Journal of Orthodontics, Vol. 29, 2002, 307–313

SCIENTIFIC SECTION

Breathing modes, body positions, and suprahyoid muscle activity

S. Takahashi and T. Ono
Tokyo Medical and Dental University, Japan

Y. Ishiwata
Ebina, Kanagawa, Japan

T. Kuroda
Tokyo Medical and Dental University, Japan

Abstract

Aim: To determine (1) how electromyographic activities of the genioglossus and geniohyoid muscles can be differentiated, and (2) whether changes in breathing modes and body positions have effects on the genioglossus and geniohyoid muscle activities.

Method: Ten normal subjects participated in the study. Electromyographic activities of both the genioglossus and geniohyoid muscles were recorded during nasal and oral breathing, while the subject was in the upright and supine positions. The electromyographic activities of the genioglossus and geniohyoid muscles were compared during jaw opening, swallowing, mandibular advancement, and tongue protrusion.

Results: The geniohyoid muscle showed greater electromyographic activity than the genioglossus muscle during maximal jaw opening. In addition, the geniohyoid muscle showed a shorter ($P < 0.05$) latency compared with the genioglossus muscle. Moreover, the genioglossus muscle activity showed a significant difference among different breathing modes and body positions, while there were no significant differences in the geniohyoid muscle activity.

Conclusion: Electromyographic activities from the genioglossus and geniohyoid muscles are successfully differentiated. In addition, it appears that changes in the breathing mode and body position significantly affect the genioglossus muscle activity, but do not affect the geniohyoid muscle activity.

Index words:
Body position, breathing mode, genioglossus muscle, geniohyoid muscle.

Received 10 January 2002; accepted 4 July 2002

Introduction

The mammalian genioglossus (GG) and geniohyoid (GH) muscles are both innervated by the medial branch of the hypoglossal nerve.[1–4] The GH muscle is one of the suprahyoid muscles, which acts during mastication and deglutition. It is well known that contraction of the GH muscle advances the hyoid bone thus dilating the upper airway.[5–7] Therefore, the GH muscle serves as an accessory respiratory muscle.[8] Previous studies have investigated electromyographic (EMG) activity of the GH muscle in reference to ingestion and respiration in both animals[9–11] and humans.[5,6,12–17] However, it is difficult to differentiate EMG activity of the GG and GH muscles using surface[16,17] or needle[5,6,12–15,18] electrodes due to the proximity of these muscles. Most previous studies have determined the position of the tip of needle electrode purely by anatomical landmarks.[12,13,15,18] However, Wiegand and colleagues[5,6] determined anatomical landmarks for placement of intra-muscular electrodes for EMG recording from the GH muscle in the cadaver. Unfortunately, they did not confirm whether the intra-muscular electrode was placed in the GH muscle and not in the GG muscle. Nevertheless, O'Dwyer and associates[14] failed to functionally differentiate EMG activities from different muscles by speech-related gesture.

Recently, we demonstrated that the resting tongue pressure on the lingual surface of the mandibular incisors showed respiratory-related oscillations, with a maximal value during expiration and a minimal value

Address for correspondence: Takashi Ono, Maxillofacial Orthognathics, Graduate School, Tokyo Medical and Dental University, 5–45 Yushima 1-chome, Bunkyo-ku, Tokyo, 113–8549 Japan. Email: t-ono.mort@tmd.ac.jp.

during inspiration.[19] In addition, changes in the mode of breathing and body position influenced tongue pressure and EMG activity of the GG muscle. As a result, we suggested that change of the maximum tongue pressure, and mode of breathing and body position was responsible for the GG EMG activity. Furthermore, we speculated that these factors may have an important role in determining the maximum tongue pressure.[19] We, therefore, suggested that change in breathing modes and body position have the same effects on the GH EMG activity as they do on the GG EMG activity. To test this hypothesis, it is necessary to establish a lay method to differentiate the GH EMG activity from that of the neighboring muscles including the GG muscle.

