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Articulatory Compensation and Adaptation for Unexpected Palate Shape Perturbation

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ABSTRACT

This paper describes compensatory articulatory behavior in response to an unexpected perturbation of the oral cavity. An artificial palate, whose thickness can be changed during speech, was constructed to provide downward (increase of thickness) and upward (decrease of thickness) perturbation on the palate shape. The compensatory articulation during the utterance of repeated syllables, which contain fricative /ʃ/ and stop-fricative /tʃ/, was recorded with an electromagnetic articulographic system. An EMG recording of tongue muscles was also made to examine the speech control mechanism of the immediate compensation of the tongue. The compensatory behavior was examined for both unmasked and masked audio-feedback conditions. The immediate compensation of the tongue to the unexpected perturbation occured within 100 ms after the perturbation for both audio-feedback conditions. It was, however, often incomplete and an overshoot of the tongue caused speech errors in the first occurrence of the fricative. The speech error disappeared and complete compensation was achieved in the successive occurrence of the phoneme during the same utterance. The time course in achieving the complete compensation was dependent on the audio-feedback condition. The masked audio-feedback condition needed a longer interval for the complete compensation.

1 INTRODUCTION

Studies on oral-articulatory perturbations have provided valuable insights into motor equivalence, or how different muscle activation patterns can achieve the same articulatory or acoustic goals [1]-[9]. In particular, previous studies on static structural perturbations caused by dental prostheses and bite-block insertions revealed that articulatory compensation made by alternating articulator positions could achieve the phoneme-specific acoustic goal [4]-[9]. The compensation was found even in the first speaking trial just after the insertions. These studies suggest that subjects use predictive control to develop compensatory articulation with respect to the sudden change in the shape of the oral cavity.

On the contrary, articulatory compensation in response to an unexpected perturbation of the oral cavity has recently been examined by using an artificial palate whose thickness can be dynamically controlled by external air pressure [10]. That study revealed that speech errors that occur in producing consonants during the perturbation are dependent on the articulation manner. Speech errors were mostly observed in producing fricative consonants; , few errors were observed for the stop consonants.

The present study examines compensatory articulation during an unexpected perturbation of the oral cavity caused by an artificial palate with the focus on the immediate adaptation process during the utterance under unmasked and masked audio-feedback conditions. The compensatory articulation of the jaw, lips, and tongue was recorded with an electromagnetic articulographic (EMA) system together with the audio signal. An EMG recording of tongue muscles was also made to examine the speech control mechanism for the immediate compensation.

2 METHOD

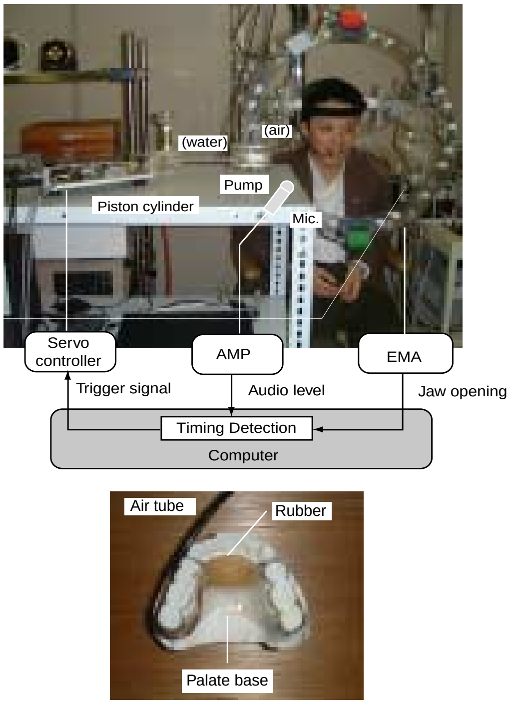
2.1 Experimental Set-up

The experimental setup is shown in Fig.1. The artificial palate has a 1-mm-thick acrylic base and a semi circular 1-mm-thick rubber piece. The rubber is attached to the base in the alveolar region to form a balloon. The thickness of the palate can be controlled by inflating the balloon by external air pressure through a lead tube. The top of the balloon is located at the mid-line of the palate 8-mm posterior to the incisors, and can be inflated from the rest position up to 4-mm in height, which is about the thickness of the artificial palate. The air pressure is controlled by using a piston cylinder that was actuated by a servo-actuator through a ball screw. The inflation time of the palate from the rest position to the height of 4 mm or vice versa is approximately 60 ms.

