Master's Thesis

Development of an Ergonomic Nasometer

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인간공학적 공명 측정기 개발

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Development of an Ergonomic Nasometer

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The undersigned have examined this thesis and hereby certify that it is worthy of acceptance for a master degree from POSTECH

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ABSTRACT

Resonance disorder occurs in 20% to 30% of individuals who have undergone cleft palate repair and in 5% to 10% of patients with a submucous cleft palate. Assessment of resonance disorder is conducted by evaluating the degree of nasality. Nasalance, a measure of degree of nasality, can be obtained by calculating the ratio of nasal sound energy to total of nasal-oral sound energy. Kay Pentax Nasometer has become a golden standard device to measure nasalance and has been widely used among therapists. The nasometer utilizes two microphones separated by a metal plate, which are attached to a head gear, to capture nasal sound energy and oral sound energy separately. However, the present nasometer needs several improvements in terms of non-intrusiveness, wearability, portability, and affordability. The main objective of this study is to propose and evaluate an ergonomic device to measure nasalance compared with nasometer for speech assessment and speech therapy. The ergonomic nasometer is proposed after determining the best layout and conditions of tool for nasality measurement including microphone position, microphone distance to mouth and nose, and separator distance to philtrum. The proposed nasometer uses a 5 mm gap distance between separator and lip (untouched separator) for non-intrusiveness

to mouth movement, while maintaining the sensitivity of measurenment. Adjustment multiplication factors for nasal (1.08~1.34) and oral (0.23~0.85) are implemented to the proposed nasometer system in order to get equivalent results with the existing nasometer.

Keywords: ergonomic design, resonance disorder, nasalance, nasometer, speech

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I. Introduction

1.1. Problem Statement

Resonance disorder often occurs among people with velopharyngeal dysfunction when the nasal cavity is not properly separated from oral cavity. People with resonance disorders have difficulty in controlling the degree of nasality to produce a proper speech. Nasality or nasal resonance is a production of sound while the velum (soft palate) is lowered (Baken, 1987), whereas some air will resonate in nasal cavity and escape through the nose during the production of sound (Figure I.1).

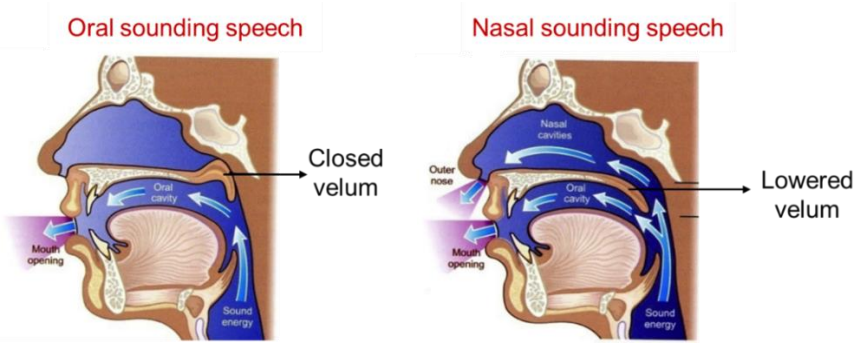


Figure I.1. Velum movement to control degree of nasality
(Adapted from Physiology of Articulation, 2016)

Resonance disorder can occur in 20% to 30% of individuals who have undergone cleft palate repair and in 5% to 10% of patients with a submucous cleft palate (Woo, 2012). The causes of resonance disorder are classified into three categories: insufficiency (anatomical

problem), incompetence (physiological problem), and mislearning (articulation problem) which may occur in both children and adults. Resonace disorder leads to three kinds of improper speech symptoms: hypernasality, hyponasality, and cul-de-sac resonance. Hypernasality occurs due to increased airflow through the nose during speech, meanwhile hyponasality occurs due to decreased airflow through the nose. In case of cul-de-sac resonance, the sound resonates in speech cavity and cannot get out due to blockage in vocal tract.

Nasometric measurement has been known to be correlated with velopharyngeal function and has been proven to be a useful assessment for patient with velopharyngeal dysfunction or resonance disorder (Dalston, Warren, & Dalston, 1991). Through nasometric measurement, resonance disorders are interpreted by nasalance as described in Eq. 1 (Fletcher et al., 1974).

$$\text{Nasalance (\%)} = \frac{Nasal\ sound\ energy}{Nasal\ sound\ energy\ +\ Oral\ sound\ energy} \quad \text{(Eq. 1)}$$

A computer based system called Nasometer (Kay Elemetronics Corp., Lincoln Park, NJ) was first developed to measure nasalance in 1987. After several modifications, it still serves as a golden standard tool to assess resonance disorder nowadays (Awan et al., 2010). Nasometer is used in many craniofacial centers and other clinical settings (Mayo, 2011). Normative nasometric data have been obtained from children and adults in many studies in America, Europe, Asia, and Australia (Seaver et al., 1991; Mayo et al. 1996; Rochet et al.,

1998; Sweeney et al., 2004; Van Doorn & Purcell, 2004; Van Lierde, 2011).

Present nasalance measurement device needs improvements in terms of non-intrusiveness, wearability, portability, and affordability. Major improvements can be addressed to the apparatus' design regarding its convenience. The existing device appears bulky and heavy due to the size (weight = 337 gr; size = 215 mm x 209 mm). Nasometer by Kay Pentax utilizes a touched voice separator with 225 gr weight (with microphone attached) which press user's lip as seen in Figure I.2. Touched voice separator design makes the users uncomfortable and their mouth cannot move naturally during assessment. Unnatural mouth movement affects the user's behavior during speech assessment or therapy, which affect the result of assessment eventually. Moreover, the present nasometer is also difficult to be operated independently at other places rather than in hospital or clinic without professional guidance. Whereas the therapy should be able to access regardless of time and location to optimize its effect.

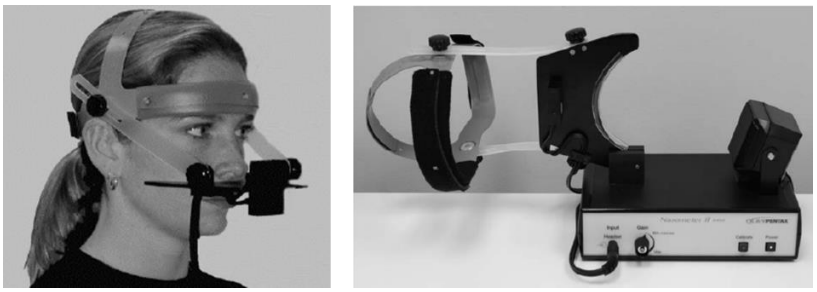


Figure I.2. Kay Pentax Nasometer 6450 (Kay Pentax Software Manual, 2010)

1.2. Objectives of the Study

The present study is to achieve two objectives as illustrated in Figure I.3. The first

objective is to develop a novel nasometer, which uses a touchless voice separator to avoid interference during speech assessment or therapy. The first objective consists of several sub objectives including measurement and analysis of nasalance on different separator gap distance and development of a nasalance adjustment algorithm so that the nasalance result from touchless separator nasometer is equivalent with the result of touched separator nasometer. The second objective of present study is to conduct a validation test for the newly developed nasometer.

