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Responses of the rat tongue in the movement and neural activity elicited by the mechanical stimulation to the intraoral mucosa

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Abstract: Innoxious mechanical stimuli were applied to six regions (midline portion and lateral portion) in the rat oral mucosa to determine the effect of the afferent input from the oral mucosa on the hypoglossal neurogram and the tongue movement. The responses in the hypoglossal nerve (XII) were classified into three patterns. Type A: The rhythmical response was elicited bilaterally. The tongue moved rhythmically in the antero-posterior direction. Type B: On either side of the XII, the transient response which was larger than that on the other side was elicited. The tongue protruded laterally with torsion away from the side where the larger response was observed. Type A+B: The mixture of type A and type B. These responses had a clear locus dependency and the mechanical stimulation to the midline portion induced only type A response, whereas type B or type A+B response was elicited by the mechanical stimulation to the lateral portion. These responses disappeared after the anesthesia of the oral mucosa.

Introduction

The tongue is a muscular organ that helps transport food in the mouth, helps move it to the back for swallowing, and functions in speech. To accomplish these functions, the tongue movement may be controlled by either central or peripheral mechanisms. Peripheral sensory information from the trigeminal (V) (lingual[1-4], masseter[5,6], temporal[7] auriculo-temporal[8] and inferior alveolar[9]), glossopharyngeal (IX)[8,10], superior laryngeal (SLN)[8,11] and hypoglossal nerves (XII)[12] have been shown to have reflex responses in the hypoglossal (XII) nucleus which innervates tongue musculature. However, studies about reflex responses to oral mucosa were limited.

An electrical stimulus has been applied to rat oral mucosa to study the reflex effects on the tongue[13-15]. Electrical stimulation has an advantage over mechanical stimulation in that timing and/or strength of the stimulus can be controlled more easily, however, it has several disadvantages such as uncertainty of the mode of stimulation and of the stimulus area[16]. When the tongue is functioning, mechanical stimuli may be the main factor which controls the tongue reflexly.

Thexton[17] introduced tongue reflex elicited by a mechanical stimulus diffusely applied to the hard palate of a cat, in which it elicited repeating reflex responses in the hypoglossal nerve. However, stimulated locus dependence has been left unclear. Hellstrand[18] studied it on the tongue reflex in cats using mechanical stimulation of the palatal and lingual surfaces. He found that the hard palate stimulation produced mainly extrinsic tongue muscle activation, however, the soft palate stimulation inhibited the activity. The intrinsic muscles were reported to respond solely to noxious stimulation[18]. After the extensive studies with electrical stimulation, Van Willigen and Weijs-Boot[16] studied mechanical stimulation of the rat palate for its effect on the oral musculature including intrinsic muscles. They found that muscle activity patterns depended on the site of stimulation, the strength of the stimulus and its duration.

Tongue reflexes reported so far were mostly related to its antero-posterior movements. During chewing, however, the tongue is expected to move laterally or twist for the purpose of food positioning[19-21]. These tongue movements may be due to unilateral tongue muscle activity[22]. However there has been no lateral tongue response investigation reported so far. Since food may stimulate mechanoreceptors around the molar teeth during chewing, the mechanoreceptors in this area are expected to generate such a response. Our purpose was to determine what type of response can be observed in the rat hypoglossal nerve after mechanical stimulation of the oral mucosa.

Materials and methods

Experimental procedure

Twenty Wistar albino rats (8 weeks old, approximately 200 g in weight) were used. Animals were anesthetized intraperitoneally with a 70% dose of mixture of 500 mg/kg urethane and 40 mg/kg alpha-chloralose after slight ether anesthesia. After the necessary operations were done, the anesthetic level was maintained under light anesthesia by additional administrations of one tenth of the first dose to prevent spontaneous activity. Body temperature was kept at 37°C. During the experiments, the animals lay in a supine position, their heads fixed by a support screwed into the calvaria. The mandible was not fixed so that the jaw musles could contract unimpeded.

Recordings

Hypoglossal neurogram was recorded. A midline cutaneous incision was made ventrally in the throat between the mental symphysis and the laryngeal prominence. Anterior digastric and geniohyoid muscles were exposed and removed to obtain access to the hypoglossal nerve. Its lateral and medial branches were dissected (Fig. 1A).

Neurograms were recorded from the medial and lateral branches. The medial branch activity was recorded from the rami which innervate genioglossal and intrinsic muscles (transverse and vertical muscles). The lateral branch activity was recorded at the more peripheral site than the site where the rami for hyoglossal and styloglossal muscles may leave. Neurograms were obtained by means of bipolar thin silver electrodes (0. 14 mm in diameter). The dissected nerve strands were picked up with these electrodes and surrounded with liquid paraffin. A pillow made of heavy impression material (Exaflex, G-C Dental, Tokyo) was placed under the hypoglossal nerve. This procedure made it possible to record only the neurogram of hypoglossal nerve without recording the EMGs from the surrounding muscles. To get access to the oral cavity, the animal's jaw had to be lowered, however jaw lowering is known to activate the tongue muscles[7,8,23]. In this study, after ascertaining the stimulus site by lowering the jaw, we stimulated the oral mucosa without lowering the jaw.

