MAKING A VOCAL TRACT CLOSURE LONGER AND SHORTER

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ABSTRACT

This study examined lip and tongue kinematics in stop and fricative consonants of different durations. Native speakers of Japanese served as subjects. An analysis of the lower lip closing movement indicated that it differed for the long and short labial consonants. In particular, the lower lip reached its highest vertical position later during the closure for the long than for the short consonants, and its deceleration was modified to keep it in contact with the upper lip for a longer time. Thus, both the magnitude and timing of the lower lip movement were changed to control closure duration. For the lingual consonants, the magnitude of the tongue movement during the closure was larger for the long than for the short consonants. However, the speakers reduced the average speed of the tongue during the closure for the long consonant This allowed the tongue to maintain contact with the palate to produce the vocal tract closure.

INTRODUCTION

This study examines lip and tongue kinematics in the production of stop and fricative consonants, where the duration of the oral closure or constriction is varied for linguistic purposes. Native speakers of Japanese served as subjects, producing words with labial and lingual consonants. For the control of lip closure in labial consonants, Löfqvist (submitted) examined the simple hypothesis that only variations in a spatial parameter, lip movement displacement, could be used to control a durational property. That is, by only moving the lower lip to a higher position, the lips would stay in contact for a longer period of time. The results indicated that the peak vertical position of the lower lip during the oral closure was, as predicted, higher for a long than for a short consonant. However, this difference was not only due to a difference in movement displacement but also in movement timing. Starting from these results, the present study examines properties of the lip movement velocity profiles and their relationship to closure duration.

In lingual stop consonants, the tongue keeps moving during the oral closure (e.g., Löfqvist & Gracco, 2002), with the movement magnitude influenced by vowel context. The factor limiting the amount of tongue movement during the oral closure is the necessity to maintain tongue-palate contact to close the vocal tract. Thus, if a speaker need to double the duration of the oral closure for a lingual consonant, as acoustic studies of Japanese have shown can be the case (e.g., Beckman, 1982; Han, 1994), some strategy must be used to maintain the tongue-palate contact. One such strategy would be to momentarily stop the tongue movement during the consonant. Given that articulators always tend to be moving, this is not a likely strategy. Another strategy would be to slow down the movement of the tongue during the consonant. This strategy will make it possible to maintain the closed oral cavity. Thus the velocity of the tongue movement during the consonant should be lower for a long than for a short consonant. Another prediction based on this strategy is that the magnitude of the tongue movement during the closure should be similar, or slightly longer for a long than for a short consonant.

METHODS

Subjects

Native female Japanese speakers served as subjects. They reported no speech, language, or hearing problems. They were naive as to the purpose of the study. Before participating in the recording, they read and signed a consent form. (The experimental protocol was approved by the IRB at the Yale University School of Medicine.)

Linguistic material

Normal bisyllabic words containing short and long consonants were used. The words were placed in a short carrier sentence, presented to the subjects in written Japanese, and produced at a self selected rate. Fifty repetitions of each word were recorded. For the labial consonants, the following words were used: ”napa”, ”nappa”, ”sama”, ”samma”, ”tofuru”, and ”daffuru”. The labial consonant in the two last words is a bilabial fricative /□/. The following words contain lingual consonants: “hata”, “hatta”, “muda”, “budda”, “hosa”, “hossa”, hasha”, “hassha”, “saka”, “sakka”, “tagu”, “taggu”.

Movement recording

The movements of the lips, the tongue, and jaw were recorded using a three-transmitter magnetometer system. Receivers were placed on the vermilion border of the upper and lower lip, on the lower incisors at the gum line, and on three positions on the tongue, referred to as tip, blade, and body. Two additional receivers placed on the nose and the upper incisors were used for the correction of head movements. All receivers were attached using Isodent, a dental adhesive. Care was taken during each receiver placement to ensure that it was positioned at the midline with its long axis perpendicular to the sagittal plane. Two receivers attached to a plate were used to record the occlusal plane by having the subject bite on the plate during the recording. All data were subsequently corrected for head movements and rotated to bring the occlusal plane into coincidence with the x axis. This rotation was performed to obtain a uniform coordinate system for all subjects.

