Original Contribution

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Nasalance scores in normal adult Japanese speakers of the Tokyo dialect

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Objective: To obtain the average value of the nasalance score (N-score) measured by the Nasometer in normal adult Japanese speakers of the Tokyo dialect.
Methods: The subjects were 40 normal Tokyo dialect speakers (20 males and 20 females; 20−46 years old). KayPENTAX Nasometer II 6450 was used for data collection. Utterance tasks were (i) 2 long sentences which included various Japanese sounds other than nasal sounds, (ii) the 5 Japanese vowels, (iii) 3 low-pressure sentences without nasal sounds, and (iv) 2 high-pressure sentences also without nasal sounds.
Results: The average of the N-scores was 12.9% in both long sentences. Among the 5 vowels, [i] showed the significantly highest N-score (38.4%). In both the low-pressure and the high-pressure sentence groups, the N-scores were significantly different among the sentences. The higher N-scores were found in sentences containing the vowel [i] and in sound environments where vowels were less likely to be devoiced. In all utterance tasks the N-scores were significantly higher in females than those in males.
Conclusion: The average value of the N-scores for the Tokyo dialect, the most common Japanese speech, was the same as those for several other languages. The selection of appropriate utterance tasks considering the characteristics of the N-scores obtained using the Nasometer was discussed.

Key words: Nasometer, nasalance score, velopharyngeal function, Japanese Tokyo dialect

Introduction

The velopharyngeal function, which divides the vocal tract into the oral cavity and nasal cavity, is important for the acquisition and maintenance of clear speech. In the evaluation of the velopharyngeal function related to speech impairment, the result of auditory judgment of consonant distortion and hypernasality due to exhaled nasal leakage is the first priority. However, because auditory judgment is a subjective evaluation, it may be difficult to ensure reliability. Therefore, the Nasometer has been used to compensate for the shortcomings of the subjective evaluation methods.

Since Fletcher[1,2] first proposed the prototype in 1970, the Nasometer has been used for years without changing its basic configuration. Figure 1. illustrates the configuration of the Nasometer. It includes a shielding plate which is placed under the nostrils of the subject wearing a headpiece, and two unidirectional microphones that collect the subject's voice from the nasal and oral sides, respectively. The collected sound is first processed using a bandpass filter of 300−750 Hz. Subsequently, it is used as the acoustic energy on the nasal cavity side (Pn) and the acoustic energy on the oral cavity side (Po) to calculate the measured value by the Nasometer; that is, the "nasalance" score (N-score), to use the term coined by Fletcher in 1974.[3] The N-score is a measured value showing the ratio of Pn to the sum of Pn and Po and is represented as a percentage. The acoustic filter of the Nasometer was adopted as a result of an experiment to determine which frequency band of speech should be analyzed to obtain an N-score that closely corresponds

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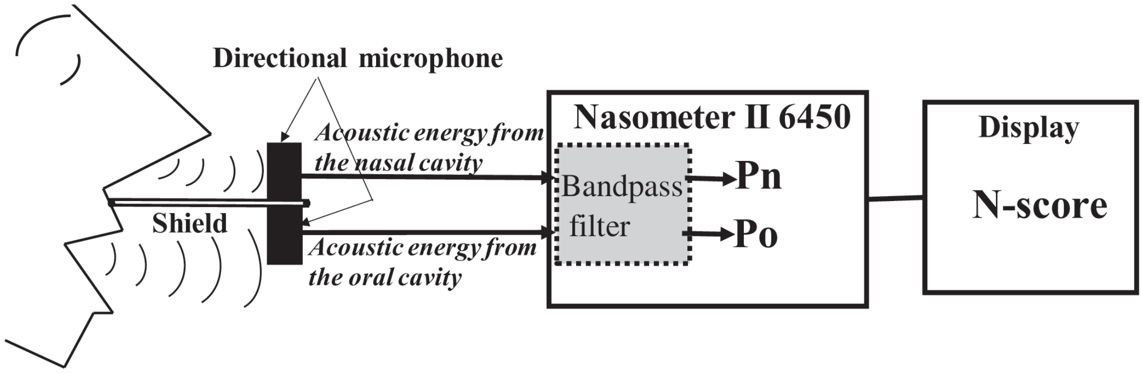

