TIMBRE STUDY ON NASALICS

PART V. STUDY ON OPEN AND BLOCKED NASALIZATIONS, ARTIFICIALLY DERIVED FROM FIVE ORAL VOWELS BY CLOSING RESPECTIVELY THE TERMINALS OF NASAL AND BUCCAL PASSAGES

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(Received May 31, 1963)

Summary—In this paper we treated a series of artificial nasal sounds (open and blocked nasalizations each derived from five Japanese vowels by closing in turn the terminals of the nasal and buccal cavities) and discussed the timbre structures of the nasals thus obtained. We examined the influences of the blocked nose upon the oral vowel sounds and those of the closed mouth upon the nasalized vocal sounds issued through the nose. Attention was focused upon the trap action of closed cavities.

Introduction

In the previous study[1], as one of our series researches on nasal sounds, we fully examined timbre patterns of the two kinds of artificial nasals derived exclusively from an oral vowel "U" only. Because of the seemingly most tubular form of buccal cavity for "U" among five Japanese vowels, we could promptly detect recurrent repression in timbre pattern of the open free nasalization with closed-mouth. In blocked nasalization with open mouth, too, we were able to detect periodical repression. Periodical repression in timbre patterns of both blocked and open nasalization seemed to be attributable to sharp selective action of side-circuit tube when closed. And, in that study, we used only nasals from a single oral "U". The study of artificial nasals derived from orals other than "U" still remains.

Meanwhile, in the study of artificial nasals carried on by J. Katzenstein[2] which really inspired us, we see four kinds of vocals, ordinary oral vowels [$\underset{\sim}{V}$], ordinary nasalized vowels [$\tilde{V}$], blocked nasaliszation by closing nose-end [$\underset{\sim}{\tilde{V}}$], and semi-nasalization closed at the uvular part [$\underset{\sim}{\bar{V}}$]. By preparing the diagram based upon the data of the table given by Katzenstein, and by expressing the four vocals by our own notation*, we showed, in Fig. 1, the result of Katzenstein. He used four vowels "A", "E", "O", "U", on the pitch of g, given by chest-voice. Because of the old-fashioned analysis, we cannot find so-called fine structure in the pattern. But it is most interesting to observe that the patterns, [$\tilde{A}$] and [$\underset{\sim}{\tilde{A}}$], [$\tilde{O}$] and [$\underset{\sim}{\tilde{O}}$], show a marked contrast (almost in the opposite phase) in

* refer to Bibl. 3.

their envelopes. We found interest in executing again this kind of experiment, adding more vowels and more pitches. It is because, the variation of vowel and pitch brings usually the different modes of vibration in the speech organ. So, we present here the results of the experiment of artificial nasals, blocked and open nasalizations, based upon five Japanese vowels, uttered on three pitches.

In short, here we aim to carry on our further pattern study of artificial nasals by adding to the kinds of vocal sounds, on one hand, and by increasing the pitch difference in pitch selection, on the other hand.

Incidentally, this experiment was actually carried out in 1955 at our Laboratory of Audiology.

Experimental Procedure

As calling voice, we use one adult (30 years male voice TF, uttered on the level of about *mezzo-forte* and at three pitches 120, 240, 320 cps* (pitches of large difference). For artificial nasals, we use two kinds, blocked nasalization with open mouth and free open nasalization with closed mouth. For mouth closure in free open nasalization, we give the following instruction to the calling subject: "Arrange your buccal cavity in exactly the same way as for odinary

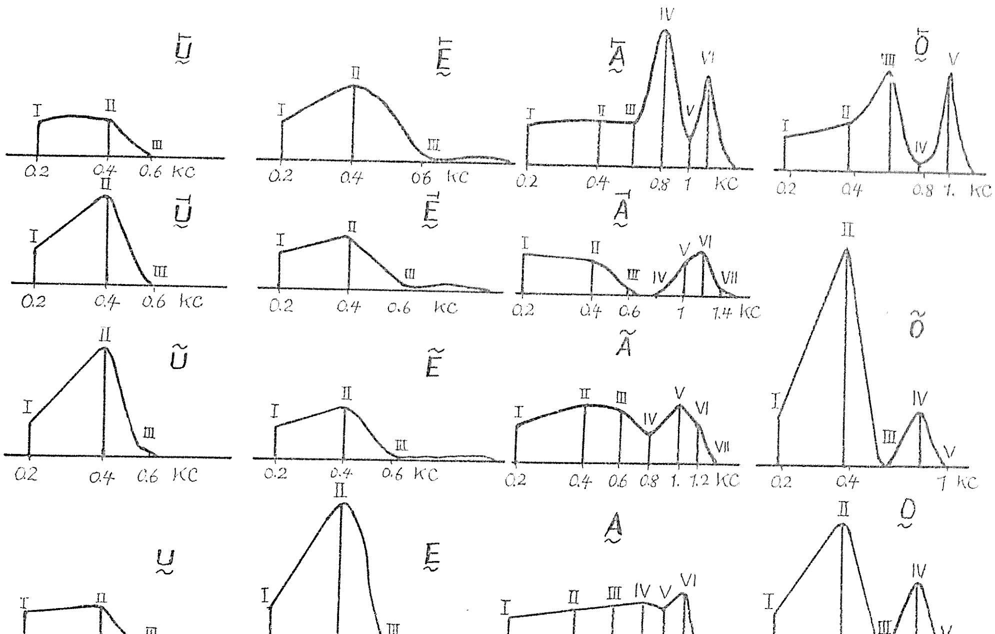

FIG. 1. Timbre pattern representation of different vowels (orals and nasals) and several artificial vowels (nose-end blocked and uvular blocked), graphed by following the data of Katzenstein.

* For the nasals of this subject, 120 and 240 cps pitches are most characteristic active ones, and 320 cps is an octave of the inactive pitch of 160 cps. (see Bibliography 3)

pronunciation of oral vowels (five Japanese vowels)". For nose blockage, we use finger pressure applied to both the nostrils. For mouth closure, we use the palm of the hand covered by rubber-glove placed over the mouth. To obtain the most reliable pattern, we instruct the subject to follow strict pitch matching. Level matching is also adopted to render the pattern-envelope most trustworthy; in this case, level matching between phones is perfectly carried out but level matching between pitches is not completely achieved.