The articulatory movement signals (induced voltages from the receiver coils) were sampled at 500 Hz after low-pass filtering at 200 Hz. 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 14 Hz; this was done forwards and backwards to maintain phase. To obtain instantaneous velocity, the first derivative of the position signals was calculated using a 3-point central difference algorithm. The velocity signals were smoothed using the same triangular window.

The acoustic signal was pre-emphasized, low-pass filtered at 4.5 kHz, and sampled at 10 kHz. The onset and release of the oral closure for the stops and nasals were identified in waveform and spectrogram displays of the acoustic signal. The onset of the closure was identified by the decrease in the amplitude. For the fricatives, the cessation and reappearance of voicing was used to identify the constriction phase.

The duration of the oral closure/constriction was measured in the acoustic signal. For the labial consonants, a number of lip and jaw measurements were made, as presented in more detail in Löfqvist (submitted). For the lingual consonants, the path of the tongue tip or tongue body receiver during the oral closure/constriction was measured by summing the Euclidean distance between successive samples from the onset to the offset of the oral closure/constriction. The average speed ($\upsilon = \sqrt{(\dot{x}^2 + \dot{y}^2)}$) of the tongue movement during the oral closure/constriction was also measured.

RESULTS

Acoustic measurements

As shown for two sound categories in Figure 1, the duration of the oral closure for the long and short consonants is clearly different. There is no overlap between the closure durations for the long and short consonants. Moreover, the durations are often very short for the short consonants.

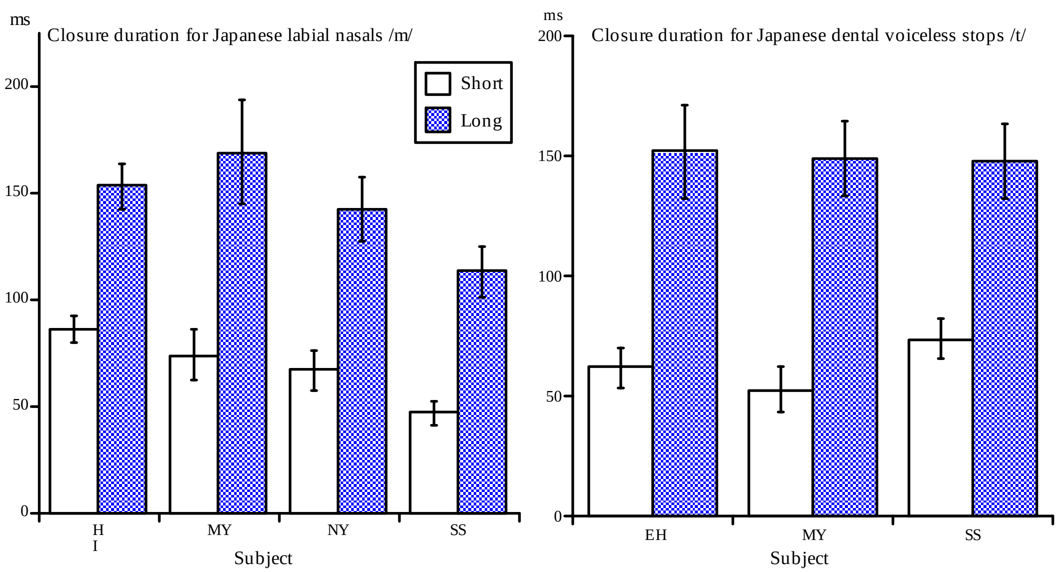

Figure 1. Closure duration for Japanese long and short labial nasals (left) and dental voiceless stops (right).

