf talkers produce variation in pitch but that this variation is reduced compared to normal talkers (Green, 1956; Hood, 1966; Voelker, 1935). However, others report that the speech of the deaf may be characterized by excessive and inappropriate changes in fundamental frequency (Monsen, 1978; Smith, 1975; Stevens, Nickerson, & Rollins, 1978). Individual differences are common, making it difficult to characterize this aspect of the speech of the deaf in a simple manner.

As mentioned above, the effect of fundamental frequency contours on the overall speech intelligibility of deaf persons has been examined in correlational studies. Serious errors of fundamental frequency such as staccato productions (perceptually described as syllables of equal

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stress) or pitch breaks are reported to be negatively correlated with overall intelligibility (McGarr & Osberger, 1978). Maassen and Povel (1985) showed a small significant improvement in speech intelligibility as a result of correcting deaf children's resynthesized intonation contours. Improvements resulted primarily from removing errors of overaccentuation; an utterance is defined as overaccented if resynthesis towards an idealized linguistic accent structure requires reducing and/or removing (rather than adding) accentuations. Maassen & Povel further showed that correcting errors of overaccentuation in combination with temporal corrections virtually nullified the improvements shown for either type of correction alone. They conclude that conflicting cues can be particularly damaging to speech intelligibility.

Although this literature clearly establishes that listeners perceive speech produced by deaf persons as abnormal with respect to intonation contour, we do not have a clear understanding of the acoustic correlates of listeners' perceptual judgments. A reasonable first approximation is that listeners use changes in F_0 across an utterance to make judgments about intonation contour, as they have been shown to do in the perception of speech produced by hearing talkers. However, this presumption has not been demonstrated experimentally. Moreover, anecdotal evidence from teachers of the deaf suggests that perceptual judgments about intonation contours are not always in agreement with simple displays of F_0 change within an utterance.

More specifically, teachers of the deaf frequently use F_0-based visual and tactile sensory aids for speech services directed at the production of more appropriate intonation contours. The motivation for using these aids has been that an F_0-based display provides consistent and objective feedback concerning F_0 patterns that are presumed to be correlated with the listener's (i.e., teacher's) perception of intonation contours. Teachers of the deaf report, however, that for a given utterance, they may see a declining F_0 contour on the visual display but perceive the student's utterance as flat or monotonous.

The lack of systematic investigation in this area is therefore unfortunate for both theoretical and pedagogical reasons. This study was undertaken to examine systematically the relationship between objective measures of fundamental frequency in utterances produced by deaf talkers and listeners' judgments of these talkers' intonation contours. We hypothesized that simple objective measures of fundamental frequency throughout an utterance would be useful in predicting experienced listeners' judgments of final intonation contour in speech produced by deaf persons.

PROCEDURE

Subjects

The speech of 8 deaf students was recorded for this study. The subjects ranged in age from 8–18 years old. Pure tone averages ranged from 98 dB HL to 118 dB HL (ANSI, 1969). Each subject had been receiving speech training as part of the regular school curriculum and was about to begin an experimental speech training program using sensory aids (McGarr, Head, Friedman, Behrman, & Youdelman, 1986). The subjects were assessed by the supervisor of the Lexington School Speech program as having fundamental frequencies appropriate for their age and sex and as not showing evidence of erratic pitch breaks in their speech. Each subject, however, was described as having difficulty in the modulation of pitch contour (generally described as "perceptually flat and monotonous"). Table 1 shows the age, sex, pure tone average, and mean F_0 of each deaf talker. Mean F_0 was calculated by averaging across all measured points described under "Acoustic Measurements." Subject D1 was considerably younger than the rest of the group and showed a higher average F_0. These data are similar to those previously reported for talkers of the same sex and similar age (Osberger & McGarr, 1982).

Audio recordings were made as part of the students' annual speech evaluation. No special acoustic environment was created for the recordings. No specific instructions were given to the talkers on how to produce the test utterances and no special markings were used to cue a specific prosodic feature. The students were simply asked to read a list of sentences (described in more detail under "Stimuli"). The F_0 characteristics of the test stimuli were generally predictable in normal speech. Therefore, a recording was also made of a normal-hearing adult female talker producing the test utterances to allow for a validity check on our instrumentation and acoustic measurement strategies. The talker was not given information on the purpose of the study. She was instructed to read the sentences as naturally as possible. This talker's average F_0 is also shown in Table 1 (Talker "H").