Uniform and not-weighted amplification must be made for the analyzing machine. For one sound at one pitch, two oscillographs are taken and, by averaging these two graphs, we get mean pattern of the sound considered. A total of 60 graphs are obtained for two categories of nasals pronounced at all the three pitches on the background of five orals.

Observation and Description

To grasp the general feature which prevails over the whole pattern and to clarify the pattern details which regulate and govern the fine structure of pattern, there are two ways to fix our attention on the phenomena of nasalization so that the phenomena can be described exactly in every detail. As the most marked point for understanding the pattern details and consequently for an understanding of the characteristic clue in our quality judgement of timbre signals of given patterns, we can list two elements: peak structure and glen structure. This means, first, that in the consideration of pattern structure peak and glen can determine the pattern envelope in detail and, further, that in our pattern perception, *viz.*, pattern identification or pattern discrimination, peak and glen play the most fundamental parts.

If the reinforcing feature in pattern, that is, the reinforcing element in vocal-tract performance, is actually the best clue in our signal judgement, the structural peak must be the most vital point in our description. On the contrary, if the repressing feature in pattern, that is, the attenuating element in vocal-tract transmission, is really the most dependable clue in our pattern perception, the structural glen must be the marked point in our observation. In the phenomena of nasalization at least, there is a reason for consideration of the latter feature, *i.e.*, for stressing the importance of the structural glen as our predominant clue. It is for this reason that, in our treatment of nasalization, especially in the treatment of artificial nasalization, we consciously stress the description of the repressing feature in pattern priorily to reinforcing feature.

To make clear the repressive trend of pattern and to determine it exactly not only qualitatively but quantitatively, it might be best to resort to the method of pattern comparison, because by comparing patterns we can easily and quickly determine the similarity or dissimilarity between them.

Experimental Result

Since our present main concern is to obtain the data to explain the transmission mode of the bifurcated system of vocal organ which, in our experiment, is forced to begin to work under the condition where either end of two branches

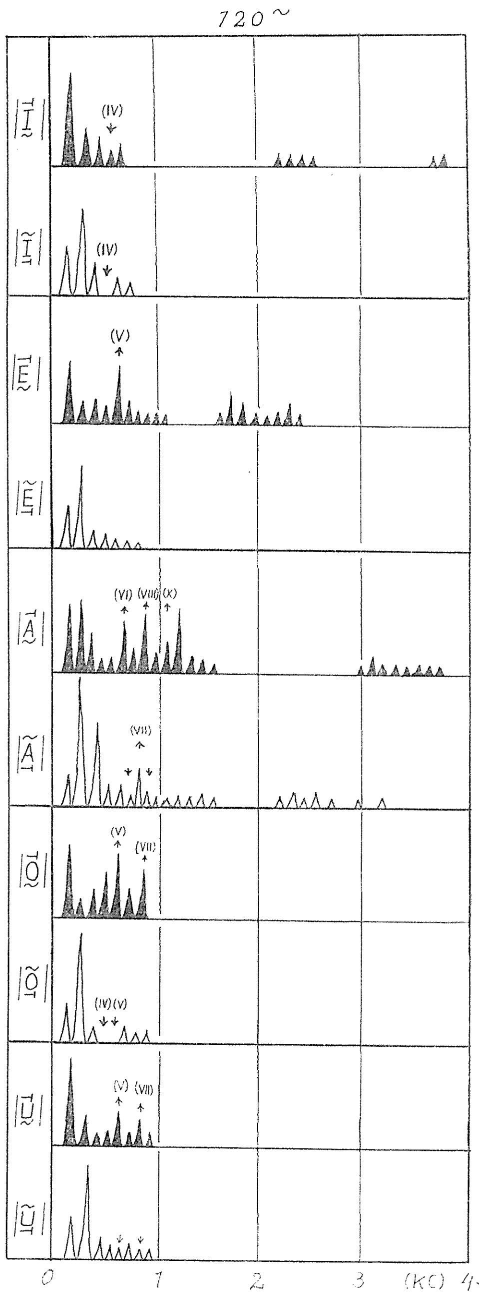

FIG. 2 (a)

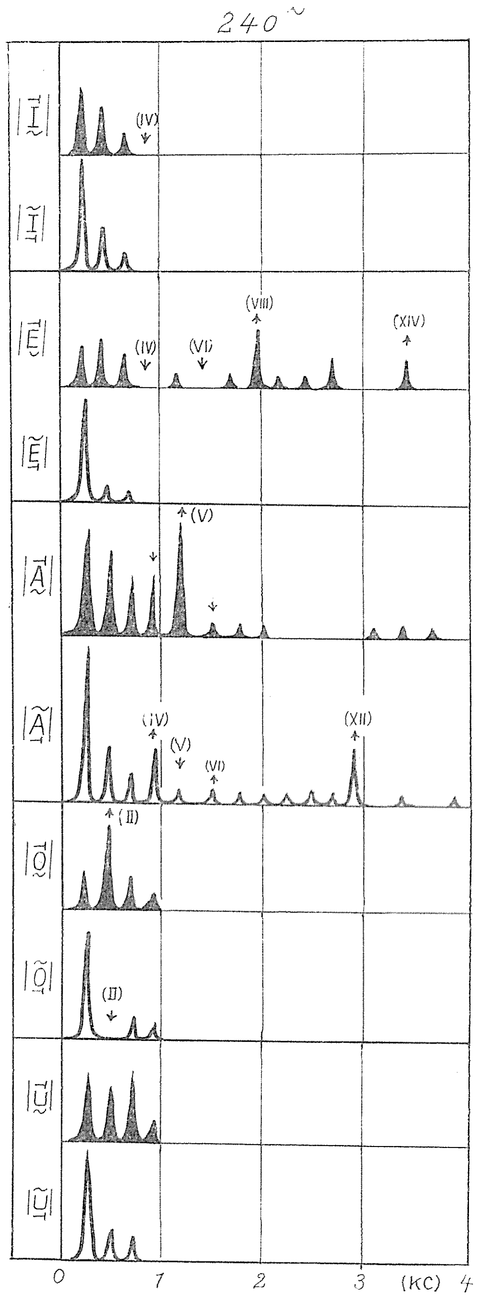

FIG. 2 (b)

of the circuit is closed or stopped up in turn, it would be best to examine the timbre patterns of two artificial nasals by arranging them so that their patterns for individual pitches come in fine contrast.

