EFFECTS OF TACTILE AND AUDITORY FEEDBACK ON COMPENSATORY ARTICULATORY RESPONSE TO AN UNEXPECTED PALATAL PERTURBATION

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ABSTRACT: We examined tactile and auditory feedback effects in ongoing speech motor control by observing compensatory responses to an unexpected perturbation of the oral cavity. Palatal perturbation experiments were performed for three male subjects under four feedback conditions; normal, auditory masking, tactile masking, and both masking. In the normal condition, an immediate downward shift of the tongue with time lag around 100ms after the inflated palatal perturbation was observed with an increased magnitude of the EMG signal of the tongue. The downward shift occurred at similar time lag for auditory masking, but it was more delayed by an additional delay 60 ms for tactile masking. When tactile and auditory feedback was masked, the displacement of the downward shift and muscle activity change was significantly reduced. These findings suggest that the tactile feedback from sensing contact between tongue and inflated artificial palate is primarily used to produce the rapid compensation, and that the auditory feedback is used in finely adjusting articulation with a longer time lag.

INTRODUCTION

Sensory feedback has been an important issue in speech motor control as well as speech adaptation. Auditory and tactile masking studies showed that these masking effects on speech production were minimal in vowels and limited to the fricatives, which suggested that skilled speech is mostly an open loop system (Hardcastle, 1975). On the other hand, it has been shown that an altered auditory feedback, like delayed auditory feedback (Lee, 1950), auditory feedback with shifted formant frequencies (Houde & Jordan, 2002) or altered fundamental frequency (Kawahara, 1994), could affect speech articulation or laryngeal function in ongoing speech motor control as well as in motor adaptation. Also, studies on oral cavity perturbation caused by insertion into the mouth of a bite block or a thick artificial palate, suggested that compensatory articulation in response to the perturbation developed over time by employing sensory feedback in a compensatory process (Lindblom et al., 1979, Hamlet & Stone, 1978).

In our previous studies, we examined compensatory responses of articulators to unexpected perturbation of the palate shape (Honda & Kaburagi, 2000, 2002). Compensation by the tongue for the palatal inflation became evident around the second syllable in the repeated fricative-vowel syllable utterance. When the auditory feedback was masked, immediate downward shift of the tongue in the compensatory response occurred at a similar time lag to that in the normal auditory feedback condition. These observations suggested that the immediate compensation of the tongue was caused by tactile sensation by the tongue-palate contact rather than auditory feedback. In this study, we examine tactile and auditory masking effects on the compensatory response to the unexpected palatal perturbation. We also examine whether the immediate compensation of the tongue is caused by active adjustments of the motor control of the tongue or a simple mechanical effect of the inflated palate by observing the tongue muscle activity change in the compensatory response.

METHOD

For the palatal perturbation, we used an artificial palate whose thickness can be changed during speech (Honda & Kaburagi, 2000). It has acrylic base and a semi-circular piece of rubber. The rubber

was attached on the artificial palatal base in the alveolar region to form a balloon. The palate height was dynamically controlled by inflating the balloon attached on the palatal base by an external air pressure.

The repeated syllable /sha sha,,,sha / was used as speech sample. Each syllable was uttered 8 times with the leading syllable /iya/. The perturbation, where the palate balloon was inflated to a height of 4 mm from the rest position, was randomly given with an occurrence probability of 20% at the moment of the production of the initial open vowel /a/ in the leading syllable. Articulatory movements for the utterance with the artificial palate were recorded on an electro-magnetic articulographic (EMA) system (Carstens AG-100). The receiver coils of the EMA were attached to the jaw, the lips, and at four positions along the tongue surface. EMG recording was simultaneously done by using surface electrodes (AgCl, 4.5mmϕ, 1 mm in thickness) attached on the tongue blade. Diagnostic test of EMG recording showed that EMG magnitude was significantly large for the tongue gesture of retroflex /r/, middle for fricative /sh/ and less for back vowels. Thus, the recorded EMG signal mostly detects longitudinal intrinsic muscle of the tongue.

Perturbation experiments were conducted under four sensory feedback conditions, namely normal, tactile masking, auditory masking, and both masking. Tactile masking was done by applying topical anaesthetic (4% Xylocaine solution, 5cc) to the tongue blade and hard palate to suppress the tactile sensation from the tongue-palate contact every 5 minutes during the experiment. Auditory masking was done by binaural presentation of masking pink noise of 88 dB SPL.

