ARTICULATORY KINEMATICS IN STOP CONSONANTS

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ABSTRACT

This paper examines tongue movement kinematics in stop consonant production with particular emphasis on variations due to vowel context and voicing.

INTRODUCTION

The aim of this work is to examine the nature and extent of articulatory variability in stop consonant production as a function of vocalic context and stop consonant voicing. Such an examination is useful for understanding the control of speech movements, since it can reveal the nature of the variability and how it is structured by different sources of influence.

PROCEDURE

The movement data were recorded using a three-coil transmitter system described in [1]. Receivers were placed on the upper and lower lips, the lower incisors, and at four positions on the tongue. For the sake of convenience, the tongue receivers will be referred to by their locations as tongue tip, tongue blade, tongue body, and tongue rear, cf. Figure 4. In addition, receivers placed on the bridge of the nose and on the upper incisors were used for correction of head movements. Two receivers attached to a plate were used to record the occlusal plane by having the subject bite on the plate during recording. All data were subsequently corrected for head movements, and then rotated and translated to bring the occlusal plane into coincidence with the x axis.

The linguistic material consisted of VCV sequences with all possible combinations of the vowels /i, a, u/ and the stop consonants /p, t, k, b, d, g/. The sequences were placed in the carrier phrase "Say ... again" with sentence stress occurring on the second vowel of the VCV sequence. Ten tokens of each sequence were recorded at self-selected speaking rates and intensity levels.

The articulatory movement signals (induced voltages from the receiver coils) were sampled at 625 Hz after low-pass-filtering at 200 Hz. The speech signal was pre-emphasized, low-pass filtered at 9.5 kHz and sampled at 20 kHz. The resolution for all signals was 12 bits. After voltage-to-distance conversion, the movement signals were low-pass filtered using a 25-point triangular window with a 3 dB cutoff at 18 Hz.

The tangential velocity of each receiver was calculated and used for velocity measurements and also for locating points in time for making position measurements. That is, movement onsets and offsets were taken as points of minimum (usually non-zero) tangential velocity. Movement displacement was calculated as the path traversed by a receiver between movement onset and offset. See [2] for a discussion of issues in the processing of two-dimensional movement signals.

RESULTS AND DISCUSSION

In this paper, we shall present results of tongue movements for two of the four subjects recorded. We shall first discuss the closing movement, then the articulatory configuration during the stop closure, and finally the release movement.

Stop consonant voicing has been shown to influence articulatory kinematics, but the data have mostly been limited to lip and jaw movements and are somewhat conflicting. We have shown [3] that the raising movement towards closure for a velar stop consonant was reliably faster, larger, and longer for a voiced than for a voiceless stop in a similar vowel context. The larger movement displacement was due to a lower position at movement onset for the voiced stop, as illustrated in Figure 1. For alveolar stops, these differences were not as robust, however. This is illustrated in Figure 2 which plots peak tangential velocity of the tongue tip receiver for the closing movement.

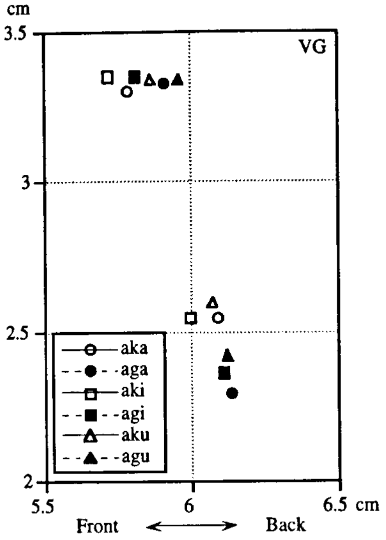

Figure 1. Average positions at onset and offset of tongue body receiver raising movement towards consonantal closure.. Onset positions in lower right, offset positions in upper left.

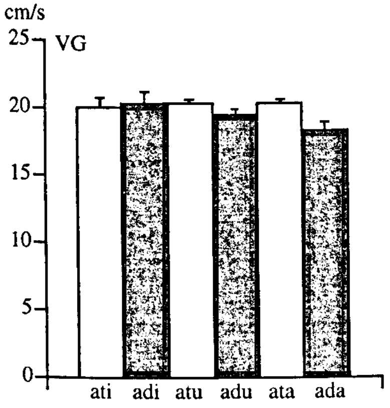

Figure 2. Peak tangential velocity of closing movement for alveolar stops (mean and standard error of the mean).

Statistical analysis showed no significant effect of vowel or voicing. The explanation for this is provided in Figure 3 plotting tongue tip receiver positions at onset and offset of the raising movement towards consonantal closure for the same data set. In contrast to the data shown in Figure 1, there is no clear difference in the onset positions in Figure 3 between voiced and voiceless stops.

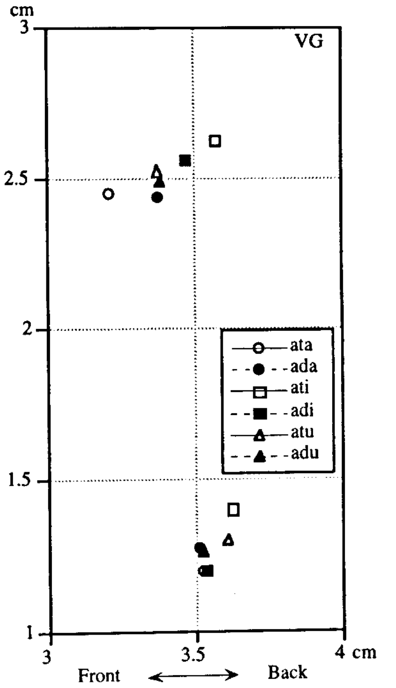

Figure 3. Average positions at onset and offset of tongue tip receiver raising movement towards consonantal closure. Onset positions in lower right, offset positions in upper left.