We show in Fig. 2, (a), (b), (c), three figures for three pitches where those

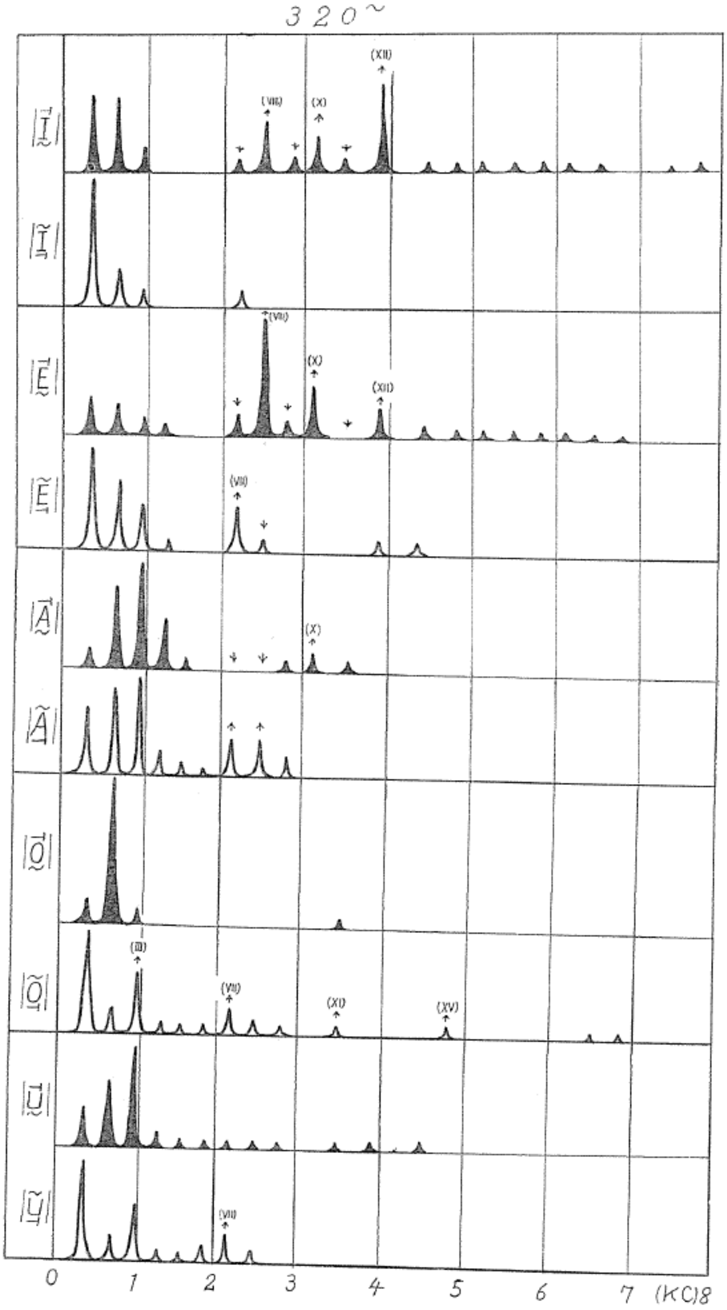

FIG. 2 (c)

FIG. 2. Pattern comparison between blocked nasalization $/\underset{\sim}{\vec{V}}/$ and open nasalization $/\tilde{V}/$ for individual back-ground phonemes. Figs. 2(a), (b), (c) show such pattern comparisons for three pitches 120, 240, 320 cps, respectively.

in black pattern mean blocked nasalization and those in white mean free open nasalization. The pattern display in white and black is planned for quick and easy pattern observation and comparison. Each figure is a result of twenty oscillographs for individual pitches. By these representations, we can trace with great facility the modification of patterns caused by the change of cavity-end conditions and can also examine the fine change in pattern due to the change in pitch. For that purpose, we plan the pattern representation in linear frequency scale because thereby the detection of structural recurrency is facilitated. For convenience, we mark the reinforced components of pattern by arrows ↑ pointing up and the repressed components of pattern by arrows ↓ pointing down, with the inscription of Roman numerals representing the number of order of the corresponding harmonics.

First, we describe the general feature of these pattern representations of two kinds of nasalizations uttered on three different pitches. With the exception of rare examples of ground phonemes on special pitches, the blocked nasalization has, in general, an upper part of pattern composed of a long uninterrupted sequence of harmonic components with sufficient intensity or intermittent series of components. In the blocked nasalization, we can nearly always find clear-cut vacant ground in the region of vocal glen. These two points are the evident mark of oralization left to be found in blocked nasalization. On the contrary, the free open nasalization with closed mouth shows the most simple pattern mode which, in the majority of cases, is composed of the powerful lower part of pattern only or some elongation of the lower pattern which extends into the region of 2–3 kc showing gradually increasing attenuation and covering the so-called vocal glen.