Stimuli

Subjects read a list of sentences from Gold's (1978) study of prosodic features in hearing-impaired persons. The sentence list consisted of one-clause and two-clause declarative sentences, wh-questions and yes-no questions. The list was designed so that reading the sentences

TABLE 1. Age, sex, pure tone average (PTA), and mean fundamental frequency of deaf talkers and normal hearing control.

Talkers	*Age (Years)*	*Sex*	*PTA (dB HL)*	*Mean F_0 (Hz)*
D1	8	M	98	307.8
D2	16	F	98	247.8
D3	17	M	98	106.0
D4	12	F	118	233.8
D5	18	M	103	118.2
D6	18	M	100	175.8
D7	15	M	110	152.5
D8	18	M	102	142.4
H	32	F	<20	195.0

in sequence would lead to a natural production of intonation (e.g., first saying, "Did the boys run home?" followed by "Yes, the boys ran home"). The sentence list was blocked and presented to the students to read in quasi-random form. Only a subset of the sentences read were in fact used for this study (as shown in Appendix). The stimuli were chosen so that listeners would be confronted with a variety of different contours and sentences of varying length and contrastive stress.

Acoustic Measurements

A Kay Elemetrics Visipitch was used to measure the fundamental frequency contour throughout each of the test utterances. With the help of a computer-controlled display program it was possible to store and analyze each contour, to isolate four points in each utterance, and to extract the F_0 associated with each marked point. The points chosen for measurement where those used in parallel investigations of terminal fall contours produced by hearing subjects (Berkovits, 1984; O'Shaughnessy, 1979; Streeter, 1978) and deaf subjects (Sussman & Hernandez, 1979). The four points were (a) the onset of the utterance (onset F_0) (b) the peak of the contour (peak F_0) (c) the peak in the final syllable (terminal peak F_0 referred to as TPK) and (d) the offset F_0. Figure 1 is an F_0 trace of the utterance "John is home" spoken by subjects D6 and H.

In addition, measures of terminal fall were derived. Terminal fall was operationally defined (as in the studies cited above) as the difference in Hz between the TPK and the offset F_0. A normalized measure of terminal fall was computed by dividing the value of the terminal fall in each utterance by the TPK of the utterance in question. This was done to determine if listener's perceptions were relative in nature, that is, affected by local context. This was not, however, a measure of the slope of the terminal fall. The potential importance of slope is considered under "Perception." The difference in Hz between the onset F_0 and the offset F_0 was also determined.

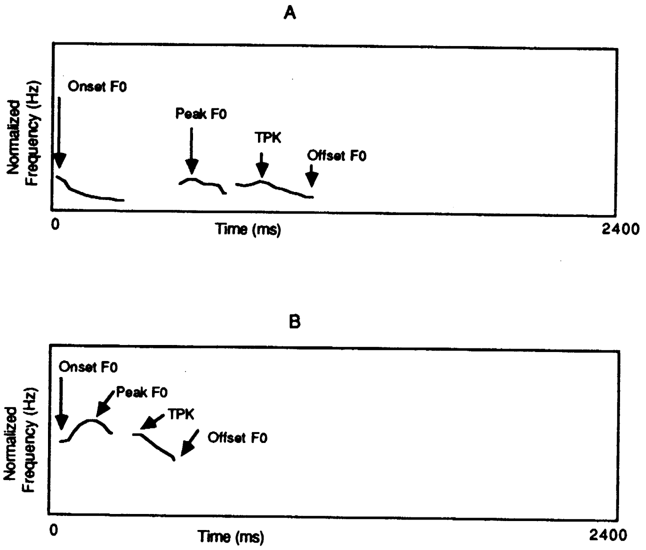

FIGURE 1. F_0 traces and measured F_0 points for the utterance "John is home," spoken by Talker D6 (A) and Talker H (B).

The dynamic nature of the F_0 contour (i.e., changes in F_0 as a function of time within the utterance) was also considered by computing the temporal location (in ms and in percentage of the total length of the utterance) of each of the F_0 points, relative to the onset of the utterance.

Finally, to compare our results to those previously reported for this population for a similar production task (Mahshie, Hasegawa, Mars, Herbert, & Brandt, 1983) the utterances were classified as declarative or nondeclarative and then compared with respect to average F_0 for each utterance type (average F_0 was calculated by averaging across measured points a–d described above). Declarative utterances consisted of the one-clause declaratives and the final clause of two-clause declaratives because a terminal fall would be typical in the production of these utterances. Nondeclaratives consisted of the yes-no questions and the first clause of two clause declaratives because a flat or rising contour would be typical in the production of these utterances. For the purposes of comparison to Mahshie et al.'s data, wh-questions were not included in this analysis.

