Measurement of nasalance scores without touching the philtrum for better comfort during speech assessment and therapy

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Abstract

Background: The Kay Pentax Nasometer uses a separator plate that touches the philtrum of a patient to separate the nasal and oral sound energies for nasalance measurement. However, the separator plate could restrict the natural movement of the patient's upper lip and generate an unpleasant pressure to the patient's philtrum. The present study was intended to measure nasalance scores without touching the philtrum for better comfort during speech assessment and therapy.

Methods: Nasalance scores of 10 males and 10 females having no speech disorders were measured under four levels (0, 5, 10, and 15 mm) of the gap between the plate and the philtrum (denoted as plate-to-philtrum gap) using Nasometer II 6450 for nasal (Nasal Sentences) and oral (Zoo Passage) stimuli. Regression formulas were established to examine the relationships between nasalance score and plate-to-philtrum gap for the Nasal Sentences and the Zoo Passge, respectively. To provide equivalent nasalance scores measured under the 5-mm plate-to-philtrum gap to those measured under the conventional contact measurement condition (i.e., the 0-mm plate-to-philtrum gap in the present study), compensation factors were identified as the ratio of the mean nasalance measured under the 0-mm gap to that measured under the 5-mm gap for the Nasal Sentences and the Zoo Passge, respectively. The validation of the identified compensation factors was examined.

Results: The nasalance scores were significantly different between the four different plate-to-philtrum gaps for the stimuli. Nonlinear and linear regression formulas were established for the relationships between nasalance score and plate-to-philtrum gap for the Nasal Sentences and the Zoo Passage, respectively. Compensation factors for the Nasal Sentences and the Zoo Passage were identified as 1.17 and 0.71, respectively. Validation results showed that the adjusted nasalance scores after mutiplying the identified compensation factors were similar to those measured under the conventional contact measurement condition for both the oral and nasal stimuli.

Conclusions: The 5-mm plate-to-philtrum gap condition after multiplying the compensation factors can provide equivalent nasalance scores to the conventional contact measurement condition and better comfort in speech assessment and therapy.

1. Backgrouond

Nasometry has been used to help physicians assess and diagnose the resonance disorder of a patient. The nasalance score (nasalance = nasal energy/(nasal energy + oral energy) × 100) [1] indicates the relative contribution of nasal energy to the patient's speech [2]. A lower nasalance score is related to hyponasality and a higher score hypernasality [3–5]. Hyponasality refers to the abnormal reduction of nasal resonance due to the obstruction of the nasal cavity or pharynx caused by deviated septum, maxillary retrusion, adenoid hypertrophy, or choanal stenosis [6–8]. In contrast, hypernasality refers to the abnormal increase of nasal resonance due to palatal cleft, oronasal fistula, or velopharyngeal dysfunction [9–11]. For the treatment of hyponasality and hypernasality, surgical interventions such as

palatoplasty, oronasal fistula closure surgery, and surgeries for velopharyngeal insufficiency or incompetence are commonly performed [7, 12–20]. After surgery, speech therapy using nasometry and video games is usually conducted for further improving a patient's velopharyngeal closure activity [15, 21].

The most commonly used nasalance measurement device is the Kay Pentax nasometers (PENTAX Medical, Montvale, NJ, USA) and corresponding normative data have been established for various languages. Three models of Kay Pentax nasometers including Nasometer 6200, Nasometer II 6400, and Nasometer II 6450 have been introduced in 1986, 2002, and 2009, respectively [2] and widely used in craniofacial centers and other clinical settings around the world [22]. Normative nasalance data for children and adults have been established across various European and Asian languages [22, 23–33]. As for English, standard passages including Zoo Passage, Nasal Sentences, and Rainbow Passage have been used for establishing normative nasalance data for oral, nasal, and oronasal stimuli, respectively [1, 3, 4]. Similar speech materials consisting of oral, nasal, and oronasal stimuli for other languages including Swedish [24], Flemish [34], Malay [35], Vietnamese [36], and Korean [37] have been developed as well. The ranges of normative nasalance scores for oral, nasal, and oronasal stimuli in different languages have been reported as 6.8 to 34.9, 41.3 to 78.0, and 16.9 to 39.5, respectively [24, 25, 27, 32, 34–50]. Factors affecting normative nasalance scores include difference in composition of phonemes in different speech materials such as higher nasalance for high vowels (e.g, /i/ and /u/) than low vowels (e.g., /æ/ and /a/), dialect, age, gender, and speech intensity [51–58].

When a Kay Pentax nasometer is used for a long time in nasalance measurement for speech assessment and therapy (Fig. 1), discomfort could be experienced due to the pressure of the separator plate against the philtrum of the patient. The separator plate of the nasometer touches the philtrum to separate the nasal and oral sound energies so that the two energies can be separately recorded by the two microphones installed above and below the separator plate for calculation of nasalance scores. Due to the significant weight of the separator plate (the weight of the plate and the two microphones = 225 g) and its contact to the philtrum, the natural movement of the patient's upper lip is restriected and an unpleasant pressure is caused to the philtrum. However, their complaints are often neglected due to the lack of alternative solutions and no studies resolving the problems have been reported.