Another important feature of the general character of pattern formation between two nasals is the relevancy of the reinforced part of one pattern toward the repressed part of the other pattern. When we trace the pattern details by following the symbols of upward ↑ and downward arrow ↓, we can find that such a charcteristic part is restricted within the region of lower pattern below about 1 kc in patterns for 120 cps pitch, and in patterns for 240 cps pitch this part is restricted within the region below about 2 kc, and finally, in patterns for 320 cps pitch, this characteristic part is shifted to a region of 2–3 kc. In other words, accordingly as the uttering pitch is increased, the characteristic pattern part which is marked by a clear-cut tendency toward "out-of phase" relation in the two patterns of blocked nasalization and open nasalization, is gradually shifted to higher regions. This is even more clearly brought out in another way by examining only the relation of correspondency in lower pattern when preparing a relief contrasting two nasals, as shown in Fig. 3. By this representation, we can see that the mode of "out-of phase" relation in lower pattern is considerably changed by the cause of pitch change. For example, the condition for vibration mode of blocked nasalization which has the fundamental pitch component as one maximum is satisfied and accomplished only for low pitch; when the pitch is increased stepwise, this mode of vibration cannot take place, as clearly shown by examples: $/\underset{\sim}{\overrightarrow{O}}/$ for pitch 240 cps and $/\underset{\sim}{\overline{O}}/$, $/\underset{\sim}{\overrightarrow{A}}/$, $/\underset{\sim}{\overrightarrow{U}}/$ for pitch 320 cps.

Lastly, as to a general argument related to overall inspection, we add our

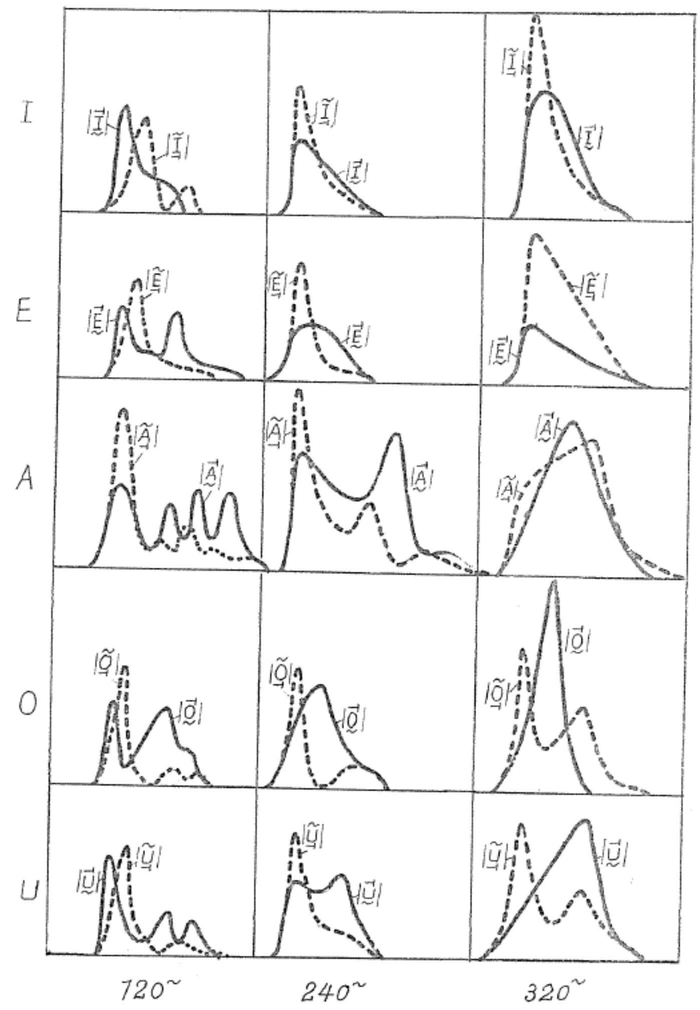

FIG. 3. Direct comparison of lower pattern between blocked nasalization (by full curve) and open nasalization (by broken curve).

conviction that for these nasalizations there is a clear distinction of pitch, that is, an active pitch and an inactive pitch. Considered from the degree of facility of establishing upper structure of timbre pattern, a 320 cps pitch is one of the active pitches and 120 and 240 cps pitches are both the inactive ones.

Inasmuch as the timbre pattern of these two artificial nasalizations is too complicated to be easily understood, we are wise to alter our examination by changing our angle of observation a little. Instead of individual comparison between blocked nasalization and open nasalization by taking each phoneme as our basis of observation, we plan here a process of summarized comparison between separate groups of blocked nasalization and open nasalization based upon timbre patterns of all phonemes. In Figs. 4 (a), (b), (c), and Figs. 5 (a), (b), (c), we give better representations which serve for our inspection and for our

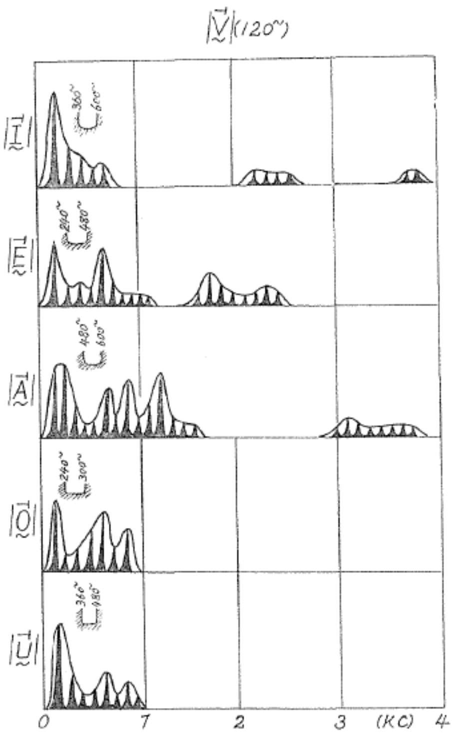

FIG. 4 (a)

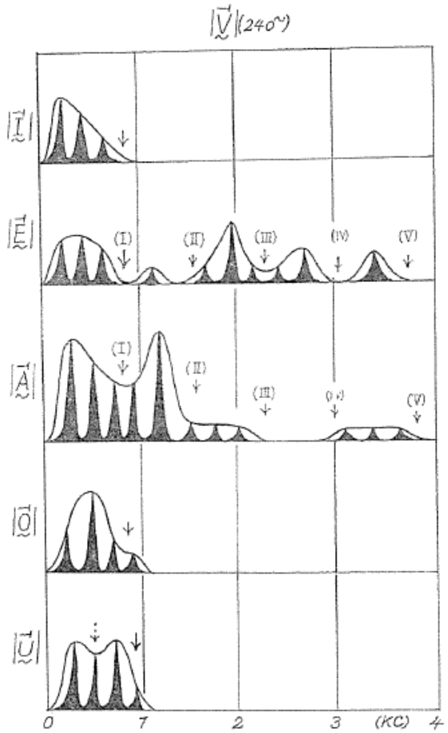

FIG. 4 (b)