It has also been shown that the canine GG muscle could be divided into horizontal and oblique compartments.[20] The horizontal compartment has a slow muscle fibre profile, suggesting that it is related to respiratory function. In contrast, the canine GH muscle has a relatively low percentage of the slow muscle fibre compared to the horizontal component of the GG muscle in canine.[21] Although the angle between the oral cavity and the upper airway in canine is apparently different from that of humans, one may be able to separate the human GG EMG activity from that of the GH muscle by the neuromuscular characteristics.

The purposes of this study were determine:

- a method of differentiating EMG activities of GG and GH;
- if changes in breathing modes and body positions had effects on the GG and GH EMG activities.

Materials and methods

Subjects

This study was carried out in 10 skeletal Class I males with a mean age of 28.6 ± 2.3 (mean ± SD) years. Subjects with an ongoing respiratory infection or who were taking any medication that was known to affect muscle activity were excluded from the study. They all had a complete dentition with the exception of the third molars. Each subject had a normal overjet and overbite. Informed consent was obtained from each person prior to the study.

EMG recording

The respiratory movement of the chest wall was simultaneously recorded using an inductance band (TR-751T, Nihon-Kohden, Tokyo, Japan). The EMG activity of the right GG and GH muscles was recorded monopolarly using a stainless steel fine-wire electrode. The electrode was inserted through the lingual sulcus for the GG muscle, while the electrode was inserted extraorally at a point 10 mm off the mid-point between the mandibular symphysis and the hyoid bone for the GH muscle.[14] A neutral electrode was placed on the right ear lobe. The wire electrodes were 0.03 mm in diameter and insulated with urethane. The tip of the electrode was bared approximately 1 mm. After waiting for 15 minutes following insertion of the electrode, we compared the EMG activity without abnormal sporadic discharge during jaw opening, swallowing, mandibular advancement, as well as tongue protrusion to confirm that the EMG signals were recorded from either the GG or the GH muscle. During experimental sessions, the subjects reported no problems with pain and discomfort due to the placement of the electrode.

Protocol

The subjects sat in a reclining chair with a headrest in an upright position and were instructed to remain awake with both eyes open. After identification of two muscles, respiratory movement, the GH, and GG EMG activities were recorded simultaneously over 20 respiratory cycles during quiet breathing through the nose with the mouth completely closed. Recordings were then repeated while the subject quietly breathed through the mouth with the nose completely occluded using a clip. The chair was then reclined and the subject lay down in a supine position. After at least 5 minutes, the protocol was repeated. EMG signals were amplified and band-pass filtered at 30 Hz to 1 kHz. After conversion of the signals through an A/D converter (Maclab/8S, ADinstruments, Castle Hill, Australia), they were then stored in a personal computer (Macintosh Performa 5270, Apple Computer, Cupertino, CA, USA) for data analysis.

Data analysis

The onset and latency of the EMG activity during four tasks were defined as described in Figure 1. A paired t-test was used to compare the latency between the GG and GH muscles for 10 trials from 10 subjects. In each subject, 10 respiratory phases were randomly selected during oral and nasal breathing in both the upright and supine positions. Both the GG and GH EMG signals that had been stored in the personal computer in selected