Pn / (Pn + Po) × 100 = N-score

Figure1. Diagram of the Nasometer

to the auditory judgment of hypernasality by clinicians.[3,4]

The N-score obtained by using the Nasometer does not actually reach 0% even if an adult with good velopharyngeal function utters a sentence that does not contain any nasal consonants. Gildersleeve-Neumann et al.[5] experimentally clarified that the reason the N-score did not reach 0% was because sound energy was transmitted to the nasal cavity through the palate and called it "transpalatal nasalance." Blanton et al.[6] found that this transpalatal transfer of acoustic energy occurs primarily through the soft palate and contributes to an increase in the N-scores of sentences containing high front vowels. On the other hand, it has also been pointed out that audible airflow noise occurs during consonant production due to a small fistula in the palate and/or mild nasopharyngeal insufficiency, which raises the Pn and results in a high N-score.[7,8] These studies revealed that the N-score of the Nasometer could not exclusively reflect the acoustic energy that flowed to the nasal side due to a velopharyngeal insufficiency, i.e., the gap between the soft palate and the pharyngeal wall. To utilize the N-score as a measured value for objectively evaluating the velopharyngeal function, the selection of appropriate utterance tasks and the interpretation of results will be important issues.

Because the Nasometer uses spoken language for measurements, it is assumed that the phonetic characteristics of each language may affect the N-score. Therefore, normative nasalance data have been reported in various languages.[9] To our knowledge, there are only two reports on Japanese N-scores,[10,11] both of which are based on data from speakers of the Western region dialects of Japan. However, speakers of the Tokyo dialect, which is generally considered the common speech in Japan, have not yet been thoroughly examined.

Along with the increasing evidence on the phonetic dependence of N-scores, the effect of the speakers' gender differences on their normative value has also been examined.[12,13] Although a variety of factors, such as the voice fundamental frequency range, vocal tract size, and speaking style, among others, can be reflected in the gender-related difference in N-scores, it is difficult to identify which aspects inherent in gender differences are more important than any others. Nevertheless, taking the speaker's gender into consideration in the Nasometry assessment is inevitable because of its practical relevance.

The purpose of this study was therefore to obtain the average value of the N-scores measured by the Nasometer in speakers of the Tokyo dialect. Thus, in these experiments, N-scores were measured using multiple types of utterance tasks for 40 normal, healthy, Tokyo dialect speakers (20 males and 20 females). Based on the resultant N-scores, both the influences of the characteristics of the utterance tasks and the subjects' gender were assessed; and accordingly, based on the subsequent analyses, a standard N-score value and the most appropriate utterance tasks were proposed.

Materials and Methods

Subjects

The subjects were 40 normal, healthy adults (20 males and 20 females, 20−46 years old; average 28.4 ± 7.4 years old; males 29.9 ± 8.3 years old, females 26.9 ± 6.3 years old) who met all three conditions: (1) no history associated with speech language, (2) no abnormal findings in hearing judgment of speech or oral organs suggestive of velopharyngeal insufficiency, and (3) born and raised in the Kanto (eastern) area of Japan.

Materials

A KayPENTAX Nasometer II 6450 (Montvale, NJ, USA) was used for data collection. All tests were performed in soundproof rooms (in the Kitasato University Hospital or in the Faculty of Allied Health Sciences, Kitasato University), and the microphone was calibrated according to the manufacturer's instructions prior to the tests.

Utterance tasks

The syllables and sentences listed in Table 1 were used as utterance tasks which partially overlap with those used by Hirata et al.[14] and Uchiyama et al.[15]: (i) 2 long sentences without nasal sounds, (ii) the 5 Japanese vowels, (iii) 3 low-pressure sentences, composed of vowels and semivowels, (iv) 2 high-pressure sentences, including unvoiced plosives and affricates.

Procedures

The subjects read aloud the utterance tasks printed on paper, 3 times for each task and recorded them with the Nasometer. Among those 3 N-scores (mean nasalance) obtained for each task, a median value N-score was selected and used for the analyses.

Statistical analyses

IBM SPSS Statistics version 24 was used for statistical data processing. Two-way mixed analysis of variance (ANOVA) was used to analyze the effects of the utterance tasks and gender. The sphericity assumption for the within-subject factor was assessed with Mauchly's test. If the assumption was violated, the degrees of freedom were adjusted using the /ε/ of Greenhouse and Geisser. Post-hoc comparisons among groups were performed using the Bonferroni test. The significance level was set at $P < 0.05$.