PERCEPTUAL ANALYSIS

A perceptual test was conducted on the speech errors that occurred in the perturbed trials. The task was to identify each fricative consonant in the repeated syllable using any consonant category of Japanese. Because of the difficulty in identifying every consonant in the eight-syllable sequence, listeners were permitted to listen to each stimulus repeatedly until a confident judgment could be made.

Table 1 is showing the score of speech errors for fricative consonant identification of the repeated syllable. In the unperturbed trials, there are few speech errors over the initial to the last fricatives for the normal feedback condition. There is a small increase in speech errors for either auditory or tactile masking and both, but the errors are still few. That suggests that in the unperturbed trial, sensory information has a small contribution to producing correctly perceived speech. On the contrary, in the perturbed trials, speech errors are particular apparent in the initial fricative for every sensory feedback conditions, and the fricative is mostly misidentified as affricate /ch/. When the sensory feedback is normal, speech error almost disappears after the second syllable. When the sensory feedback is masked, some errors remain in the last syllable. The error score for both auditory and tactile masking is approximately the sum of the error rate for each masking condition. That means that auditory and tactile masking has an additive contribution to speech errors.

Table 1. Mean error score for fricative consonant identification (%)

Syllable No.	1	2	3	4	5	6	7	8
Unperturbed Trial								
Normal	0	0	0	3	3	5	3	0
Auditory mask.	0	3	3	3	3	5	14	0
Tactile mask.	0	8	5	3	5	5	11	11
Auditory & Tactile mask.	0	5	14	14	19	11	8	8
Perturbed Trial								
Normal	72	24	8	8	8	12	4	8
Auditory mask.	88	52	12	16	20	24	20	20
Tactile mask.	76	24	0	16	16	12	20	36
Auditory & Tactile mask.	68	44	36	36	40	48	60	56

ARTICULATORY AND EMG ANALYSIS

The compensatory responses to the palatal perturbation were compared among sensory feedback conditions in terms of their movements and EGG signal. Figure 1 shows speech waveforms, articulatory movements of the horizontal and vertical positions of the lower jaw and three points on the tongue from the tongue tip to the tongue body, and EMG signals. The unperturbed trial is denoted by thick line and the perturbed trial is denoted by thin line. The perturbation was given at the trigger onset, right here, and the subject become aware of the palatal change at the tongue-palate contact onset denoted by the vertical line.

Comparing articulatory trajectories in unperturbed and perturbed trials, rapid downward and backward shifts of the tongue for the perturbed trial are observed. The arrows in the figure show the instant at which perturbed and unperturbed trajectories become significantly departure. The downward shift occurs with time lag of around 100 ms from the tongue-palate contact onset. The backward shift of the tongue is more delayed and the time lag range of 200-400 ms. EMG magnitude in the perturbed trial rapidly increases just after the tongue-palate contact and gradually restores to the level of the unperturbed trial after the 4th syllable. This suggests that the rapid downward shift of the tongue is an active compensation by adjusting the motor control rather than a simple mechanical reaction by the tongue against the inflated palate.

Figure 2 shows articulatory movements and EMG signals of unperturbed and perturbed trials in tactile masking condition. Similar compensatory responses are observed in tongue movements, but the significant increase in the EMG magnitude associated to the downward shift of the tongue was not observed as compared with that in the normal feedback condition.

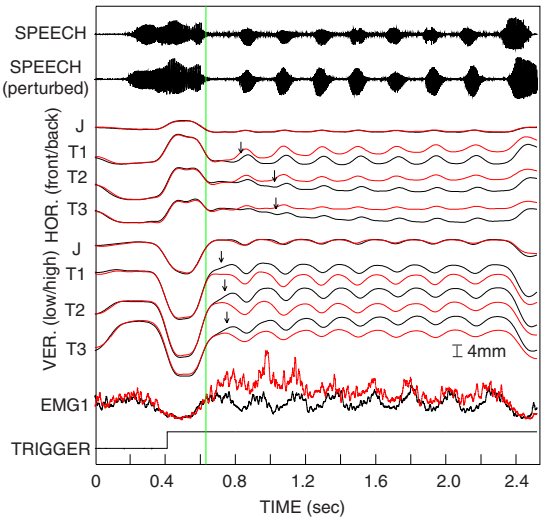


Fig. 1 Articulatory movements and EMG signals of unperturbed and perturbed trials in normal condition.