Stimulation

A natural mode of stimulation was applied to six intraoral regions; incisive papilla, mid-palate, right and left buccal mucosa near the 1st upper molar, and right and left lingual mucosa near the 1st upper molar. They are shown schematically in Fig. 1B and marked by "1" through "6" respectively. The innoxicous pressure stimulation was performed using a laboratory made mechanical stimulator (Fig. 1C). It consisted of a rounded tip (2 mm in diameter) made of acrylic resin, a cobalt-chrome wire (0. 9 mm in diameter), a copper plate and a handle made of acrylic resin. A strain-gauge was attached on the copper plate so that the pressure strength could be gauged. Since it was difficult to manipulate the stimulus tip

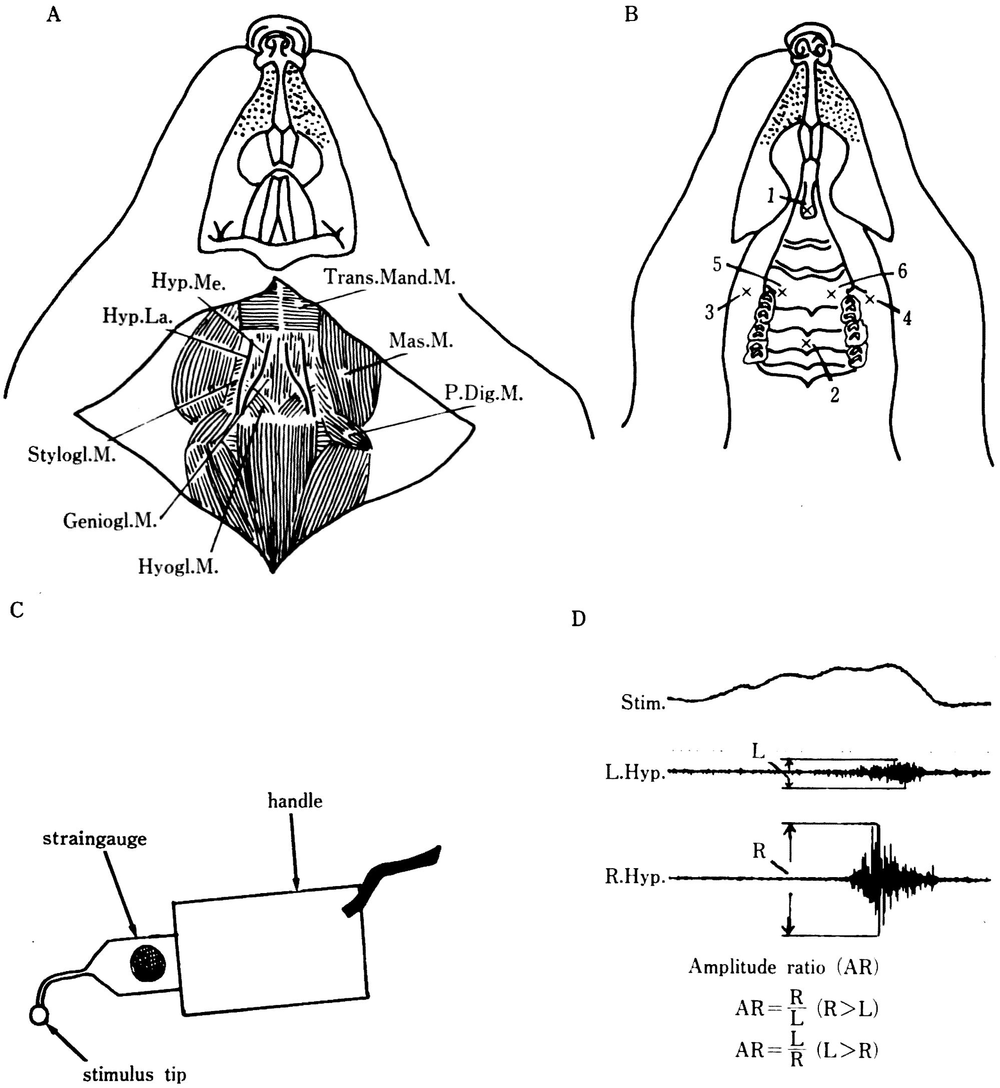

Fig. 1 A: A Schematic illustration of the dissection. Anterior digastric and geniohyoid were removed to get access to the hypoglossal nerve. Two branches of the hypoglossal nerve were shown. Hyp. Me.: medial branch of hypoglossal nerve, Hyp. La: lateral branch of hypoglossal nerve, Stylogl. M.: Styloglossal muscle, Geniogl. M.: Genioglossal muscle, Trans. Mand. M.: Trans-mandibular muscle, Mas. M.: Masseter muscle, P. Dig. M.: posterior digastric muscle.

