JAW KINEMATICS IN HEARING-IMPAIRED SPEAKERS

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ABSTRACT

This study examines jaw movements as a function of vowel height and stress in real-word phrases produced by deaf and hearing speakers. There were statistically significant main effects for vowel height in nearly all measures for all speakers. However, there were no statistically significant main effects for stress. The hearing speaker distinguished stressed and unstressed segments by maintaining the jaw in a lowered position for a longer period in the stressed vowels. With few exceptions, kinematic values for the hearing and the deaf were comparable.

INTRODUCTION

Persons who sustain severe-profound congenital hearing loss learn to produce speech using limited residual hearing as well as information derived from visual and kinesthetic sources. Acoustic cues accompanying changes in stress are perceptible to even the most profoundly impaired [1]. With respect to visual and kinesthetic information, deaf speakers frequently place their articulators fairly accurately especially for places of articulation that are highly visible, but fail to coordinate articulatory movements [2]. However, the overall timing of the articulatory event is longer than normal. Unfortunately, the locus of this timing difference at the articulatory level cannot be recovered. Existing cineradiographic data on hearing-impaired speech production [5,6,7] is equivocal having examined either a limited set of utterances (owing to the methodology) or having averaged across speakers with different etiologies. Also, some [8,9] argue that differential vowel productions by deaf speakers are made with extreme movements of the jaw, a visible articulator, as a substitute for the more appropriate but less visible tongue configuration. Thus, the present study examines kinematics of jaw movements in deaf subjects with particular focus on vowel and stress effects.

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METHOD

Subjects The subjects were three congenitally, severely-profoundly deaf adult females (mean pure tone average for .5, 1, and 2 kHz 90 dB+ ISO in the better ear), and a hearing adult female who served as a control. All of the deaf subjects received their early training in oral schools for the deaf; two of the subjects, D1 and D2, were mainstreamed in hearing schools. No subject had any additional handicaps. Using a rating scale for intelligibility [10] deaf speakers 1 and 2 could be characterized as difficult to understand although the content could be understood. Deaf speaker 3 was difficult to understand with only isolated words or phrases intelligible.

Procedure Articulatory movements in the vertical dimension of the jaw, the lower lip, and the upper lip were recorded tape using an optical tracking system. Acoustic recordings were obtained simultaneously and all signals were digitized. Velocity records for the different articulators were obtained and a number of measurements made: amplitude, duration, and peak velocity of raising and lowering movements. In some cases, jaw lowering and raising was not executed as a single uninterrupted movement. Rather, the jaw maintained a lowered position for a short period of time. In these instances, the lowering and raising movement was taken as the interval of uninterrupted movement and the "hold" phase was analyzed separately.

Linguistic material The stimuli were short phrases of English words containing a labial medial consonant [p, b, f, v, m, w] flanked by one high (or close) [i] and one low (or open) [a] vowel, respectively. The noun "Pa" was paired with the verbs "peal, beep, meet, weed, feel, veto"; the noun "Bea" was paired with the verbs "pop, bop, mop, want, farm, varnish". The words were produced in the carrier phrase "And ... it". (e.g., "And Pa peals it") with sentence stress occurring on the noun or on the verb. Five repetitions of each utterance type were recorded, giving a total of 120 tokens for each speaker (6 consonants * 2 vowels * 2 stress patterns * 5 repetitions).

RESULTS

Movement duration The effects of vowel and stress on kinematic measures of jaw movements were tested using a 2-way analysis of variance for repeated measures for each subject. Significant differences in main effects reported below are≤0.01.

Movement durations of the jaw lowering gesture for the first vowel, the raising gesture into the medial consonant, and the lowering gesture for the second vowel were made. Overall, the means and standard deviations for the deaf speakers are similar to the hearing speaker. The duration of the jaw lowering gesture for the first vowel was significantly longer for both hearing and deaf subjects when the vowel was open. There was also a strong vowel effect on the duration of the raising gesture for the medial consonant and the lowering gesture for the second vowel for all speakers. Again, duration was longer when the vowel was open. Thus, all movement durations were significantly affected by the vowel for the speakers.

Turning to the effects of stress, the results are much more variable. In particular, it was not always the case that stressed segments were produced with movements of longer duration than unstressed ones. For the lowering gesture of the first vowel, there were no significant stress effects for any subject. The raising gesture for the medial consonant was significantly effected by stress for Deaf speakers 1 and 3; for the hearing speaker and Deaf speaker 2, the effect was not significant. Finally, the lowering gesture for the second vowel was significantly increased in the stressed condition for the hearing speaker but there were no statistically significant differences for any of the deaf speakers.

Thus, most of the movement durations were not sensitive to stress variations for any of the speakers. Since this finding was somewhat unexpected, at least for the hearing speaker, we analyzed the "hold phase". Deaf speaker 3 differs from the other subjects in this measure as her durations are significantly longer. Statistically significant differences in "hold phase" for the hearing speaker were noted i.e., longer for the open than for the closed vowel and also longer for the stressed than for the unstressed condition. Only for Deaf speaker 1 was there a significant effect of vowel;for Deaf speakers 2 and 3, the effect was not significant. Stress was not significant for the hold phase for all three deaf subjects.