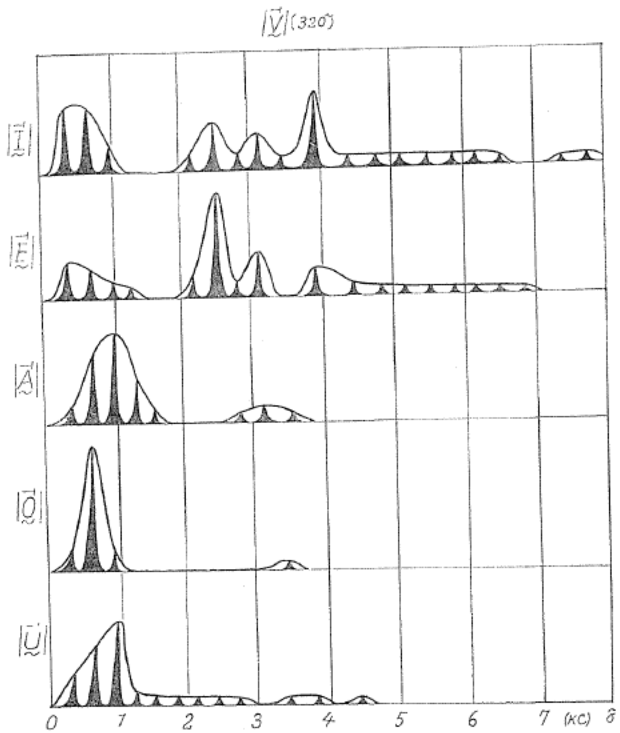

FIG. 4 (c)

FIG. 4. Representation of blocked nasalization patterns of five back-ground phonemes. Figs. 4 (a), (b), (c) show respectively patterns of blocked nasalization for three pitches, 120, 240, 320 cps.

conclusion. In these representations of both the blocked nasalization and open nasalization, we show pattern envelopes clearly and thus can read them readily. To bring out pattern details and to comprehend their general feature, it is wise for the time being to concentrate our attention on repression phenomena.

In blocked nasalization /$\tilde{\bar{V}}$/, the region where the repression phenomena begin, depends, in some measure, on the kind of back-ground phoneme. We can enumerate conspicuous examples of the region where the repression starts by referring, for example, to the patterns for a pitch of 120 cps as shown in Fig. 4 (a): For /$\tilde{\bar{E}}$/, we find the repression in the region of harmonics II-III-IV; for /$\tilde{\bar{A}}$/, in the region of harmonics IV-V; for /$\tilde{\bar{O}}$/, in the region of harmonics II-III; for /$\tilde{\bar{U}}$/, in the region of harmonics III-IV; and for /$\tilde{\bar{I}}$/, III-IV, particularly at the point of harmomics IV. In the patterns for pitches 240 cps and 320 cps as shown in Figs. 4 (b) and 4 (c), the fundamental position of repression varies and changes accordingly as the back-ground phoneme changes. Therefore, in these cases, we cannot determine a fixed position or strictly limit the starting position within a narrow region. This suggests to us that under the condition of back-ground of oral pronunciation, the effective length of nasal cavity system in playing the role of side-circuit to buccal passage is susceptible to change as

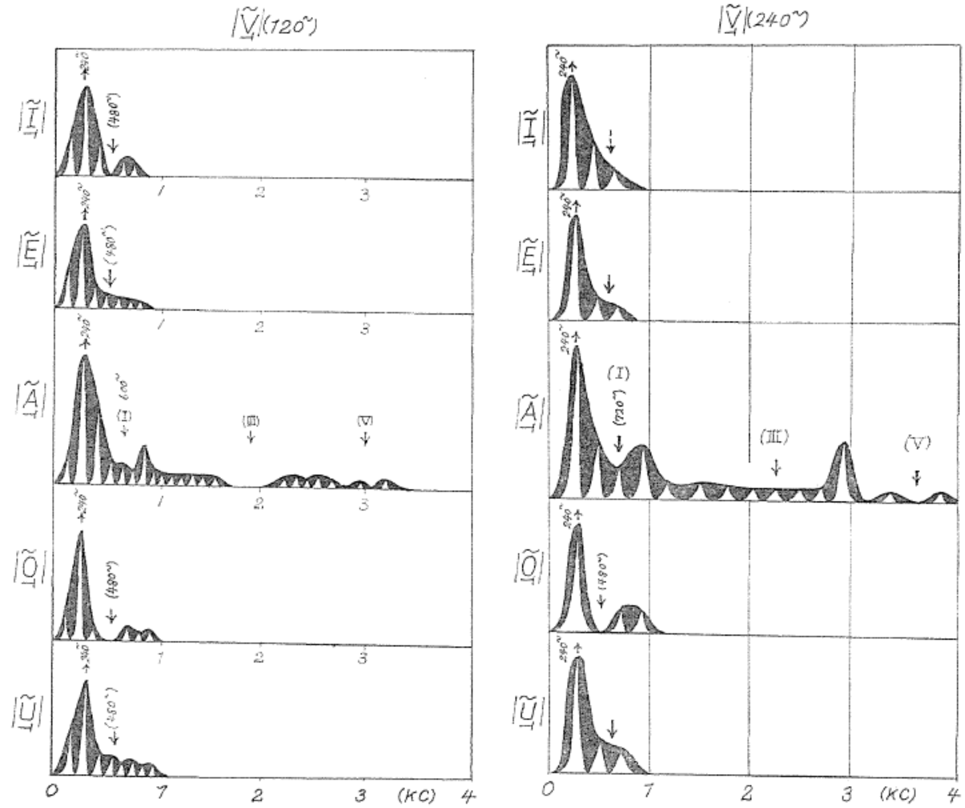

FIG. 5 (a) FIG. 5 (b)

the result of the slight shifting of velum part when vowel is varied.