Lip kinematics

Figure 2 shows signal averages of position, velocity, and acceleration for the lower lip closing movement for productions of labial nasal consonants by two subjects. Several observations can be made about these results. First, the position signals show that the peak position of the lower lip occurs later for the long and short consonants. Second, the peak velocity of the lower lip closing movement does not differ for the long and short consonants. Third, the lower lip raising velocity signals for the short consonant show the bell-shaped characteristic of simple movements. However, for the long consonants, the velocity of the lower lip shows a change around the second zero crossing, so that the velocity curve is not

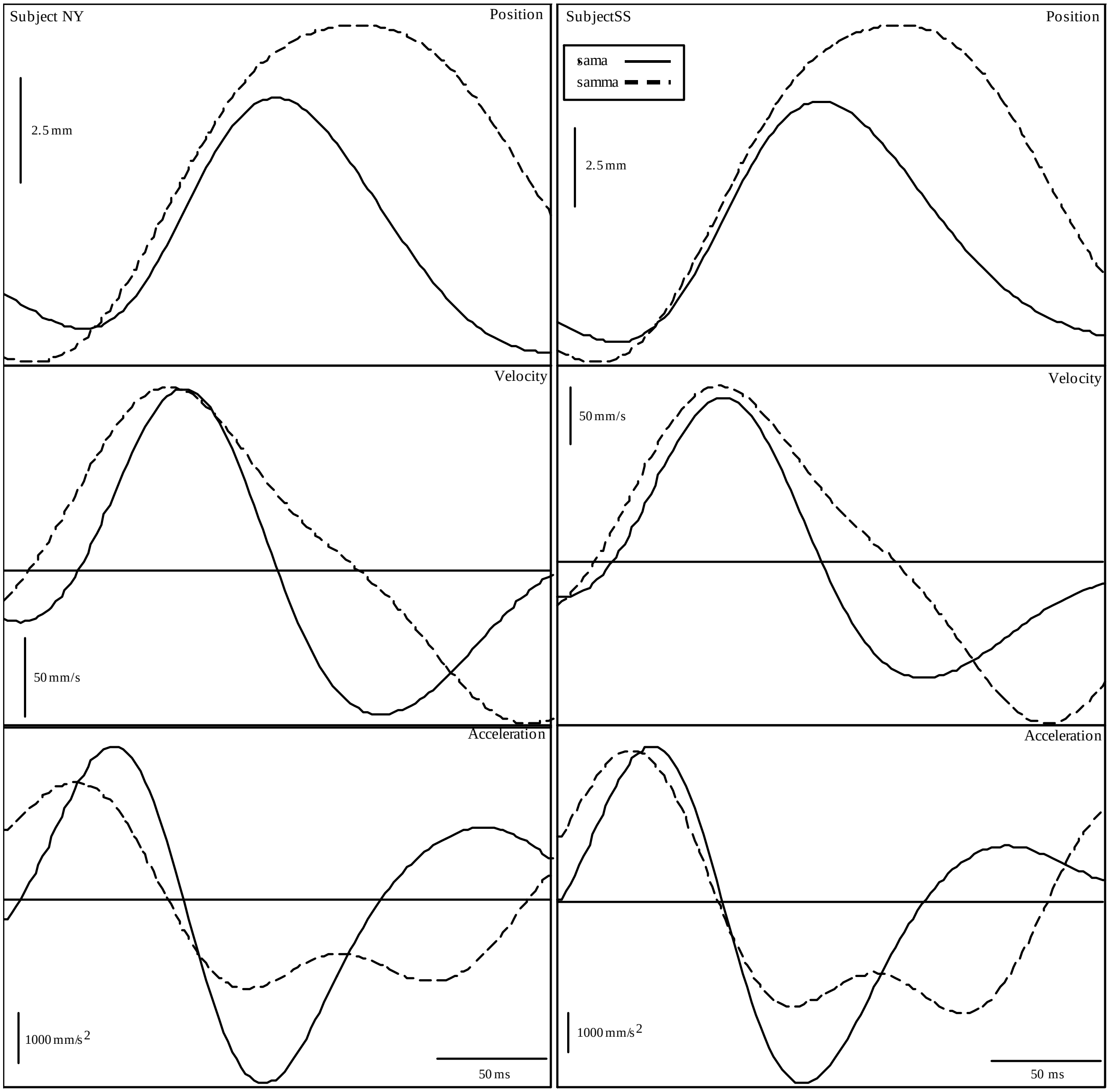

Figure 2. Signal averages of lower lip position, velocity, and acceleration for the labial nasals produced by the Japanese subjects NY and SS. The vertical line in the velocity and acceleration panels represents zero velocity and acceleration.