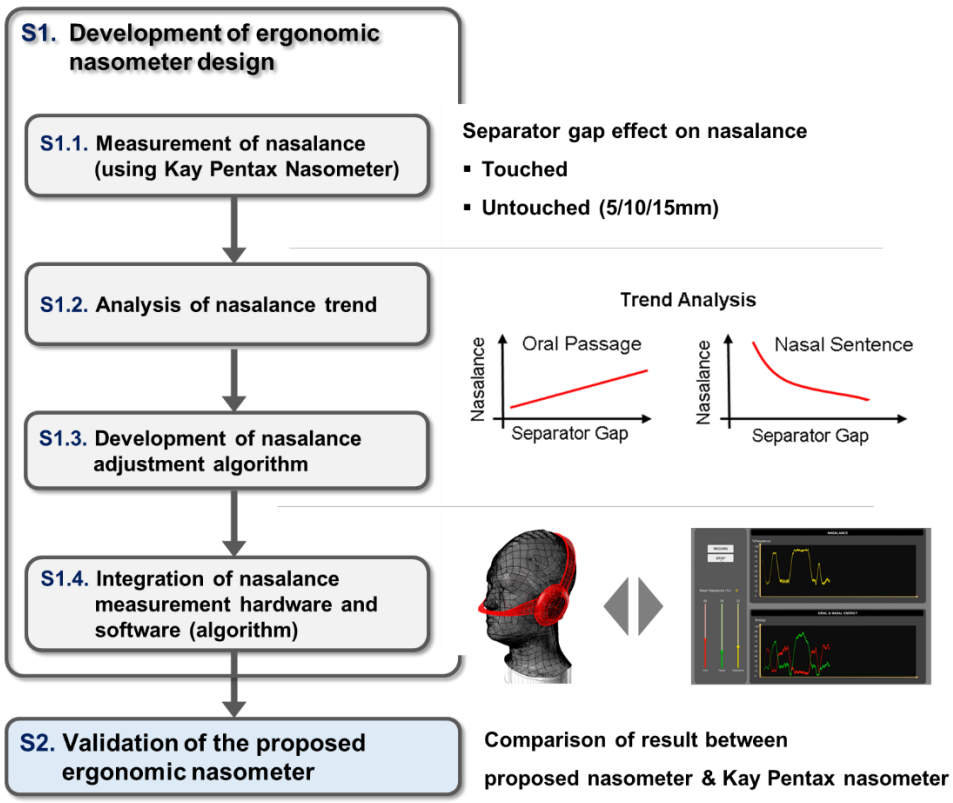


Figure I.3. Ergonomic nasometer design study

1.3. Organization of the Thesis

This thesis is organized into six chapters. The introduction chapter describes the background and research objectives. The literature review discusses the key references related to speech anatomy and disorders, resonance disorders, speech assessment and therapy, and nasality measurement. The methods chapter explains the experimental protocol of untouched separator nasometer, the method for developing nasalance adjustment algorithm, and the method for validation. The results chapter discusses the findings of experiment, how the results of experiment can be used for the nasalance adjustment algorithm development and the results of validation. The discussion chapter describes the analysis, limitations, applications, and potential further studies from current research. Lastly, the conclusion chapter summarizes the contribution of this study.

II. Literature Review

2.1. Speech Anatomy and Process

The central organs involved in the production of speech sound include the lungs, larynx, and vocal tract (the oral cavity, nasal cavity, and pharynx) as illustrated in Figure II.1. Speech production is started when air expelled from the lungs and travels up the traches into the larynx. The Larynx itself consists of two thick, muscular folds of tissue known as vocal cords. Whenever a person wants to produce a word, muscles in the vocal cords tighten up and begins to vibrate because of the air which passes through.

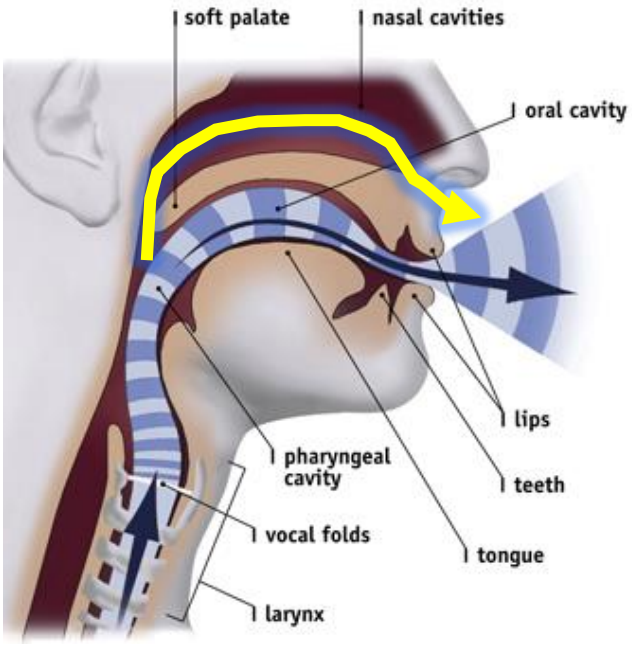


Figure II.1. Speech anatomy and production
(Adapted from QA International, 2016)

The characteristics of produced voice, are determined by how much the air pushes and how tight the cords are strained. After the air leaves the vocal cords, then other organs including tongue, lips, soft palate, hard palate, and teeth will alter the characteristics of sound produced. The passing air can be made into different sound by controlling speech anatomies into various shapes or positions (Seikel, 2009).

Resonance refers to the way airflow for speech is produced when it passes through the oral (mouth) and nasal (nose) cavity (Children's Hospitals and Clinics of Minnesota, 2012). The goal in making speech is to have enough airflow through the mouth for all speech sounds except from nasal consonants, which are character 'm', 'n', and 'ng'. In order to direct the air movement to the mouth, the soft palate lifts and moves toward the throat to close the velopharyngeal valve (opening between the mouth and the nose) as illustrated in Figure II.2. Therefore, the ability to control the amount of soft palate closing is important to produce a proper speech resonance.

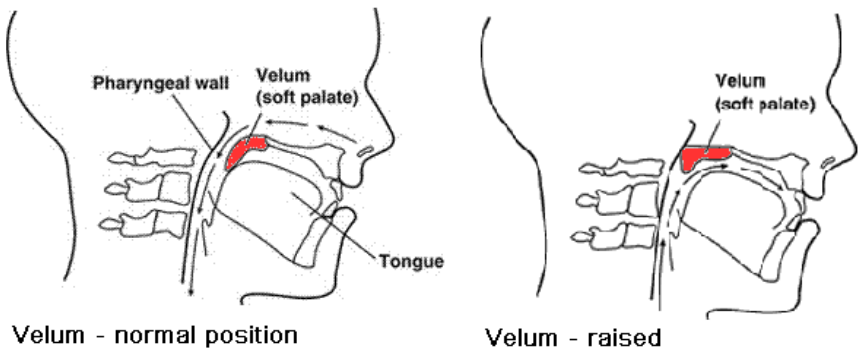


Figure II.2. Velum movement during speech production

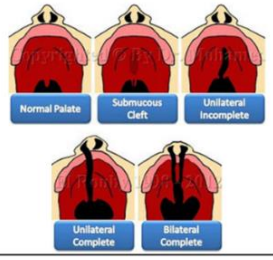
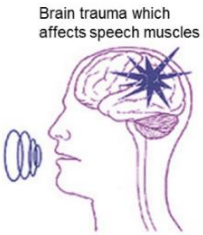
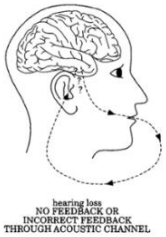
(Adapted from http://www.speech pathology.com/articles, 2016)

2.2. Resonance Disorders

Resonance disorder is the inability to have proper airflow through mouth for producing speech sound. Resonance disorder occurs when there is difference in the amplified voice caused by structural anomaly or by inefficient or ineffective use of the structures of the supraglottal airway (ASHA, 2012). The symptoms of resonance disorders contain: hypernasality, hyponasality, and cul-de-sac resonance. In the hypernasality case, abnormal resonance occurs in a human's voice due to increased airflow through the nose during speech. Meanwhile in the hyponasality case, abnormal resonance happens due to decreased airflow through the nose. In case of cul-de-sac resonance, the airflow through the mouth is obstructed due to blockage in vocal tract, resulting in a "muffled" speech quality.

Velopharyngeal Dysfunction (VPD), the incapacity of completely or consistently close the opening between mouth and nose, is believed to be the reason for resonance disorder. VPD can be classified into three types: insufficiency, incompetence, and mislearning. Velopharyngeal Insufficiency occurs when there is not enough ("insufficient") tissue in the palate or throat to let the palate contact the back of the throat during speech. Velopharyngeal Incompetence happens when there is a problem in how the soft palate moves to make speech sounds. Velopharyngeal mislearning (VPM) happens when a child learns wrong ways to make sounds. Some children develop unusual speech behavior that do not use the palate even though their palate works properly (Seattle Childrens Foundation, 2016). The summary information regarding each causes is described within Table II.1.