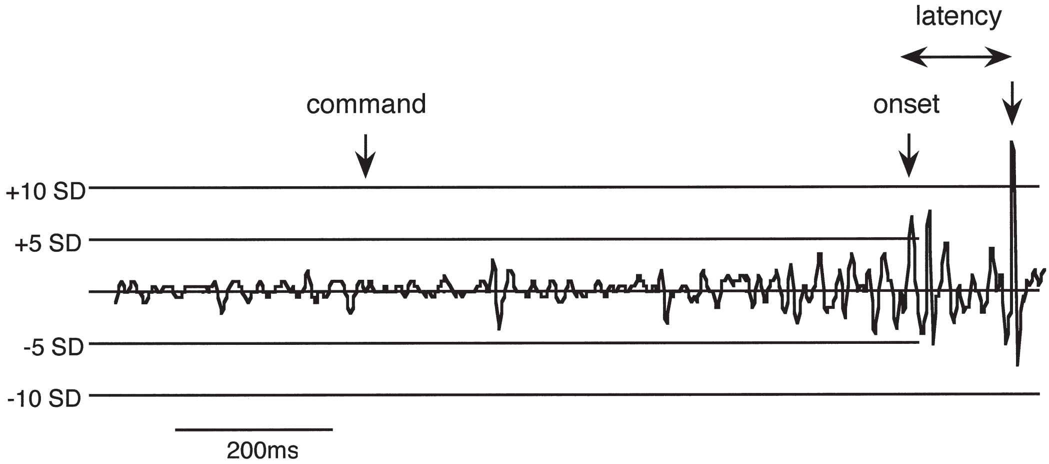

Fig. 1 Definitions of the onset and latency of the electromyographic activity. The onset was defined when the electromyographic activity exceeded the level of 5 standard deviations of the baseline electromyographic activity in association with jaw opening. The baseline electromyographic activity was calculated during 200 ms before verbal command of jaw opening. The latency was measured between the onset and the timing when the electromyographic activity reached the level of 10 standard deviations of the baseline electromyographic activity. Abbreviation: *SD*, standard deviation.

respiratory phases were integrated with a time constant of 200 ms. The mean minimum amplitude of EMG activity in the expiratory phase was determined in each condition. The mean EMG amplitude in each condition was normalized to the mean EMG amplitude in the expiratory phase during nasal breathing in the upright position in each subject. A one-way repeated analysis of variance (ANOVA) and contrasts were used to compare the maximum value of the tongue pressure, and both the GG and GH EMG activities among the different respiratory modes and body positions. Statistical significance was established at $P < 0.05$.

Results

Both the GG and GH muscles show EMG activity during jaw opening, swallowing, mandibular advancement, and tongue protrusion (Figure 2A). In all 10 subjects, maximum GH EMG activity was always greater than that of the GG muscle during jaw opening. The latency of the GG EMG activity elicited by jaw opening was significantly longer than the GH muscle (Figure 2B). On the other hand, there were no significant differences between the latency of the two muscles during swallowing, and mandibular advancement and tongue protrusion.

Figure 3A shows a typical simultaneous record of chest wall movement, the GG and GH EMG activities during nasal breathing in the upright position in a subject. Among the 10 subjects, seven subjects showed the respiratory-related EMG activity in both muscles (Table 1). However, neither muscle showed any respiratory-related EMG activity in one subject. The mean amplitude of the GG EMG activity during expiration in different breathing modes and body positions is illustrated in Figure 3Ba. A significant difference was found between nasal and oral respiration in the supine position, while there was no significant difference between nasal and oral respiration in the upright position. In addition, there were significant differences between the upright and supine positions during both oral and nasal respiration. The GH EMG activity during expiration in

Table 1 The degree of inspiratory phasic EMG activity in 10 subjects

Subject	GG	GH
1	++	+
2	++	–
3	++	++
4	++	++
5	++	+
6	–	–
7	++	+
8	+	++
9	+	++
10	++	–

The degree of EMG activities of the GG and GH muscles was arbitrarily graded as evident (++), weak (+), or indiscernible (–) to describe the phasic EMG activity during inspiration.