B: Stimulus sites.

1: incisive papilla, 2: mid-palate, 3 or 4: right (3) or left (4) buccal gingiva near the upper molar, 5 or 6: right (5) or left (6) lingual gingiva near the upper molar.

C: Mechanical stimulator (See text for details).

D: Amplitude ratio.

The larger amplitude divided by the smaller one was defined as the amplitude ratio (AR). AR is R/L (R> L) or L/R (L> R). (where R or L is the amplitude in the right (R. Hyp) or left (L. Hyp) hypoglossal nerve activity responding to a mechanical stimulation (Stim). The ratio was obtained from the medial and lateral branch respectively.

by a mechanism within such a limited area as around the molar teeth, the stimulus was applied manually. To emulate food stuff, we applied moderate pressure stimulation and selected the data elicited by the prolonged mechanical stimulation which met such criteria that its pressure amounted to its maximum levels less than 100 g within one second and continued for more than 0.5 second.

Data analysis

The output signals from the straingauge transducer and the electrodes were amplified by high gain amplifiers (Nihon Kohden, AB-601G, Tokyo) and monitored on a memory oscilloscope (Nihon Kohden, VM-680G, Tokyo). All data were recorded on an FM tape recorder (Sony, A-69, Tokyo).

For rough analysis, the data were transcribed onto a paper chart. Details were then analyzed using a personal computer. The raw data were digitized (12 bit resolution, sampling rate of 2 kHz) and displayed on a screen. The maximum amplitude of the response was measured on the screen using an application program (Wave master, Canoupus, Kobe). To clarify the amplitude difference of the lateral or medial branch of the hypoglossal nerve between the right and left side, the raw amplitudes were normalized using the formula shown in Fig. 1D. We named the result "amplitude ratio(AR)". When the right hypoglossal nerve was more active than the left, the ratio was obtained by dividing the amplitude in the right (R) by that in the left (L) (i.e. $AR=R/L$). Conversely when the left hypoglossal nerve was more active, the ratio was obtained from dividing the amplitude in the left (L) by that in the right (R) (i.e. $AR=L/R$). Parametric data were analyzed using paired and unpaired t tests. A p value of less than 0.01 was considered to be statistically significant.

Results

A mechanical stimulation applied to the oral mucosa generally induced rhythmical short burst and/or a transient large burst in the hypoglossal nerve with rhythmical and/or phasic tongue movements depending on the stimulus site. A stimulus lower than 30 g induced no response. The responses in the neurogram were compared with the associated tongue movements. When the tongue moved in antero-posterior direction, burst patterns in the lateral and medial branches were very similar, however, there was a small difference in the time-to-peak of the bursts in the right and left neurograms (Fig. 2A). When the tongue moved laterally, obvious difference was seen in the amplitude between the right and left nerve, however, no noticeable difference was seen between the lateral and medial branches (Fig. 2 B). This was a contrary result to our expectation for reciprocal activities in the branches, since medial and lateral branches are believed to innervate only muscles for protrusive and retrusive tongue movements respectively[24-26]. A suspicion in which the dissection might be erroneous arose. To exclude the suspicion, the branches were electrically stimulated (0.5 mA, 40 Hz, 0.1 ms). Unilateral stimulation of the medial branch resulted in protrusive movement of the tongue with torsion to the contralateral side from the stimulus side. The unilateral stimulation of the lateral branch resulted in a little retrusive movement with torsion towards the ipsilateral side. The bilateral medial branch stimulation resulted in straightforward protrusion without torsion. The bilateral lateral branch stimulation caused a little retrusive movement without torsion. Although the simultaneous stimulation of unilateral hypoglossal nerves which may be the similar situation to that seen in Fig. 2 elicited the tongue protrusion, the degree of the tongue protrusion at this time was smaller than that when the medial branch solely was stimulated. These results indicated the dissection was carried out appropriately. Since we shed light on the tongue protrusion in this paper, the response in the medial branch solely was analyzed for further experiments. All the raw data were generated based on the same animal. Details of the response will be described in order of stimulus sites.