Ethics

This study was reviewed by the Research Ethics Review Board of Kitasato University School of Allied Health Sciences, Kitasato University (No. 2013-023).

Results

Long sentences without nasal sounds [(a), (b)]

Table 2 shows the N-scores of 2 long sentences, (a) and (b), that do not include nasal sounds. The average N-score was 12.9% for each sentence. As a result of the

Table 1. Utterance tasks

Vowels		[a] [i] [ɯ] [e] [o]
Long sentences without nasal sounds	(a)	[ʥidoːɕaɕojɯːdaisɯːwa kokoɕibaɾakɯ ʣoːkaoʦɯzɯkeɾɯdeɕoː]
	(b)	[wakaisedaito taiwasɯɾɯkotowa kaɾeɾaoɾikaisɯɾɯɯede çiʦɯjoːdeaɾɯ]
Low-pressure sentences	(c)	[ɯeo o:ɯ]
	(d)	[jo:iwa o:i]
	(e)	[aoo oejo]
High-pressure sentences	(f)	[koʦɯkoʦɯ ʦɯkɯsɯ]
	(g)	[kiʦɯʦɯki ʦɯʦɯkɯ]

Table 2. N-scores in long sentenses

Utterance tasks			Mean nasalance %		
			N = 40	Males (n = 20)	Females (n = 20)
			Average ± SD (Range)	Average ± SD (Range)	Average ± SD (Range)
Long sentences without nasal sound	(a)	[ʥidoːɕaɕojɯːdaisɯːwa kokoɕibaɾakɯ ʣoːkaoʦɯzɯkeɾɯdeɕoː]	12.9 ± 5.8 (5−31)	10.6 ± 4.3 (5−22)	15.2 ± 6.3 (7−31)
	(b)	[wakaisedaito taiwasɯɾɯkotowa kaɾeɾaoɾikaisɯɾɯɯede çiʦɯjoːdeaɾɯ]	12.9 ± 5.9 (5−30)	10.8 ± 4.3 (5−18)	14.9 ± 6.6 (7−30)

two-way mixed ANOVA of the 2 sentences × gender, the interaction was not significant. Only gender had a significant effect, and the value was significantly higher in females than that in males (F (1,38) = 7.20, P < 0.05).

Vowels

Table 3 lists the N-scores of the 5 Japanese vowels. As a result of the two-way mixed ANOVA of those 5 vowels × gender, the interaction was not significant, and a significant effect was observed for both vowels and gender [F (2.59, 98.28) = 72.77, P < 0.01; F (1, 38) = 9.64, P < 0.01]. The N-score of females was significantly higher than that of males. Multiple comparisons of the 5 vowels showed that [i] was significantly higher and [o] significantly lower than the other 4 vowels (both P < 0.01). For the 3 middle vowels, only [a] > [ɯ] had a significant difference (P < 0.01).

Low-pressure sentences [(c), (d), (e)] and high-pressure sentences [(f), (g)]

Table 4 shows the N-scores for low-pressure and high-pressure sentences. As a result of the two-way mixed ANOVA of 3 low-pressure sentences × gender, the interaction was not significant, and a significant effect

Table 3. N-scores in vowels

Utterance tasks	Mean nasalance %		
	N = 40	Males (n = 20)	Females (n = 20)
	Average ± SD (Range)	Average ± SD (Range)	Average ± SD (Range)
[a]	21.9 ± 12.4 (4−49)	15.9 ± 9.1 (4−40)	27.9 ± 12.5 (5−49)
[i]	38.4 ± 15.4 (14−73)	31.8 ± 14.8 (14−60)	45.1 ± 13.1 (26−73)
[ɯ]	14.5 ± 9.8 (4−42)	11.5 ± 7.8 (4−28)	17.5 ± 10.8 (4−42)
[e]	18.9 ± 13.2 (4−53)	16.5 ± 12.5 (4−53)	21.4 ± 13.7 (4−44)
[o]	9.6 ± 7.7 (2−34)	6.7 ± 4.4 (2−21)	12.4 ± 9.2 (3−34)