In blocked nasalization the region where the repressing phenomena begin, depends considerably on the kind of pitch. For example, in patterns for pitch 120 cps the repressed position is found in the harmonics group, between 240 and 480 cps; in patterns for pitch 240 cps the repressed position is 960 cps; and in patterns for 320 cps pitch, it is about 1300 cps. For open nasalization with closed mouth $/\tilde{V}/$, the fundamental repressed position is comparatively constant, notwithstanding the variety of back-ground phoneme, as shown in Figs. 5 (a), (b), (c). For example, in patterns for 120 cps pitch in Fig. 5 (a), the point of harmonic IV (480 cps) is the first repression point. Only for pattern $/\tilde{A}/$, in this pitch case, does the repressed position seem to extend a little way into the region of harmonics IV-V-VI (mean 600 cps). For patterns $/\tilde{V}/$ for pitch 240 cps in Fig. 5 (b), the repression starting point seems to be in an exceedingly narrow region between harmonics II-III, that is, in a region of 480–720 cps. For patterns for pitch 320 cps in Fig. 5 (c), especially for patterns $/\tilde{O}/$ and $/\tilde{U}/$, there is an evident tendency toward repression of the second harmonic 640 cps,

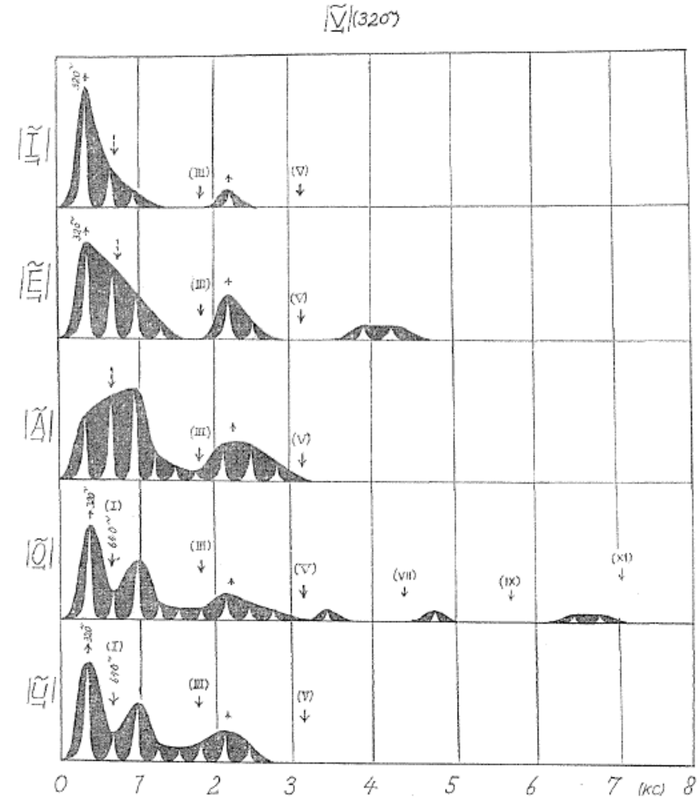

FIG. 5 (c)

FIG. 5. Representation of open nasalization patterns of five back-ground phonemes. Figs. 5 (a), (b), (c) show patterns of open nasalization for three pitches, 120, 240, 320 cps, respectively.

a point which exactly corresponds to the repressed region we clearly observed in the patterns for pitches 120 and 240 cps. This tendency toward near constancy of a repression starting point suggests to us the fact that, in open nasalization with closed mouth, the trap action of closed buccal system performing as a side-circuit of some kind in the utterance of this artificial nasalization is nearly constant notwithstanding the condition that the mouth-cavity itself can vary considerably as oral pronunciation is changed. Incidentally, we should not neglect to mention that this observation is made relative to the pronunciation of Japanese oral vowels during which no degree of front-and-back movements of jaw can clearly be seen and meanwhile up-and-down movement of jaw is so often observable. Among the artificial nasals for pitch 320 cps, the nasals $/\tilde{\underline{O}}/$ and $/\tilde{\underline{U}}/$ are most typical: showing thereby the fundamental of the greatest amplitude, accompanied by many components of gradually decreasing amplitude; if we assume the closed tube having fundamental absorption of 640 cps, the odd harmonics series absorption (III, V, VII, IX, XI) would well explain the structure of this pattern. By the way, from the observation of the patterns for 320 cps where the phonemic elements of oral vowels are almost lost, we can point out the fact that the components, 240–320 cps and 2000-2200 cps, are considered the *nasal formants.* As to the constancy of repressed position inspite of the change of phonemes, there is a little difference between blocked and open nasalizations. This difference is, however, a matter of degree. The most important and essential difference between them is revealed in settling the point whether the influence of pitch upon the position of fundamental repression really exists or not. In the blocked nasalization with free mouth passage, the inflnence of pitch upon repressing position is clear and vital, as we have described in some detail by citing actual data. In open nasalization, the repression point does not change when the position of fundamental repression is found in the narrow region of 480-720 cps.

When stepping into the study of the recurrency of repression phenomena, we cannot expect too much from the pattern representations already presented because there are not many which show a long sequence of component trains. We are obliged to examine the patterns of $/\overline{\underset{\sim}{I}}/$, $/\overline{\underset{\sim}{E}}/$, $/\overline{\underset{\sim}{A}}/$ in blocked nasalization and the patterns of $/\tilde{\underline{A}}/$ and $/\tilde{\underline{O}}/$ only in open nasalization. In Fig. 6 we show the patterns of $/\tilde{\underline{A}}/$ and $/\tilde{\underline{O}}/$ in which we trace the recurrency of repressing phenomena by ordering the harmonic relation among four repression regions. By Roman numerals I, III, V, VII, we show that the relation among repression regions can be explained by odd-harmonic relation and this suggests the presence of absorbing mechanism of a closed tube. We can infer that the closed tube is formed by buccal passage artificially stopped up at its open end.