Table II.1. Types of *Velopharyngeal Dysfunction* (VPD)

	Causes		
	Insufficiency	**Incompetence**	**Mislearning**
Cause	Anatomy (structure)	Physiology (movement)	Learning (articulation)
Example	Cleft palate (main cause), submucous cleft, or short velum	Neurologic disorder or injury (e.g. stroke, dysarthria, cerebral palsy, traumatic brain injury)	Hearing loss/problem, improper speech learning (usually in children)
Types of Symptom	Hypernasality	Hypernasality & hyponasality	Hypernasality, hyponasality, cul-de-sac resonance
Patients	Mainly children	Children & Adults	Children & Adults
Figures			
Incidence	0.14% (1 of every 700 births)	25%-40% stroke victims	10% of US population

2.3. Speech Assessment and Therapy Procedure

The treatment of resonance disorders may differ according to the cause. In general, the approaches of assessment for resonance disorder are classified into two categories of invasive and non-invasive. The invasive techniques involve the medical instruments such as nasendoscopy and videofluoroscopy, which require the apparatuses to be inserted through patient's nose to assess the velopharyngeal function of patient. Non-invasive techniques use perceptual judgment of well-trained listener or digital signal processing-based analysis.

Each technique has its own strengths and limitations as summarized in Figure II.3. In case of anatomy or structure insufficiency, then surgical intervention will be needed before receiving speech therapy. Meanwhile, physiology and learning causes only need diagnosis and speech therapy in order to help patient to learn and reach a proper speech resonance.

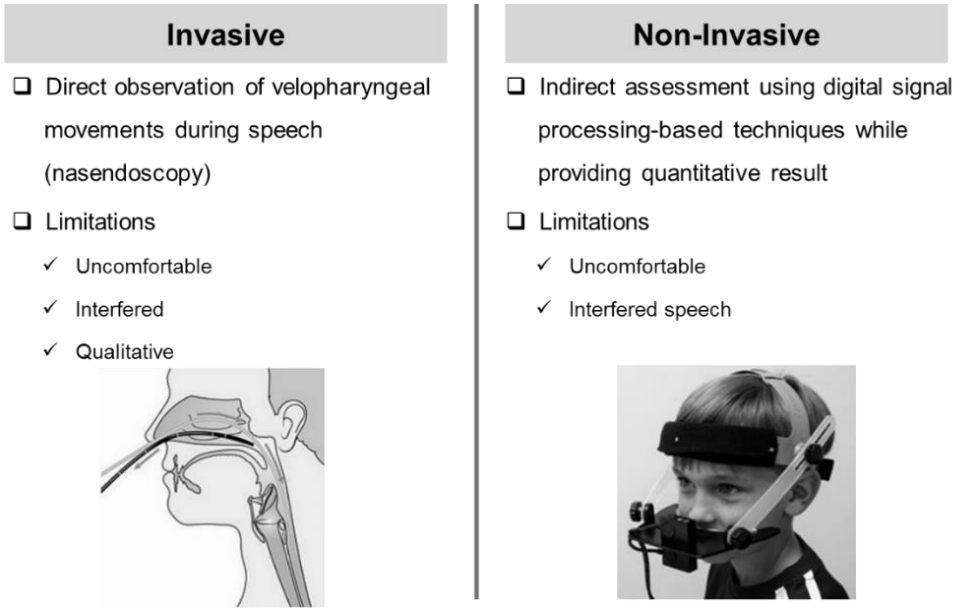


Figure II.3. Invasive and non-invasive speech assessments

Several non-invasive methods had been invented, including the use of: (1) voice intensity, (2) voice frequency, (3) vibration, and (4) airflow through nose/mouth. In order to support those techniques, some clinical devices are available as tool for quantifying the speech resonance. One of standard methods used in clinical environment is nasometry. Using nasometry technique, therapist/clinician captures user's nasal voice energy and oral voice

energy to calculate the ratio of nasal voice total total of nasal and oral voice which is known as nasalance. Nasometer has become a golden standard device to help the therapist to measure nasalance. It utilizes two microphones separated by metal plate, which are attached to a head gear, to capture nasal and oral sound energy respectively.

The development of nasalance measurement device began with a device known as The Oral Nasal Acoustic Ratio (TONAR) by Fletcher (1970). The second version of TONAR was the first commercial nasalance measurement system and was used for biofeedback and contingency-management therapies (Fletcher, 1972). At the moment, TONAR II also encouraged early nasalance studies of Esophageal (Colyar & Christensen, 1980), hearing-impaired patient (Fletcher & Daly, 1976), and hypernasal speech (Fletcher, Soodi, & Frost, 1974; Kahane, 1979). In 1986, Kay Pentax introduced the first Nasometer Type 6200 (Figure II.4.) which was originally the TONAR system and became a popular instrument among clinicians.

Figure II.4. Kay Pentax Nasometer Type 6200

(Adapted from Awan et al., 2013)

In 2002 Nasometer 6200 was replaced with the Nasometer II 6400 which uses preamplifier together with computer soundcard. After that, Kay Pentax introduced the Nasometer II 6450 in 2009, which is known as the latest model of Nasometer in the market until now. Nasometer II untilizes an external universal serial bus soundcard and transfers a digital sound file to the computer. The timeline of nasalance measurement device development is shown in the Figure II.5.

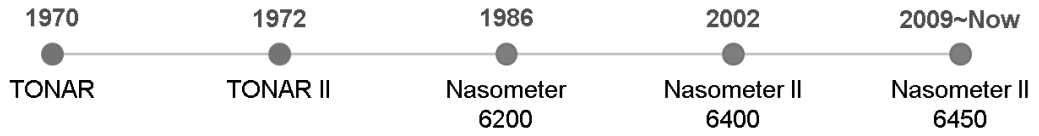


Figure II.5. Timeline of Nasalance Measurement Device Development

Affecting factors of nasalance assessment are reported, such as the device specification, age, gender, language, or physical characteristics. Bressmann (2005) found that there are statistically significant differences between nasometer and other nasalance measurement instruments such as NasalView and OroNasal System (Figure II.6.).

Figure II.6. NasalView (Left) and OroNasal System (Right)
(Adapted from Glottal Enterprises Inc., 2014)

Awan and Virani (2013) also showed the nasalance value difference obtained from Nasometer 6200 and Nasometer II 6400, which implicates the need of different normative data for each device. Age also affects nasalance assessment since one's age may influence the vocal tract length and physiological changes such as soft tissue, bony tissue, and muscle (Rochet et al., 1998). Zajac & Mayo (1996) and Rochet (1998) reported that gender affect the nasalance value due to the difference in velum length and velopharyngeal closure pattern. Several studies also discussed the effect of dialect on nasalance. Dialects or language that use more "high" vowels (higher tongue position) might be expected to have higher nasalance as compared to those with low vowels or a lower tongue position (Kummer, 2008).

Mayo et al. (1996) also hypothesized that across dialects, there may be differences in the timing of velopharyngeal closure when transitions are made between nasal consonants and vowels. Lastly, many studies (Seaver et al., 1991; Mayo et al. 1996; Rochet et al., 1998; Sweeney et al., 2004; Van Doorn & Purcell, 2004; Van Lierde, 2011) also found that language has effect on nasalance according to pronunciation characteristics. One of the reason is because the stimulus passages may also be different among studies conducted in several nations, in term of its nasal consonant (/n/, /m/, /ng/) rate over number of total phonemes (Table II.2.). The nasal consonant rate within a passage is calculated using an equation as follow (Eq. 2).

$$\text{Nasal Consonant Rate (\%)} = \frac{\text{Number of nasal consonant}}{\text{Number of phonemes}} \text{ x } 100\% \qquad \text{(Eq. 2)}$$

Table II.2. Nasal consonant rate of stimulus passages & normative data of nations

Languages	Oral Passage		Oro-nasal Passage		Nasal Sentences	
	Nasal consonant rate	**Mean Nasalance**	**Nasal consonant rate**	**Mean Nasalance**	**Nasal consonant rate**	**Mean Nasalance**
Korean		11.7	17%	34.0	55%	63.7
Cantonese		15	17%	35.5	41%	55.7
Flemish		10.9	11%	33.8	35%	59
English	0%	11.2	11%	36.0	35%	59.5
Irish English		-	11%	26.0	51%	51
Puerto Rican Spanish		21.9	11%	36.0	49%	62.1
Mexican Spanish		15	-	-	20%	55.3

III. Methods

3.1. Nasalance Measurement Experiment

The experiment in the present study includes two parts: (1) nasalance measurement at different gap distance and (2) validation experiment of the proposed nasometer design (Figure III.1.). The first experiment measures the nasalance behavior of participants while reading certain nasal or oral stimulus. Different gap distances (5/10/15 mm) between separator edge and participant's philtrum (a point between lip and nose) are used in this experiment. Validation experiment is conducted to the existing nasometer and proposed nasometer in order to compare their performance by analyzing its nasalance mean and pattern.