Table 4. N-scores in sentences

Utterance tasks			Mean nasalance %		
			N = 40	Males (n = 20)	Females (n = 20)
			Average ± SD (Range)	Average ± SD (Range)	Average ± SD (Range)
Low-pressure sentences	(c)	[ɯeo o:ɯ]	9.8 ± 5.6 (3−22)	8.4 ± 4.4 (3−18)	11.3 ± 6.3 (5−22)
	(d)	[jo:iwa o:i]	16.5 ± 9.1 (6−34)	14.3 ± 8.5 (6−4)	18.7 ± 9.3 (8−34)
	(e)	[aoo oejo]	11.2 ± 6.8 (4−25)	8.1 ± 4.6 (4−17)	14.3 ± 7.4 (5−25)
High-pressure sentences	(f)	[kotsɯkotsɯ tsɯkɯsɯ]	10.7 ± 4.1 (5−19)	9.2 ± 3.9 (5−19)	12.2 ± 3.9 (7−19)
	(g)	[kitsɯtsɯki tsɯtsɯkɯ]	18.2 ± 6.5 (7−32)	15.8 ± 6.7 (7−30)	20.7 ± 5.5 (13−32)

was observed for both sentence type and gender (F (1.63,62) = 36.02, P < 0.01; F (1,38) = 5.08, P < 0.05). Females showed higher N-scores than did males for all the sentences. When multiple comparisons were performed for the 3 low-pressure sentences, (d) [jo:iwa o:i] showed a significantly higher N-score than did the sentences (c)[ɯeo o:ɯ]and (e) [aoo oejo] (both P < 0.05).

As a result of the two-way mixed ANOVA of 2 high-pressure sentences × gender, the interaction was not significant; and significant effects were observed for both sentence type and gender (F (1,38) = 192.23, P < 0.01; F (1,38), respectively) = 6.58, P < 0.05). (g) [kitsɯtsɯki tsɯtsɯkɯ] showed a higher N-score than did (f) [kotsɯkotsɯ tsɯkɯsɯ]; and, in both sentences, females showed a higher N-score than did males.

Discussion

We performed Nasometry on speakers of the Tokyo dialect using multiple different types of utterance tasks. As a result, it became clear that the N-score differed depending on the vowel, and the highest value was shown for the front high vowel [i]. In addition, gender differences were observed in all utterance tasks, with females showing higher N-scores. The fact that the N-score was significantly different among the sentences in both the low-pressure and high-pressure groups was also a remarkable result considering the selection of the utterance task. We believe that the results of the present study provide basic data for applying the Nasometer to the clinical practice of speech disorders in Japanese speakers of the Tokyo dialect.

The standard value of the N-score of Tokyo dialect speakers

In daily conversation, it is often observed that vowels, which are originally oral sounds, become nasalized due to the influence of adjacent nasal sounds. It is assumed that these co-articulations are influenced by the types and order of the speech sounds, utterance speed, and the speaker's utterance habits, among others. To evaluate velopharyngeal function without these fluctuating factors, it is useful to perform utterance tasks that do not include nasal consonants and contain various other speech sounds. In English-speaking countries, the "Zoo Passage" has long been used as a standardized reading passage that excludes nasal consonants. The 2 long oral sentences [(a) and (b)] adopted in this study include all the Japanese phonemes except /p, b, m, n/, and /g/. The phonemes /p/ and /b/ appear less frequently than do the others in Japanese,[16] and in the Tokyo dialect, /g/ is often nasalized when it occurs in positions other than at the beginning of a word. Therefore, it can be assumed that these sentences have validity comparable to that derived from the "Zoo Passage" in English as utterance tasks for obtaining the Japanese standard value of the N-score.

The average N-score values of each oral sentence, (a) and (b), obtained from Tokyo dialect speakers were both 12.9%. According to the data of Mayo et al.,[9] which included N-scores from multiple languages, the average N-score value of the oral passages in adults was 10%−21%, and the results in the present study for the Tokyo dialect speakers were also within this range. Regarding gender differences, Mayo et al.[9] acknowledged that they affected the N-score but concluded that the differences were not sufficient to determine specific standard values for men and women. In the results in the present study, the average N-score values were significantly higher in women than those in men for both sentences (a) and (b), but none deviated from the 10%−21% range. Therefore, it can be said that the standard value of the N-score is almost the same even if the language is different; the Tokyo dialect, which is the most common speech in Japan, is no exception. Uchiyama et al.,[17] who examined cases of cleft palate in Japan, proposed a cut-off value of 21% for the N-score to determine velopharyngeal insufficiency. This value also supports the validity of our results.

