HEARING-IMPAIRED AND NORMAL-HEARING ADULTS' USE OF LOW-FREQUENCY CUES TO INITIAL FRICATIVE VOICING

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1. ABSTRACT

The contribution of various acoustic components to the perception of voicing in syllable-initial /f,s,v,z/ was investigated for hearing-impaired and normal-hearing listeners. Syllable-segment deletion and high-pass filtering were employed to eliminate potential voicing cues. Relative to the normal-hearing, the hearing-impaired group's voicing perception was more dependent upon low-frequency cues in the frication. For /vʌd/ and /zʌd/, with the frication segments deleted, above-chance fricative voicing perception, particularly by the normal-hearing, signified the existence of cues in the vowel stem.

2. INTRODUCTION

Perception of consonant voicing is often troublesome for persons with severe to profound hearing impairments, especially since this distinction is not easily conveyed through lip reading. During the past decade, some of our research efforts have involved the employment of various acoustic-signal enhancements to improve hearing-impaired persons' perception of spoken consonants. However, preliminary to the development of such enhancements, we must discover which acoustic elements in the speech signal can elicit particular consonant-feature distinctions.

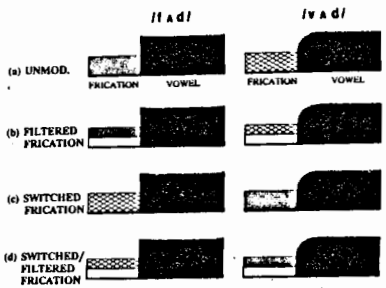
This study examined the contribution of various acoustic elements to the perception of voicing for the fricatives /f,s,v,z/ in the syllable-initial position of naturally-spoken /Cʌd/. We made controlled alterations to syllable acoustic-segments suspected to characterize voiced, that is /v/ and /z/, versus voiceless, /f/ and /s/, fricatives. To determine the perceptual utility of syllable segments for cuing fricative voicing, systematic syllable-modifications were performed to either eliminate or place in competition various components of the acoustic signal.

3. METHOD

3.1. Stimuli

The core set of stimuli consisted of 10 utterances each of /fʌd/, /sʌd/, /vʌd/, and /zʌd/, spoken citation-style by an adult male. Consonant-vowel boundaries for the utterances were established from the digitized waveform displays, guided by syllable segmentation criteria described in Revoile et al. [2]. Temporal and spectral measurements were made for the utterances' fricative and vowel segments, to enable examination of acoustic characteristics differing between voicing cognate syllables. Inspection of these attributes targeted the presence of a low-frequency component in the frications, and the vowel onset transitions as the most apparent indicators of acoustic difference between the voicing cognates. Thus, our syllable modifications were designed to examine the relative importance of these low-frequency components (i.e., potential voicing cues) by isolating or removing these elements, and by placing them in direct competition.

Fig. 1. Schematics of /fʌd/ and /vʌd/ stimuli per test condition.



From the 40 unmodified utterances, conditions of syllable-alteration (Figure 1) were prepared by computer manipulation of the waveform segments. The unmodified (panel a) utterances formed the basis for development of the other conditions. The rounded upper-left edge of the vowel symbol following the voiced frication in /vʌd/ signifies the presence of characteristic vowel-onset transitions. In the condition of filtered frication (panel b), the frication segments were high-pass filtered (1 kHz cutoff), as indicated in Figure 1 by the clear lower region in the frications. The 1 kHz filter cutoff was selected to eliminate the low-frequency spectral information present predominantly in the voiced frications. The next condition, switched frication (panel c), involves the exchange of frication segments between the voiceless and the voiced initial-fricative syllables. Between panels (a) and (c), note that the frication from the unmodified /vʌd/ -- represented by the cross-hatching -- has been appended to the vowel stem of the original /fʌd/, and vice versa. This alteration was intended to produce competition between voicing cues residing in the frication and those in the vowel stem. In panel (d), switched/filtered frication is a combination of the high-pass filtering and the switching of frications, carried out to examine whether the cue-competition effect expected with the switched frication stimuli would be nullified. Stimuli for a final condition, frication deleted (not shown in Figure 1), were developed by omitting the frications from the unmodified stimuli. This condition was intended to gauge the sufficiency of fricative-voicing cues remaining in the vowels.

3.2. Procedure

The 40 utterances in each condition were randomly presented in single-interval identification trials. Listeners' responses were limited to "FUD", "SUD", "VUD", or "ZUD". No feedback of correct response was provided. Stimuli were presented to each hearing-impaired subject's better ear at listener-determined most comfortable listening levels (MCL), using the procedure described in Revoile et al. [1]. Normal-hearing listeners were presented the stimuli at 73 dB SPL. At least five 40-syllable blocks per condition were tested per listener. Tests were administered in random order throughout 24 one-hour listening sessions.

3.3. Subjects

Twenty-two hearing-impaired and 10 normal-hearing young adults from Gallaudet University participated as paid listeners. The hearing-impaired listeners had tone-threshold averages ranging from 34 to 82 dB HL, with a median of 54 dB. Pure-tone threshold contours for these subjects were classified as either flat (n = 8) or sloping (n = 14). All subjects attained at least 70% correct fricative-voicing recognition for the unmodified test utterances.