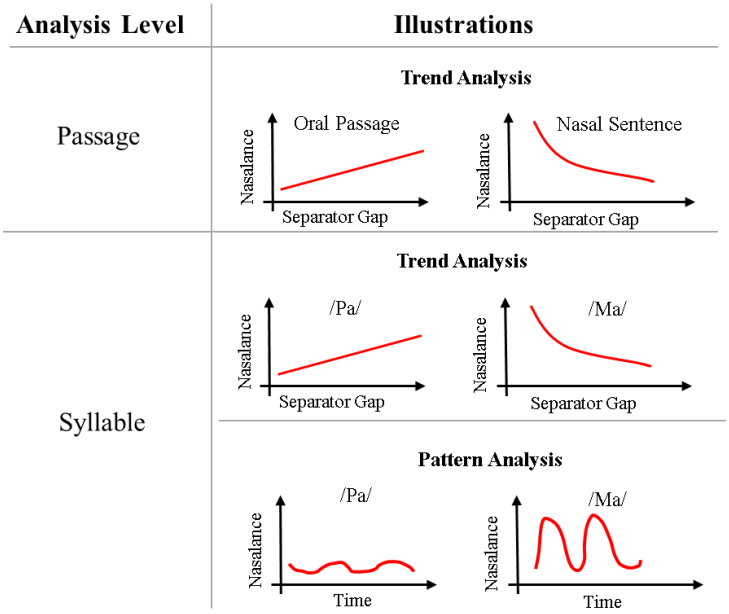


Figure III.1. Scheme of experiment and analysis

The data analysis of experiment result consists of three parts: (1) regression analysis of nasalance on gap distance difference, (2) comparison of mean nasalance between existing nasometer and proposed nasometer in passage and word level, and (3) comparison of nasalance pattern between existing nasometer and smart naso in word level.

3.1.1. Participants & Apparatus

In total 20 adults including 10 males and 10 females (16~51 years old), with no craniofacial or neurological problem participated in the nasalance measurement experiment. The participants include 10 Korean, 8 Indonesian, 1 Malaysian, and 1 Chinese. The Nasometer II type 6450 (Kay Pentax, 2010) was used for measuring nasal & oral sound energy (*volt*) and nasalance during stimulus reading. The nasometer system, separator extension plate, and the nasal/oral stimulus were used in the nasalance measurement experiment. The scaled separator extension plate made of rigid cardboard was used for the untouched separator testing session. The extension plate was attached to the original separator before participant put on the head gear. Then, after fixing the position of head gear and separator to participant's head, the extension plate was detached to provide a gap between the original separator and participant's lip. The extension plate itself had a length indicator of 5 mm, 10 mm, and 15 mm to determine the gap distance in the experiment.

Each participant was asked to read a certain English passage or pronounces syllable as stimulus. Two types of nasalance testing passage were used in the present experiment: nasal sentence and zoo passage (Fletcher, 1973). Nasal sentences are heavily loaded with nasal consonants (35% of phonemes number), while zoo passage is including no nasal consonant

(Table III.1). Two types of testing syllables: nasal consonant + ‘a’ (/ma/) and non-nasal consonant + ‘a’ (/pa/) were also utilized for the syllable level experiment.

Table III.1. Stimulus passage for nasalance measurement experiment

Nasal Sentence (35% nasal consonants)	**Zoo Passage (0% nasal consonants)**
Ma**m**a **m**ade so**m**e le**m**o**n** ja**m**. Te**n** **m**e**n** ca**m**e i**n** whe**n** Ja**n**e ra**ng**. Da**n**'s ga**ng** cha**ng**ed **m**y **m**i**n**d. Be**n** ca**n**'t pla**n** o**n** a le**ng**thy rai**n**. A**m**a**n**da ca**m**e fro**m** Bou**n**di**ng**, **M**ai**n**e Nasal consonant rate calculation • Number of nasal consonant = 35 • Number of phonemes = 100 • Nasal consonant rate = 35%	Look at this book with us. It's a story about a zoo. That is where bears go. Today it's very cold out of doors, but we see a cloud overhead that's a pretty white fluffy shape. We hear that straw covers the floor of cages to keep the chill away; yet a deer walks through the trees with her head high. They feed seeds to birds so they're able to fly.

3.1.2. Experimental Procedure

The nasalance measurement experiment content an approximately 50-min of six steps procedure as shown in Figure III.2. First, preparation step was conducted to make sure the nasometer is well connected to the computer system and calibrated properly according to the Kay Pentax manual. The calibration was important to set each audio sensor (nasal & oral) to be able to capture a balance input. Second, in the briefing session, the purpose and procedure

of the experiment were explained to the participant. Then, before conducting the real measurement, participant had 5 min. to read the stimulus passages consist of nasal sentence and zoo passage, to get familiar with the words and to try how to pronounce it.

The testing session was divided into touched separator testing and untouched separator testing. In the first session, nasalance was measured using a touched separator as the original setting of Kay Pentax Nasometer II 6450. In the second session, nasalance was measured with an untouched separator. The gap between participant and separator was determined by the scaled separator extension plate which was attached to the original separator. After the extension is attached, participant was requested to wear the device then the extension plate was detached in order to leave a gap as shown in the Figure III.3. There were three different gap distances for the second session nasalance measurement: 5 mm, 10 mm, and 15 mm. The vertical position of separator plate is controlled by setting the head gear so that the edge of separator plate touches the point between the edge of nose and philtrum.

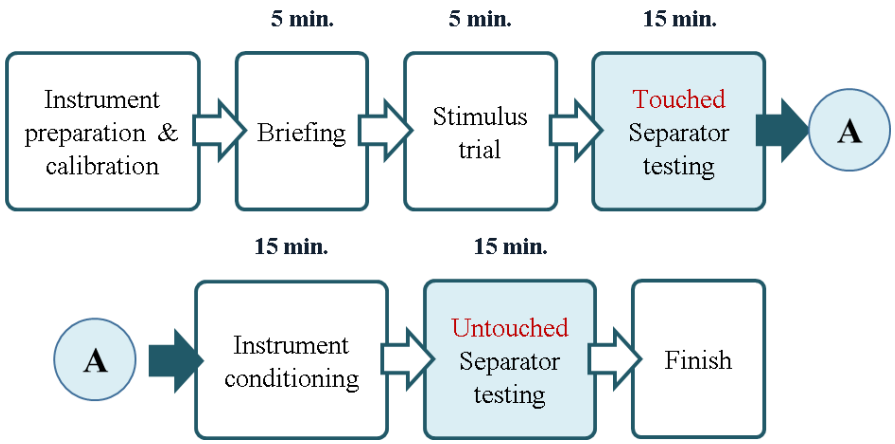


Figure III.2. Procedure of experiment

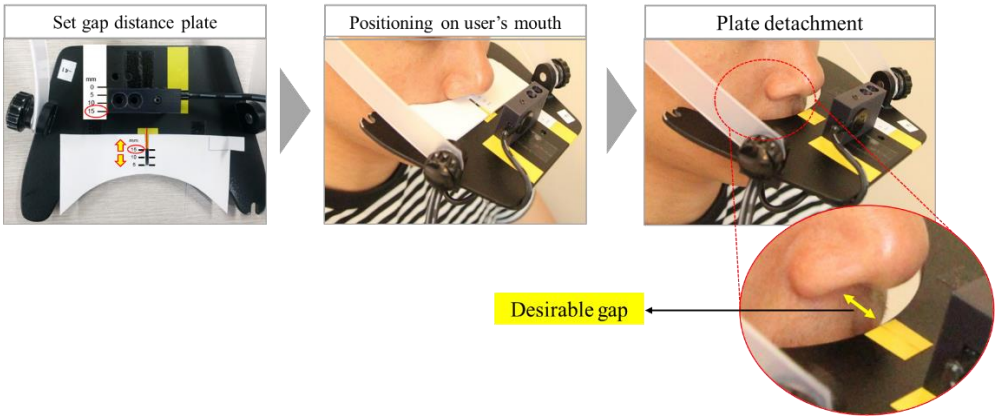


Figure III.3. Setting of untouched separator condition

3.2. Development of Nasalance Value Adjustment Algorithm

Nasalance measured by proposed nasometer need to be adjusted due to the difference to nasalance of touched separator nasometer. Proposed nasometer in present work uses untouched separator in order to prevent intrusiveness to user's lip/mouth movement. However, this design will implicate to different nasalance result compare to touched separator nasometer. Thus, an adjustment algorithm for the untouched separator was required to get an equivalent nasalance value with touched separator. From nasalance measurement experiment result we can know behavior of nasalance value under different separator gap distance and to determine a proper adjustment value to the untouched separator. Using regression analysis, the trend of nasalance change on several separator gap distance (0/5/10/15 mm) can be identified. Furthermore, we can utilize the ratio of nasalance value on untouched separator and the touched separator (e.g. nasalance 5 mm/nasalance 0 mm) as adjustment multiplier of the untouched nasalance.