symmetric. Fourth, the acceleration signals indicate that the deceleration of the lower lip is momentarily reduced for the long consonants to keep it moving upwards and thus in contact with the upper lip for a longer period of time. One way of assessing the shape of the raising lip movement velocity profile is to calculate the time from movement onset to peak velocity. Plots of this parameter and movement duration for labial nasals are shown in Figure 3 for the same two subjects. For both subjects, there is a negative correlation between the time to peak velocity

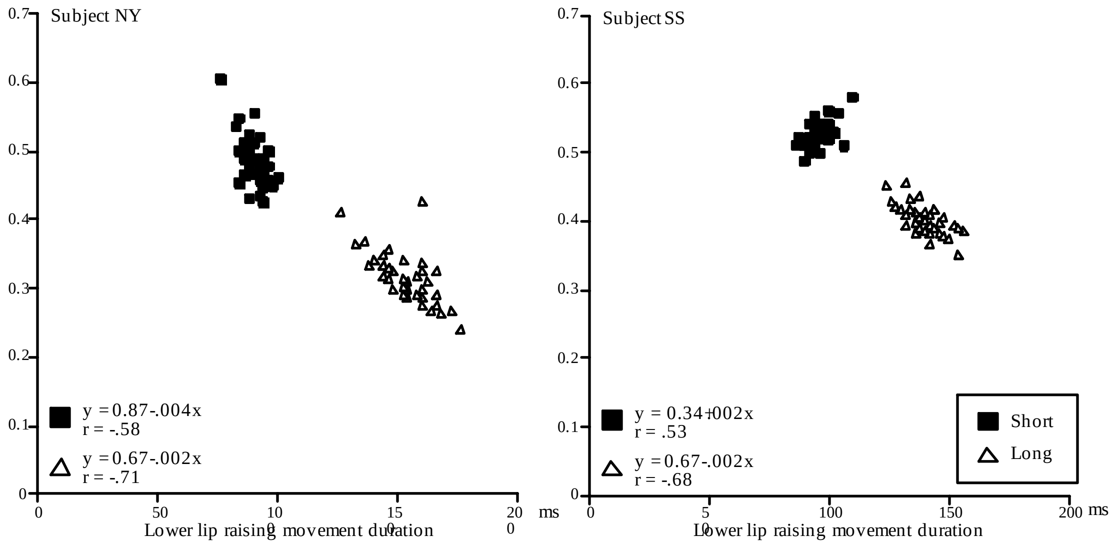

Figure 3. The time from movement onset to peak velocity for labial nasal consonants plotted against lower lip raising movement duration.

and movement duration for the long consonants. This was true for all subjects, whereas the relationship differed between subjects for the short consonants. Similar results have been presented by Adams et al (1993) for changes in movement duration with speaking rate.

Lingual consonants

According to the hypotheses outlined above, the magnitude of the tongue movement during the closure should be similar, or slightly longer for the long consonants, and the average speed of the tongue during the closure should be slower for the long than for the short consonants. Results for the tongue tip movements in voiceless stops are shown in Figure 4. The tongue tip movement during the oral closure is generally longer for the long than for the short stops. The difference is significant for all cases except for subject MY. Within each stop category, there is a positive correlation between the movement magnitude and the duration of the closure, with higher correlations for the short than for the long stops. The average speed of the tongue tip during the closure is consistently lower for the long than for the short stops. There is only a weak correlation between the closure duration and the average speed during the closure for the long stops. Similar results were found for the fricatives and the velar stops.