The articulatory movements for the utterance with the artificial palate were recorded on an EMA system (Carstens AG-100). The receiver coils of the EMA were attached to the lower jaw, the lips, and at four positions along the tongue surface. The seven positions on articulators and two reference positions on the nose and upper jaw were sampled at a rate of 125 Hz. The audio signal was also recorded and sampled at 8 kHz. Activities of the extrinsic tongue muscles, genioglossus posterior (GGP) and anterior (GGA), were simultaneously recorded with the articulatory movements by using a hooked wire electrode. The timing of the perturbation of the palate was controlled in real time by using both the jaw opening level measured by the EMA and the acoustic power level.

2.2 Experiments

The perturbation tests were conducted in the downward (rest to inflated palate) and the upward (vise versa) perturbation conditions. Both tests were carried out under unmasked and masked



Air-controlled artificial palate

Figure 1: Experimental setup and air-controlled artificial palate.

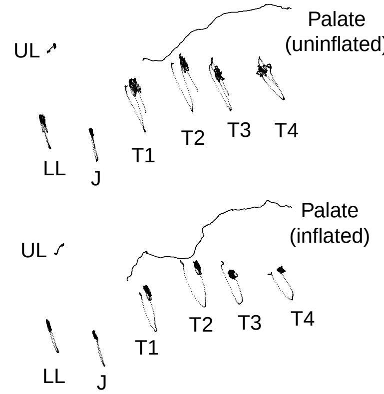


Figure 2: Plots of jaw (J), lips (UL, LL) and tongue (T1,T2,T3, T4) positions for repeated syllables /ʃa/ uttered with normal (un-inflated) and modified (inflated) palate.

audio-feedback conditions. The audio-feedback masking was implemented by listening to pink noise of 88 dB SPL during the utterance.

The repeated syllables /ʃa/ and /tʃa/ were used as speech sample. Each syllable was uttered eight times with the leading syllable /iya/. The fricative and fricative-stop pairs, each which have a different articulation manner but the same articulation place, were selected to investigate the compensatory articulation caused by the perturbation of the palate shape. The subjects were two male adults. The number of speaking trials for each perturbation condition was 30

The perturbation was randomly given at the timing of the production of the open vowel /a/ in the leading syllable /iya/ so that the subject was unaware of the modified palate shape until his tongue contacted the palate. In order to minimize the expectation effect on the perturbation by the subject, the perturbation was given with occurrence probability of 0.2, and the perturbation tool was placed in an acoustic shelter to prevent mechanical noise.

3 RESULTS

3.1 Compensatory articulation with modified palate shape

Figure 2 shows the articulatory motions in the midsagittal plane during repeated syllable /ʃa/ uttered with the normal (un-inflated) and modified (inflated) palate. Both fricative and stop-fricative speech uttered with the palate inflated was correctly perceived in most of the speaking trials. This finding is identical to that of previous studies, in which a fixed device was inserted into the oral cavity. Articulatory compensation with respect to the inflated palate is apparent in tongue positions T_1 to T_3. These positions shift downward along the modified palate shape. On the contrary, the lower jaw, the lips and the tongue back position T_4 showed no significant differences compared with their normal articulatory positions.

3.2 Unexpected perturbation

3.2.1 Downward perturbation

Figures 3 to 5 show the time function of the horizontal and vertical positions of the jaw and the tongue, EMG signals of two extrinsic tongue muscles, and speech signal for difference perturbation conditions. The articulatory and EMG data were averaged over speaking trials, in which each reference timing was set at the onset of tongue constriction or closure in the initial consonant. Speech signal for a typical trial was displayed. The onset of the trigger signal corresponds to the instant at which the perturbation was given.

Figure 3 shows the result for the downward perturbation. in the repeated syllable /ʃa/. The articulatory movements to the unexpected perturbation are almost identical to those in the normal condition until the onset of articulating /ʃ/. Then, during production of /ʃ/, the vertical positions of the points on the tongue are immediately lowered to by about 4 mm and moved backward to by about 3 mm. Although the contact timing cannot be accurately estimated from the EMA data, the lowering begins around 100 ms after the onset of the articulation of /ʃ/. The speech sound was most often misidentified as /tʃ/ in the initial syllable and was correctly perceived as /ʃ/ in the following syllables. Speech error in the initial syllable is interpreted as an overshoot of the tongue relative to the modified palate shape, which results in vocal-tract closure. The complete compensation by the tongue continued from the second to the end syllable in most of the speaking trials.