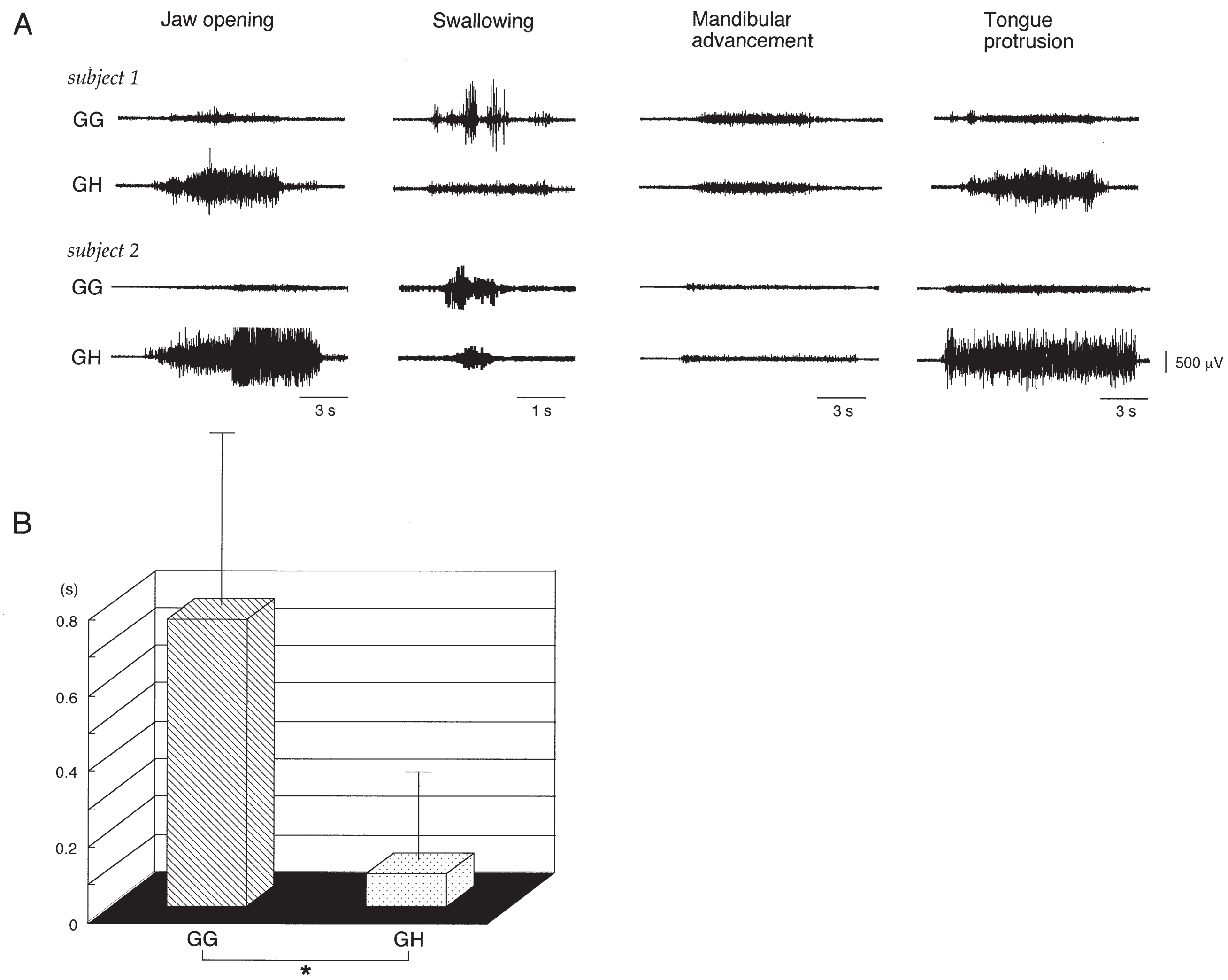

Fig. 2 (A) Typical simultaneous records of electromyographic activities of the genioglossus and geniohyoid muscles during jaw opening, swallowing, mandibular advancement and protruding the tongue in representative two individuals. Vertical bar represents 500 μV for both the genioglossus and geniohyoid muscle activities, and horizontal bar represents 1 second for swallowing and 3 seconds for other maneuvers. The geniohyoid muscle activity is truncated in the second half during jaw opening in the subject 2. (B) Comparison of the latency of electromyographic activity between the genioglossus and geniohyoid muscles during jaw opening. $*P < 0.05$. Abbreviations for this and the following figure: *GG*, genioglossus muscle; *GH*, geniohyoid muscle.

different breathing modes and body positions is illustrated in Fig. 3Bb. No significant differences were found between different breathing modes and body positions.

