A Study on the Inner Structure of the Tongue in the Production of the 5 Japanese Vowels by Tagging Snapshot MRI

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Introduction

The purpose of this experiment was to determine the contraction of the tongue-related muscles during the production of the 5 Japanese vowels by tagging pulse MRI, a newly developed method by which the displacement of the tissue of the tongue can be visualized by labeling some parts of the tissue.

For a precise estimation of the tongue-related muscles, several methods should be combined. Previously, there were 4 principal methods, i.e. (1) anatomical studies of tongue specimens of the tongue; (2) Image analysis using MRI, ultrasound echo, X-ray microbeam etc. to observe the configuration of the tongue; (3) EMG of the tongue-related muscles; and (4) tongue models based on the data from (1), (2) and (3) to simulate the transformation of the tongue.

However, each of the above methods has its own limitations: Namely, (1) anatomical studies can not be performed in living humans but only on specimens. (2) By the ultrasound echo, ordinary MRI etc., it is difficult to visualize the inner construction of the tongue. (3) In EMG studies, the electrical activity of a muscle does not always indicate the contraction of the muscle. In addition, where two muscle bundles cross (for example, the transvers and the verticalis), it is impossible to identify from which muscle the data of the EMG are obtained. (4) Although tongue models can rectify some of the deficiencies of the methods above, they also have their limitations because they depend on the data of the above methods.

The newly developed method of tagging snapshot MRI can overcome the deficiencies in these methods using data for surmising the 'inner' construction of the tongue of a living human and the contraction of the muscles during speech production.

Method

We used a whole body MR imager (Sigma, software version 4.6; GE Medical Systems, Milwaukee) operating at 1.5T, with standard, actively shielded gradients (10mT/m, 600 sec rise time to full scale).

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The technical details of the tagging snapshot MRI are described elsewhere in this issue (Niitsu et al.).

The tagging snapshot pulse sequence had three components:a contrast preparation pulse(1), a subsequent tagging phase(2) and a data acquisition phase(3).

The tongue was at the reference position during (1) and (2). In the reference position in this experiment, the tongue tip touched the upper incisors with the dorsum touching the hard plate intentionally. Between the end of (2) and the onset of (3), one of the 5 Japanese vowels was produced. And during (3), the utterance was maintained steadily.

In (2), the tagged areas were labeled as horizontal or vertical straight stripes with high intensity. When the tongue kept its reference position throughout the above 3 phases, an image with straight stripes could be obtained. When a vowel was uttered, the stripes were displaced, indicating the displacement of the tissues. In this experiment, images were taken only in the mid-sagittal plane because the mid-sagittal plane would not slide laterally and the stripes could be identifiable in this plane if the tongue moved symmetrically.

A 34- year-old Japanese male served as the subject. Images of the 5 Japanese vowels and the reference position were obtained. In order to get an image with crossing stripes, an image with vertical stripes and another with horizontal stripes were superimposed on each other(fig.1).

For better visualization of the displacement of the stripes, schemata of the MR images of fig.1. were made (fig.2). The crossing lines in fig.2 were drawn to present the crossing stripes in fig.1.

For the quantitative analysis, 6 anatomically relevant lines were drawn as in fig.3, with the crossing lines and the crossing points referred. The length of these lines were measured and the results are given in Tables 1 and 2.

Result

In Fig.1, synthesized MR images of the reference position and the 5 Japanese vowels with the crossing stripes are shown.

In Figure 2, the same schemata as in Figure 1 are shown.

During the utterance of /a/, the dorsum of the tongue took a lower position than the reference position but the tongue body as a whole remained in the same position (neither to the back nor to the front). The vertical stripes became shorter than at the reference position, while the length of the horizontal lines remained nearly the same as in the reference position. The horizontal lines and the dorsum showed concave lines. These findings would seem to indicate that the anterior part of the tongue was pulled down to the mandible.

During the utterance of /i/, the tongue took the highest and most anterior position. The lower horizontal lines became very short, which probably shows the contraction of the posterior part of the genioglossus muscle. The higher horizontal lines showed convex curves ,which may show that they were passively curved.

During the utterance of /u/, the tongue took a 'middle position'(neither to the back nor to the front, higher than /a/ but lower than /i/) and the length of both the horizontal and the vertical lines became shorter in general. The middle vertical line took a shape resembling the figure '>'.

During the utterance of /e/, the shape and the position of the tongue appears to have been similar to that for /i/, but lower.

