

Facial skin stretch induces reflexes for articulatory adjustment

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***Abstract.** Due to the lack of muscle spindles and tendons in the perioral motor system, cutaneous afferents may contribute to speech sensorimotor processes. We have investigated this possibility in the context of the upper lip cortical reflex response, which we have induced by an unexpected skin stretch around the skin lateral to angle of mouth. As a result, the functional reflex response was reliably observed by stretching the skin area under speech condition, whereas it did not under resting condition. This would suggest that the cutaneous mechanoreceptors at a specific local facial region provide kinesthetic information for functional rapid sensorimotor processing in speech motor control.*

1. Introduction

It is well known that sensory information strongly contributes to motor control (Wolpert et al. 2000). In multi-articulator coordination during speech, somatosensory information also plays an important role in the adjustment of articulatory motion (Abbs et al. 1983; Tremblay et al. 2003). During production of the bilabial fricative consonant / ϕ /, when jaw position is unexpectedly perturbed by an external force, an intact labial aperture is maintained by a quick response of the upper lip. This quick compensatory response is driven not only by mechanical muscle linkages (Gomi et al. 2002), but also by a transcortical reflex (Ito et al. 2005a). In the limb control system, this kind of reflex adjustment mainly depends on muscle proprioceptors (muscle spindles and tendons), which play a major role in providing kinesthetic information (McCloskey 1978). However, since perioral muscles lack spindles and tendons (Folkins et al. 1978; Stål et al. 1987; Stål et al. 1990), other afferents are expected to contribute to precise articulatory control. Recent finger studies (Collins et al 1996; Collins et al. 2006; Edin et al. 1995) have suggested that both cutaneous mechanoreceptors and muscle proprioceptors contribute to providing kinesthetic information. In perioral region, it has been reported that skin strain during articulatory motion is of sufficient magnitude to elicit a response in cutaneous mechanoreceptors (Conner et al. 1998) and that the infraorbital nerve is excited during speech movement (Johansson et al. 1988; Nordin et al. 1989). However, it is still unclear whether sensory information from cutaneous mechanoreceptors actually contributes to speech motor control.

To investigate this idea, we focused here on the upper lip cortical reflex for articulatory adjustment (Ito et al. 2005a) mentioned above, and examined whether or not stimulating cutaneous mechanoreceptors alone can induce this cortical reflex. We have observed that the skin lateral to the angle of mouth is stretched by the jaw perturbation that elicit this reflex (Ito et al. 2005b), accordingly we hypothesized that the facial skin lateral to angle of mouth is involved in the cortical reflex. To test this hypothesis, we have examined the upper lip muscle response to cutaneous stimulation by applying an unexpected facial skin stretch. We compared the responses to the skin stretches of three areas: above the angle of mouth (S_1), lateral to angle of mouth (S_2), and cheek lateral to S_2 (S_3).

2. Method

Four neurologically normal individuals (three Japanese speakers and one Korean speaker) participated in the experiment. All signed the informed consent form of the ethics committee of the NTT Communication Science Laboratories. Participants were seated in a dental chair and asked to sustain the bilabial fricative consonant / ϕ / for 2-3 s in the sentence 'kono / $a\phi a$ '. While producing the consonant, the facial skin was unexpectedly stretched downward by pulling two plastic plates (height: 3 cm, width: 4 cm) that were attached bilaterally on the face using double-sided tape. A thin wire cable was used to attach each plastic plate to a single-arm robotic device, which was used to apply a force with a magnitude and onset timing that was precisely controlled by a digital signal processor (TMS320C40, Texas Instrument Co., Dallas, Texas, USA). The perturbation force acted in stepwise manner, and its magnitude was set so as to generate 3 N at the point attached to the wire. A schematic view is shown in Fig. 1. Three stretch locations (S_1 : above angle of mouth, S_2 : lateral to angle of mouth and S_3 : around cheek lateral to S_2) are also depicted in this figure. 30 trials were carried out at each location, and the skin stretch perturbation (PTB) was applied in one third of 30 trials, which were selected randomly.