Listeners

Six listeners participated in the perception experiment. Each listener had a minimum of 2 years experience listening to the speech of the deaf on a daily basis. Three groups of 2 listeners each were presented with the test stimuli in a quiet room under free-field listening conditions. The test stimuli were digitized and randomized across talkers. For every utterance, the listeners were instructed to judge whether they heard a falling contour, a rising contour, or a flat contour, and to indicate their response by checking the appropriately labeled column on an answer sheet. They were not specifically instructed to attend to any portion of the utterance in making their decision. The listeners were generally familiar with the test materials although they did not know the order of the stimuli. Listeners could hear each item as often as they wished.

RESULTS

Production

The purpose of this study was to consider the acoustic correlates of the perception of intonation contours produced by the deaf. However, to show that the deaf talkers in this experiment were representative of the population with respect to speech production, a subset of the acoustic data is considered. As stated above, for the purposes of comparison with other published data the test utterances have been categorized as either declarative or nondeclarative.

Table 2 shows the average F_0 for each talker for declarative and nondeclarative utterances. For the hearing talker, the average F_0 for nondeclaratives (223.3 Hz) was 56.3 Hz higher than for declaratives (166.9 Hz). The difference between nondeclaratives and declaratives was reduced in the utterances of the deaf talkers. Averaging across the deaf talkers yields a mean difference of .24 Hz between the two utterance types. Considering the deaf talkers individually reveals a range of difference measures from 17.6 Hz for deaf talkers D2 to −11.7 Hz for deaf talker D4.

Table 3 shows three of the four F_0 measurements made on each talker's declarative utterances (data regarding peak F_0 are not shown because this point was synonymous with the TPK for some of the utterances). Also shown are the terminal fall measures described earlier (TPK—offset F_0), both in absolute (Hz) as well as relative terms (percent change). Table 4 shows the same data for each talker's nondeclarative utterances. In each case, the data have been averaged across all instances of the given utterance type.

The hearing talker (H) differentiated the two utterance types by producing declarative utterances with an average terminal fall of 23 Hz and producing nondeclaratives with an average terminal fall of −35 Hz (that is, an F_0 rise of 35 Hz). In percentage change, the normal hearing talker produced a 13.6% decrease in F_0 at the end of her declarative utterances and a 16.5% increase in F_0 at the end of her nondeclarative utterances.

None of the deaf talkers followed this pattern for nondeclarative utterances (although some deaf talkers were like the hearing talker in their production of declaratives). More specifically, the deaf talkers produced both types of utterances with terminal contours that declined in F_0. Moreover, for 2 of the 8 talkers (D6 and D8) the contours fell substantially more during nondeclaratives than during declarative utterances. For talkers D1, D3, D5, and D7 there was less than a 5-Hz difference between the mean terminal fall in declarative versus nondeclarative utterances. These data represent averages across test sentences that are inherently different with respect to their phonetic, syntactic, and semantic constraints on intonation. However, it is not the case that these differences necessarily obviate a distinction between declarative and nondeclarative utterances, as can be seen in the data for the normal-hearing talker.

TABLE 2. Average F_0 for declarative and nondeclarative utterances of a talker.

Talkers	*Average F_0 Declaratives (Hz)*	*Average F_0 Nondeclaratives (Hz)*	*Difference (Hz)*
D1	313.5	302.1	−11.4
D2	239.0	256.6	17.6
D3	105.0	106.9	1.9
D4	239.6	227.9	−11.7
D5	118.1	118.3	.2
D6	172.5	179.1	6.6
D7	152.0	153.0	1.0
D8	143.5	141.2	−2.3
Mean HI			.2
H	166.9	223.2	56.3

TABLE 3. Terminal fall in Hz and percent change for each talker: Declaratives.

Talkers	*Onset F_0 (Hz)*	*TPK (Hz)*	*Offset F_0 (Hz)*	*F_0 Change (Hz)*	*F_0 Change (%)*
D1	296.7	389.0	254.7	134.3	34.5
D2	219.7	279.0	218.3	60.7	21.8
D3	107.7	122.5	84.7	37.8	30.9
D4	256.5	268.2	194.0	74.2	27.7
D5	119.7	126.7	107.8	18.8	14.8
D6	187.2	174.0	156.3	17.7	10.2
D7	153.5	172.8	129.7	43.2	25.0
D8	137.5	164.3	128.8	35.5	21.6
H	185.3	169.2	146.2	23.0	13.6

TABLE 4. Terminal fall in Hz and percent change for each talker: Nondeclaratives.