When the mechanical stimulation was tested at the incisive papilla (site 1) or mid-palate (site 2), the response elicited in either the neurogram or tongue movements was the same as those in the previous studies by others. Namely rhythmical bursts (4-5 Hz) were elic-

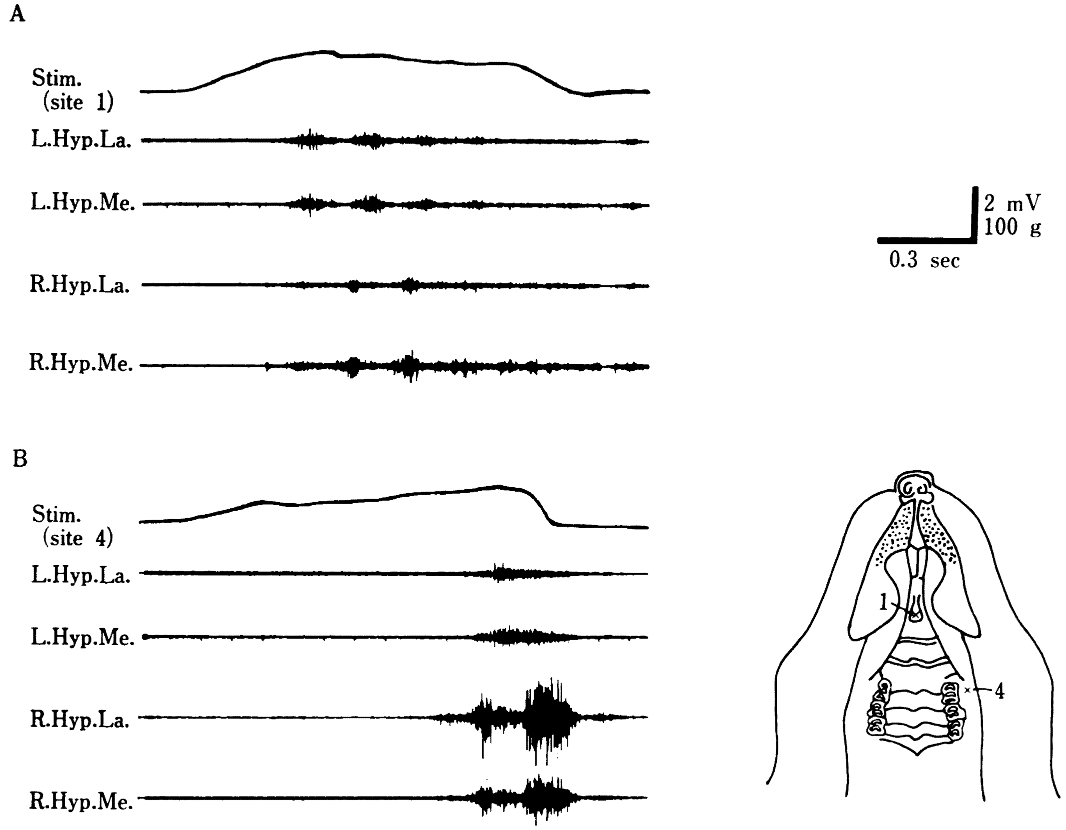

Fig. 2 Responses in the lateral and medial branches of the hypoglossal nerve.

Neural responses shown are a bilateral rhythmical response (A) and unilateral response (B) obtained from the mechanical stimulation applied to site 1 and site 4 respectively. Although the obvious difference in the burst was seen between the right (R. Hyp.) and left (L. Hyp.) hypoglossal nerves with the lateral tongue movement, no noticeable difference was seen between the lateral (La.) and medial (Me.) branches in either behavior.

ited in the hypoglossal nerves bilaterally (Fig. 3), and the bilateral response in the neurogram coincided with the tongue rhythmical movements in the antero-posterior direction. The tongue usually stayed within the oral cavity, even in the protrusive phase. Although the time-to-peak of the bursts was different between the right and the left side, this was not reflected on the tongue movement, i.e., no lateral deviation was observed in the rhythmical antero-posterior movement of the tongue.

When the mechanical stimulation was applied to the buccal mucosa near the upper molar (site 3 or 4), responses observed were rather unique (Fig. 4). The rhythmical feature either remained or disappeared in the neural respone, however, a large burst now occurred in the contralateral branch. The amplitudes of the responses in the ipsilateral branch (1.65 ± 0.88 mV, mean$\pm$SE: $n=20$) and in the contralateral branch (5.79 ± 0.24 mV: $n=20$) were statistically different ($p<0.01$: $n=20$). The transient large response in the contralateral branch coincided with the protrusive tongue movement and torsion toward the stimulus side. In detail, the tongue moved as if its dorsal surface covered the stimulus site therefore the ventral surface could be observed from the outside. The downward curl of the tongue was seen and the tip of the tongue was near the stimulated site. It should be noted that the tongue moved more drastically