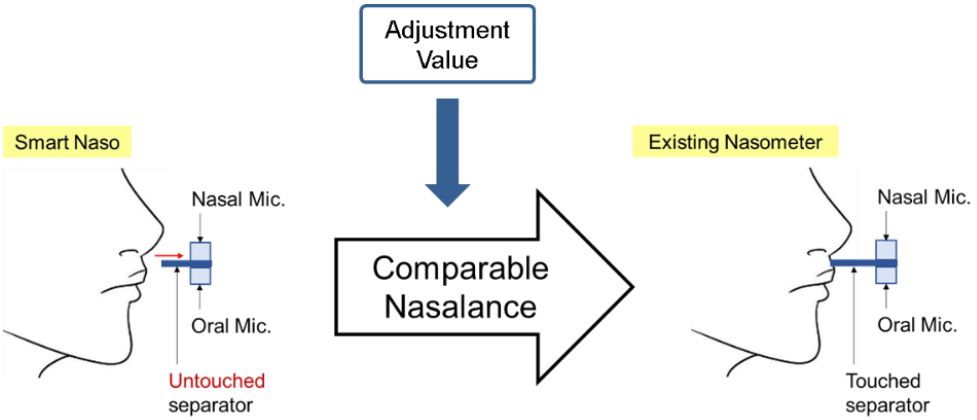


Figure III.4. Nasalance adjustment for proposed separator nasometer

3.3. Validation Method

Validation in present study was to check whether the nasalance value obtained from the proposed system was equivalent with the Kay Pentax Nasometer. Two kinds of validation were included in the present work: validation of mean nasalance and validation of nasalance pattern. Validation of mean nasalance was conducted by comparing the mean nasalance value between the proposed nasometer and Kay Pentax Nasometer in passage level (nasal sentence and oral passage). Validation of nasalance pattern is conducted by comparing nasalance data from both systems using testing syllable of nasal consonant + /a/ syllables (/ma/) and oral consonant + /a/ syllables (/pa/).

IV. Results

4.1. Experiment Results

4.1.1. Nasalance Measurement

Nasalance measurement experiment was conducted to obtain nasalance scores and trend from subject while reading particular stimulus on the passage level and syllable level using existing nasometer. On the passage level, the experiment used nasal sentence and oral (zoo) passage, while on syllable level the experiment used /ma/ and /pa/ as stimulus. On both measurements of 0 mm separator gap using passage and syllable stimulus, the average value of nasalance agree with the normative data of Kay Pentax Nasometer (Table IV.1.). The nasalance average of all participants on nasal sentence is 55.37 (SD: 6.58), while average on zoo passage is 11.46 (SD: 5.35) as shown in Table IV.2. and 4.3. The average of nasalance on /ma/ syllable is 52.19 (SD: 6.92), while average on /pa/ syllable is 6.38 (SD: 2.43) as shown in Table IV.2. and 4.3.

Table IV.1. Nasalance normative data

Stimulus	Mean Nasalance (n = 40)	SD of Mean
Nasal Sentence	59.55	7.96
Zoo Passage	11.25	5.63
/Ma Ma Ma/	53.00	13.00
/Pa Pa Pa/	6.00	3.00

Table IV.2. Nasalance (%) on passage level

	Nasal Sentence				Zoo Passage			
	0 mm	5 mm	10 mm	15 mm	0 mm	5 mm	10 mm	15 mm
Mean (n = 20)	**55.37**	47.11	43.53	41.16	**11.46**	15.67	19.72	24.11
SD	**6.58**	4.70	4.19	3.65	**5.35**	4.58	4.35	4.07
Min	41.74	36.52	33.93	31.38	4.86	8.50	13.53	17.57
Max	70.29	54.35	50.19	48.52	25.23	25.67	27.50	30.84

Table IV.3. Nasalance (%) on syllable level

	/Ma Ma Ma/				/Pa Pa Pa/			
	0 mm	5 mm	10 mm	15 mm	0 mm	5 mm	10 mm	15 mm
Mean (n = 20)	**52.19**	44.20	39.84	37.29	**6.38**	15.96	21.61	26.50
SD	**6.92**	5.29	4.26	4.06	**2.43**	2.64	2.80	2.98
Min	39.38	33.82	32.14	30.83	3.23	11.28	16.08	22.27
Max	66.39	56.34	47.33	45.42	14.28	22.08	26.24	32.52

4.1.2. Regression Analysis

Regression analysis of nasalance on different separator gap distance was conducted to obtain an equation which represents the relation between nasalance on different separator gap (5, 10, and 15 mm) of individual subject. This study used linear regression analysis on oral stimulus data and polynomial regression (2^{nd} order) on nasal stimulus data in order to see the trend of nasalance value. Utilizing regression analysis, we can see that in nasal stimulus (nasal sentence and /ma/ syllable) the nasalance value decreases when the separator gap increases. On presented graphs of both nasal stimulus, the curve shows a greater decrease occurred from 0 mm separator to 10 mm separator condition, and saturated on 10 mm to 15 mm separator gap (Figure IV.1.a. and Figure IV.2.a.). On the other hand, using

oral stimulus (zoo passage and /pa/ syllable), there was increase of nasalance when separator gap increases (Figure IV.1.b. and Figure IV.2.b.).

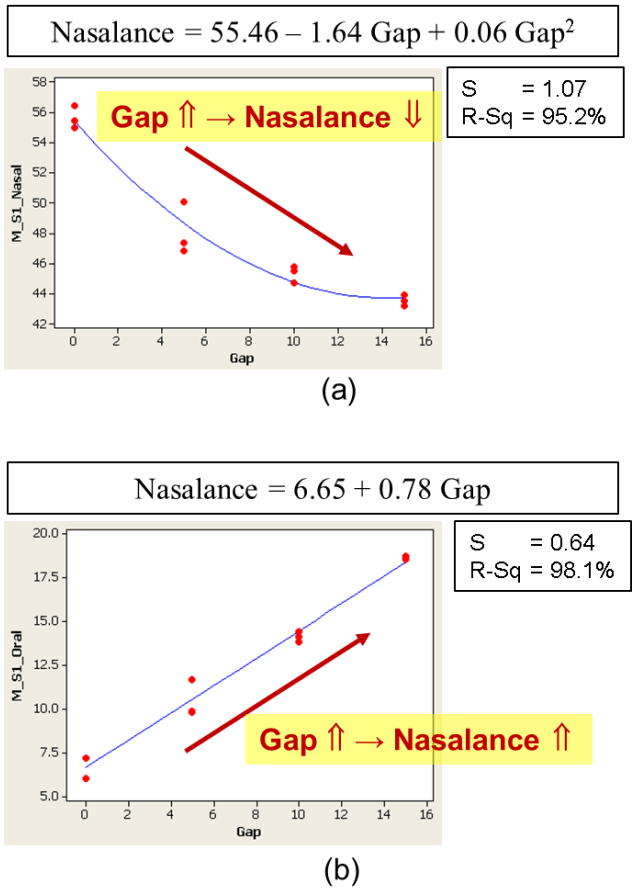
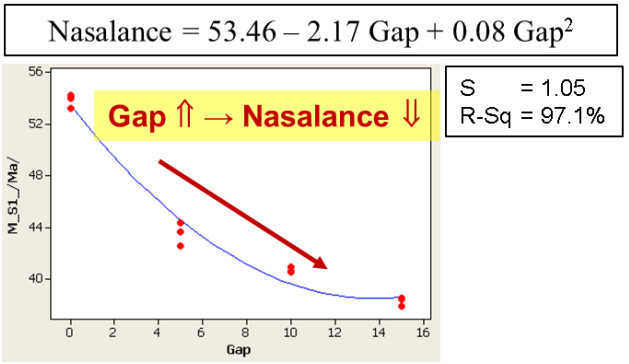
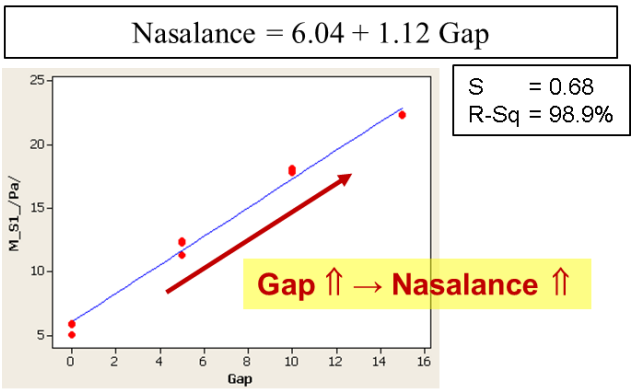