N-scores of vowels

This study demonstrated a significant difference in the N-scores of single vowels, with higher values in the descending order of [i] > [a], [e], [ɯ] > [o]. Comparatively, also in Japanese, Hirata et al.[14] reported that Kansai dialect speakers had different vowel N-scores but in the same order. Furthermore, also for Japanese vowel sounds, Takeuchi et al.[18] stated that "(the N-score of) /i/ was the highest, followed by /a/, /o/ was always low, /e/ was lower than /i/, and /u/ was not constant." There are multiple reports in English-speaking countries that the N-score measured by the Nasometer is the highest for /i/.[19,20]

Gildersleeve-Neumann et al.[5] conducted an experiment comparing the N-scores when the nostrils were closed and when the nostrils were open. As a result, it was concluded that transpalatal nasalance, which is a major factor of N-score during non-nasal production, was significantly higher in the vowel /i/ than in the vowels /a/ and /u/ or the "Zoo Passage." They inferred why transpalatal nasalance was high at /i/ and low at /u/ as follows: the posterior tongue suppressed the vibration of the soft palate during /u/ production, or the palatal surface exposed to acoustic vibration during /i/ production was wider. Blanton et al.[6] conducted an experiment in which an acrylic cover was attached to the palate to measure the N-score and revealed that the transpalatal transfer of acoustic energy occurs mainly through the soft palate. They also showed that this phenomenon increased the N-score only for the high front vowel /i/.

On the other hand, Lewis et al.[21] compared N-scores measured by the Nasometer and those measured by the Nasal View, which is a measuring device without an acoustic filter. Five sentences composed of different vowels were used as utterance tasks for 50 normal, healthy children. As a result, it was clarified that N-scores by the Nasometer were significantly higher in sentences containing high front vowels and significantly lower in sentences containing low vowels than those measured by the Nasal View.

Rothenberg[22] developed a measuring device called Mask-Based Nasometry (later the Oro-Nasal Nasality System mask) that can measure "F0-derived" nasalance using voice in the band corresponding to the fundamental frequency for each gender. He called the N-score by the Nasometer "F1 derived" N-score because of the frequency range of its acoustic filter (i.e., the N-score derived from the acoustic component corresponding to the first formant of the vowel).[22] He pointed out that "F1 derived" N-scores are more likely to be affected by vowel differences, speaker pitch, and strength than are "F0 derived" N-scores.[22]

These series of reports on the N-score of vowels show that the transpalatal transfer of acoustic energy (i.e., the acoustic energy transmitted to the nasal cavity by the vibration of the soft palate) is an important factor in the high value of the N-score during the production of the high front vowel /i/. It has also been suggested that the frequency components analyzed by the Nasometer are particularly susceptible to this phenomenon.

Generally, in the auditory evaluation of cleft palate speech, high vowels, which require stronger velopharyngeal closure than do low vowels for normal articulation,[23] are emphasized as a sensitive judgment index. This is because, even in the case of mild velopharyngeal insufficiency, hypernasality is heard with high vowels.[24] In contrast, in the evaluation of velopharyngeal function by the Nasometer, it is recommended to use utterance tasks that do not include /i/, in which the transpalatal transfer of acoustic energy is strongly involved.

N-scores of low-pressure sentences and high-pressure sentences

Karnell[7] proposed the use of high-pressure and low-pressure sentences as Nasometer utterance tasks. This is because it is not possible to determine whether the acoustic energy on the nasal cavity side is due to hyper nasal resonance or turbulent nasal air flow only by the N-score of the "Zoo Passage" containing various speech sounds. Tachimura et al.[8] also reported that it would be useful to compare the N-scores of high-pressure and low-pressure sentences based on a study of cleft palate cases with turbulent nasal airflow. The perspective of these two reports is that low-pressure sentences play a role in detecting hypernasality associated with excessive nasal resonance of speech and high-pressure sentences play a role in detecting nasal noise associated with exhaled nasal leakage during high-pressure consonant production.