The configurational change in the tongue during the utterance of /o/ was the most impressive. The upper half of the tongue appears to have been pulled back while the lower half took almost the same position as the reference position. Thus, a kind of a 'landslide' can be seen at the bottom of the mouth. This 'landslide' was probably caused by the contraction of the styloglossus muscle(SG).

In Fig.3, 6 lines are imposed with their anatomical meanings. Lines No.1(L1), No.2(L2) and No.3(L3) may represent the fibers of the anterior, middle and posterior part of the genioglossus muscles (GGa, GGm and GGp) respectively. Line No.5(L5) may be the superior-longuitudinalis muscle(SL). Line No.4(L4) and line No.6(L6) are also included as the representatives of the crossing lines.

In Table 1, the lengths of these 6 lines are given. The figures in parentheses are the relative lengths compared to the reference position.

In Table 2, the relative lengths are given with the following symbols: +++(less than 70%), ++(from 70% to 79%), +(from 80% to 89%), +-(from 90% to 99%) and -(not less than 100%).

During the utterance of /a/, L1 became much shorter (58%). This may indicate the contraction of GGa, which may also have caused the shortening of L4(70%). L2(92%), L3(88%) and L5(95%) did not become shorter to such an extent, which may indicate that GGm, GGp and SL did not contract.

During the utterance of /i/, L3(59%) became much shorter, which may indicate that GGp contracted to pull the tongue toward the mandible. L5(88%) also became shorter, which may indicate that the contraction of SL contributed to making the tongue shorter in the longitudinal axis. The high position of the tongue may have been caused passively by the contraction of GGp and SL.

Also during the utterance of /u/, L3(66%) and L5(77%) became much shorter, but the tongue did not take as high a position as for /i/. It may be that in addition to GGp and SL, the verticalis muscle(V) also contracted and shortened the tongue in the vertical axis. The shortening of L4(88%) may indicate the contraction of V.

During the utterance of /e/, the shortened lengths of L3(63%) and L5(87%) may indicate the contraction of GGp and SL as for /i/ and /u/. However for /e/, L1(82%) and L2(75%) also became shorter. This may indicate a contraction of GGa and GGm to make the tongue position for /e/ lower than that for /i/.

During the utterance of /o/, L3 became shorter(80%), which may indicate a contraction of GGp to pull the bottom of the tongue against the contraction of SG as a result of the 'landslide'. The shortening of L5 (78%) may indicate the contraction of SL to make the upper part of the tongue tight.

Discussion

In this experiment, 6 lines were drawn with reference to a previous anatomical study (Miyawaki). It was assumed that the shortening of a line would indicate the contraction of muscle bundles along the line. Furthermore, the present data were compared with the EMG data reported by Miyawaki et al. and Baer et al.

We determined a contraction of GGa during the utterance of /a/. However, for /a/, the EMG activity of GGa was not reported as remarkable in previous EMG experiments. This apparent discrepancy may be due to the following reasons.

As mentioned in METHOD, an intentional posture was taken by the tongue even at the reference position, with its tip touching the upper incisors and its dorsum touching the hard plate. Therefore, the tongue may not have been 'at rest' and some muscles may have contracted to stretch GGa at the reference position. It may be the case that, instead of contracting, GGa took its resting length in the utterance of /a/.

Another possible explanation for this contradiction is that GGa may not run along L1. It may be that GGa curves more toward the tip of the tongue.

In this experiment, images were taken only in the mid-sagittal plane. Therefore, it is difficult to discuss the muscles which are not in this plane, namely, the verticalis, transvers, inferior longitudinalis etc. For a discussion of these muscles and the establishment a new tongue-model, it is necessary to get 3-dimensional information of images from at least 2 additional sagittal planes. Images of the horizontal planes from which horizontal tagged lines can be identified must also be obtained for this purpose.

References

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Figure Captions

FIG.1
MR images in the mid-sagittal plane during production of the 5 Japanese vowels with crossing stripes obtained by tagging snapshot MRI. 'r.p.' indicates the reference position.

FIG.2
Schemata of MR images of Fig.1. Crossing lines were drawn with reference to the crossing stripes in Fig.1.

FIG.3
Schemata of MR images with 6 lines imposed. Each of the 6 lines has an anatomical referent.