The present study proposed to measure nasalance scores without touching a patient's philtrum for better comfort during speech assessment and therapy. The effect of the gap between the separator plate and the philtrum (denoted as plate-to-philtrum gap) on nasalance was examined. To provide equivalent nasalance socres for the proposed touchless measurement method to those measured by the conventional contact measurement method, compensation factors were analyzed as the ratio of the mean nasalance measured by the conventional method to that measured by the proposed touchless method. Lastly, the validation of the identified compensation factors was examined.

2. Methods

2.1. Participants

Twenty participants (10 males and 10 females; age = 24.3 ± 6.0 years, range = 16 to 40) having no craniofacial or neurological disorders were recruited for the nasalance measurement experiment. The participants included ten Koreans, eight Indonesians, one Malaysian, and one Chinese who could speak English fluently as their second language. The protocol of the present study was approved by the Institutional Review Board at Pohang University of Science and Technology.

2.2. Experimental Design

A within-subjects design with one factor (plate-to-philtrum gap) that may affect nasalance score was used in this study. The plate-to-philtrum gap consisted of four levels: 0 mm (the contact measurement method), 5 mm, 10 mm, and 15 mm (Fig. 2). Nasometer II 6450 (PENTAX Medical, Montvale, NJ, USA) was used for nasalance measurement and two standard passages including the Zoo Passage and the Nasal Sentences [1, 3, 4] were used as oral and nasal stimuli, respectively. The plate-to-philtrum gaps and sound stimuli were randomized. The nasometer was calibrated before the experiment. The plate-to-philtrum gap was controlled by a cardboard with three scales (5, 10, and 15 mm) (Fig. 3a). Before wearing the nasometer, the cardboard was attached to the separator plate by vertically aligning the center (hollwed out) of the carboard with that (marked as a red line) of the plate and horizontally aligning a desired scale on the cardboard with the edge of the plate (Fig. 3a). After properly wearing the nasometer, the plate with the attached cardboard was adjusted so that the edge of the cardboard touched the philtrum of a participant (Fig. 3b). The plate was then secured and the cardboard was detached to obtain the desired plate-to-philtrum gap (Fig. 3c).

The nasalance measurement experiment was conducted in the following four steps: (1) introduction, (2) practice, (3) main experiment, and (4) debriefing. First, the purpose and procedure of the experiment were explained to the participant and informed consent was obtained. Second, the participant was asked to wear the nasometer and get familiarized with the

Third, the main experiment was conducted in a random order for 24 experimental conditions (4 plate-to-philtrum gaps × 2 stimuli × 3 repetitions). For each condition, after the plate-to-philtrum gap was adjusted to the desired gap of that condition by an experimenter, the participant was asked to read a oral or nasal passage and nasalance scores were measured. Lastly, opinions of the participant regarding the experiment was collected.

2.3. Statistical Analysis

One-factor (plate-to-the philtrum gap) within-subjects analysis of variance (ANOVA) was conducted in this study. Regression formulas were established to describe the relationships between nasalance score and plate-to-philtrum gap for each participant for the Zoo Passage and the Nasal Sentences, respectively. A residual analysis was conducted to assess the adequacy of fit of the regression models. All statistical analyses were performed at $\alpha = .05$ using Minitab 14.0 (Minitab Inc., USA).

3. Results

3.1. Nasalance Scores

ANOVA showed that nasalance score was significantly different between the four different plate-to-the philtrum gaps for both the Zoo Passage ($F(3,76) = 27.63$, $p < .0001$) and the Nasal Sentences ($F(3,76) = 32.24$, $p < 0.001$). Turkey's post hoc test showed that nasalance score significantly differed between all the gaps for the Zoo Passage and between the 0-mm and 5-mm gaps for the Nasal Sentences, but not between the 5-mm, 10-mm, and 15-mm gaps for the Nasal Sentences, as shown in Table 1.

3.2. Regression Models

Nonlinear and linear regression formulas were established in Table 2 for the relationships between nasalance score and plate-to-philtrum gap for each participant for the Nasal Sentences and the Zoo Passage, respectively. The established formulas showed high performance in terms.

Table 1 Turkey's post hoc test on the nasalance scores (mean ± SD) between different plate-to-philtrum gaps for the Nasal Sentences and Zoo Passage

Stimuli	Plate-to-philtrum gap (mm) (Nasalance score: mean ± SD)		Mean difference	p-value
	Gap 1	Gap 2		
Nasal Sentences	0 (55.4 ± 6.4)	5 (47.2 ± 4.6)	8.20	0.000 **
	5 (47.2 ± 4.6)	10 (43.6 ± 4.2)	3.66	0.096
	10 (43.6 ± 4.2)	15 (41.1 ± 3.6)	2.44	0.402
Zoo Passage	0 (11.5 ± 5.2)	5 (15.7 ± 4.5)	4.20	0.026 *
	5 (15.7 ± 4.5)	10 (19.7 ± 4.3)	4.05	0.034 *
	10 (19.7 ± 4.3)	15 (24.1 ± 4.1)	4.38	0.018 *
* $p < 0.05$, ** $p < 0.001$				

of adjusted R^2 (97.1% ± 3.0% for the Nasal Sentences and 97.6% ± 1.6% for the Zoo Passage) and mean squared error (MSE) (.90 ± .33 for the Nasal Sentences and .76 ± .32 for the Zoo Passage). The result of a female participant for the Zoo Passage was excluded due to the different behavior of the participant's data from those of the rest of the participants. As shown in Fig. 4, nasalance score rapidly decreases as plate-to-philtrum gap increases from 0 mm to 10 mm and slowly decreases as plate-to-philtrum gap

increases from 10 mm to 15 mm for the Nasal Sentences, while nasalance score linearly increases as plate-to-philtrum gap increases from 0 mm to 15 mm for the Zoo Passage.

