Cutaneous mechanoreceptors contribute to the generation of a cortical reflex in speech

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Owing to the lack of muscle spindles and tendon organs in the perioral system, cutaneous receptors may contribute to speech sensorimotor processes. We have investigated this possibility in the context of upper lip reflexes, which we have induced by unexpectedly stretching the facial skin lateral to the oral angle. Skin stretch at this location resulted in long latency reflex responses that were similar to the cortical reflexes observed previously. This location reliably elicited the reflex response, whereas the skin above the oral angle and the skin on the cheek did not. The data suggest that cutaneous mechanoreceptors are narrowly tuned to deformation of the facial skin and provide kinesthetic information for rapid sensorimotor processing in speech. *NeuroReport* 18:907–910 © 2007 Lippincott Williams & Wilkins.

Keywords: articulatory coordination, kinesthetic information, perioral reflex, sensorimotor processing

Introduction

It is well known that sensory information contributes significantly to motor control [1]. In multiarticulator coordination during speech, somatosensory information also plays an important role in the adjustment of articulatory motion [2,3]. 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 [4], but also by a transcortical reflex [5]. In the limb control system, this kind of reflex adjustment mainly depends on muscle proprioceptors (muscle spindles and tendon organ afferents), which play a major role in providing kinesthetic information [6]. As perioral muscles lack spindles and tendons [7–9], however, other receptors must contribute to precise articulatory control. Recent studies of finger movement [10–12] suggest that cutaneous mechanoreceptors and muscle proprioceptors both contribute to providing kinesthetic information. In the perioral region, it has been reported that skin strain during articulatory motion is of sufficient magnitude to elicit a response in cutaneous mechanoreceptors [13] and that the infraorbital nerve is excited during speech movement [14,15]. It is, however, 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, described above [5], and examined whether stimulating cutaneous mechanoreceptors alone can induce this cortical reflex. We have observed that the skin lateral to the oral angle is stretched by the jaw perturbation that elicits this reflex [16], so we suggest that the facial skin lateral to the oral angle 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 response with skin stretch that was applied in three areas: above the oral angle (S_1), lateral to the oral angle (S_2), and on the cheek lateral to S_2 (S_3).

Methods

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/ in the sentence ‘kono /aϕa/’ for 2–3 s. As the subject produce the consonant, the facial skin was unexpectedly stretched downward by pulling two plastic tabs (height: 3 cm; width: 4 cm) that were attached bilaterally to the face using double-sided tape. A thin wire cable was used to attach each plastic tab to a robotic device, which, in turn, applied 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 3N at the point attached to the wire. A schematic view is shown in Fig. 1. Three stretch locations (S_1, S_2, and S_3) are also depicted in this figure. Thirty trials were carried out at each location, and the skin stretch perturbation was

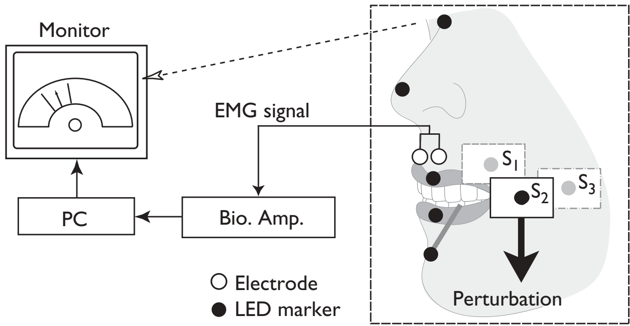

Fig. 1 Schematic view of the experimental set up and stretch locations (S_1: above the oral angle, S_2: lateral to the oral angle, and S_3: on the cheek lateral to S_2). The skin stretch perturbation is also delivered to the right side of the face at the corresponding site depicted in figure.