4. RESULTS AND DISCUSSION

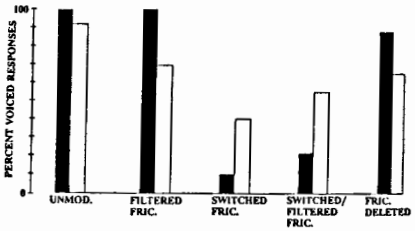
Percent correct voicing scores were calculated separately for the voiced, and the voiceless, initial-fricative syllables -- place of articulation errors disregarded. Mean voicing scores per listener were calculated for each test condition, arcsin transformed, then submitted to a repeated-measures ANOVA. Tukey's *hsd* was used for pairwise comparisons of condition means. A criterion alpha level of .05 was used for all tests of statistical significance. Interactions of listener group, fricative voicing, and test condition dictated that analyses be conducted separately within each listener group for the voiced and for the voiceless initial-fricative syllables.

4.1. Voiced Fricatives

Figure 2 shows percent "voiced fricative" responses for the /vʌd/ and /zʌd/ syllables. Fricative voicing recognition for the unmodified utterances approached 100% for the normal-hearing and the hearing-impaired listeners. While the pattern of response across test conditions was generally similar for the two listener-groups, magnitudes of the modification effects did differ between groups. Also, the hearing-impaired group's average standard deviation per condition (7%) was greater than the 2% seen for the normal-hearing -- evidence of greater intra-group performance variability among the hearing-impaired listeners.

The effect of filtering the frications' low frequencies can be observed by comparing voicing perception in the filtered frication condition with that for the unmodified utterances. While the normal-hearing group showed virtually no reduction in fricative voicing perception for the filtered stimuli, the hearing-impaired group's mean fricative voicing score of 69% represents a significant effect from the filtering. The importance of the frications' low frequencies to voicing perception is also exemplified by the similarity in the hearing-impaired group's performance for the conditions of filtered frication versus frication deleted. The 4% differential indicates that acoustic elements remaining in the frications after filtering did not contribute significantly to fricative voicing perception.

Fig. 2. Perception of VOICED fricatives by the normal- (black bars) and impaired- (clear bars) hearers.



Results from the switched frication condition show for both listener groups that appending the voiceless frications to the vowel stems from /vʌd/ and /zʌd/ greatly reduced the perception of voicedness. The normal-hearing group's identification of these hybrid stimuli as voiced in only 9% of the cases represents a near-complete domination of the voicing cues in the voiceless frication over the cues to voicedness in the vowel stem. For the hearing-impaired group, the perceptual decline of voicedness from the 92% in the unmodified condition to the 39% in the switched frication condition again shows that these concatenations of voiceless frications to vowel stems from voiced fricative syllables are identified /fʌd/ and /sʌd/ -- the appended frications dictating the perceived voicing value. Filtering the switched frications produced no

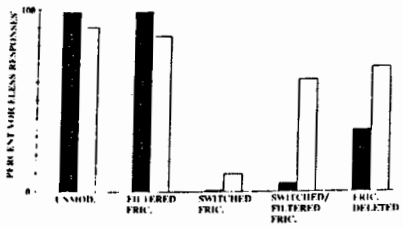
significant recovery from the perceptual domination of the frication segments for either group, as apparent from the increases of no more than 13% in fricative voicing scores for switched/filtered frication over the switched frication.

Finally, relative to perception for the unmodified stimuli, deletion of the frications significantly reduced voicing scores, though fricative voicing identification remained above-chance for both listener groups. This good voicing recognition in the absence of the /v/ or /z/ frications supports the utility of vowel stem characteristics for cuing fricative voicing.

4.2. Voiceless Fricatives

Figure 3 displays results for perception of the /fʌd/ and /sʌd/ syllables. Mean scores for the unmodified condition are 90% or better for both listener groups. The effect from high-pass filtering the voiceless frications was negligible, as relatively little spectral content existed in the lower spectral region of these voiceless fricatives.

Fig. 3. Perception of VOICELESS fricatives by the normal- (black bars) and impaired- (clear bars) hearers.



The switched frication condition again produced a dramatic reversal in fricative voicing perception, now with voiced frications appended to the vowel stems of /fʌd/ and /sʌd/. Neither normal-hearing nor hearing-impaired listeners provided many "fud" or "sud" responses to these stimuli. Thus, fricative voicing cues in the vowel stem again proved no match for those in the frication. For the hearing-impaired group, filtering low frequencies from the switched voiced frications did produce a significant release from this voicing reversal effect. For the normal-hearing group, higher-frequency components in the appended /v/ and /z/ frications were sufficient to sway listener responses toward voiced fricatives. Deletion of the /f/ and /s/ frications produced a significant decline in fricative voicing perception, when compared to performance for the unmodified utterances, though this reduction was more pronounced for the normal-hearing than the hearing-impaired group.

5. SUMMARY

The relative low-frequency energy in the frications of /vʌd/, /zʌd/ versus /fʌd/, /sʌd/ considerably influenced fricative voicing perception for the hearing-impaired listeners. When placed in competition, cues in the frication dominated those in the vowel stem, for prompting fricative voicing. However, in the absence of the frication segments, cues in the vowel stem were capable of eliciting voiced fricative percepts, particularly for normal-hearing listeners.

REFERENCES

[1] Revoile, S., Holden-Pitt, L., Pickett, J., and Brandt, F. (1986), "Speech cue enhancement for the hearing impaired: I. Altered vowel durations for perception of final fricative voicing", Journal of Speech and Hearing Research, 29, 245-255.

[2] Revoile, S., Pickett, J., Holden-Pitt, Talkin, D., and Brandt, F. (1986), "Burst and transition cues to voicing perception for spoken initial stops by impaired- and normal-hearing listeners", Journal of Speech and Hearing Research, 30, 3-12.