Discussion

With respect to the motor task to differentiate EMG signals from either the GG or the GH muscles, we asked the subjects to perform jaw opening and mandibular advancement because both the GG and GH muscles have close anatomical relationship with both the tongue and mandible. Likewise, both muscles show close temporal interaction during swallowing. It is known that the GG muscle shows maximum contraction during tongue protrusion. Consequently, we employed these four tasks to segregate EMG signals from either the GG muscle or the GH muscle. Maximum EMG activity of GH was greater than that of the GG muscle during jaw opening in all subjects. In addition, the latency of the EMG onset of the GH muscle was significantly shorter than that of the GG muscle. While, we applied unipolar electrode technique that inevitably accompanies the problem of picking up EMG activity from adjacent muscles. However, our results suggest that jaw opening

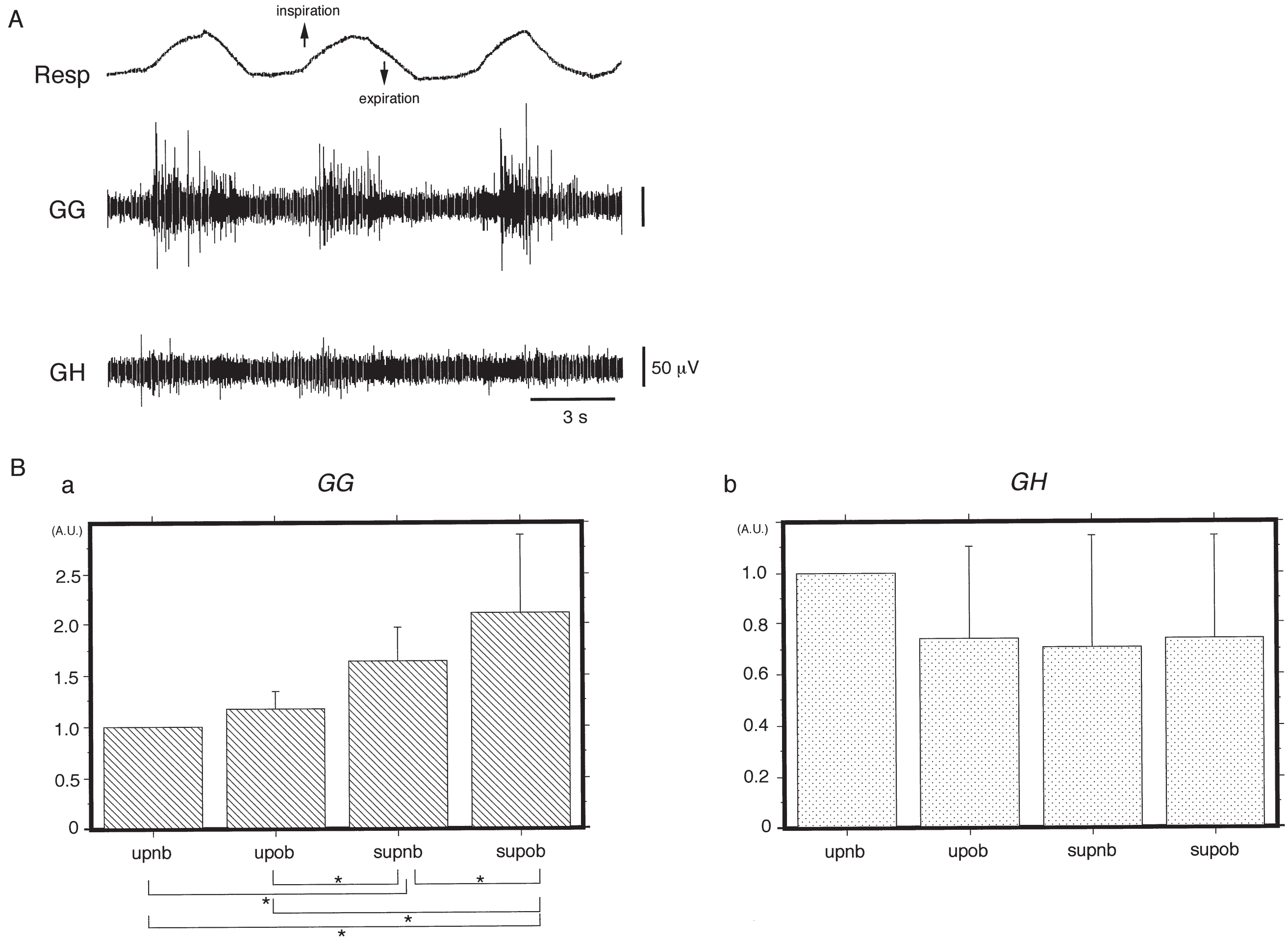

Fig. 3 (A) Representative simultaneous record of ribcage movement (*Resp*) and electromyographic activities of the genioglossus (*GG*) and geniohyoid (*GH*) muscles during nasal breathing in the upright position in a subject. *Upward* and *downward* arrows indicate inspiration and expiration, respectively. Vertical bar represents 50 μV for both the genioglossus and geniohyoid muscle activities, and horizontal bar represents 3 seconds. (B) Comparisons of expiratory electromyographic activities of the genioglossus (a) and geniohyoid (b) muscles in different modes of respiration and body position. Note that electromyographic activities were normalized to that during nasal respiration in the upright position. Means and standard deviations are shown. Abbreviations: *upnb*, nasal respiration in the upright position; *upob*, oral respiration in the upright position; *supnb*, nasal respiration in the supine position; *supob*, oral respiration in the supine position; *A.U.*, arbitrary unit. $*P < 0.05$.