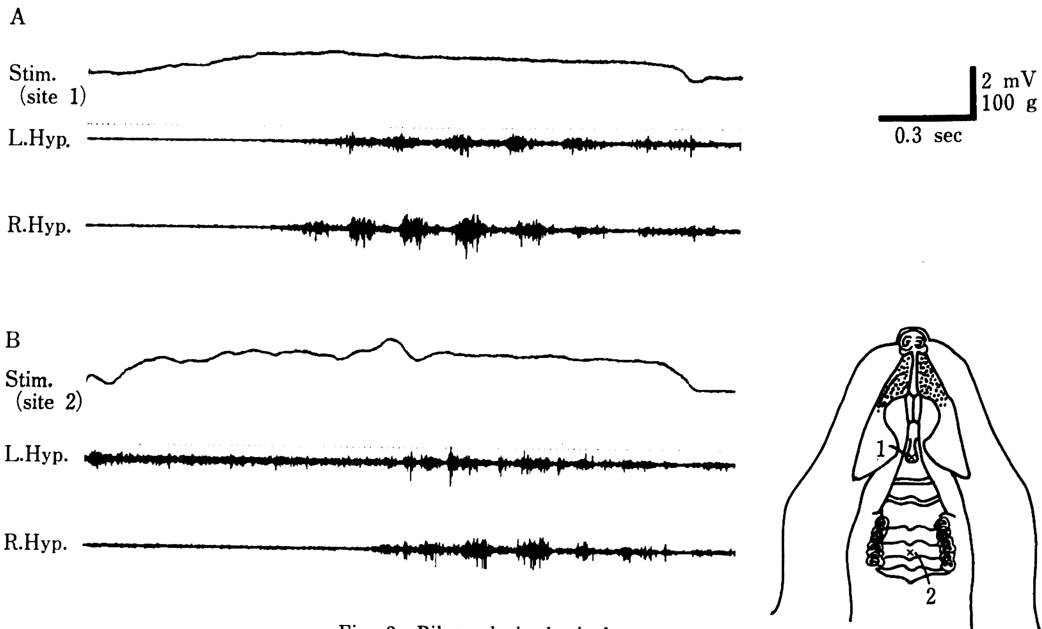

Fig. 3 Bilateral rhythmical response.

The neruogram response was elicited bilaterally by the mechanical stimulation in the midline portions. The tongue rhythmically protruded straight forward. Stim: mechanical stimulus applied to site 1 or site 2, L.Hyp.: left medial branch of the hypoglossal nerve, R.Hyp.: right medial branch of the hypoglossal nerve.

with the mechanical stimulation than when the electrical stimulus was applied to the unilateral branch.

When the stimulus was applied to the lingual mucosa near the upper molar, the response was more complex. The stimulus elicited a transient burst in either side of the nerve. Basically the stimulus elicited a transient large burst as seen when the buccal mucosa was stimulated. However, it was elicited in the ipsilateral branch. Therefore the tongue moved toward the opposite side from the stimulus site. The lingual stimulation also elicited an identical response to the buccal stimulation, although the occurrence frequency was less than that when the response was elicited in the ipsilateral branch. The details will be described below.

Neural responses observed in the twenty rats were further compared to see the locus dependence of the tongue movements. For this purpose the responses were classified into six types of patterns based on primary neurogram patterns as shown in Fig. 5, where three typical neural responses (types A, B, and C) and the associated tongue movements (top view and lateral view) are illustrated. Since our study was focused on the amplitude of bursts, the difference of the time-to-peak is not considered in the scheme of neurogram.

Type A: This type of response was rhythmical with an average amplitude ratio of 1.37 ± 0.01 (n=20) which was smaller than that in type B ($p<0.01$: n=20). The associated tongue movements were rhythmical in the antero-posterior direction. (i.e. straightforward movement). Responses elicited from the incisive papilla or mid-palate were classified as this type. A typical example is seen in Fig. 3.

Type B: The response was rather transient than rhythmic. The average amplitude ratio was 3.73 ± 0.08 (n=20), namely one side of the neurogram amplitude was about four times larger than that in the other side ($p<0.01$: n=20). Type B could be further subdivided into two types [type B (CL) and type B (IL)] based on the branch in which the transient large response was elicited. In type B (CL), the response was larger in the contralateral nerve and thus the tongue protruded with