The vowel context has been shown to affect the articulatory configuration during stop closure, in particular for velar stops [4, 5, 6, 7].

Figure 4 shows average tongue receiver positions in six VCV sequences with velar stops and identical vowels before and after the consonant. The positions have been identified from minimum tangential velocity of each tongue receiver during consonantal closure. Cubic splines have been fitted to the data to get an estimate of the tongue shape. The influence of the vowel on the consonantal closure is clearly evident from the different horizontal positions of the signals. The whole tongue is shifted horizontally depending on the vowel, and the order from front to back is /i/, /a/, and /u/.

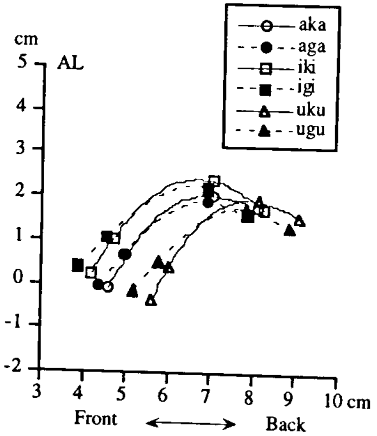

Figure 4. Average tongue receiver positions for velar consonants located at point of minimum tangential velocity during consonantal closure for each receiver. Cubic splines have been fitted to the data.

Figure 5 shows average tongue receiver positions for sequences with velar stops and an identical first vowel. Here, the tongue body receiver shows a similar, although smaller, horizontal variation depending on the second vowel. The positions of the tongue tip and tongue blade receivers show larger variability, most likely because they are less directly involved in making the velar closure.

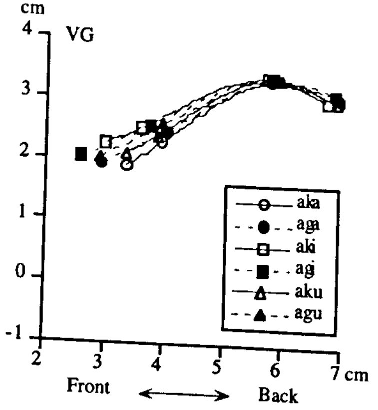

Figure 5. Average tongue receiver positions for velar consonants.

Figure 6 presents a similar plot for alveolar consonants in sequences where the first vowel is identical. Here, the tongue body and tongue rear receivers show more variation as a function of vowel context than those on the tongue tip and tongue blade. Again, most likely because the anterior part of the tongue is making the closure.

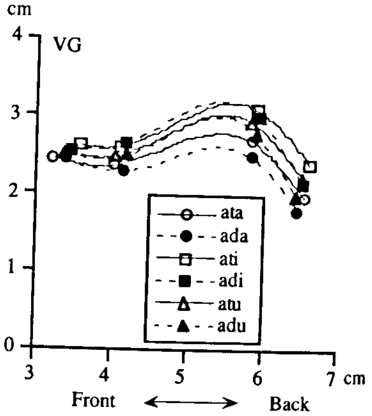

Figure 6. Average tongue receiver positions for alveolar consonants.

The release movement from the consonantal closure to the following vowel was heavily influenced by the quality of the vowel. Figure 7 plots peak tangential velocity of the tongue body receiver for the release movement. The increasing order of velocity is /i/, /u/, /a/, which corresponds to the displacement of the movement. While the vowel effect was robust, there was no consistent influence of stop consonant voicing on the release movement across subjects.

The point of minimum tangential velocity during consonantal closure offers an instant in time that can be used for measuring receiver positions. It is not necessarily the case, however, that such a minimum can be found for a given receiver, in particular for receivers on

those parts of the tongue that are not directly involved in making the closure. We should also note that at this point the tangential velocity is usually not zero. Tongue movements for velar stops usually follow curved paths, and there is thus continuous movement during the stop closure. cf. [6, 8]. This is also evident from the fact that the vertical and horizontal velocity profiles do not show any period of zero velocity. Thus, the goal in velar stop production should properly be seen as the making of a closure and not as a spatial position of the articulators.

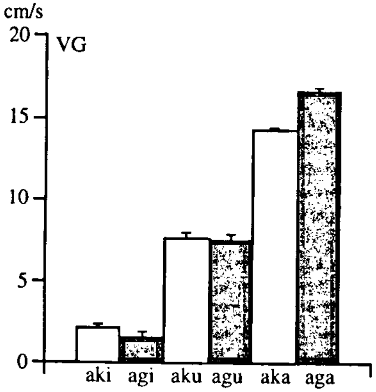

Figure 7. Peak tangential velocity of tongue body receiver for release movement for velar stops (mean and standard error of the mean)

In summary, the present results exemplify how articulatory movements in stop consonant production vary as a function of context. As we have argued elsewhere [9], such variability can be seen as the result of dynamic processes that operate on speech motor programs to scale them according to phonetic context.

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