Talkers	*Onset F_0 (Hz)*	*TPK (Hz)*	*Offset F_0 (Hz)*	*F_0 Change (Hz)*	*F_0 Change (%)*
D1	310.0	367.0	229.2	137.8	37.5
D2	255.8	279.8	234.2	45.7	16.3
D3	115.2	119.7	85.7	34.0	28.4
D4	239.5	255.3	189.0	66.3	26.0
D5	118.8	127.0	109.0	18.0	14.2
D6	200.0	188.7	148.7	40.0	21.2
D7	163.2	169.0	126.8	42.2	25.0
D8	134.7	167.5	121.3	46.2	27.6
H	210.8	212.0	247.0	−35.0	−16.5

Perception

Two multiple linear regression analyses were used to determine if any combination of the acoustic measurements could predict listeners' perception of terminal contours produced by the deaf talkers. Because so few of the test stimuli were identified by the listeners as having a terminal rise, these individual data points were omitted from further statistical analysis. The classification variable for both analyses, therefore, was the proportion of "fall" responses for each stimulus. These data were transformed into arcsine units to stabilize the variance (Brownlee, 1965).

There were eight criterion variables for the first regression analysis: the four F_0 measures (onset F_0, peak F_0, TPK, and offset F_0) and the temporal location, in ms, of each measured F_0 point (time of onset F_0, time of peak F_0, time of TPK, time of offset F_0). It should be noted that the temporal location of the onset F_0 was always 0 or close to 0 (in cases where the onset of the utterance was appropriately or inappropriately unvoiced), and so could have been omitted from the analysis. The following rule was invoked for handling the cases where peak F_0 and TPK were synonymous: if peak F_0 and TPK are identical in both time and frequency, then use the same data point for both variables; if peak F_0 and TPK are not identical in both time and frequency, then use the appropriate data point for each variable. Whereas an alternative strategy would have been to eliminate peak F_0 from the regression analysis, it was assumed that the potentially redundant nature of this variable would simply cause it to drop out of the regression equation.

The second regression analysis used the following criterion variables: terminal fall in Hz, terminal fall in percent, difference in time between TPK and offset F_0 in ms, difference in time between TPK and offset F_0 in percent and the difference in frequency between the onset F_0 and the offset F_0.

The results of the first analysis reveal a multiple correlation of .67 between the classification and criterion variables accounting for 45% of the observed variance [$F(8,45) = 4.683$; $p = .0003$]. Only two out of the eight independent variables had significant regression coefficients. These were (a) the time (in ms) of the TPK ($p = .0001$) and (b) the time (in ms) of the offset F_0 ($p = .0001$).

The results of the second regression analysis revealed a correlation of .65 between the classification and criterion variables accounting for 42% of the observed variance [$F(5,48) = 6.855$; $p = .0001$]. The only variable with a significant regression coefficient was the time between the TPK and the offset F_0 in ms ($p = .0009$); hereafter referred to as "fall time." The simple correlation between fall time and the proportion of "fall" responses was −.58; the negative sign suggesting that the more slowly the contour fell the more likely listeners were to perceive the contour as flat. Specifically, the average fall time for tokens perceived as having flat versus falling contours was 422 versus 271 ms respectively. Had both fall time and terminal fall been significant variables in the regression equation one could infer that the slope of the contour was a significant factor. This was not the case, suggesting that the slope of the terminal F_0 contour was not the important perceptual event.

Table 5 shows the relationship between the acoustic and perceptual data for individual listeners. Specifically, Table 5 shows the fall time and the F_0 change for tokens judged to be flat and for those judged to be falling by each listener. It is clear that the statistical trends reported above can be seen for the individual listeners. Irrespective of listener, the fall time for utterances perceived as flat was nearly twice that of utterances perceived as falling. It is clear from the data in Table 5 that there was little if any difference in the average F_0 change for tokens perceived as flat versus falling (53 vs. 50 Hz, respectively). Stimuli were judged to be intonationally flat despite acoustic data indicating a relatively large decrement in F_0 (45.8 to 72.1 Hz). Although one could propose a response bias working against a perception of the tokens as falling, the regression analysis revealed that listeners identified 47% of the utterances in the test corpus as falling, suggesting that they were not unwilling to label the tokens in this way. Instead, as indicated by the regression analysis, F_0 change was simply not a good predictor of listeners' responses.

TABLE 5. Fall time and F_0 change for contours perceived as flat versus falling: Individual listeners.