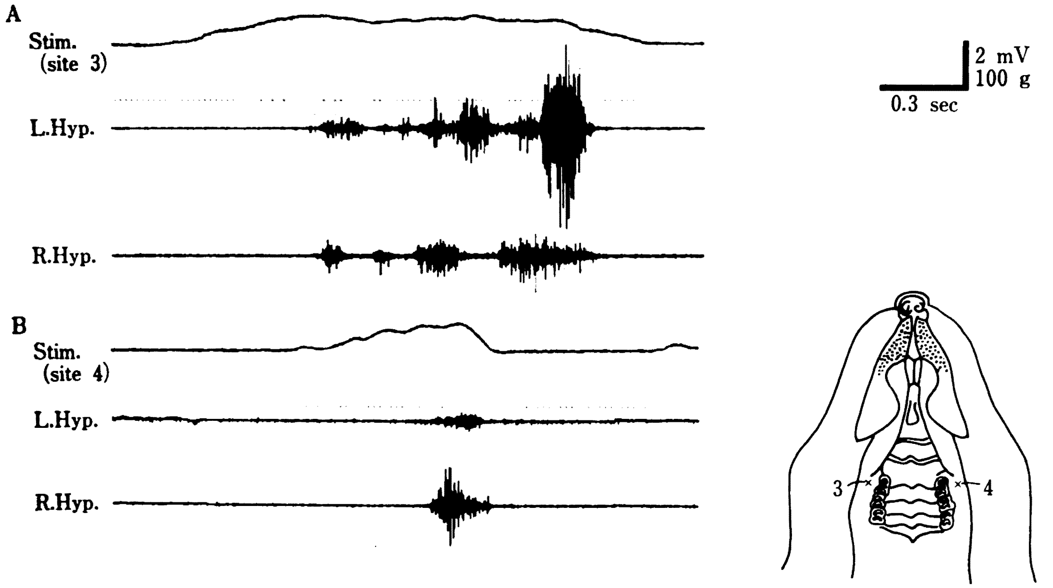

Fig. 4 Unilateral response.

The neurogram response was elicited unilaterally to the mechanical stimulation in the mucosa near to the upper molar.

The tongue protruded laterally with torsion away from the side where the larger response was observed. Stim.: mechanical stimulus applied to site 3 or 4.

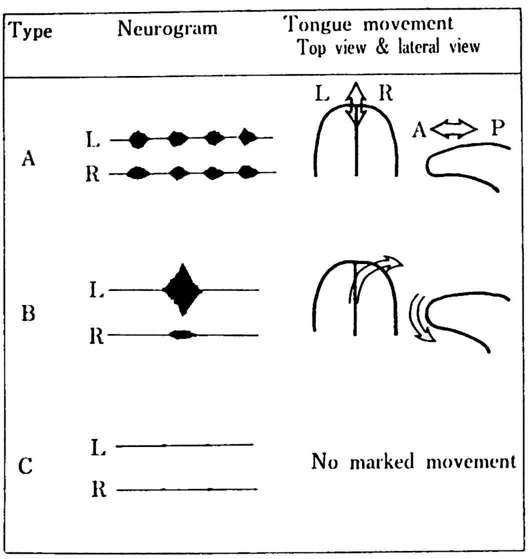

Fig. 5 Type of responses in the neurogram and corresponding tongue movement. See text for detail.

Table 1 Occurrence frequency pooled for several types and stimulation sites.

Type	stimulation site frequency (%) 1 n =100	2 n =100	3 or 4 n =200	5 or 6 n =200
A	100	100	0	0
B(CL)	0	0	60	11
A+B(CL)	0	0	32	11
B(IL)	0	0	0	31
A+B(IL)	0	0	0	34
C	0	0	8	13

torsion towards the stimulated side. In type B (IL), the response was larger in the ipsilateral nerve and the tongue protruded away from the stimulated side. A typical example for type B is seen in Fig. 4B.

Type C: Only a very small response (less than 0.1 mV in amplitude) was seen in this type, and no obvious movement was seen.

Table 2 Characteristics of the responses in the right (R) and left (L) medial branches pooled for the midline portion of the oral mucosa (bilateral response), and in the contralateral (CL) and ipsilatral (IL) medial branch pooled for lateral portion of the oral mucosa (unilateral response).

Type A+B is defined as the mixture of types A and B. The character in the parenthesis (i.e. CL or IL) means the side where the greater response is induced in the neurogram.

Bilateral reflex

Stimulation site	Type	Duration (ms)	Latency (ms)	Amplitude R (mV)	Amplitude L (mV)	Amp. ratio	Total burst number pooled
Incisive papilla (site 1)	A	262.8±2.5	989.9±25.1	1.77±0.06	1.23±0.04	1.46±0.01(R> L)	237
	A	277.8±2.5	994.3±21.5	1.41±0.06	1.95±0.08	1.39±0.01(L> R)	242
Mid-palate (site 2)	A	216.7±1.6	1032.8±21.0	2.67±0.10	1.32±0.08	1.30±0.01(R> L)	266
	A	214.9±1.3	1050.6±21.8	1.91±0.07	2.51±0.09	1.33±0.01(L> R)	249