Movement displacement These measurements show that the values for the hearing and the deaf subjects again do not differ in any systematic manner as to the absolute values; this is also true for the standard deviations. Vowel quality had a significant effect on all displacements for all subjects. Displacements were greater for the open than for the close vowel. The effect of stress on jaw displacement was more variable and not consistent. The lowering movement for the first vowel was significantly greater in stressed syllables than in unstressed ones for Deaf speakers 1 and 3. The difference between stressed and unstressed segments was not significant for the hearing subject and Deaf speaker 2. The raising gesture for the medial consonant was unaffected by stress in all speakers. Similarly, the lowering movement for the second vowel was significantly longer in the stressed condition for the hearing subject and Deaf speaker 3; for the other two Deaf subjects, 1 and 2, no difference was found. The results for displacement thus indicate that movement amplitude was always larger for the open than for the close vowel for all subjects. The stress effects were more variable and mostly non-significant.

Movement velocity For peak velocity, it is, again, not necessarily the case that the hearing subject and the deaf subjects differ in any systematic way. Noteworthy is that Deaf speaker 3 executed the raising gesture of the jaw for the medial consonant with a very low peak velocity. Vowel quality had a significant effect on peak velocity of jaw lowering for the first vowel for all speakers. Peak velocity was higher for the low vowel. The difference in peak velocity between stressed and unstressed segments was significant for the hearing subject and Deaf speakers 1 and 3. The effect of stress was not significant for Deaf speaker 2. Also the closing velocity for the medial consonant was higher for the open vowel for all subjects; However, stress had no significant effect for any speaker. Finally, peak velocity during jaw lowering for the second vowel was significantly faster for the open vowel compared to the close vowel for all subjects. As for stress, stressed segments were produced with a faster lowering gesture for the hearing subject and Deaf speaker 3. For Deaf speakers 1 and 2, this effect was not significant. Again, there was a clear and consistent vowel effect on peak velocity of jaw movements; the open vowel [a] was produced with higher velocity than the close vowel [i]. Stress mostly affected the lowering movements of the jaw which were produced with higher peak velocity in stressed segments.

DISCUSSION

The results of this study indicate that vowel quality has a strong and reliable effect on jaw movements in speech. That is, the open vowel [a] was consistently produced with jaw movements of greater amplitude, longer duration and higher peak velocity than those associated with the vowel [i]. This, was true, in general, for both the hearing and the deaf speakers.

The effect of stress on jaw movements was, on the other hand, much less reliable and consistent. In many cases, there was no discernible difference between stressed and unstressed segments for either group of talkers. However, the hearing speaker reliably differentiated stressed and unstressed vowels by the "hold phase" of jaw lowering. This phase was longer for stressed than for unstressed vowels. Peak velocity of jaw lowering was also reliably higher for the hearing subject and Deaf subject 3; also, Deaf speaker 1 had a higher peak velocity of jaw lowering for the first vowel in the stressed productions.

The hearing subject in the present investigation did not show stress effects on jaw displacement. This differs from previous results for normals [11,12,13,14] and may be due to methodological differences. This study did not use reiterant speech or nonsense syllables. Further, the present results suggest that speakers can choose among different strategies in producing stressed and unstressed segments. Thus, at the articulatory level, the hearing speaker differentiated stressed and unstressed segments by a longer "hold phase" of the jaw gesture in the stressed condition while holding movement times and displacement constant. By inference, vowel duration was longer in the stressed syllables. While the hearing subject differentiated stressed and unstressed segments, the deaf speakers did not do so. At the same time, the deaf speakers showed reliable vowel effects. Overall, the kinematic measures of jaw movements did not differ between the hearing and the hearing-impaired speakers. Only Deaf speaker 3, the least intelligible, differed in that some measures were significantly longer than those for the other subjects.

These data refine some of the notions frequently reported to characterize deaf speech. In fact, deaf speakers do coordinate fairly accurately articulatory movements as evidenced by the results of this study for jaw and lip control. This is not too surprising since movements of the lips and jaw are visible. Moreover, we found no evidence that these hearing-impaired subjects distinguished vowel height by exaggerated jaw displacement. Durations, displacements and peak velocities did not differ remarkably among the subjects in the present study. Thus, the slow speaking rate of the deaf is not necessarily due to the fact that they move their articulators more slowly than hearing speakers. Deaf speaker 3, the least intelligible, had speech that was characterized by pauses between words reflected in the measures of the jaw hold phase and the interval from onset of jaw lowering for the first vowel to offset of jaw raising for the medial consonant. However, it is significant to note that this speaker is not distinguished from the other deaf talkers, or the hearing speaker, in any of the other measures.

Variability has often been reported as one of the hallmarks of the speech of the deaf [15]. The results of the present study do not show any good evidence of such variability in kinematic measures of a highly visible articulator. Moreover, we obtained similar results in our study of laryngeal-oral coordination [16]. We argue that this is the result of examining articulators which inherently have few degrees of freedom such as the jaw or laryngeal abduction/adduction. Measures for an articulator such as the tongue may show more variability. However, the nature of articulatory variability in normal speakers is far from understood and is most likely substantial. Results of stress implementation indicate that several strategies are available. We argue that an understanding of normal articulatory variation is a necessary prerequisite before we can hope to understand speech in disordered groups.

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