The reflex responses were quantified from electromyographic (EMG) signals of the upper lip muscle (orbicularis oris superior: OOS). Bipolar surface electrodes (Ag-AgCl) were placed on OOS just above vermilion border at right side of the face in Fig. 1. The EMG signal was amplified and filtered (band-pass: 50-1500 Hz) with a biomedical amplifier (MME-3116, Nihon Kohden, Shinjuku, Tokyo, Japan), and sampled by a computer. The participants monitored their muscle activity level and were instructed to maintain it within a particular range centered at a level for normal production of the task consonant. EMG amplitude was calculated by temporally averaging the rectified EMG signal using a 15 ms time window. This period was set based on the fact that 15 ms bin width have been adequate to capture both short and long perioral reflexes in previous study (McClellan 1991). The background EMG level was calculated based on the same time bin using the signal from the control condition. 10 control trials selected randomly were ensemble averaged after aligning the signals with respect to the trial onset and using EMG from the interval that would have been associated with the perturbation.

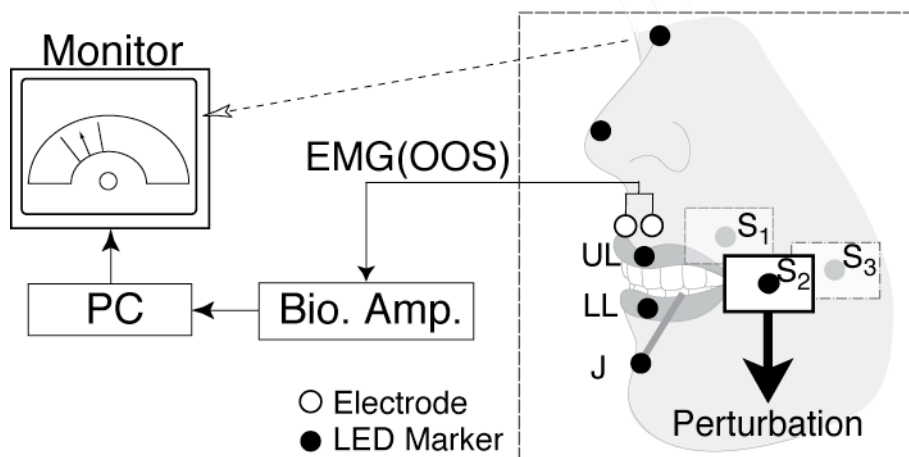


Figure 1. Schematic view of experimental set up and stretch locations [S_1 : above angle of mouth, S_2 : lateral to angle of mouth, and S_3 : around cheek lateral to S_2]. In left facial side, stretch PTB is also delivered at the same site depicted in figure.

Displacement of the articulators [the jaw (J), the upper lip (UL) and lower lip (LL)], and the amplitude of skin stretch PTB were measured concurrently using OPTOTRAK system (NDI, Waterloo, Ontario, Canada) at 250 Hz. LED markers were put on the midline of the vermillion for the UL and LL, on the end of a bar attached from left canine tooth for the J, on the center of the plastic plate for the PTB, and on the nasion and the top on the nose for off-line calibration, as shown in Fig. 1.

The reflex was also recorded under resting condition in order to verify speech-specific characteristics and to assess its similarity to the perioral reflex that is induced by lip tapping (Bratzlavsky 1979; McClean 1991), stretching the angle of mouth (Folkins et al. 1972), or electrical stimulation of trigeminal nerve (Gandiglio et al. 1967). Since one participant did not show the short latency reflex, this experiment was carried out only for the other three participants. The participants were asked to rest completely without any muscle activation and to hold a static posture, in which the mouth was opened slightly so as to eliminate muscle activation for mouth closing. We verified using the muscle activation monitored that there was little or no activation of OOS during this experiment. Perturbations were delivered on each of 10 trials.