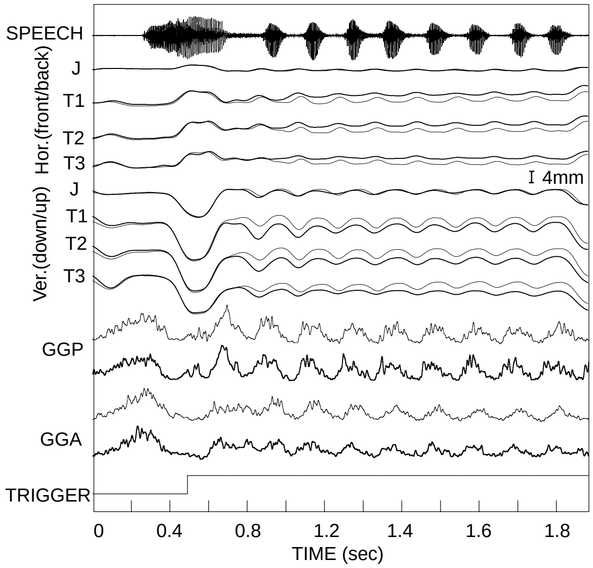


Figure 3: Articulatory movements of the jaw (J) and tongue (T_1, T_2 and T_3) and EMG signals in the unperturbed (thin line) and downward-perturbed (thick line) conditions for repeated syllables of /ʃa/. Audio-feedback is unmasked.

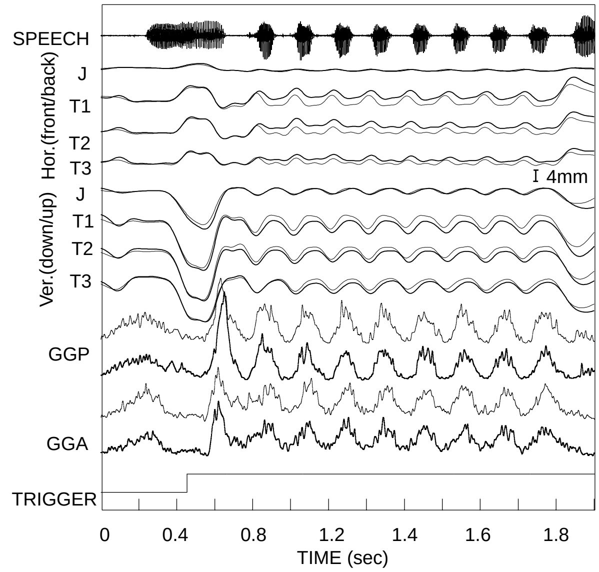


Figure 4: Articulatory movements of the jaw (J) and tongue (T_1, T_2 and T_3) and EMG signals in the unperturbed (thin line) and downward-perturbed (thick line) conditions for repeated syllables /tʃa/. Audio-feedback is unmasked.

The immediate compensation seems to be an active compensation produced by the subject adjusting his motor control. The EMG signal on the tongue muscle GGA is slightly smaller in magnitude, but there is no significant difference in the magnitude of the EMG signals between the unperturbed and perturbed conditions. Although the EMG magnitude significantly differs across the vowel /i/, fricative /ʃ/ and stop-fricative /tʃ/ (see Fig. 4), which are characterized by difference of tongue height, the downward displacement caused by the compensation is not explained by both muscle activities. Further studies on EMG measurement are be needed in order to ascertain the muscle adjustment related to the downward compensation of the tongue.

Figure 4 shows the result for the downward perturbation in repeated syllable /tʃa/. Compared with /ʃa/, the magnitude of the downward displacement is small, but the time course is very similar. The speech sound during the perturbation was correctly perceived in all speaking trials. This means that the vocal tract closure for the stop consonants is less disturbed even if the palate shape suddenly changes, while the narrow constriction of the vocal tract in the case of the fricative consonant is severely disturbed by it.

3.2.2 Upward perturbation

Figure 5 shows the result for the upward perturbation in a repeated syllable /ʃa/. In the unperturbed condition, the palate shape was inflated during speech. The articulatory compensation to the modified palate begins before the onset of the vocal-tract constriction in the initial syllable. This suggests that predictive motor control is employed to adapt the tongue movement to the modified palate shape, if the subject is aware of the modified palate shape.. When the palate shape is upward perturbed (un-inflated), the tongue articulation is immediately restored to that with the normal palate and does not show any undershoot to the palate. Then, the upward perturbation causes no speech error.