Table 2 Regression formulas for the relationships between nasalance score (NS) and plate-to-philtrum gap (Gap) for the Nasal Sentences and the Zoo Passage and their performance in terms of adjusted R^2 and mean squared error (MSE)

Participants		Performance of regression formulas					
		Nasal Sentences			Zoo Passage		
#	Gender	Formulas	adj. R^2 (%)	MSE	Formulas	adj. R^2 (%)	MSE
1	Male	NS = 55.46−1.64 Gap + 0.06 Gap^2	96.1	1.07	NS = 6.65 + 0.78 Gap	98.2	0.64
2	Male	NS = 57.18−1.44 Gap + 0.03 Gap^2	98.8	0.68	NS = 11.26 + 0.55 Gap	92.6	0.96
3	Male	NS = 59.08−2.59 Gap + 0.09 Gap^2	99.2	0.74	NS = 13.73 + 0.64 Gap	98.5	0.49
4	Male	NS = 49.71−1.19 Gap + 0.03 Gap^2	98.9	0.49	NS = 7.23 + 0.94 Gap	96.2	1.14
5	Male	NS = 42.72−1.05 Gap + 0.03 Gap^2	94.7	1.03	NS = 5.45 + 1.29 Gap	98.4	1.00
6	Male	NS = 49.12−1.25 Gap + 0.04 Gap^2	90.5	1.54	NS = 8.73 + 0.99 Gap	97.2	1.03
7	Male	NS = 44.12−1.64 Gap + 0.07 Gap^2	97.7	0.66	NS = 4.83 + 0.92 Gap	98.6	0.06
8	Male	NS = 44.72−0.98 Gap + 0.04 Gap^2	87.5	0.91	NS = 7.50 + 1.03 Gap	95.6	1.35
9	Male	NS = 53.75−2.34 Gap + 0.07 Gap^2	99.7	0.43	NS = 21.74 + 0.55 Gap	96.2	0.67
10	Male	NS = 54.72−1.81 Gap + 0.05 Gap^2	98.0	0.97	NS = 12.27 + 0.97 Gap	99.1	0.56
11	Female	NS = 56.96−1.43 Gap + 0.04 Gap^2	98.0	0.80	NS = 7.49 + 0.81 Gap	96.7	0.92
12	Female	NS = 61.73−2.53 Gap + 0.09 Gap^2	95.3	1.61	NS = 9.34 + 0.78 Gap	96.8	0.86
13	Female	NS = 55.03−1.76 Gap + 0.05 Gap^2	98.7	0.71	NS = 8.42 + 0.81 Gap	99.3	0.42
14	Female	NS = 68.93−3.40 Gap + 0.13 Gap^2	97.6	1.52	-	-	-

Participants		Performance of regression formulas					
		Nasal Sentences			Zoo Passage		
15	Female	NS = 55.92−1.95 Gap + 0.06 Gap^2	99.6	0.44	NS = 7.98 + 0.84 Gap	99.6	0.33
16	Female	NS = 53.70−2.29 Gap + 0.08 Gap^2	97.4	1.15	NS = 12.61 + 0.97 Gap	99.4	0.48
17	Female	NS = 60.79−2.63 Gap + 0.09 Gap^2	99.4	0.67	NS = 4.83 + 0.92 Gap	98.6	0.66
18	Female	NS = 60.10−1.39 Gap + 0.03 Gap^2	97.9	0.91	NS = 14.86 + 0.99 Gap	97.9	0.89
19	Female	NS = 57.40−1.35 Gap + 0.03 Gap^2	97.9	0.87	NS = 12.11 + 1.08 Gap	98.3	0.86
20	Female	NS = 57.64−1.88 Gap + 0.06 Gap^2	98.7	0.77	NS = 13.91 + 1.16 Gap	97.3	1.18
mean		-	97.1	0.90	-	97.6	0.76
SD		-	3.0	0.33	-	1.6	0.32

3.3. Compensation Factors

Compensation factors for the nasalance scores measured under the 5-mm plate-to-philtrum gap for the Zoo Passage and the Nasal Sentences for each participant were identified as the ratio of the mean nasalance measured under the 0-mm plate-to-philtrum gap to that measured under the 5-mm plate-to-philtrum gap (Eq. 1). The mean compensation factors were 0.71 ± 0.15 for the Zoo Passage and 1.17 ± 0.05 for the Nasal Sentences, as shown in Table 3.