3. Results

By stretching the skin lateral to angle of mouth (S_2) during bilabial fricative production, reflex responses of the upper lip were induced in multiple phases. The typical response was shown in Fig. 2(a). First phase occurred 30 ms after PTB onset, and second one followed 50 ms after PTB onset. Based on the previous findings concerning the perioral reflex (Bratzlavsky 1979; Gandiglio et al. 1967; McClean 1991; Smith et al. 1987) and the cortical reflex for speech adjustment (Gomi et al. 2002; Ito et al. 2005a), we distinguished responses according to response latency as R1: 30-45 ms after PTB, and R2: 50-65 ms after PTB [shaded areas in Fig. 2(a)]. Although the muscle activity increase sustained after 65 ms in Fig. 2(a), we did not examine it in our analysis because this sustained activity after 65 ms was not observed consistently across all participants.

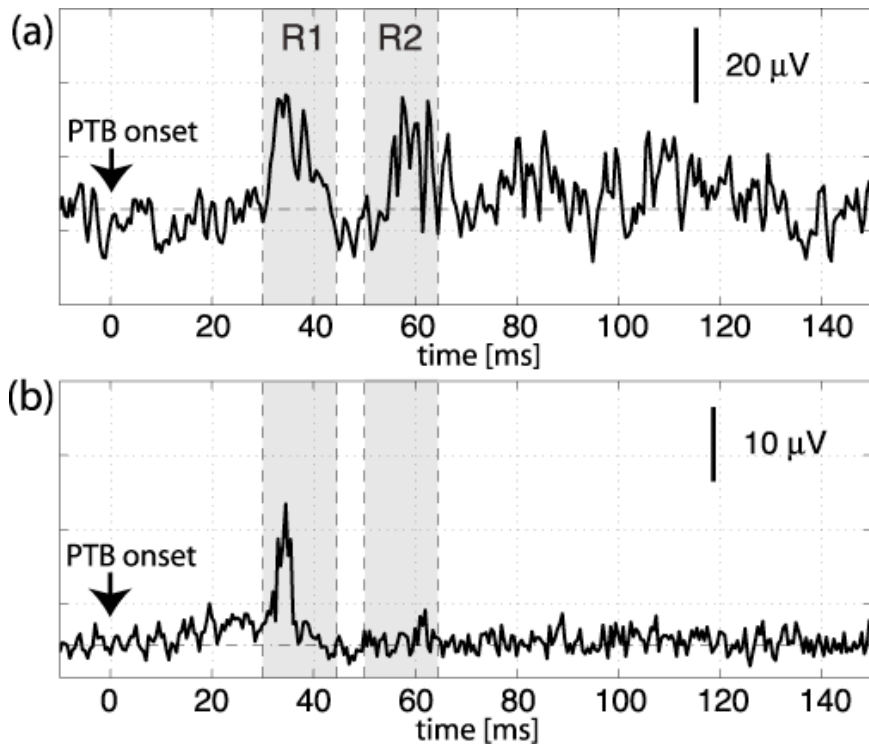


Figure 2. Typical response of the upper lip muscle (OOS) following skin stretch at S₂ (a) during bilabial fricative consonant production, and (b) under resting conditions (Participant 4). Time zero is the onset of the skin stretch perturbation. The horizontal dashed lines show average background EMG levels in each task condition. The two shaded areas denote the period 30-45 ms and 50-65 ms after perturbation onset, respectively.

The R2 response was clearly observed in all participants; whereas R1 was induced in three of four participants. The average of maximum downward displacement of the jaw in the period between 0-100 ms after PTB onset was quite small (0.20 ± 0.11 mm in all participants), indicating little influence of this skin stretch PTB on jaw position. Therefore, it seems unlikely that afferent information due to jaw motion is involved in generating the observed reflexes.

Under resting condition (without speech), R1 was clearly present but R2 was not [Fig. 2(b)]. This pattern was observed for all three participants, suggesting that different neural processing is involved in generating R1 and R2. Taken together with the previous studies of perioral and cortical reflexes (Ito et al. 2005a; McClean 1991), it is reasonable to assume that R2 corresponds to the cortical reflex for articulatory adjustment, and R1, the perioral reflex mediated within the brainstem.

To examine involvement of the skin lateral to angle of the mouth, we compared muscle responses with those resulting from skin stretch in the other two locations (S₁, S₃). Note that skin stretch at S₁ and S₃ had similarly small effects on jaw position. The R2 amplitudes for stimuli at the three skin areas are summarized in Figure 3. R2 was not reliably produced by skin stretch at S₁ and S₃, while it was clearly induced by stretch at S₂.