Figure IV.1. Regression analysis of nasalance of a participant for nasal sentence and zoo passage



(a)



(b)

Figure IV.2. Regression analysis of nasalance of a participant for /ma/ syllable and /pa/ syllable

The regression model of each type of stimulus (passage & syllable) fits well with the individual data. R-Squared (adj.) and standard error of regression (S) are used as measure to determine how well the model fits the data. On passage stimulus, the average R-Squared (adj.) reaches 94.86% and standard error 0.87 (Table IV.4). On syllable stimulus, the average R-Squared reaches 96.07% and standard error 1.32 (Table IV.5).

Table IV.4. Regression result of nasalance using passage stimulus

Subject				Stimulus	*Adj-R^2*	*S*	Regression Equation N: Nasalance (%); G: Gap (mm)
Gender	**No.**	**Age**	**Nationality**				
Male	1	25	Indonesia	Nasal	95.20	1.07	$N = 55.46 – 1.64\ G + 0.06\ G^2$
				Oral	98.10	0.64	$N = 6.65 + 0.78\ G$
	2	30	Korea	Nasal	98.50	0.68	$N = 57.18 – 1.44\ G + 0.03\ G^2$
				Oral	91.80	0.96	$N = 11.26 + 0.55\ G$
	3	25	Korea	Nasal	99.00	0.74	$N = 59.08 – 2.59\ G + 0.09\ G^2$
				Oral	98.30	0.49	$N = 13.73 + 0.64\ G$
	4	27	Indonesia	Nasal	98.70	0.49	$N = 49.71 – 1.19\ G + 0.03\ G^2$
				Oral	95.80	1.14	$N = 7.23 + 0.94\ G$
	5	25	Indonesia	Nasal	93.50	1.03	$N = 42.72 – 1.05\ G + 0.03\ G^2$
				Oral	98.30	1.00	$N = 5.45 + 1.29\ G$
	6	28	Korea	Nasal	88.40	1.54	$N = 49.12 – 1.25\ G + 0.04\ G^2$
				Oral	96.90	1.03	$N = 8.73 + 0.99\ G$
	7	24	Indonesia	Nasal	97.20	0.66	$N = 44.12 – 1.64\ G + 0.07\ G^2$
				Oral	98.50	0.06	$N = 4.83 + 0.92\ G$
	8	17	Korea	Nasal	87.40	0.91	$N = 44.72 – 0.98\ G + 0.04\ G^2$
				Oral	95.20	1.35	$N = 7.50 + 1.03\ G$
	9	25	Korea	Nasal	99.60	0.43	$N = 53.75 – 2.34\ G + 0.07\ G^2$
				Oral	95.80	0.67	$N = 21.74 + 0.55\ G$
	10	28	Korea	Nasal	97.60	0.97	$N = 54.72 – 1.81\ G + 0.05\ G^2$
				Oral	99.00	0.56	$N = 12.27 + 0.97\ G$
Female	1	24	Indonesia	Nasal	97.60	0.80	$N = 56.96 – 1.43\ G + 0.04\ G^2$
				Oral	96.40	0.92	$N = 7.49 + 0.81\ G$
	2	23	Korea	Nasal	94.30	1.61	$N = 61.73 – 2.53\ G + 0.09\ G^2$
				Oral	96.50	0.86	$N = 9.34 + 0.78\ G$
	3	22	Indonesia	Nasal	98.40	0.71	$N = 55.03 – 1.76\ G + 0.05\ G^2$
				Oral	99.20	0.42	$N = 8.42 + 0.81\ G$
	4	28	Korea	Nasal	97.10	1.52	$N = 68.93 – 3.40\ G + 0.13\ G^2$
				Oral	14.70	2.08	$N = 22.71 + 0.18\ G$
	5	16	Korea	Nasal	99.50	0.44	$N = 55.92 – 1.95\ G + 0.06\ G^2$
				Oral	99.50	0.33	$N = 7.98 + 0.84\ G$

Subject				Stimulus	*Adj-R²*	*S*	Regression Equation N: Nasalance (%); G: Gap (mm)
Gender	**No.**	**Age**	**Nationality**				
	6	16	Korea	Nasal	96.80	1.15	$N = 53.70 – 2.29\ G + 0.08\ G^2$
				Oral	99.30	0.48	$N = 12.61 + 0.97\ G$
	7	16	Korea	Nasal	97.40	0.67	$N = 60.79 – 2.63\ G + 0.09\ G^2$
				Oral	98.50	0.66	$N = 4.83 + 0.92\ G$
	8	29	Korea	Nasal	97.40	0.91	$N = 60.10 – 1.39\ G + 0.03\ G^2$
				Oral	97.70	0.89	$N = 14.86 + 0.99\ G$
	9	40	Korea	Nasal	97.50	0.87	$N = 57.40 – 1.35\ G + 0.03\ G^2$
				Oral	98.20	0.86	$N = 12.11 + 1.08\ G$
	10	17	Korea	Nasal	98.50	0.77	$N = 57.64 – 1.88\ G + 0.06\ G^2$
				Oral	97.00	1.18	$N = 13.91 + 1.16\ G$
				Average	94.86	**0.86**	

Table IV.5. Regression result of nasalance using syllable stimulus

Subject				Stimulus	*Adj-R²*	*S*	Regression Equation N: Nasalance (%); G: Gap (mm)
Gender	**No.**	**Age**	**Nationality**				
Male	1	25	Indonesia	/ma/	97.10	1.05	$N = 53.46 – 2.17\ G + 0.08\ G^2$
				/pa/	98.90	0.68	$N = 6.04 + 1.12\ G$
	2	25	Korea	/ma/	95.70	0.86	$N = 45.81 – 1.37\ G + 0.05\ G^2$
				/pa/	95.20	1.45	$N = 11.26 + 0.55\ G$
	3	30	Korea	/ma/	99.20	0.51	$N = 50.73 – 1.09\ G + 0.01\ G^2$
				/pa/	92.60	2.22	$N = 5.63 + 1.35\ G$
	4	25	Indonesia	/ma/	93.40	1.10	$N = 43.20 – 1.13\ G + 0.03\ G^2$
				/pa/	93.30	2.12	$N = 6.28 + 1.36\ G$
	5	24	Indonesia	/ma/	99.30	0.51	$N = 50.73 – 1.09\ G + 0.01\ G^2$
				/pa/	92.60	2.22	$N = 5.63 + 1.35\ G$
	6	30	Korea	/ma/	94.00	0.91	$N = 40.49 – 0.90\ G + 0.02\ G^2$
				/pa/	95.70	1.57	$N = 5.82 + 1.27\ G$
	7	17	Korea	/ma/	96.10	0.91	$N = 51.56 – 0.88\ G + 0.01\ G^2$
				/pa/	98.00	1.57	$N = 5.41 + 1.89\ G$
	8	51	Korea	/ma/	98.60	0.85	$N = 54.08 – 2.63\ G + 0.09\ G^2$
				/pa/	98.30	1.19	$N = 8.49 + 1.56\ G$