Equation 1: Identification of compensation factor to obtain equivalent nasalance scores for the touchless measurement method (i.e., the 5-mm plate-to-philtrum gap condition in the present study) to those measured by the conventional contact measurement method (i.e., the 0-mm plate-to-philtrum gap condition in the present study)

$$Compensation\ factor_{touchless} = \frac{Mean\ nasalance_{contact}}{Mean\ nasalance_{touchless}}$$

where Compensation $factor_{touchless}$ denotes compensation factor for touchless measurement method (i.e., the 5-mm plate-to-philtrum gap condition in the present study); Mean $nasalance_{contact}$ is the mean nasalance measured by the conventional contact measurement method (i.e., the 0-mm plate-to-philtrum

gap condition in the present study); Mean $nasalance_{touchless}$ is the mean nasalance measured by the touchless measurement method.

Table 3 Compensation factors identified as the ratio of the mean nasalance measured under the 0-mm plate-to-philtrum gap to that measured under the 5-mm plate-to-philtrum gap for the Nasal Sentences and Zoo Passage

Participants		Nasal Sentences			Zoo Passage		
Mean nasalance scores		Compensation factors	Mean nasalance scores		Compensation factors		
#	Gender		0-mm gap	5-mm gap		0-mm gap	5-mm gap
1	Male	55.54	48.49	1.15	6.94	10.17	0.68
2	Male	57.23	50.68	1.13	11.49	14.00	0.82
3	Male	59.25	47.93	1.24	13.46	17.09	0.79
4	Male	49.82	44.18	1.13	8.14	11.09	0.73
5	Male	42.76	38.00	1.13	5.76	11.96	0.48
6	Male	49.32	43.16	1.14	8.03	15.10	0.53
7	Male	44.22	37.36	1.18	4.95	8.79	0.56
8	Male	44.89	40.43	1.11	6.44	13.60	0.47
9	Male	60.57	52.25	1.16	21.33	25.00	0.85
10	Male	55.01	46.13	1.19	12.33	16.79	0.73
11	Female	57.16	50.88	1.12	7.10	11.66	0.61
12	Female	62.33	49.79	1.25	9.79	13.04	0.75
13	Female	54.89	48.03	1.14	8.46	12.49	0.68
14	Female	69.48	53.64	1.30	24.57	21.54	1.14
15	Female	55.88	47.73	1.17	8.16	12.09	0.67
16	Female	53.96	43.56	1.24	12.27	18.02	0.68
17	Female	60.97	49.24	1.24	19.90	23.44	0.85
18	Female	60.17	53.66	1.12	14.70	19.65	0.75
19	Female	57.62	50.75	1.14	12.37	17.38	0.71
20	Female	57.87	48.99	1.18	13.11	20.46	0.64
Mean		-	-	1.17	-	-	0.71
SD		-	-	0.05	-	-	0.15

3.4. Validation of Compensation Factors

After adjusting nasalance scores measured under the 5-mm plate-to-philtrum gap condition by multiplying the identified compensation factors, the adjusted nasalance scores (mean ± SD = 55.3 ± 5.4 for the Nasal Sentences and 10.4 ± 3.8 for the Zoo Passage) were similar to those (mean ± SD = 55.4 ± 6.4 for the Nasal Sentences and 11.5 ± 5.2 for the Zoo Passage) measured under the 0-mm plate-to-philtrum gap condition for both the Nasal Sentences and Zoo Passage.

Cross validation for the identified compensation factors was further conducted from syllable level with different participants. Syllables '/pa/' and '/ma/' were used as oral and nasal stimuli, respectively. Four healthy adults (2 males and 2 females; age = 22.5 ± 4.4 years, range = 16 to 25) including two Koreans and two Indonesians who spoke English fluently as their second language participated in the cross validation experiment.

The adjusted nasalance scores (Mean ± SD = 7.3 ± 1.8 for the oral syllable and 51.3 ± 8.5 for the nasal syllable) after multiplying the nasalance scores (measured under the 5-mm plate-to-philtrum gap condition) by compensation factors were found similar to those (Mean ± SD = 8.0 ± 4.0 for the oral syllable and 54.3 ± 5.6 for the nasal syllable) measured under the 0-mm plate-to-philtrum gap condition.

4. Discussion

The present study proposed a touchless method for nasalance measurement to avoid unnatural movement of the upper lip and unpleasant pressure due to the contact of the separator plate to the philtrum in the contact measurement method and identified compensation factors to provide equivalent nasalance scores to the contact measurement method. A 5-mm plate-to-philtrum gap was recommended in the touchless measurement method and compensation factors of 0.71 and 1.17 were identified for oral and nasal stimuli, respectively.