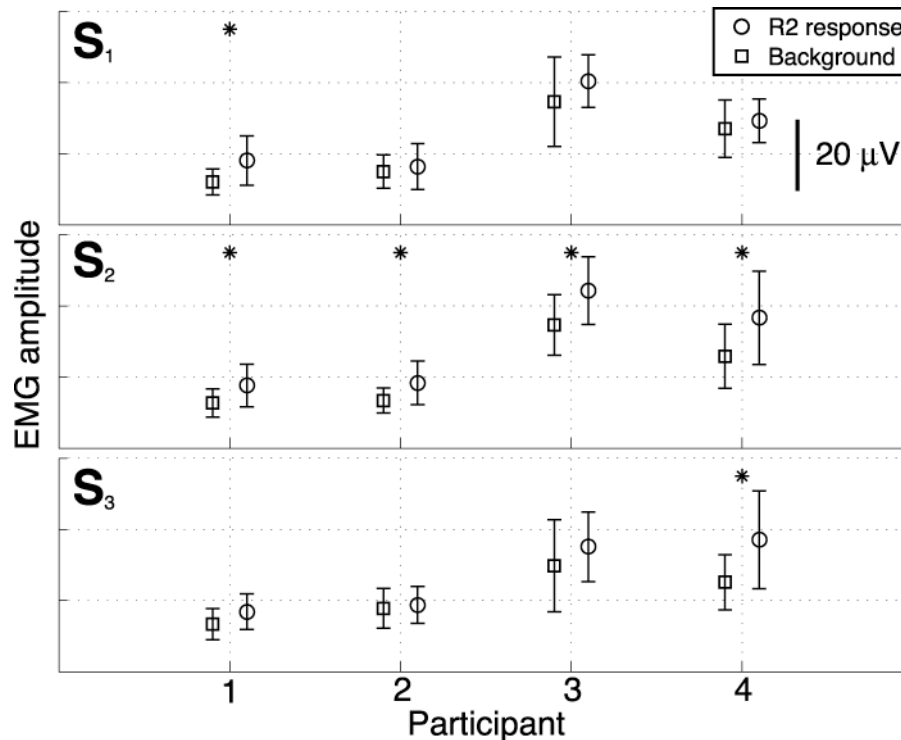


Figure 3. The difference in the R2 response among the three stretch locations (S_1 , S_2 , and S_3) for all participants. Each row gives the results of each stretch location. Circles represent average magnitude of R2 response, and squares represent background EMG levels in the speech task. Error bars show standard deviations. * represents significant differences between reflex amplitude and background EMG level by t-test ($p < 0.05$).

This suggests that afferent information from specific mechanoreceptors associated with the skin lateral to angle of the mouth plays a crucial role in the sensorimotor processing for this cortical reflex.

The skin stretch PTB around the angle of the mouth also induced a downward motion of the upper lip because of the mechanical connection to the skin. The afferent signal associated with the upper lip motion could be involved in generating the resultant reflex muscle activity. In case of the skin stretch at S_2 , the average and standard deviation of maximum displacement of the upper lip was 0.90 ± 0.38 mm in all participants. Compared to the lip displacement due to skin stretch at the other locations, the stretch at S_1 produced smaller lip displacement in two participants and larger in the other two, although its average (0.96 ± 0.34 mm) was not significantly different from the displacement due to the stretch at S_2 ($p > 0.8$ by t-test). As for S_3 , on the other hand, smaller lip displacement (0.31 ± 0.21 mm) was observed in all participants probably because the stimulus location was far from the lip. Given that R2 was observed primarily in conjunction with the stretch at S_2 and that the correlation coefficient between amplitude of R2 EMG activity and the amplitude of upper lip displacement across four subjects was small ($r = 0.11 \pm 0.13$), there is little or no relation between the upper lip motion due to the skin PTB and the inducement of R2. We therefore conclude

that R2 is mediated not by autogenic afferent signal associated with upper lip motion, but by the cutaneous afferent signal due to skin stretch around the angle of the mouth.