In Fig. 7 we show the patterns of $/\overline{\underset{\sim}{I}}/$ and $/\overline{\underset{\sim}{E}}/$ for certain pitches. In these pattern representations, we add some explanations on the order and mechanism of absorbing components.

Concerning the sharp contrast in pattern detail between two artificial nasalizations, we add one final note that is quite important: When we take up the patterns for pitch 320 cps, we are easily led to the fact that the patterns of blocked nasalization have the components of even-number harmonic predominant type, while the patterns of open nasalization are composed of constituents of odd-number harmonic predominant type. This is the most evident character. For example, /Ĩ/ and /Ẽ/ are characterized by having marked components of harmonics VIII, X, XII, whereas /Õ/ and /Ũ/ are characterized by the predominancy of harmonic components I, III and VII, and /Ĩ/ and /Ẽ/ are marked by the predominancy of components I and VII. In these patterns, harmonic V is either

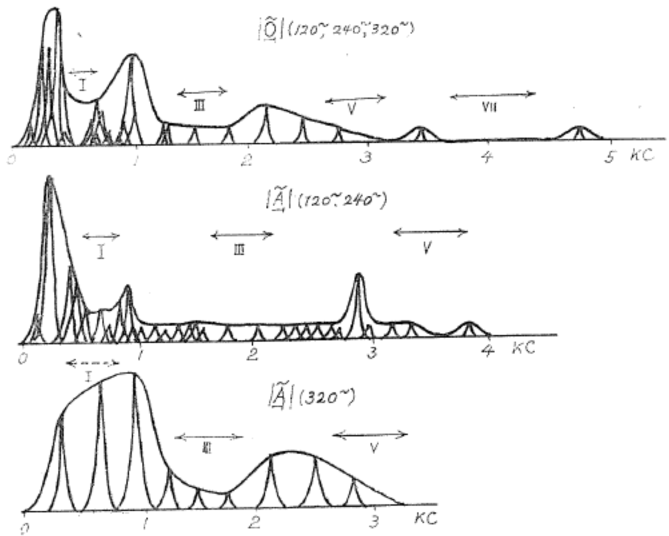

FIG. 6. Examples of open nasalization showing relatively clear recurrent nature of repression in pattern.

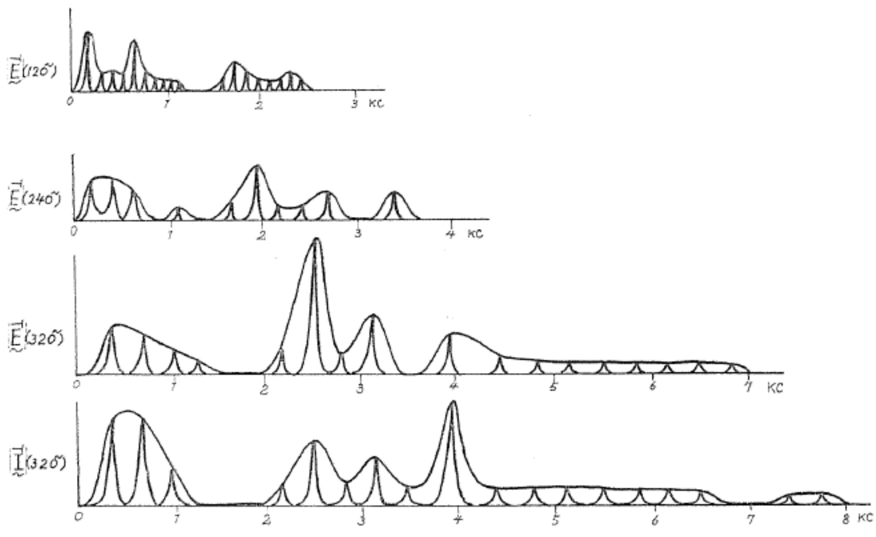

FIG. 7. Examples of recurrent nature of repression in blocked nasalization.

zero or exceedingly weak because it corresponds to the very region of the first absorbing position.

As to why the open nasalization with closed mouth is rich in odd-number harmonics and why the nose-blocked oralization, that is, the so-called blocked nasalization with open mouth, is rich in even-number harmonics, these are the exact points most vital for us to know. But this does not always apply to all possible nasalizations, as we know from the pattern study for 120 cps and 240 cps pitches. Only in the cases where we meet the most typical pitches, does the above tendency prevail.

Specialized Observation—Pattern Difference Representation

As we have already clearly distinguished in Figs. 2 (a), (b), (c), there is a sharp contrast between patterns of blocked nasalization and open nasalization. For instance, a tendency toward establishment of "out-of phase" relation in the lower pattern is found in the majority of cases and, moreover, on the point of fine construction, there is seen a type of structure tending toward even-harmonic predominancy in blocked nasalization, and, meanwhile, there is a tendency toward odd-harmonic predominancy in open nasalization. By way of this sharp contrast, we arrive at the stage of our study where we can advance in understanding of