The plate-to-philtrum gap showed a significant effect on nasalance scores for both the Zoo Passage and Nasal Sentences. For the Zoo Passage, a linear increasing relationship between nasalance score and plate-to-philtrum gap was observed for each participant. For example, as shown in Fig. 5a, nasalance scores significantly increased by 4.2 from 0-mm gap to 5-mm gap, 4.0 from 5-mm gap to 10-mm gap, and 4.4 from 10-mm gap to 15-mm gap with a linear increase trend. The increase of nasalance score can be explained by the decreases of 10.0%, 5.5%, and 4.3% in oral energy and the increases of 53.1%, 28.8%, and 28.6% in nasal energy as the gap changes to 5 mm, 10mm, and 15 mm, respectively, due to the leakage of oral energy to the nasal microphone for the Zoo Passage. As shown in Fig. 5b, the leakage of oral energy was the largest (10.0%) from 0-mm gap to 5-mm gap and similar to each other from 5-mm gap to 10-mm gap (5.5%) and from 10-mm gap to 15-mm gap (4.3%). For the Nasal Sentences, a nonlinear decreasing relationship between nasalance score and plate-to-philtrum gap was observed for each participant. For example, as shown in Fig. 6a, nasalance scores decreased by 8.2 (significant decrease) from 0-mm gap to 5-mm gap, 3.6 (not significant) from 5-mm gap to 10-mm gap, and 2.5 (not

significant) from 10-mm gap to 15-mm gap with a nonlinear decrease trend. The decrease of nasalance score can be explained by the decreases of 18.6%, 4.7%, and 1.4% in nasal energy and the increases of 3.5%, 8.3%, and 3.7% in oral energy as the gap changes to 5 mm, 10mm, and 15 mm, respectively, due to the leakage of nasal energy to the oral microphone for the Nasal Sentences. As shown in Fig. 6b, the leakage of nasal energy was the largest (18.6%) from 0-mm gap to 5-mm gap, the second largest from 5-mm gap to 10-mm gap (4.7%), and the smallest from 10-mm gap to 15-mm gap (1.4%).

The adjusted nasalance scores after multiplying the nasalance scores measured with the proposed touchless measurement method by the identified compensation factors were similar to those measured with the contact measurement method for both the Nasal Sentences (mean ± SD of absolute difference = 2.1 ± 1.5) and Zoo Passage (mean ± SD of absolute difference = 2.3 ± 3.1). The 5-mm plate-to-philtrum gap was recommended to avoid unnatural movement of the upper lip and unpleasant pressure without much loss of oral energy (10.0%) for oral stimuli and nasal energy (18.6%) for nasal stimuli. Different compensation factors were identified for oral and nasal stimuli due to the decrease of oral energy (10.0%) and increase of nasal energy (53.1%) for oral stimuli and the decrease of nasal energy (18.6%) and increase of oral energy (3.5%) for nasal stimuli.

As future research, various populations in age and language need to be examined for the generalization of the present study. Native English speakers can be included in the nasalance nasalance measurement experiment to assess the effect of native and nonnative English speakers on nasalance scores. Children also can be included in the experiment to identify compensation factors for children. Furthermore, a validation study of the identified compensation factors needs to be further conducted with patients having resonance disorders.

5. Conclusions

To avoid the possible restriction of the separator plate of the Kay Pentax Nasometer to the natural movement of a patient’s upper lip and the unpleasant pressure to the patient’s philtrum caused by the contact of the separator plate to the philtrum, the present study proposed to measure nasalance scores without touching the philtrum (5-mm plate-to-philtrum gap) for better comfort during speech assessment and therapy. Compensation factors (1.17 for the Nasal Sentences and 0.71 for the Zoo Passage) were identified for the proposed touchless measurement method to obtain equivalent nasalance scores to the conventional contact measurement method. The adjusted nasalance scores after multiplying the nasalance scores measured with the proposed touchless measurement method by the identified compensation factors were similar to those measured with the contact measurement method for both the Nasal Sentences and Zoo Passage. Touchless measurement of nasalance scores can provide equivalent nasalance scores to the conventional contact measurement method after multiplying the idenfified compensation factors and better comfort during speech assessment and therapy.

Abbreviations

ANOVA: Analysis of variance; MSE: Mean squared error; NS: Nasalance score

Declarations

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Authors' contributions

Conceptualization: HY and MHK. Data Acquisition: XY, GBP, and YC. Data Processing: XY and GBP. Data Interpretation: XY, GBP, NPMT, GWK, and YJJ. Statistial Analysis: XY and GBP. Origial Draft Preparation: XY. Review & Editing: HY, MHK, XY, and GBP. All authors read and approved the final manuscript.

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Availability of data and materials

Please contact the corresponding author.

Ethics approval and consent to participate

This study was conducted according to the declaration of Helsinki and had ethical approval from Pohang University of Science and Technology Institutional Review Board, Pohang, Korea. All subjects gave written informed consent prior to data collection.

Consent for publication

All participants gave written informed consent.

Competing interests

The authors declare that they have no competing interests.

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Figures

Figure 1

Nasalance measurement with Nasometer II 6450 by touching the philtrum with the separator plate.