is a reliable maneuver to distinguish EMG signals from the GG and GH muscles. O'Dwyer and associates[14] recorded the GG and GH EMG activities by using the needle electrode during eight tasks: curling up sides of the tongue, saliva swallow, drawing the tongue back and up, gentle tongue protrusion, lowering the mandible against resistance, intercuspal biting on hard objects, and curling up tip of the tongue. However, they could not show clear difference in EMG activities of the two muscles during these tasks.[14] With regard to the sequential temporal activation of the GG and GH muscles during swallowing, Cunningham & Basmajian[12] reported that the onset of the GG EMG activity precedes that of the GH muscle. However, we could not find this trend during swallowing. This discrepancy may be attributable to neuromuscular specialization of the compartmentalized muscle.[20]

We could not neglect the possibility that EMG signals from the mylohyoid muscle contaminated with those from the GH muscle. The mylohyoid muscle, locating beneath the GH muscle, shows similar activity during mastication, swallowing and respiration as the GH muscle.[22] When we advanced the needle electrode upward by the extra-oral approach, we could feel a sudden increase in resistance. If we advanced deeper (*ca.* 5 mm from the surface), the resistance was increased again. We believe that the initial resistant feeling was provided from the mylohyoid muscle, while the following from the GH muscle. Therefore, it is easy to differentiate the GH muscle from the mylohyoid muscle. This sensational differentiation appears to be a useful tool, and we suppose that previous researchers probably used this method for differentiation between the two muscles.