Unilateral reflex

Stimulation site	Type	Duration (ms)	Latency (ms)	Amplitude CL (mV)	Amplitude IL (mV)	Amp. ratio	Total burst number pooled
Buccal	B(CL)	286.3±5.2	939.0±20.4	4.65±0.24	1.32±0.07	3.61±0.05(CL> IL)	211
Gingival	A+B(CL)	299.6±6.3	974.3±23.6	7.87±0.46	2.24±0.15	3.77±0.10(CL> IL)	116
(site 3 or 4)	C	—	—	—	—	—	29
	B(IL)	314.6±6.9	973.5±22.7	1.05±0.07	3.81±0.31	4.10±0.18(IL> CL)	143
Lingual	A+B(IL)	292.2±5.2	1014.9±21.4	0.96±0.06	3.04±0.20	3.35±0.09(IL> CL)	120
Gingiva	B(CL)	325.0±17.9	915.0±42.7	3.84±0.34	1.45±0.15	3.13±0.19(CL> IL)	43
(site 5 or 6)	A+B(CL)	280.6±8.0	996.0±28.7	4.51±0.67	1.34±0.22	3.55±0.31(CL> IL)	30
	C	—	—	—	—	—	29

A mixture of type A and B was classified as type A+B, in which the transient lateral movements and rhythmical antero-posterior movements were observed. A typical example is seen in Fig. 4A.

Appearance frequency pooled for six types of response was shown in Table 1. The basic parameters including duration of the burst, latency, amplitude ratio and the number of bursts pooled were shown in Table 2.

Although the responses described above appeared to be evoked by the mechanical stimulus, we also injected an anesthetic (0.5% Xylocaine, 0.2 m*l*) into the stimulated site to ascertain the source of responses. Local anesthesia blocked the responses which reappeared as the anesthetic wore off.

Discussion

Innoxious mechanical stimulation applied to the oral mucosa elicited rhythmical short burst and/or a transient large burst in the hypoglossal nerve with rhythmical and/or phasic movements of the tongue. The responses disappeared under the application of local anesthetics, suggesting those were mechanoreceptor mediated responses. The stimulus used here was prolonged mechanical stimulation, by which we expected to see a tongue response related to food manipulation in chewing. An electrically controlled mechanical stimulator was initially considered, however, it was determined not applicable for the desired sites around the molar tooth because of the size. We thus decided to manipulate the stimulator by hand and rather to select data whose stimulus parameters were appropriate to the criteria mentioned in the methods section.

Mechanical oral stimulation has been tested and known to elicit rhythmical tongue movement[16-18]. The rhythmical tongue movements reported in these studies coincide with a type A response in this study of which the movement direction is the antero-posterior. The aspect of the movement was quantitatively described by small amplitude ratios, which indicated the activities in the right and left hypoglossal nerves were more or less the same. In fact electrical stimulation to the bilateral medial branches, which emulated the small amplitude ratio, resulted in straight forward protrusive movement of the tongue. Although the difference in the time-to-peak between the right and left side of the bursts was observed in the type A reaction (see Fig. 3), any lateral deviation of the tongue was not observed. This suggests that the time-to-peak difference between the right and left sides is not the conclusive factor for the lateral deviation of the tongue when the amplitude difference is small. Van Willigen and Weijs-Boot[16] tested mechanical stimulation of the rat palate on the masticatory and intrinsic tongue muscle activities. They found a rhythmic activity in the tongue muscle as well as the masticatory muscles which they never found with the electrical stimulation[13-15]. The stimulus parameters employed by them were almost identical to those in this study. The threshold of 0.3 N and the successful stimulus strength (about 1 N) found in this study were in the range indicated by them. They reported that the rhythmic activity was most easily elicited in the region of the incisive papilla and less easily in the antemolar region. No rhythmic activity was found in the intermolar region. The locus dependency on the rhythmic activity was more obvious in this study. As shown in Table 1 (also see Fig. 2), a type A response could be elicited even in the midline of the palate (the intermolar region in their study). The conclusion made by Van Willigen and Weijs-Boot[16] did not include the difference between the midline and lateral region. From the results of this study, their conclusion could be modified as follows; the rhyhthmic activity may be most easily elicited in the midline, less easily in the lateral region. It would be noteworthy to state that the pure type A response could not be elicited from the lateral regions (Table 1).

One of the innovative results found in this study was the type B response, which is characterized by a large amplitude ratio in accordance with the transient lateral tongue movement. There has been no identical response reported so far. Hellstrand[18] studied effects of touch (tap) and pressure (long lasting) stimuli on the hard and soft palate of the cat. Reflex activation on the ongoing activities was observed in the extrinsic, protrusive and retrusive muscles with the hard and soft palate stimulation. However, no noticeable tongue movement was described. Oral reflex responses to the hard palate were also studied in the human jaw closing system[27]. They tested innocuous mechanical stimulation applied to eight sites on the palate or tongue dorsum while subjects maintained a constant biting force. They stressed that the nature of the reflex responses strongly depended on the site of stimulation. Weber and Smith[28] studied reflex responses in human jaw, lip, and tongue muscles elicited by mechanical stimulation and reported that the low-level, localized stimulation of cutaneous receptors did not modulate EMG activity of the genioglossus muscle. However, the type B response elicited by mechanical stimulation in the present study denotes obvious heterogenetic response in the tongue muscle. The conflict between the studies may be due to the difference in subjects used and/or experimental conditions.