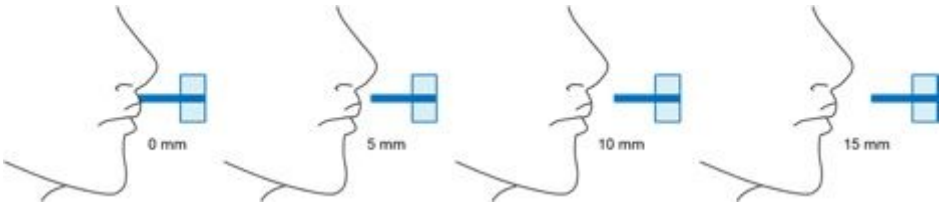


Figure 2

Four plate-to-philtrum gaps tested for nasalance measurement with Nasometer II 6450

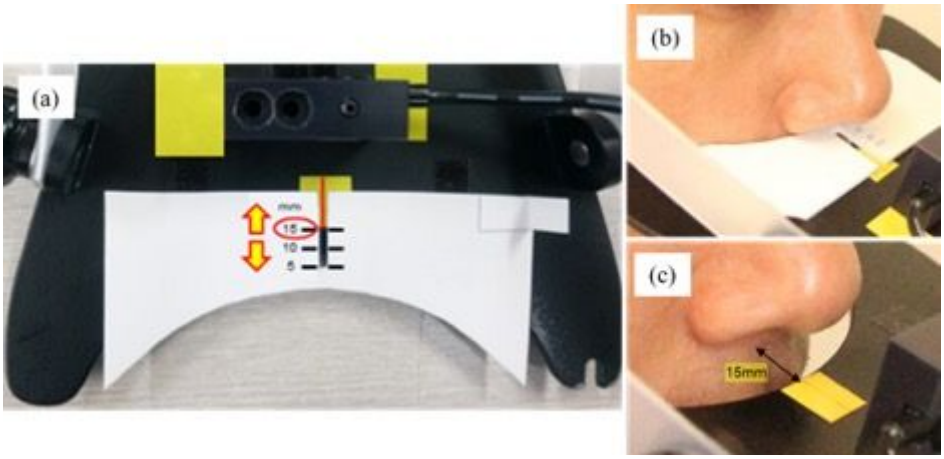


Figure 3

Control of the gap between the separator plate of Nasometer II 6450 and the philtrum of a patient: (a) attaching a cardboard with three scales (5, 10, and 15 mm) to the separator plate by vertically aligning the center (hollowed out) of the cardboard with that (marked as a red line) of the plate and horizontally aligning a desired scale on the cardboard with the edge of the plate, (b) wearing the nasometer and adjusting the plate so that the edge of the cardboard touches the philtrum, and (c) detaching the cardboard to obtain the desired plate-to-philtrum gap experiment

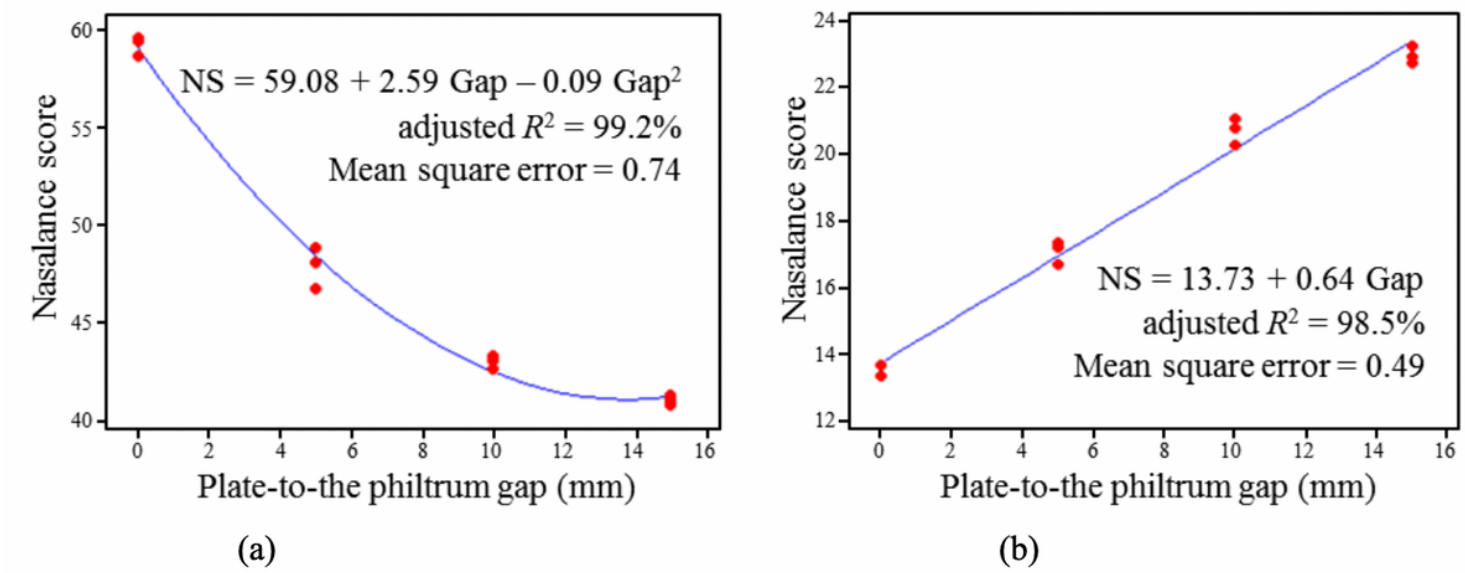


Figure 4

Relationships between nasalance score (NS) and plate-to-philtrum gap (Gap) of a participant: (a) Nasal Sentences and (b) Zoo Passage