Finally, it is noteworthy that all participants reported that they felt a sensation of jaw downward movement mostly in case of the skin stretch at S₂, although they were aware of little or no jaw motion due to the skin stretch.

4. Discussion

Our previous works demonstrated that transcortical reflexes are involved in speech motor control (Ito et al. 2005a). However, it is still unclear which mechanoreceptors provide kinesthetic information in this rapid sensorimotor processing because of the lack of muscle spindles and tendon afferents in the perioral motor system. In the present study, skin stretch alone induced two reflex responses of the upper lip (R1 and R2) that were not associated with systematic articulatory motion. One of them, R2, was reliably observed under speech conditions, but not under rest conditions. This was consistent with the previous result (Gomi et al. 2002) that reflex articulatory adjustment was induced by jaw perturbation during fricative consonant production, but was not observed during vowel production (little muscle activation of OOS). Moreover, the response latency of R2 was similar to that resulted from jaw perturbation (48.25 ± 1.2 ms in Gomi et al. 2002). Specifically, it appears that R2 may be the same cortical reflex observed in the previous study using jaw perturbation (Gomi et al. 2002; Ito et al. 2005a). Our result concerning R2 therefore suggests that cutaneous mechanoreceptors in the perioral region contribute in providing kinesthetic information for the cortical reflex. Since we have examined there was little contribution of airflow and periodontal receptors to generating the cortical reflex due to jaw perturbation (Ito et al. 2005b), cutaneous mechanoreceptors might possibly be a primary source of kinesthetic information, although we have to explore the involvement of spindles in the jaw.

According to preliminary observation that the skin lateral to angle of the mouth was primarily stretched by jaw perturbation (Ito et al. 2005b), we had initially hypothesized that the cutaneous mechanoreceptors in the skin were involved in generating the cortical reflex for speech adjustment. This hypothesis is supported by our results that R2 was induced due to skin stretch lateral to angle of mouth, although our skin stretch method may be coarse because of relatively large stimulus area (12 cm²) compared with the median innervation territory per a fascicle (3.8 cm² in Nordin et al. 1989). This location is accord with the area in which cutaneous mechanoreceptors were activated in relation with a passive jaw motion (Appenteng et al. 1982). Considering the participant's report that they felt sensation of downward shift of the jaw, despite little or no jaw motion, mostly due to the skin stretch PTB at S₂, the mechanoreceptors in the skin lateral to angle of the mouth could be utilized for sensing the jaw motion. Moreover, this might imply that, even though there is little physical jaw motion, the observed R2 reflex is caused by a false sensation of jaw motion induced by kinesthetic information produced by the skin stretch.

The R1 reflex was elicited in this experiment under both speech and non-speech conditions. This was incompatible with the task dependency of the cortical reflex mentioned above. Moreover, R1 has shorter latency (around 30 ms) than that of the

cortical reflex (around 50 ms). It thus seems to be equivalent to the perioral reflex with longer latency shown in McClean 1991. Given that the perioral reflex is induced by the stimulus to the cutaneous mechanoreceptors (Bratzlavsky 1979; Gandiglio et al. 1967), our skin stretch PTB provided adequate stimulation for activating cutaneous mechanoreceptors in the perioral region. Previous studies showed that stretching laterally angle of mouth induced the perioral reflex (Larson et al. 1978), whereas innocuous mechanical stimuli at the skin 5 mm lateral to angle of mouth and the cheek did not (Smith et al. 1987). Therefore, we suggest that R1 originate from the mechanoreceptors around the vermilion rather than in the skin lateral to angle of the mouth, unlike R2 response.

Previous studies have investigated whether the gain of the perioral reflex could be adjusted according to the orofacial task, such as mastication and speech (Bratzlavsky 1979, McClean 1991). In our current observations, R1 was not induced in the speech task for one participant who exhibited a normal perioral reflex in response to tapping on the vermilion, whereas, in the other three participants, R1 was induced in both speech and non-speech conditions. This is consistent with the possibility that the gain of the perioral reflex may be adjusted depending on individual strategies for speech motor control. However, further investigation is required to clarify the control of the perioral reflex.

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