With an emphasis on this perspective, we adopted 3 low-pressure and 2 high-pressure sentences as utterance tasks. As a result, the N-score was significantly different among sentences in both the low-pressure and high-pressure groups. In the low-pressure group, (d) [jo:iwa o:i] and in the high-pressure group, (g) [kitsɯtsɯki tsɯtsɯkɯ], each showed a higher N-score. For the low-pressure group, (d) [jo:iwa o:i] contains a high front vowel [i] and an approximation [j] starting from the same tongue position, while (c) [ɯeo o:ɯ] and (e) [aoo oejo] do not include [i], but contain multiple [o] vowels. This difference in constituent vowels is presumed to be one of the factors behind the significant difference in the N-scores among sentences. In both sentences in the high-pressure group, unvoiced consonants sandwich narrow vowels; therefore, the sound environment was such that vowels were easily devoiced in the Tokyo dialect. However, of these, (g) [kitsɯtsɯki tsɯtsɯkɯ] has a series of narrow vowel syllables, which partially suppresses the devoicing of vowels, and this sentence contains the vowel [i] twice. Therefore, it is presumed that this sentence showed a significantly higher N-score than did that of (f) [kotsɯkotsɯ tsɯkɯsɯ].

If low-pressure sentences play a role in assessing excessive nasal resonance resulting from velopharyngeal insufficiency, (c) [ɯeo o:ɯ], (e) [aoo oejo], which showed a low N-score, will be a more sensitive utterance task. On the other hand, if the role of high-pressure sentences is in the detection of turbulent nasal air flow, (f) [kotsɯkotsɯ tsɯkɯsɯ], which showed a low N-score, may be a more sensitive utterance task.

Gender difference

The Tokyo dialect speaker's N-score obtained in this study was higher in females than in males. Regarding the gender difference in the N-score of normal, healthy adults, there are many reports that the N-score obtained in utterance tasks including nasal consonants is higher in females than that in males.[25-28] Furthermore, there are some reports that the N-score is higher in females in the evaluation of non-nasal tasks.[11,29,30]

The pitch of the voice is considered to be one of the factors that contributes to the gender difference in the N-score. Bundy et al.[31] measured the N-score during voiced plosive production with the OroNasal Nasality System mask in adult men and women with previously confirmed complete velopharyngeal closure. As a result, it was clarified that 80% of the N-score was affected by transpalatal transfer of acoustic energy. Furthermore, they compared the "F1 derived" N-score that imitated the Nasometer with a 350－750 Hz digital filter and the "F0 derived" N-score that set the analysis band separately for men and women (male 80－160 Hz, female 120－240 Hz). The results showed that the pitch of the subject's voice was more strongly reflected in the "F1-derived" N-score. This report suggests that the characteristics of the acoustic filter built into the Nasometer contribute to the tendency of female voices showing higher N-scores than do male voices.

Limitations and clinical implications

The results obtained in the utterance tasks, sentences (a) and (b), which include various speech sounds other than nasal sounds, showed the standard values of the N-score measured by the Nasometer for speakers of Japanese common speech. However, the cutoff value, which is a guideline for velopharyngeal insufficiency, is not necessarily the same as the values obtained in this study. To clarify the cutoff value, it is necessary to examine the N-score of cleft palate cases with various velopharyngeal functions in comparison with the auditory evaluation of speech.

In Japan, the N-score is sometimes called the "hypernasality score." However, the term "hypernasality score" leads to the misunderstanding that " the N-score is a value that quantitatively measures hypernasality." As evident from the discussion, the N-score by the Nasometer reflects not only the velopharyngeal patency during speech but also various factors, such as acoustic propagation through the soft palate, noise caused by the palatal fistula, and the pitch of the subject's voice. I.e., the N-score is neither a value that reflects only velopharyngeal insufficiency nor a value that quantitatively measures hypernasality. The Nasometer is a device developed for objective evaluation of velopharyngeal closure; however, in its clinical application, it is necessary to avoid judgment by only depending on the Nasometer. In assessing velopharyngeal function, it is necessary to prioritize the auditory assessment of speech by trained clinicians. The Nasometry is an evaluation method that supplements (i.e., assists), clinicians' auditory evaluation, and dynamic observation by velopharyngeal endoscopy is an indispensable evaluation method.

Conflicts of Interest: None

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