Subject				Stimulus	*Adj-R^2*	*S*	Regression Equation N: Nasalance (%); G: Gap (mm)
Gender	**No.**	**Age**	**Nationality**				
	9	28	Indonesia	/ma/	98.10	1.12	$N = 53.75 – 2.34 G + 0.07 G^2$
				/pa/	98.30	0.97	$N = 5.81 + 1.28 G$
	10	27	Indonesia	/ma/	97.20	1.23	$N = 57.79 – 2.33 G + 0.08 G^2$
				/pa/	90.60	3.04	$N = 7.96 + 1.62 G$
Female	1	24	Indonesia	/ma/	97.20	0.91	$N = 52.18 – 1.70 G + 0.05 G^2$
				/pa/	98.10	1.07	$N = 4.51 + 1.31 G$
	2	23	Korea	/ma/	98.30	0.76	$N = 52.02 – 1.26 G + 0.02 G^2$
				/pa/	95.80	1.68	$N = 5.648 + 1.377 G$
	3	23	Malaysia	/ma/	98.40	0.86	$N = 61.35 – 2.37 G + 0.08 G^2$
				/pa/	90.90	2.22	$N = 7.431 + 1.21 G$
	4	22	Indonesia	/ma/	98.00	1.00	$N = 59.50 – 2.34 G + 0.08 G^2$
				/pa/	96.20	1.25	$N = 10.29 + 1.09 G$
	5	24	Indonesia	/ma/	98.60	1.08	$N = 64.73 – 2.76 G + 0.08 G^2$
				/pa/	95.50	1.68	$N = 8.76 + 1.33 G$
	6	29	Korea	/ma/	93.30	1.32	$N = 51.40 – 1.39 G + 0.04 G^2$
				/pa/	98.40	0.92	$N = 9.23 + 1.22 G$
	7	33	China	/ma/	96.90	1.59	$N = 55.54 – 3.17 G + 0.12 G^2$
				/pa/	90.80	2.21	$N = 8.63 + 1.19 G$
	8	16	Korea	/ma/	92.30	1.81	$N = 60.55 – 1.83 G + 0.05 G^2$
				/pa/	96.60	1.28	$N = 5.72 + 1.18 G$
	9	16	Korea	/ma/	97.60	0.99	$N = 51.13– 1.85 G + 0.05 G^2$
				/pa/	95.00	2.02	$N = 9.26 + 1.52 G$
	10	16	Korea	/ma/	96.30	0.65	$N = 42.22 – 1.11 G + 0.04 G2$
				/pa/	96.50	1.33	$N = 8.56 + 1.19 G$
				Average	**96.07**	**1.32**	

4.2. Nasalance Value Adjustment Algorithm

Nasalance obtained from the proposed nasometer system needs adjustment in order to get an equivalent result with the existing nasometer. From the nasalance on separator gap experiment we found a decrease of nasalance in the high-nasalance stimulus (e.g. nasal sentence and /Ma/), whereas an increase of nasalance occurred in the low-nasalance stimulus

(e.g. oral passage and /Pa/). Therefore, this study proposed to adjust the nasalance value according to the level of nasalance (high or low) as shown in Figure IV.3.

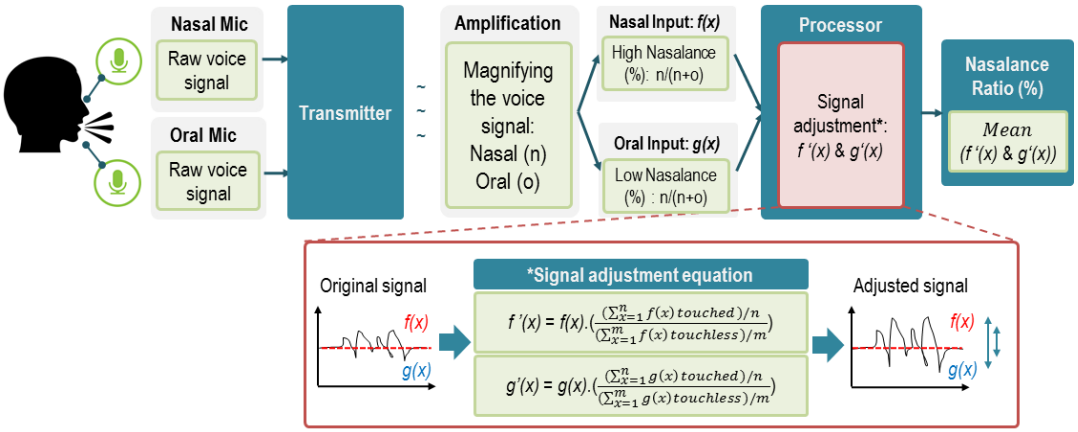


Figure IV.3. Adjustment algorithm for untouched separator nasalance

Experiment was conducted to identify the nasalance value trend under different separator conditions, which further became the basis of adjustment multiplier for nasalance from untouched separator nasometer. There are three conditions of separator used in the experiment: 5mm, 10mm, and 15mm separator gap. The calculation of adjustment multiplier was accomplished by subtracting each mean nasalance on separator with gap (5/10/15 mm) with 0 mm nasalance to get the difference between them. The subtraction results from all subjects then averaged to get the adjustment multiplier for nasal and oral stimulus (see Table IV.6. as example).

Table IV.6. Calculation table of adjustment multiplier value

Gender	Subject	Nasalance (%)					
		Nasal Sentence			Zoo Passage		
		0 mm	5 mm	Adjustment Multiplier	0 mm	5 mm	Adjustment Multiplier
Male	1	55.54	48.49	55.54/48.49 = 1.15	6.94	10.17	6.94/10.17 = 0.68
	2	55.65	48.11	1.16	11.49	14.00	0.82
	3	59.25	47.93	1.24	13.46	17.09	0.79
	4	49.82	44.18	1.13	8.14	11.09	0.73
	5	42.76	38.00	1.13	5.76	11.96	0.48
	6	49.32	43.16	1.14	8.03	15.10	0.53
	7	44.22	37.36	1.18	4.95	8.79	0.56
	8	44.89	40.43	1.11	6.44	13.60	0.47
	9	60.57	52.25	1.16	21.33	25.00	0.85
	10	55.01	46.13	1.19	12.33	16.79	0.73
Female	11	57.16	50.88	1.12	7.10	11.66	0.61
	12	62.33	49.79	1.25	9.79	13.04	0.75
	13	54.89	48.03	1.14	8.46	12.49	0.68
	14	69.48	53.64	1.30	24.57	21.54	1.14
	15	55.88	47.73	1.17	8.16	12.09	0.67
	16	53.96	43.56	1.24	12.27	18.02	0.68
	17	60.97	49.24	1.24	19.90	23.44	0.85
	18	60.17	53.66	1.12	14.70	19.65	0.75
	19	57.62	50.75	1.14	12.37	17.38	0.71
	20	57.87	48.99	1.18	13.11	20.46	0.64

In order to know the effect of adjustment multiplier, a trial to 5mm nasalance data was conducted on both passage and syllable level. As can be seen from the error comparison between 0 mm, 5 mm, and adjusted 5 mm separator, nasalance data of 5mm separator can be adjusted to be closer to the 0mm nasalance data.

The error was calculated by |0 mm – 5 mm| nasalance or |0 mm – adjusted 5 mm| nasalance. On passage level, the error before applying adjustment multiplier were 8.25 (nasal sentence) and 4.51 (zoo passage). Meanwhile the error after applying adjustment multiplier were decreased to be 1.30 (nasal sentence) and 1.61 (zoo passage) as shown in Table IV.7. and Figure IV.4.