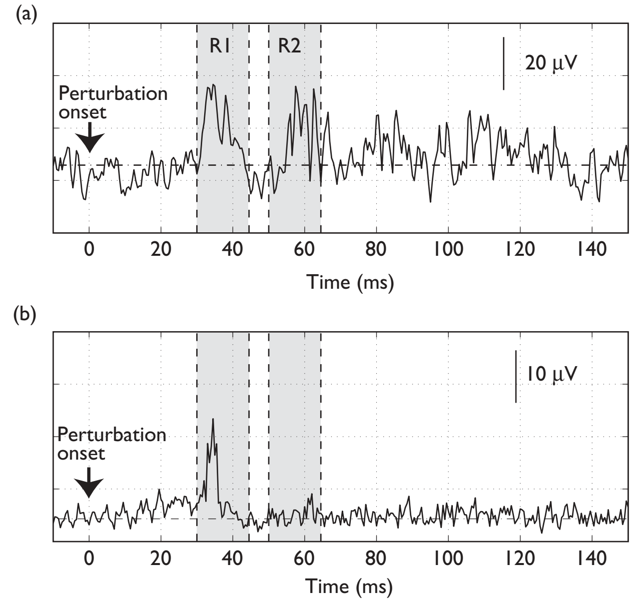

Fig. 2 Typical response of the upper lip muscle following skin stretch at S_2 (a) during bilabial fricative consonant production and (b) under resting conditions (participant 4). Time zero is the onset of the skin stretch perturbation. The horizontal dashed lines show average background electromyogram levels in each task condition. The two shaded areas denote the period 30–45 and 50–65 ms after perturbation onset, respectively.

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). Bipolar surface electrodes (Ag–AgCl) were placed on the upper lip muscle just above the 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 chosen because a 15-ms bin width had been adequate to capture both short and long perioral reflexes in a previous study [17]. The background EMG level was calculated using the same time bins from the EMG signal of the control condition. Ten randomly selected control trials 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.

Displacement of the articulators (jaw, upper lip, and lower lip), and the amplitude of skin stretch perturbation were measured concurrently at 250 Hz using the OPTOTRAK system (NDI, Waterloo, Ontario, Canada). Light-emitting diode (LED) markers were put on the midline of the vermilion border for the upper lip and lower lip, on the end of a bar attached to the left canine tooth of the jaw, on the center of the plastic tab for the point of perturbation application, and on the nasion and the top on the nose for offline calibration, as shown in Fig. 1.

The reflex response was also recorded under resting conditions to determine the extent to which it is task specific and to assess its similarity to the perioral reflex [17–20]. As 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 that there was little or no activation of the upper lip muscle during the resting phase of this experiment. Perturbations were delivered on each of 10 trials.

Results

By stretching the skin lateral to the oral angle (S_2) during bilabial fricative production, reflex responses of the upper lip were induced in multiple phases. The typical response is shown in Fig. 2a. The first phase occurred 30 ms after perturbation onset, and the second one followed 50 ms after perturbation onset. On the basis of previous findings concerning the perioral reflex [17,18] and the cortical reflex for speech adjustment [4,5], we distinguished responses according to response latency as R1: 30–45 ms after the perturbation, and R2: 50–65 ms after the perturbation (shaded areas in Fig. 2a). Although the muscle activity increase was in some cases present after 65 ms in Fig. 2a, we did not examine this in our analysis because sustained activity after 65 ms was not observed consistently in all participants. The R2 response was clearly observed in all participants; whereas R1 was induced in three of the four participants. The average of maximum downward displacement of the jaw in the period between 0 and 100 ms after perturbation onset was quite small (0.20 ± 0.11 mm in all participants), indicating little influence of the skin stretch perturbation on jaw position. Therefore, it seems unlikely that afferent information owing to actual jaw motion is involved in generating the observed reflexes.

Under resting conditions (without speech), R1 was clearly present but R2 was not (Fig. 2b). 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 [5,17], it is reasonable to assume that R2 corresponds to the cortical reflex for articulatory adjustment, and R1, is the perioral reflex mediated within the brainstem.

To examine the involvement of the skin lateral to the oral angle, we assessed muscle responses to skin stretch in two

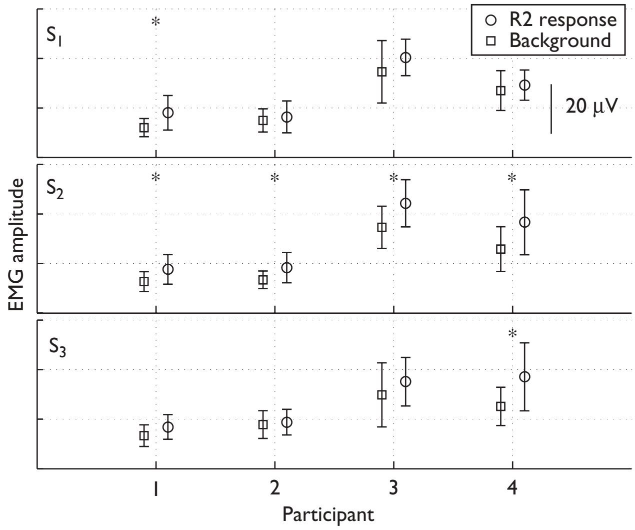

Fig. 3 The difference in the R2 response among the three stretch locations (S_1, S_2, and S_3) for all participants. Each row gives the results at each stretch location. Circles represent the average magnitude of the R2 response, and squares represent background electromyogram (EMG) levels in the speech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

other locations (S_1, S_3). Note that skin stretch at S_1 and S_3 had similarly small effects on jaw position. The R2 amplitudes for stimuli at the three skin locations are summarized in Fig. 3. R2 was not reliably produced by skin stretch at S_1 and S_3, whereas it was clearly induced by stretch at S_2. This suggests that afferent information from specific mechanoreceptors associated with the skin lateral to the oral angle plays a crucial role in the sensorimotor processing for this cortical reflex.