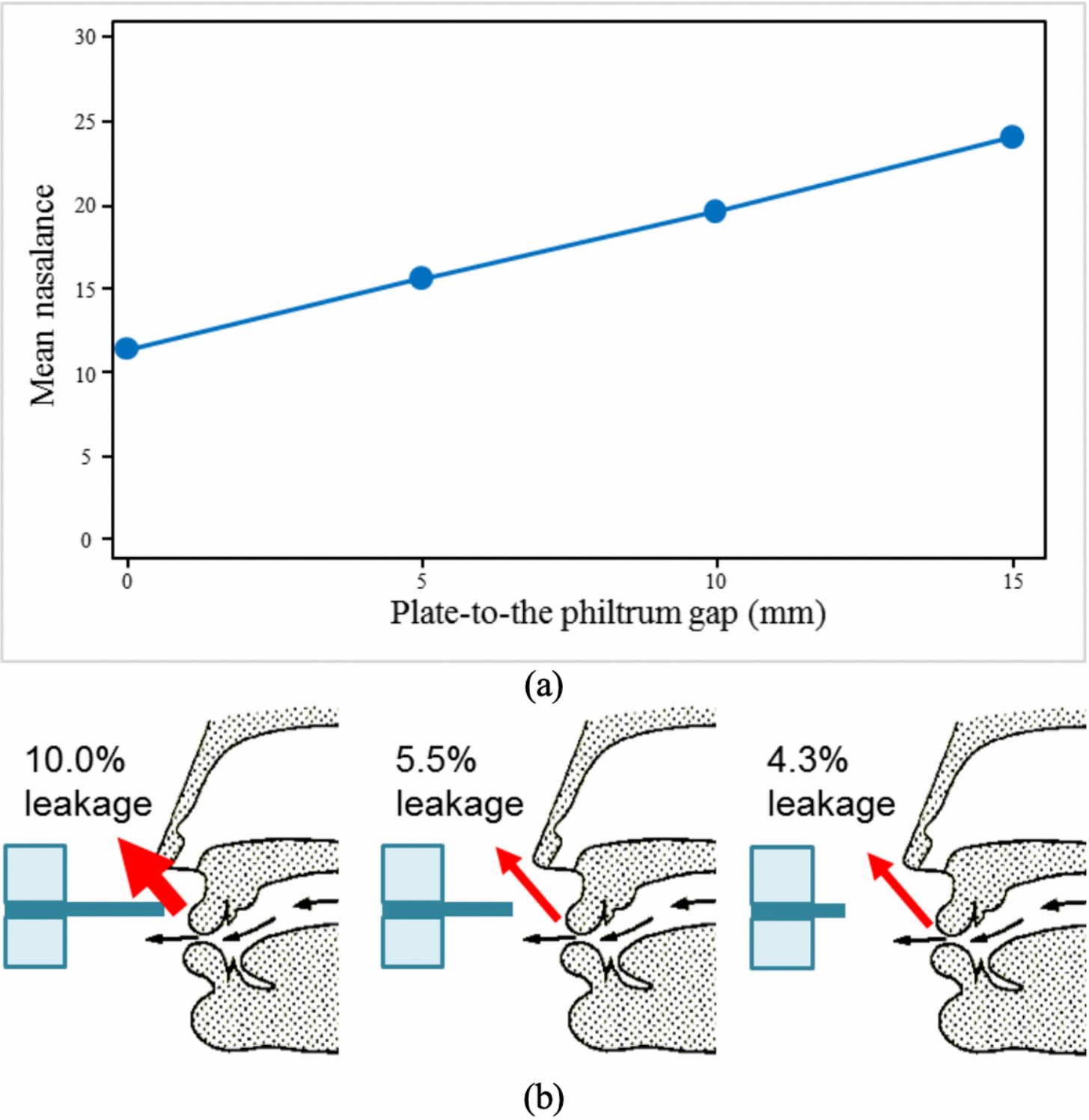
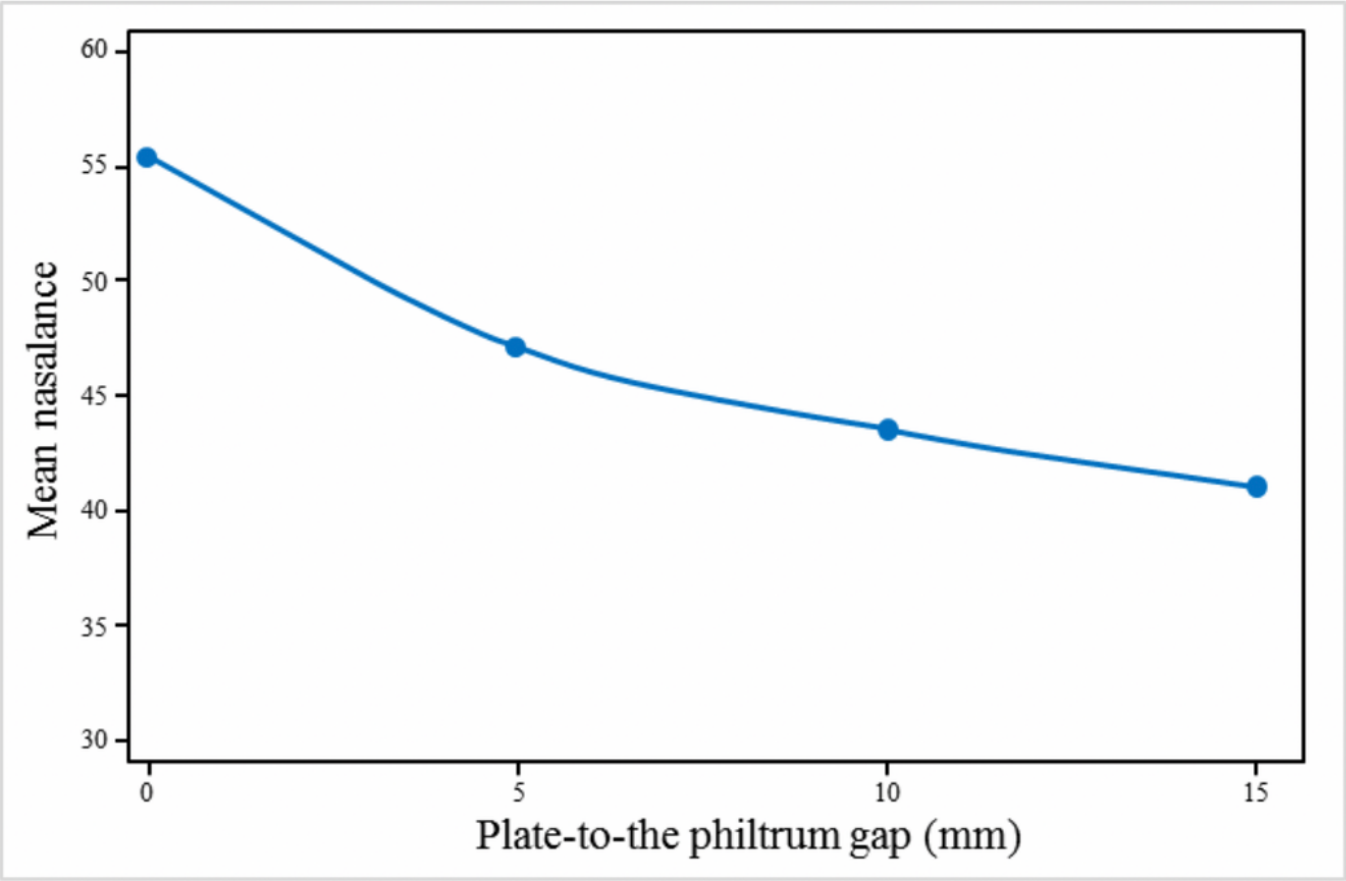
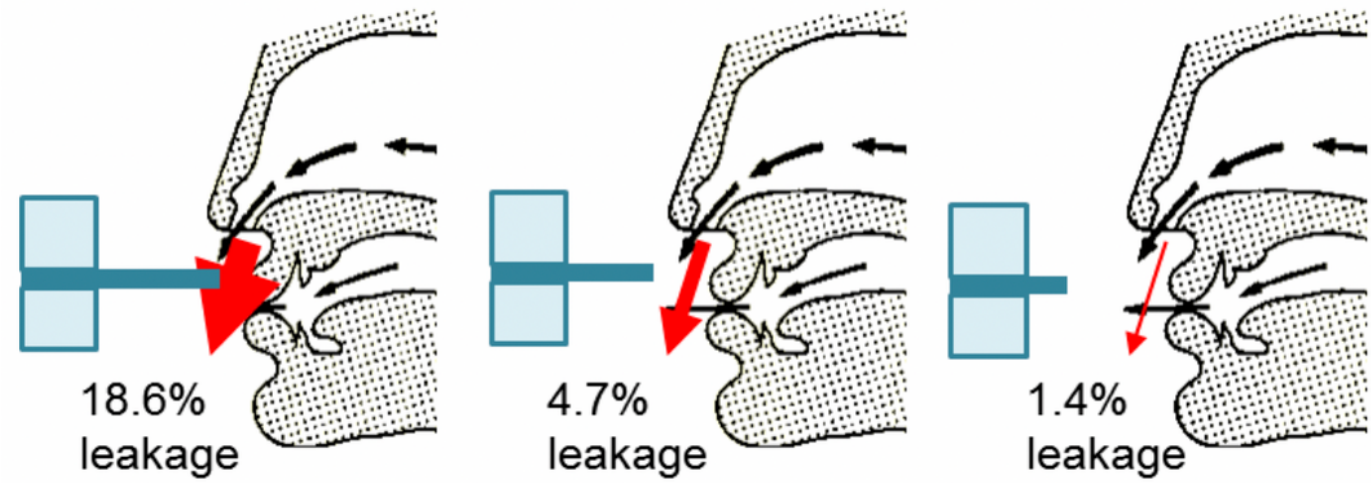


Figure 5

(a) Trend of nasalance change as the plate-to-philtrum gap increases for the Zoo Passage and (b) the percentage of oral energy leakage as the gap increases from 0 mm to 5mm, from 5 mm to 10 mm, and from 10 mm to 15 mm



(a)



(b)

Figure 6

(a) Trend of nasalance change as the plate-to-philtrum gap increases for the Nasal Sentences and (b) the percentage of nasal energy leakage as the gap increases from 0 mm to 5mm, from 5 mm to 10 mm, and from 10 mm to 15 mm