In type A+B, the transient bursts were usually preceded by the rhythmical short ones, however, large neural activity of the lateral movement was observed independent from the rhythm (see Fig. 3A). The rhythmical tongue movements may originate from a pattern generator[29]. The lateral tongue movement, however, may be due to peripheral modulation[30]. We speculate that the role of the type A+B response including type B response on food manipulation during chewing food. In fact, rotation of the tongue was considered to be associated with the rhythmic tongue movements in the chewing cycle[21], whereas straight forward movements only were obseved during lapping movements[31]. The fact that type B responses were often preceded by type A responses suggests a functional role to push the food between the teeth on the working side during chewing[19].

In the present study, the medial and lateral branches of the hypoglossal nerve were activated concurrently (see Fig. 2). Since the bilateral electrical stimulation of them resulted in protrusive or retrusive tongue movement respectively, there could be expected reciprocal activities in these branches when the rhythmical or transient tongue movement occurred. Namely, the medial branch was expected to be active only in the tongue protrusion and the lateral one only in the tongue retraction. Kaku[32] studied about the relationship between the hypoglossal nerve action potential and the rhythmical jaw movement induced by the electrical stimulation to the cortex and the amygdala in the rat. He found that the maximum integrated activity of the medial branch was found in the middle of the opening phase and that of the lateral one was near the end of the closing phase. The above findings suggest the reciprocal activities in the medial and lateral branches. There could be two possibilities to explain the concurrent activities obtained in our study. One may be the cocontraction in the protrusive and retursive muscles. In fact, Bennet and Hutchinson[22] reported that the electrical stimulation of the main trunks of the hypoglossal nerve caused the tongue protrusion, in which the tip of the tongue did not extend beyond the mandibular arch, however, the tongue protrusion beyond the oral cavity was elicited by the electrical stimulation of only the medial branch. They then explained the reason why the tongue stayed in the oral cavity by the cocontraction of the protrusive and retrusive muscles. In the present study, the tongue similarly stayed within the oral cavity even during the protrusive phase. This suggests the existence of the cocontraction. The other may be due to the sites where the neural activity was recorded. The lateral branch innervates intrinsic muscles as well as extrinsic muscles. From the lateral branch, the rami which innervate extrinsic muscules (hyoglossal muscle and styloglossal muscle) sprout at first and the remainder of the lateral branch innervates intrinsic muscles (superior and inferior longitudinal muscles)[26]. Since the lateral branch was dissected as long as possible to make the recording easy, the branch for the intrinsic muscles predominantly could be recorded in this study. Intrinsic muscles would be active[33] to harden the tongue when the tongue protruded with the extrinsic muscle activity. Since electrical stimulation of the lateral branch resulted in a little retrusive movement, the latter explanation would be more reasonable.

The latency for the type A, type B and type A+B responses are rather long. This suggests that the response may pass through a higher center. In fact, cortically induced tongue movements include rhythmical and tonicmovements[34], whereas those induced from the bulbar region consist of only phasic and stereotyped movements[35]. Excitation of motoneurons in the hypoglossal nuclei are suggested to be largely conditional on inputs from the higher center[36].

Type B response, including type A+B, elicited from buccal mucosa was found solely in the contralateral hypoglossal nerve to the stimulus site, whereas that elicited from the lingual region was in either the ipsilateral or contralateral nerve. Again locus dependency was found in type B and type A+B responses. However, since tongue responses would be complex and the feature could be largely dependent on the jaw position or background muscle activities[37,38], functional implications of the locus dependency may need further study.

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抄録：口腔粘膜の 6 つの部位（正中部および側方部）に非侵襲性の機械刺激を加え口腔粘膜からの求心性情報が舌下神経活動および舌運動に及ぼす効果を明らかにした。機械刺激に対する舌の応答は 3 つのタイプに分類された。Type A: 舌下神経に両側性にリズミカルな応答が誘発され，この時，舌はリズミカルに前後方向に運動した。Type B: 左右舌下神経のいずれか一方に，他方と比較して大きな一過性の応答が記録され，この時，舌は大きな神経応答が記録された側と逆方向に捻転しながら突出した。Type A+B: Type A と Type B の混合タイプ。機械刺激に対する舌の応答は明らかな部位特異性を示し，正中部刺激では Type A のみ，側方部刺激では Type B および Type A+B が多く認められた。これらの応答は，口腔粘膜を麻酔することで消失した。

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