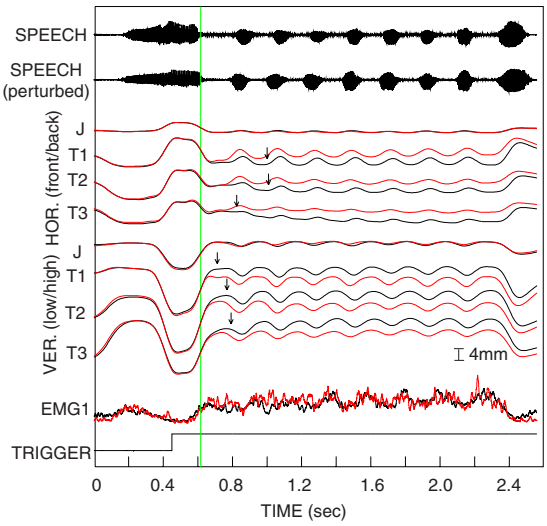
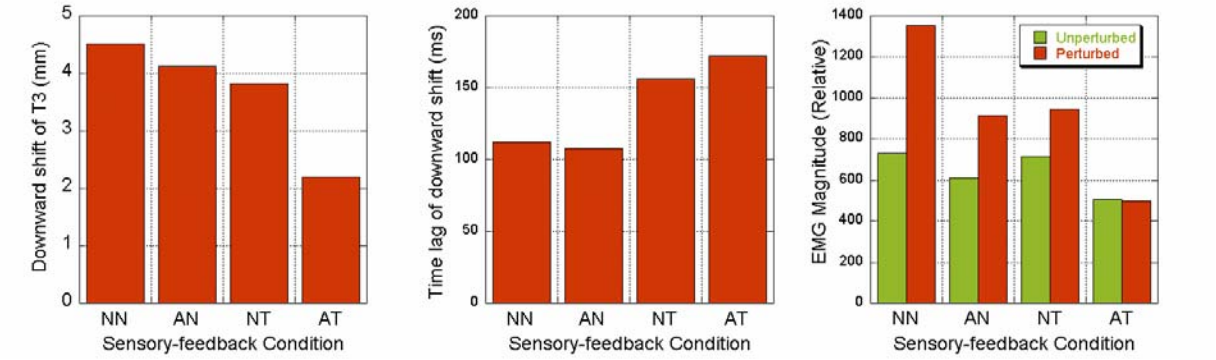


Fig.2 Articulatory movements and EMG signals of unperturbed and perturbed trials in tactile masking condition

Figure 3 summarizes the displacement of the downward shift, the time lag, and EMG magnitude at the first syllable for every feedback condition. When the sensory feedback is masked, displacement of the downward shift becomes smaller, which is most significant when auditory and tactile feedback is masked. The time lag in auditory masking is almost similar to that in the normal feedback. When tactile feedback masked, it becomes longer with by an additional delay 60 ms.This suggests that tactile feedback from sensing the contact between tongue and inflated palate has primarily contribution to the rapid downward shift of the tongue. EMG magnitude is nearly the same for every sensory feedback condition in the unperturbed trial. The muscle activity, however, is more suppressed in the perturbed

trial when either auditory or tactile feedback is masked, as compared with those in the normal feedback condition.



(a) (b) (c)

Fig. 3 (a) Displacement of downward shift of the tongue position T2, (b) time lage of the downward shift from the tongue-palate contact, and (c) EMG magnitude during the downward shift for normal (NN), auditory masking (AN), tactile masking (NT) and both masking (AT) conditions.

SUMMARY

We examined sensory feedback effects on the compensatory articulation in response to an unexpected palatal perturbation. Rapid compensatory tongue movement and change in the EMG magnitude were observed, which is suggesting that sensor feedback was used in active adjustment of speech motor control. Perceptual and articulatory results provided evidence of different contributions of auditory and tactile feedback to the compensatory response.

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