DISCUSSION

These results illustrate the articulatory strategies speakers use to make durational contrasts. In producing a long lingual consonant, a speaker reduces the overall speed of the tongue movement during the closure to maintain the tongue-palate contact and thus a closed vocal tract; there was no production where the tongue stopped moving. In labial consonants, variations in the magnitude and timing of the lip closing movements are used to control closure duration. All subjects showed the same overall kinematic results, suggesting that they used the same basic strategies that most likely have been mastered during the period of speech and language acquisition.

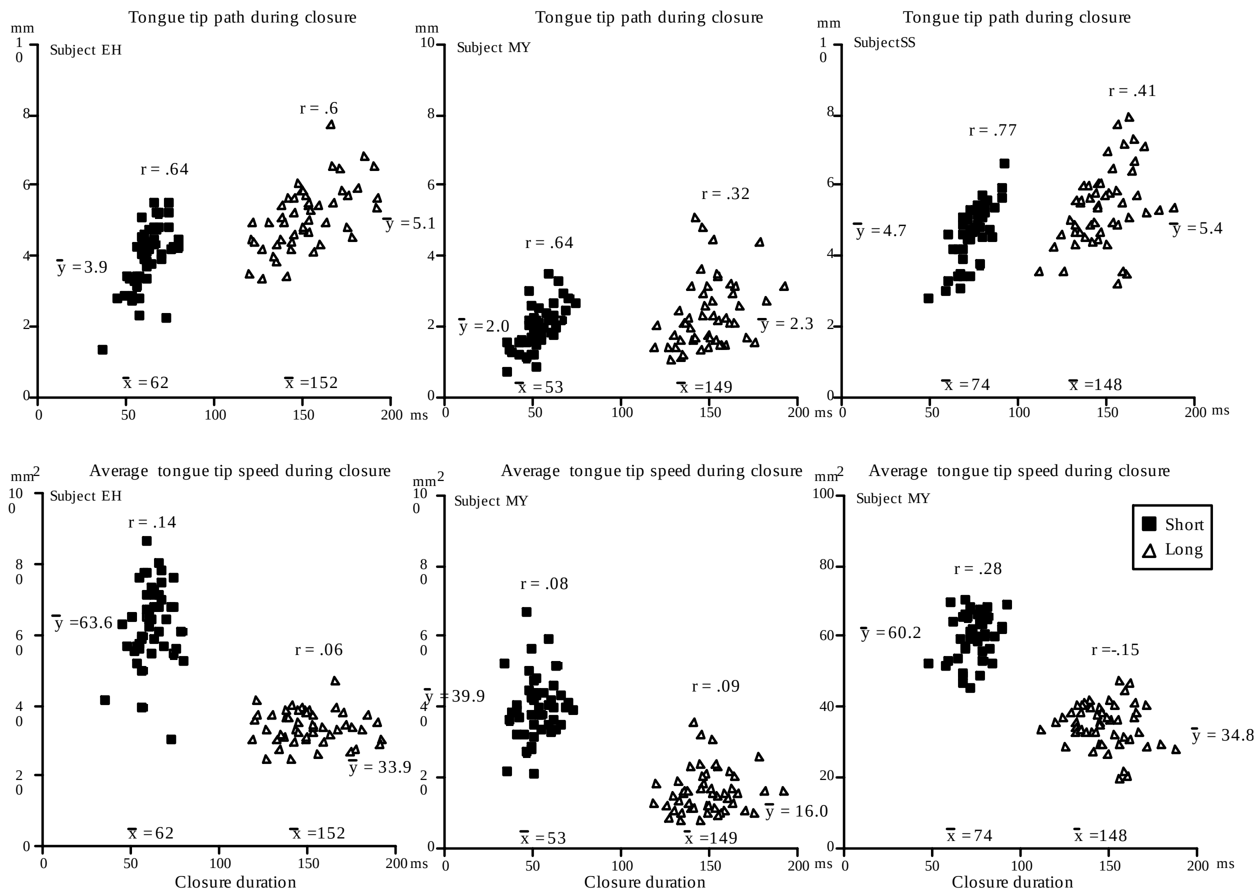

Figure 4. Plots of closure duration against tongue tip movement path during closure (top) and average tongue tip speed during closure (bottom).

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