It has been demonstrated in animal studies the GH muscle is one of accessory respiratory muscles.[9–11,23,24]. It has also been reported that the human GH muscle shows the respiratory-related activity during inspiration.[5,6,16,17] As the GH muscle runs beneath the GG muscle, it is likely that the GH muscle plays a role in correct functioning of the upper airway, which is similar to the GG muscle. Nonetheless, changes in the breathing mode and body position had no effect on the GH EMG activity, whereas the GG muscle was affected as reported previously.[19] This may indicate that the GH muscle plays a minor role as a respiratory muscle compared to the GG muscle. However, this does not foreclose the GH muscle from the respiratory-related function because the GH muscle attaches directly to the hyoid bone, which is important in the maintenance of upper-airway patency. Previous studies have demonstrated both the similarity and divergence in the respiratory function of upper-airway muscles including the GH muscle.[22,24–26] For instance, Bishara and colleagues[24] showed that the electrical stimulation of the GG and GH muscles both resulted in a significant reduction in upper-airway resistance. However, stimulation of the GG muscle was more effective than that of the GH muscle in reducing upper-airway resistance at low magnitude.[27] Furthermore, electrical stimulation of the GG muscle, but not of the GH muscle released total airway obstruction.[24] In contrast, electrical stimulation of the sternohyoid and sternothyroid muscles produced no significant change in upper-airway resistance.[24] Therefore, there is a divergence in respiratory function even in upper-airway muscles. Although the GH muscle activity did not change with alteration in the breathing mode and body position in our study, it might change under more critical conditions. Indeed, Salmone and Van Lunteren[28] showed that the ability of the GH muscle to maintain force output during high levels of activation was adversely affected by severe hypoxia, but not mild hypoxia or hypercapnia.

Based on the findings in our study, it is concluded that EMG activities from the adjacent GG and GH muscles are successfully differentiated. In addition, it appears that changes in the breathing mode and body position significantly affect the GG EMG activity but do not affect the GH EMG activity. In other words, there is a likelihood that contraction of the GG muscle is more effective than that of the GH muscle in correct functioning of the upper airway.

Acknowledgments

We are grateful to Dr Ryo Otsuka and Dr Gen Kuribayashi for their co-operation throughout the experiment. This work was supported by Grants-in-Aid for Scientific Research Projects, (10307052 and 09470467) from the Japanese Ministry of Education, Science, Culture and Sports.

References

1. Uemura M, Matsuda K, Kume M, Takeuchi Y, Matsushima R, Mizuno N. Topographical arrangement of hypoglossal motoneurones: a HRP study in the cat. *Neurosci Lett* 1979; **13:** 99–104.
2. Uemura-Sumi M, Mizuno N, Nomura S, Iwahori N, Takeuchi Y, Matsushima R. Topographical representation of the hypoglossal nerve branches and tongue muscles in the hypoglossal nucleus of macaque monkey. *Neurosci Lett* 1981; **22:** 31–5.
3. Chibuzo GA, Cummings JF. An enzyme tracer study of the organization of the somatic motor center for the innervation of different muscles of the tongue: evidence for two sources. *J Comp Neurol* 1982; **205:** 273–81.
4. Altschuler SM, Bao X, Misalis RR. Dendritic architecture of hypoglossal motoneurons projecting to extrinsic tongue musculature in the rat. *J Comp Neurol* 1994; **342:** 538–50.
5. Wiegand DA, Latz B, Zwillich CW, Wiegand L. Upper airway resistance and geniohyoid muscle activity in normal men during wakefulness and sleep. *J Appl Physiol* 1990; **69:** 1252–61.
6. Wiegand DA, Latz B, Zwillich CW, Wiegand L. Geniohyoid muscle activity in normal men during wakefulness and sleep. *J Appl Physiol* 1990; **69:** 1262–9.
7. Guyron B. Problem neck, hyoid bone, and submental myotomy. *Plast Reconst Surg* 1992; **90**: 830–40.
8. Van de Graaff WB, Gottfried SB, Mitra J, Van Lunteren E, Cherniack NS, Strohl KP. Respiratory function of hyoid muscles and hyoid arch. *J Appl Physiol* 1984; **57:** 197–204.
9. O'Halloran KD, Curran AK, Bradford A. Effect of upper airway cooling and CO_2 on diaphragm and geniohyoid muscle activity in the rat. *Eur Respir J* 1996; **9:** 2323–7.
10. O'Halloran KD, Curran AK, Bradford A. Effect of almitrine on ventilation and on diaphragm and geniohyoid muscle activity in the rat. *Clin Sci* 1996; **91:** 337–45.
11. Curran AK, O'Halloran KD, Bradford A. Upper airway cooling reduces upper airway resistance in anaesthetized young guinea-pigs. *Eur Respir J* 1998; **11:** 1257–62.