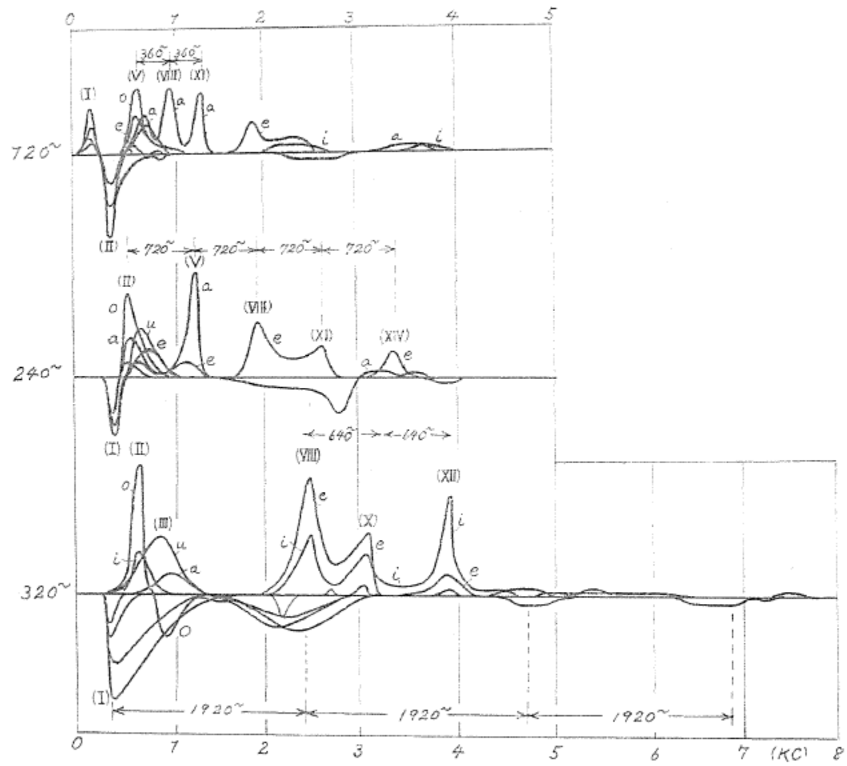

FIG. 8. Pattern-difference representation of white-voice of two artificial nasalizations, blocked and open, displayed for individual pitches.

pattern formation and gain a foothold for interpretation of timbre quality as well. To bring out the differences between patterns and to stress the contrast, we naturally utilize the process of pattern differentiation. By making a differentiation of patterns, points of similarity are compensated for and those of dissimilarity remain in bold relief. In Fig. 8 we show the pattern-difference representation of white-voices for individual pitches. In the positive side of the ordinate of each graph, the elements of *oralization* are expressed and in the negative side of the ordinate the elements of *nasalization* are represented. We note with interest that the oralization elements due to several certain phonemes pulsate with some fixed intervals and that the nasalization elements to no degree pulsate, extending and covering continuously a considerable range. What must be noted in these representations are two things: The interval found in the oralization for 240 cps is 720 cps and the interval found in the nasalization for 320 cps is 1920 cps. This is clearly shown in Fig. 8. The interval of 720 cps is exactly three times its original pitch of 240 cps and the interval of 1920 cps is exactly six times its original pitch of 320 cps. These cycle numbers of intervals must be remembered, because they are important for our further interpretation of vocal timbres of this calling subject.

Conclusion

We have studied in detail the timbre patterns between two kinds of nasalization, open nasalization (more precisely, mouth-closed nasalization $/\underline{\tilde{V}}/$) and blocked nasalization (more exactly, nose-stopped oralization $/\underset{\sim}{\bar{V}}/$), by employing five oral Japanese vowels as back-ground phonemes uttered on three kinds of pitch. According to their timbre patterns, mouth-closed nasalization gives a distinct feature of so-called nasals—almost gradually attenuating envelope of amplitude as the component frequency advances—conditioned with the specific repression of amplitudes (480 cps, 640 cps or 720 cps) seemingly due to a trap action of closed mouth: there is no evidence of phonemic value of back-ground vowels in this nasalization pattern, but rather in certain regions (for example, 240–320 cps and 2000–2200 cps) there seems exist common elements of nasals which we could name "nasal formants," if necessary. On the contrary, in the nose-stopped oralization, we can trace with ease and evidence the phonemic elements of the corresponding vowels, and in addition to these elements there exists a sort of nasal effect caused by downward or upward shift of the first formant of the corresponding orals. As the result of these tendencies of two nasal sounds, we have, in the case of the most typical nasal pitch (for example, 120 cps), an "out-of phase" relation (almost opposite in phase), that is almost maximum-minimum correspondence between two kinds of nasals, blocked and open nasalizations. However this typical contrast becomes less conspicuous when the pitches are increased, particularly for the narrower vowels (for example, for vowels "I" and "E").

It should be carefully stressed that the so-called nasal effect of human nasal sounds is not quite equal as to its degree when uttering pitches are varied. There are certain pitches for which nasal effect appears most easily and conspicuously; and for others it does not appear so evidently or it appears only very reluctantly. In other words, there exist so many degrees and so many grades concerning the nasalization which we actually have in human nasal pronunciation.

As to the description more in detail, we can point out the following facts. For example, in the blocked nasalization for the typical pitch of 120 cps, we can observe, in its lower pattern, an existence of a kind of very narrow band-elimination filter action (for example, 240–480 cps for $/\tilde{\bar{E}}/$, and 360 480 cps for $/\tilde{\bar{U}}/$), but for higher pitches this filter-like action disappears.

As to the repression of higher order we are able to trace only about limited examples of timbre patterns which incidentally extend wide in the higher frequency domain, forming thus a broad series of higher components. Among the five vowels as back-ground basis, the timbres of relatively wide vowels, for example "A" and "E", in all cases, and in some cases of relatively tubular cavity vowels, for example "O" and "U", come to the objective of our inspection. Concerning these vowels, we can find that, in addition to the repression of the fundamental on which we have already discussed and which are, according to our opinion, attributable to the absorption of the buccal cavity for sounds $/\tilde{V}/$, and to that of the pharyngo-nasal cavity for sounds $/\tilde{\bar{V}}/$, there exists further a series of repressions of higher order, and particularly the odd-harmonics series III, V, VII, ... of the fundamental repression source is evident. This fact means that the nasal cavity system and even the buccal cavity (but only when the wider vowels and the tubular vowels come to our consideration) can have the possibility to operate not only as a Helmholtz Resonator branched to the main circuit but also as a kind of tube, particularly as a tube with a far-end terminal closed. Here we add one remark: in rare but possible cases, we can observe an evidence of all series of components of repression, that is I, II, III, IV, V, ... including even and odd-harmonics series, meaning that the side-circuit operates apparently as an open tube notwithstanding the fact that its terminal is actually closed.

For an exact verification of the existence of higher-order repression, the present stage of our study is not sufficient to insist upon it. Our aim is only to suggest the possibility of this type of repression. This type of repression is most valuable in the consideration of personal color or personal nuance in vowel pronunciation.

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