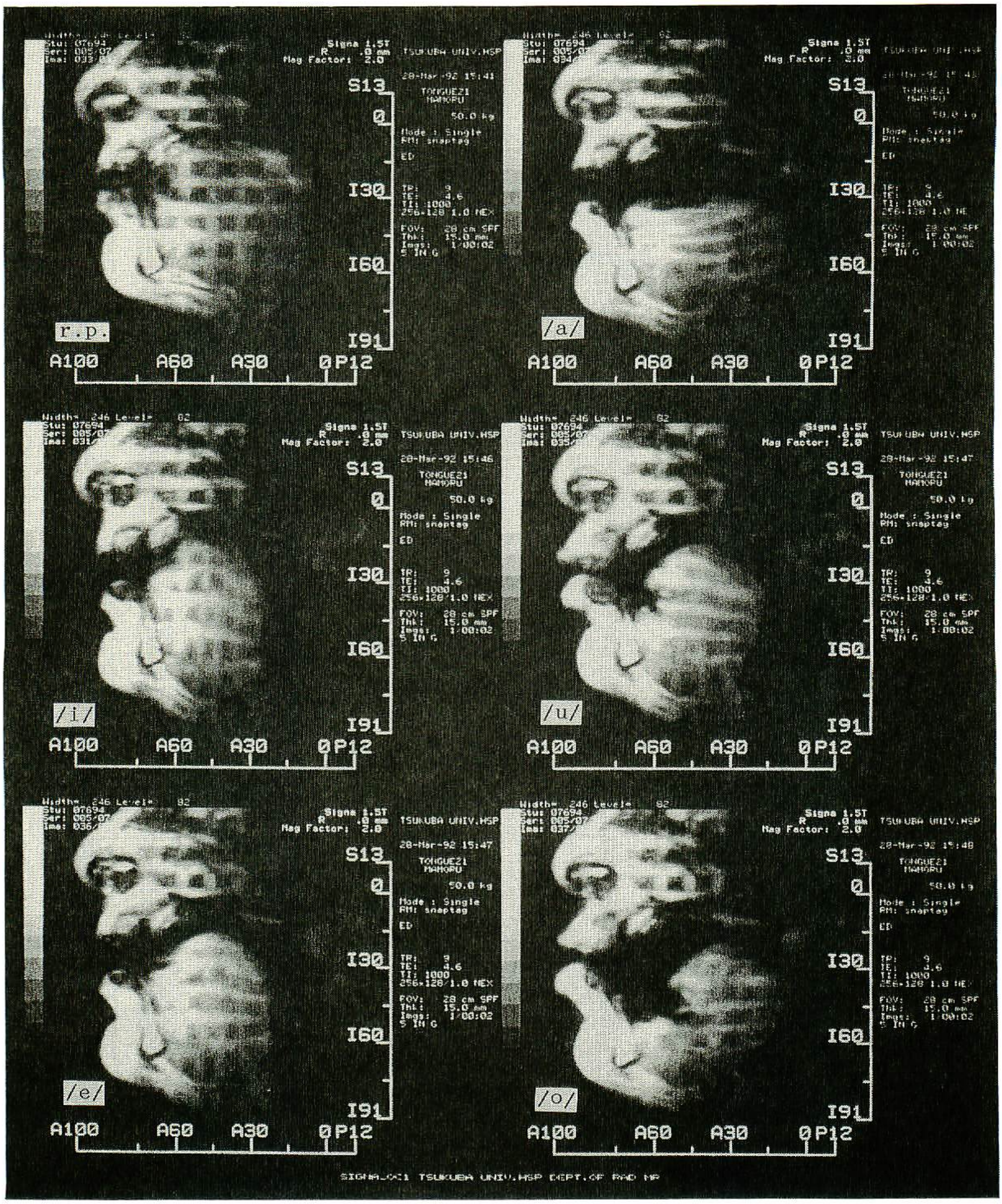

Fig.1

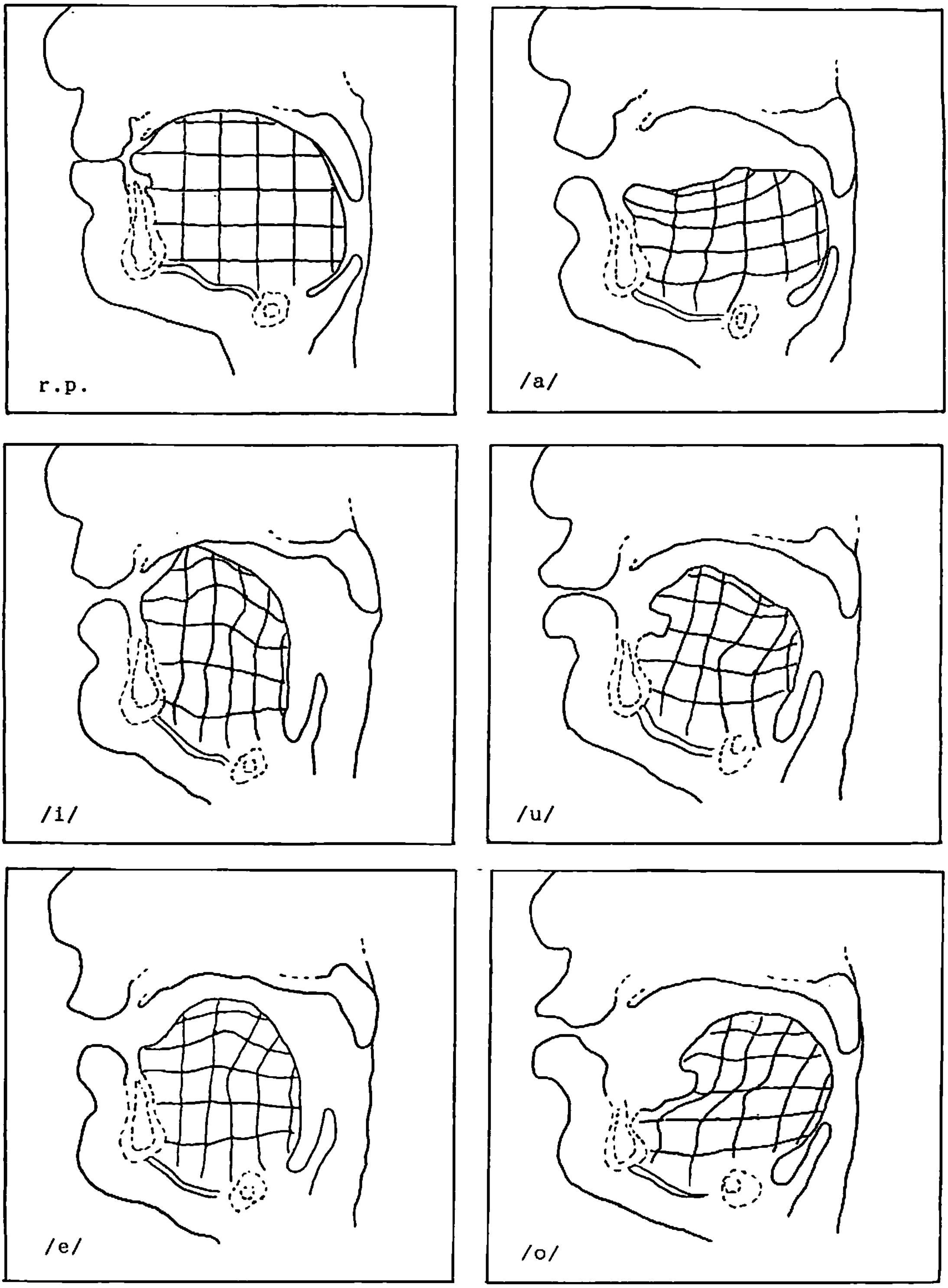

Fig.2

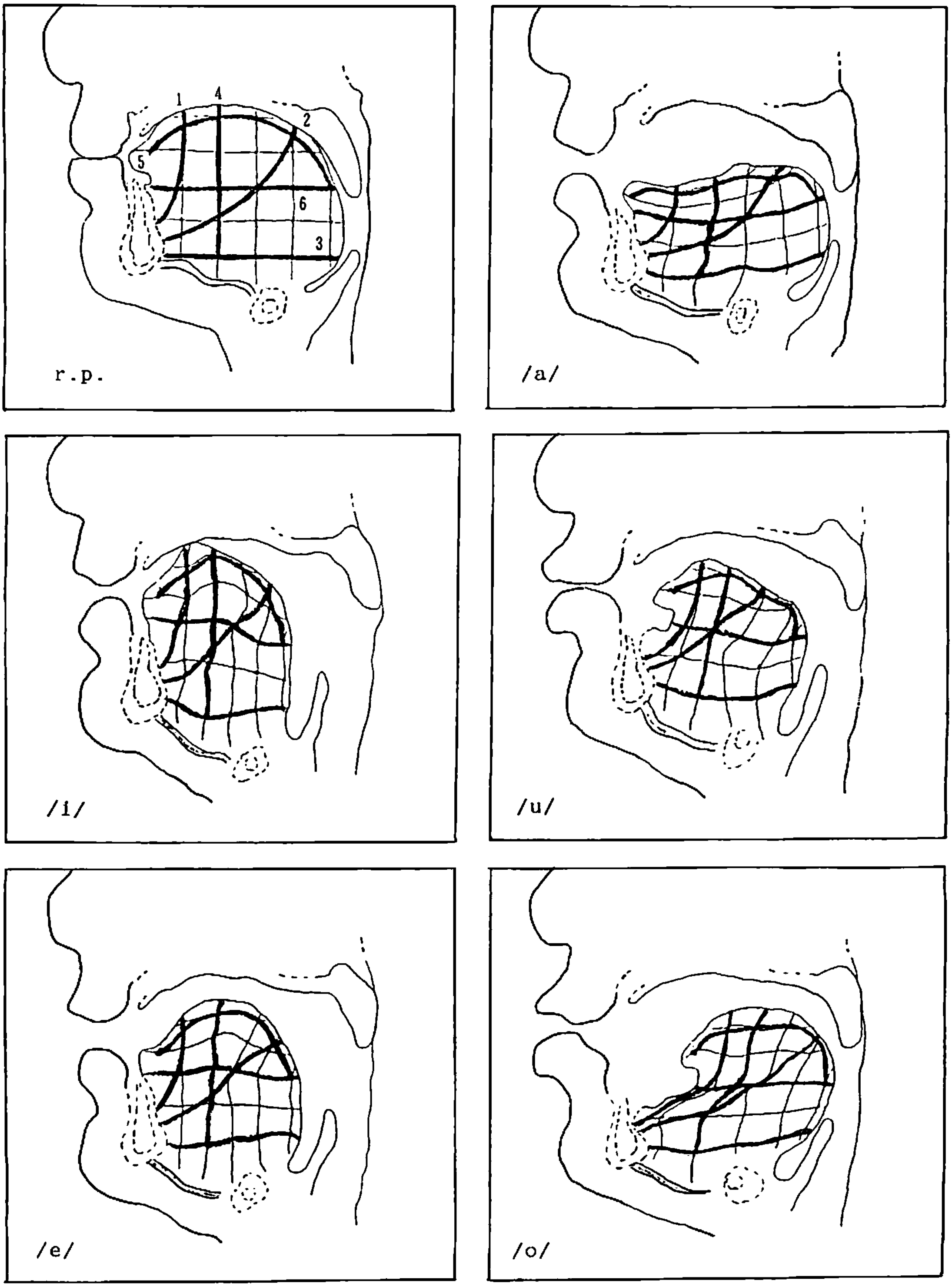

Fig.3

No.	r. p.	/a/	/i/	/u/	/e/	/o/
1	3.3	1.9	3.7	3.4	2.7	4.3
	(100)	(58)	(112)	(103)	(82)	(130)
2	5.2	4.8	4.4	4.3	3.9	5.7
	(100)	(92)	(85)	(83)	(75)	(110)
3	5.9	5.2	3.5	3.9	3.7	4.7
	(100)	(88)	(59)	(66)	(63)	(80)
4	4.0	2.8	4.4	3.5	3.8	4.3
	(100)	(70)	(110)	(88)	(95)	(108)
5	6.0	5.7	5.3	4.6	5.2	4.7
	(100)	(95)	(88)	(77)	(87)	(78)
6	5.0	5.2	4.0	3.6	4.0	3.6
	(100)	(104)	(80)	(72)	(80)	(72)

Table 1. Length of the 6 lines in arbitrary units.
The figures in parentheses are the relative lengths (%) compared with the reference position (=r. p.).

No.	r.p.	/a/	/i/	/u/	/e/	/o/
1	-	+++	-	-	+	-
2	-	+-	+	+	++	-
3	-	+	+++	+++	+++	+
4	-	++	-	+	+-	-
5	-	+-	+	++	+	++
6	-	-	++	++	++	++

Table 2. Relative lengths of 6 lines compared to the reference position (=r.p.).

+++ -69% compared to the r.p.

++ 70%-79% compared to the r.p.

\+ 80%-89% compared to the r.p.

+- 90%-99% compared to the r.p.

\- 100%- compared to the r.p.