3.2.3 Masked audio-feedback effect

Figure 6 shows the result for the downward perturbation when the audio-feedback is masked during the repeated syllable /ʃ a/. The immediate compensation occurs just after the onset of the initial fricative, even if the audio feedback is masked. This suggests that the tactile information gathered by sensing the tongue-palate contact or intra-oral pressure is used to develop the compensation. Although the compensatory behavior is similar to that in the unmasked condition, the downward displacement of the tongue to the perturbation is smaller and the compensation in first several syllables is incomplete in producing the correctly perceived sound /ʃ/. The interval in which the complete compensation was achieved, varied among the speaking trials. This suggests that audio-feedback is efficiently used in finely adjusting the tongue position to form a vocal-tract constriction. The audio-feedback effect on the articulatory compensation is more apparent for the fricative in the downward perturbation. In the stop-fricative and the upward perturbation, correctly perceived speech was produced in the masked audio-feedback condition. The effect seems to be dependent on the difficulty in the perturbation task as well as the articulation manner.

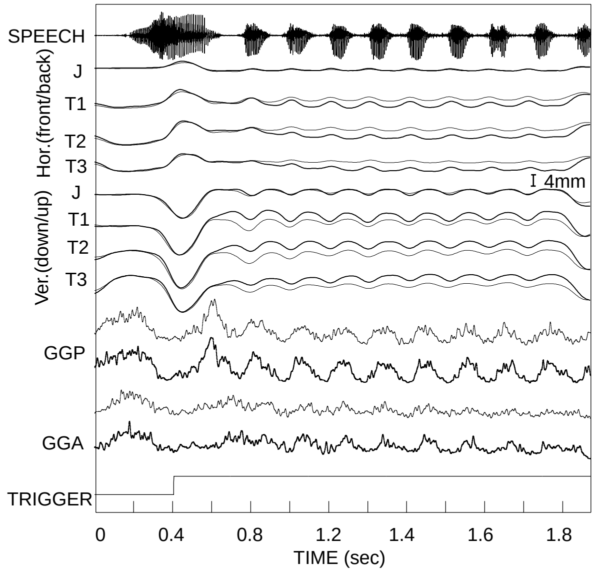


Figure 5: Articulatory movements of the jaw (J) and tongue (T_1, T_2 and T_3) and EMG signals in the unperturbed (thin line) and upward-perturbed (thick line) conditions for repeated syllables /ʃa/. Audio-feedback is unmasked.

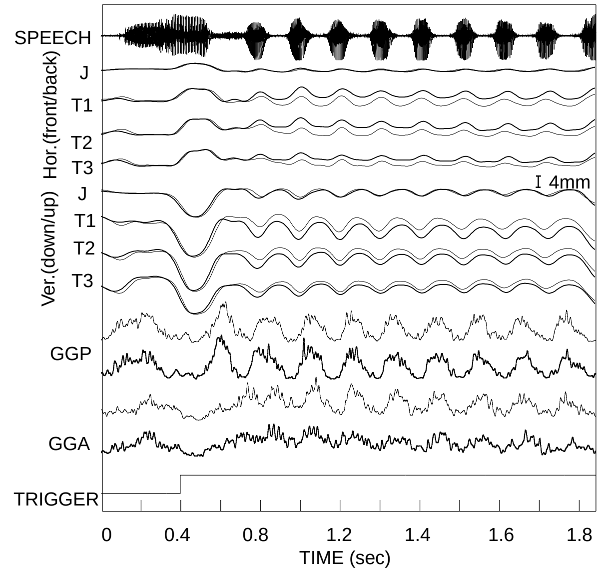


Figure 6: Articulatory movements of the jaw (J) and tongue (T_1, T_2 and T_3) and EMG signals in the unperturbed (thin line) and downward-perturbed (thick line) conditions for repeated syllables /ʃa/. Audio-feedback is masked.

4 SUMMARY

Compensatory articulation in response to the unexpected perturbation to the palate shape was examined. The results showed that the compensation occurs immediately during the utterance after the perturbation under both masked and unmasked audio-feedback conditions. When the audio-feedback was masked, a longer adaptation interval was needed to achieve the complete compensation.

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