The skin stretch perturbation around the oral angle also induced a downward motion of the upper lip because of the mechanical connection to the skin. An afferent signal associated with upper lip motion could be involved in generating the resulting 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 with the lip displacement because of skin stretch at the other locations, the stretch at S_1 produced smaller lip displacement in two participants and larger displacement in the other two, although its average (0.96 ± 0.34 mm) was not significantly different from the displacement because of the stretch at S_2 ($p > 0.8$ by *t*-test). As for S_3, in contrast, 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 the amplitude of R2 EMG activity and the amplitude of upper lip displacement across the four participants was small ($r = 0.11 \pm 0.13$), there is no indication of a relation between the upper lip motion owing to the skin perturbation and the inducement of R2. We therefore conclude that R2 is mediated not by an autogenic afferent signal associated with upper lip motion, but by the cutaneous afferent signal because of skin stretch around the oral angle.

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 S_2 despite little or no jaw motion because of the skin stretch.

Discussion

Our previous work demonstrated that transcortical reflexes are involved in speech motor control [5]. It is, however, 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 this study, skin stretch alone induced two reflex responses of the upper lip (R1 and R2). One of them, R2, was reliably observed under speech conditions, but not under rest conditions. This was consistent with the previous result [4] that reflex articulatory adjustment was induced by jaw perturbation during fricative consonant production, but was not observed during vowel production (little activation of the upper lip muscle). Moreover, the response latency of R2 was similar to that which resulted from jaw perturbation (48.25 ± 1.2 ms in Ref. [4]), and R2 was not associated with systematic articulatory motion. Specifically, it appears that R2 may be the same cortical reflex observed in the previous study using jaw perturbation [4,5]. Our result concerning R2 therefore suggests that cutaneous mechanoreceptors in the perioral region contribute in providing kinesthetic information for the cortical reflex.

Although our skin stretch method may not be precisely focused because of its relatively large stimulus area ($12\,cm^2$), R2 was specifically induced by skin stretch lateral to angle of mouth. This observation is consistent with our hypothesis that cutaneous mechanoreceptors in the skin lateral to the oral angle are involved in generating the cortical reflex for speech adjustment as suggested in the Introduction. Passive jaw motion activates cutaneous mechanoreceptors in this same area of facial skin [21]. Moreover, the participants reported that they felt a sensation of downward shift of the jaw mostly because of the skin stretch perturbation at S_2 despite little or no jaw motion. Taken together, the mechanoreceptors in the skin lateral to the oral angle could be utilized for sensing jaw motion. If so, the observed R2 reflex would be caused by a false sensation of jaw motion induced by kinesthetic information produced by the skin stretch even though there is little physical jaw motion.

The R1 reflex was elicited in this experiment under both speech and rest conditions. This was unlike the task dependency of the cortical reflex mentioned above. Moreover, R1 has a shorter latency than the cortical reflex (30 vs. 50 ms). It thus seems to be identical to the perioral reflex reported in Refs. [17–20,22]. Although the R1 reflex was induced easily by the current skin stretch perturbation, this type of reflex has never been observed in our previous studies using jaw perturbation [4,5]. A possible reason for this difference is that the cutaneous mechanoreceptors involved in the R1 and R2 responses may be in different areas of the facial skin. This idea is consistent with our current demonstration that stretching the skin lateral to the oral angle is involved in the generation of R2 and the fact that tapping and stretching the vermilion boarder of the lip is particularly effective in inducing a perioral reflex [17–19,22].

Previous studies have investigated whether the gain of the perioral reflex could be adjusted according to the orofacial task, such as mastication or speech [17,22]. 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 border of the lip, whereas, in the other three participants, R1 was induced in both speech and rest 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. Further investigation is, however, required to clarify the control of the perioral reflex.

Conclusion

The effect of mechanical stimulation of cutaneous mechanoreceptors in the perioral skin was studied in the context of the upper lip cortical reflex for articulatory adjustment. Stimulation of the skin lateral to angle of mouth produced a task-specific long latency (around 50 ms) reflex that is presumably cortical in origin. This would suggest that, in the perioral region that lacks muscle spindles and tendon organs, cutaneous receptors provide kinesthetic information used in high-level computations in speech motor control.

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