12. Cunningham DP, Basmajian JV. Electromyography of genioglossus and geniohyoid muscles during deglutition. *Anat Rec* 1969; **165:** 401–9.
13. Vitti M, Basmajian JV. Integrated actions of masticatory muscles: simultaneous EMG from eight intramuscular electrodes. *Anat Rec* 1977; **187:** 173–89.
14. O'Dwyer NJ, Quinn PT, Guitar BE, Andrews G, Neilson PD. Procedures for verification of electrode placement in EMG studies of orofacial and mandibular muscles. *J Speech Hear Res* 1981; **24:** 273–88.
15. Spiro J, Rendell JK, Gay T. Activation and coordination patterns of the suprahyoid muscles during swallowing. *Laryngoscope* 1994; **104:** 1376–82.
16. d'Honneur G, Slavov V, Merle JC *et al*. Comparison of the effects of mivacurium on the diaphragm and geniohyoid muscles. *Br J Anaesth* 1996; **77:** 716–19.
17. d'Honneur G, Combes X, Leroux B, Duvaldestin P. Postoperative obstructive apnea. *Anesth Analg* 1999; **89:** 762–7.
18. Palmer JB, Rudin NJ, Lara G, Crompton AW. Coordination of mastication and swallowing. *Dysphagia* 1992; **7:** 187–200.
19. Takahashi S, Ono T, Ishiwata Y, Kuroda T. Effect of changes in the breathing mode and body position on tongue pressure with respiratory-related oscillations. *Am J Orthod Dentofac Orthop* 1998; **115:** 239–46.
20. Mu L, Sanders I. Neuromuscular specializations of the pharyngeal dilator muscles: II. Compartmentalization of the canine genioglossus muscle. *Anat Rec* 2000; **260:** 308–25.
21. Mu L, Sanders I. Neuromuscular specializations of the pharyngeal dilator muscles: I. Compartments of the canine geniohyoid muscle. *Anat Rec* 1998; **250:** 146–53.
22. Song H, Pae E. Changes in orofacial muscle activity in response to changes in respiratory resistance. *Am J Orthod Dentofac Orthop* 2001; **119:** 436–42.
23. Miller AJ, Vargervik K, Chierici G. Experimentally induced neuromuscular changes during and after nasal airway obstruction. *Am J Orthod* 1984; **85:** 385–92.
24. Bishara H, Odeh M, Schnall RP, Gavriely N, Oliven A. Electrically-activated dilator muscles reduce pharyngeal resistance in anaesthetized dogs with upper airway obstruction. *Eur Respir J* 1995; **8:** 1537–42.
25. Reed WR, Roberts JL, Thach BT. Factors influencing regional patency and configuration of the human infant upper airway. *J Appl Physiol* 1985; **58:** 635–44.
26. Van Lunteren E, Brass EP. Metabolic profiles of cat and rat pharyngeal and diaphragm muscles. *Respir Physiol* 1996; **105:** 171–7.
27. Schnall RP, Pillar G, Kelsen SG, Oliven A. Dilatory effects of upper airway muscle contraction induced by electrical stimulation in awake humans. *J Appl Physiol* 1995; **78:** 1950–6.
28. Salmone RJ, Van Lunteren E. Effects of hypoxia and hypercapnia on geniohyoid contractility and endurance. *J Appl Physiol* 1991; **71:** 709–15.