Listener	*Fall Time (ms)* *Flat*	*Falling*	*F_0 Change (Hz)* *Flat*	*Falling*
L1	418.5	238.9	48.6	57.7
L2	467.5	258.1	72.1	45.3
L3	402.7	287.3	57.3	48.6
L4	403.0	298.7	46.6	43.5
L5	418.5	250.3	45.8	59.7
L6	424.1	297.4	48.3	45.0

DISCUSSION

In general, the production data obtained in this study on intonation contours for declarative and nondeclarative utterance types are comparable to those previously reported in the literature. Specifically, the data from this study indicated little if any differentiation between mean F_0 of declarative and nondeclarative utterances by the deaf talkers. This is contrasted to a sizable distinction made by the hearing control. Results reported by Mahshie et al. (1983) are quite similar for their deaf and hearing subjects. They showed that in an oral reading task, normal-hearing talkers tended to have a higher mean F_0 for questions than for statements. They report that this trend is less pronounced in deaf talkers performing the same task.

The data for this study also revealed that when averaged across sentences, a measure of terminal fall (the change in F_0 over the final word in an utterance) does not easily differentiate declarative from nondeclarative utterances in the speech of the deaf (see Tables 2 and 3). Similar results have been reported by Sussman & Hernandez (1979), Sorenson (1974), and Phillips et al. (1968).

None of these studies, however, considered the perceptual effect of the measured acoustic parameters. The results of the perceptual experiment suggest that several measures of F_0 change, as measured here, cannot in themselves account for the listeners' perceptual decisions. Listeners judged many of the stimuli to be intonationally flat despite relatively large decrements in F_0. The results of this study lead to the conclusion that the more quickly the contour falls, the more likely is a listener to identify the utterance as falling, regardless of the amount by which it fell. This suggests that listeners are more affected by the dynamic nature of the intonation contour than by the change in frequency across the contour itself.

However, it should be noted that fall time, although of some predictive value, did not account for a large proportion of the observed variance. This suggests that other variables, not measured in this study, play an important role in the perception of utterance-final intonation contours in the speech of the deaf.

To consider what these variables might be, we note evidence from the normal perception and production literature indicating that changes in duration (e.g., terminal vowel lengthening) and amplitude (e.g., overall decrement in amplitude envelope) normally coexist with and complement changes in F_0 (Berkovits, 1984; Delattre, 1966; Klatt, 1975; Lyberg, 1979; Sholes, 1971). These cues provide the listener with redundant and/or additional information for the perception of utterance final contours. In the speech of the deaf, one cannot assume that changes in duration and amplitude coexist with and/or complement variations in F_0. Maassen and Povel's study (1985) clearly showed the negative impact that conflicting cues can have on listeners' abilities to make perceptual decisions. If faced with potentially conflicting cues, experienced listeners may abandon F_0 as a primary source of information for differentiating between contours. The listener may instead attend to durational and/or amplitude cues, a strategy that may or may not lead to the same conclusion as that of an F_0 strategy. Acoustic analyses of fundamental frequency, amplitude contour, and terminal vowel duration in the production and perception of final intonation contours in the speech of the deaf would result in a better understanding of how these variables interact.

Although the results of this study are interesting from a theoretical point of view, there are also pedagogical implications that should be considered. It is assumed that when using a sensory aid, the student is receiving consistent and perceptible feedback concerning a variable that is important to potential perceivers of his or her speech. The results of this study suggest that there is not always a straightforward relationship between F_0 change within an utterance and perception of intonation produced by the deaf. It may be that teachers should focus their students' attention primarily on the temporal nature of the F_0 change at the end of an utterance.

These data exemplify the classic dilemma in sensory aids research: whether to code the entire speech signal and let the subject find the aspects of the signal that are correlated to a listener's perception or to simplify the subject's task by extracting and presenting only a portion of the total signal. The latter strategy assumes that the experimenter's notion of cue saliency is correct. The data obtained in this study suggest that this may not be the case.

The systematic approach followed in specifying the relationship between perception and production for normal-hearing talkers needs to be pursued in studying the speech of the deaf. Information gathered from such studies should improve our understanding of the speech of deaf persons, and may also improve the effective use of F_0 displays and other sensory aids.

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APPENDIX

Test Stimuli (subset of test sentences from Gold, 1978).

What is green?
The apple is green.
This apple is green, the other one is red.
Is the apple blue?
Did the boys run home?
Yes, the boys ran home.
Who is home.
John is home.
John is home, Mary is in school.