Table IV.7. Comparison of nasalance on passage stimulus before and after applying multiplier

Subject		Nasal sentence					Zoo passage				
		0 mm	5 mm	Adjust 5 mm	Error		0 mm	5 mm	Adjust 5 mm	Error	
					Before adjusted	After adjusted				Before adjusted	After adjusted
Male	1	55.54	48.49	54.31	7.04	1.22	6.94	10.17	7.60	3.23	0.66
	2	55.65	48.11	57.42	7.54	1.76	11.49	14.00	10.39	2.51	1.10
	3	59.25	47.93	57.90	11.32	1.35	13.46	17.09	13.63	3.64	0.18
	4	49.82	44.18	48.53	5.65	1.30	8.14	11.09	7.98	2.95	0.16
	5	42.76	38.00	38.53	4.76	4.23	5.76	11.96	8.68	6.20	2.92
	6	49.32	43.16	46.86	6.16	2.46	8.03	15.10	11.02	7.07	2.99
	7	44.22	37.36	41.20	6.86	3.02	4.95	8.79	6.27	3.84	1.32
	8	44.89	40.43	43.09	4.47	1.80	6.44	13.60	10.02	7.16	3.59
	9	60.57	52.25	60.31	8.32	0.26	21.33	25.00	23.11	3.67	1.78
	10	55.01	46.13	54.10	8.88	0.91	12.33	16.79	12.64	4.46	0.31
Female	11	57.16	50.88	56.12	6.28	1.04	7.10	11.66	8.75	4.56	1.64
	12	62.33	49.79	61.50	12.54	0.83	9.79	13.04	10.00	3.25	0.21
	13	54.89	48.03	53.65	6.86	1.24	8.46	12.49	10.04	4.03	1.58
	14	69.48	53.64	69.44	15.84	0.04	24.57	21.54	19.12	3.03	5.45
	15	55.88	47.73	54.77	8.15	1.11	8.16	12.09	8.83	3.93	0.67
	16	53.96	43.56	52.51	10.40	1.45	12.27	18.02	13.56	5.76	1.29
	17	60.97	49.24	60.87	11.73	0.10	19.90	23.44	19.37	3.54	0.52
	18	60.17	53.66	59.62	6.51	0.55	14.70	19.65	16.30	4.95	1.60
	19	57.62	50.75	56.89	6.87	0.72	12.37	17.38	14.08	5.01	1.71
	20	57.87	48.99	57.20	8.88	0.66	13.11	20.46	16.32	7.35	3.21
Mean		**55.37**	**47.12**	**54.24**	**8.25**	**1.30**	**11.47**	**15.67**	**13.08**	**4.51**	**1.61**
SD		**6.58**	**4.70**	**7.50**			**5.36**	**4.58**	**6.45**		
SE		**1.50**	**1.10**	**1.68**			**1.20**	**1.00**	**1.44**		

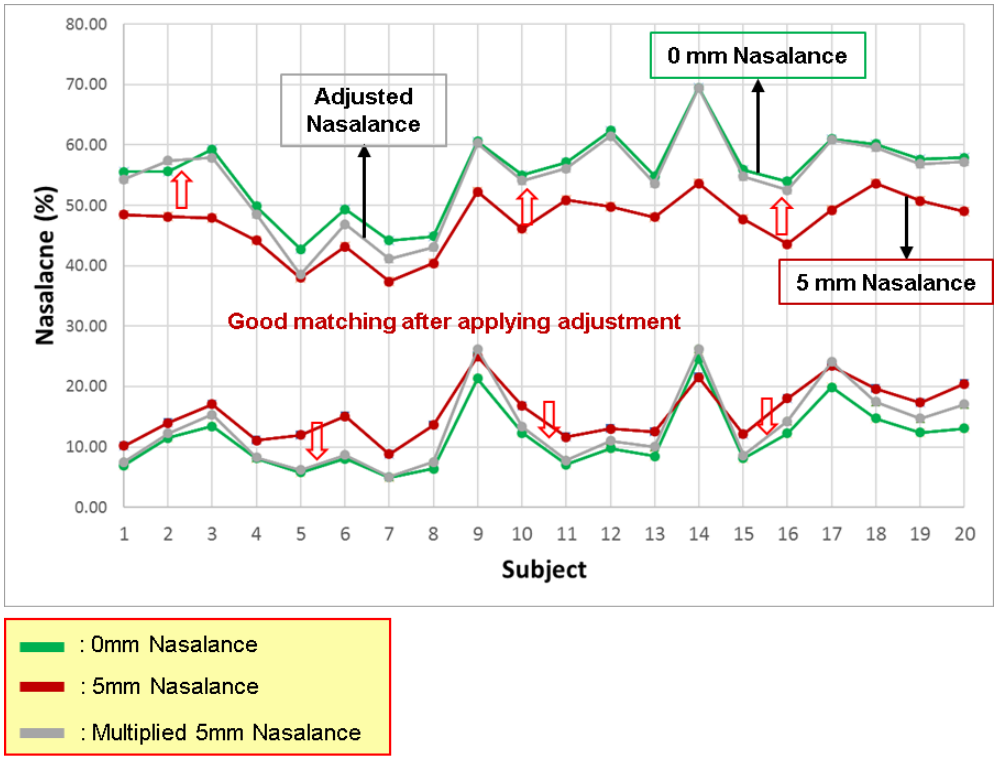


Figure IV.4. Effect of applying adjustment multiplier on passage level

On syllable level, we can also observe a decrease of nasalance error by applying adjustment multiplier to the 5 mm gap condition (Table IV.8. and Figure IV.5.). The error before applying adjustment multiplier were 7.99 (/ma/ syllable) and 9.58 (/pa/ syllable). Meanwhile the error after applying adjustment multiplier were decreased to be 2.10 (/ma/ syllable) and 1.52 (/pa/ syllable).

Table IV.8. Comparison of nasalance on syllable stimulus before and after applying multiplier

Subject		/ma/					/pa/				
		0 mm	5 mm	Adjust 5 mm	Error		0 mm	5 mm	Adjust 5 mm	Error	
					Before adjusted	After adjusted				Before adjusted	After adjusted
Male	1	53.81	43.51	53.81	10.30	0.00	5.59	12.00	5.59	6.41	0.00
	2	45.99	39.61	45.99	6.37	0.00	13.09	21.69	13.73	8.60	0.64
	3	40.64	34.66	38.64	5.99	2.00	9.36	17.90	9.56	8.54	0.20
	4	43.40	37.65	43.09	5.75	0.31	4.35	15.23	4.35	10.88	0.00
	5	50.74	45.46	50.74	5.28	0.00	3.47	15.06	3.47	11.60	0.00
	6	40.43	36.63	40.13	3.80	0.30	5.04	12.47	5.06	7.43	0.01
	7	51.53	47.39	51.53	4.14	0.00	4.02	16.23	4.42	12.21	0.40
	8	54.28	42.78	54.28	11.50	0.00	7.59	16.95	7.65	9.36	0.05
	9	53.75	43.72	53.75	10.03	0.00	5.21	12.93	5.21	7.72	0.00
	10	57.85	47.87	57.85	9.97	0.00	5.02	20.20	5.18	15.19	0.16
Female	11	52.13	45.14	52.13	7.00	0.00	3.57	12.42	3.57	8.85	0.00
	12	52.10	45.93	52.10	6.18	0.00	4.06	14.37	4.12	10.31	0.07
	13	61.49	51.19	61.49	10.30	0.00	5.31	15.99	5.40	10.68	0.09
	14	59.61	49.42	59.61	10.19	0.00	9.46	16.34	9.58	6.88	0.12
	15	64.77	52.84	64.77	11.93	0.00	7.20	17.24	7.21	10.04	0.01
	16	51.63	44.66	51.63	6.97	0.00	8.46	16.63	8.46	8.17	0.00
	17	55.91	41.49	55.40	14.42	0.51	6.61	17.25	6.91	10.64	0.30
	18	60.40	53.14	60.39	7.27	0.02	5.18	13.01	5.28	7.83	0.10
	19	50.94	43.73	50.91	7.21	0.03	7.36	19.18	9.59	11.82	2.23
	20	42.37	37.18	42.35	5.18	0.02	7.62	16.13	7.62	8.51	0.00
Mean		**52.19**	**44.20**	**52.03**	**7.99**	**0.16**	**6.38**	**15.96**	**6.59**	**9.58**	**0.22**
SD		**6.92**	**5.29**	**7.14**			**2.43**	**2.64**	**2.61**		
SE		**1.50**	**1.20**	**1.60**			**0.54**	**0.59**	**0.58**		

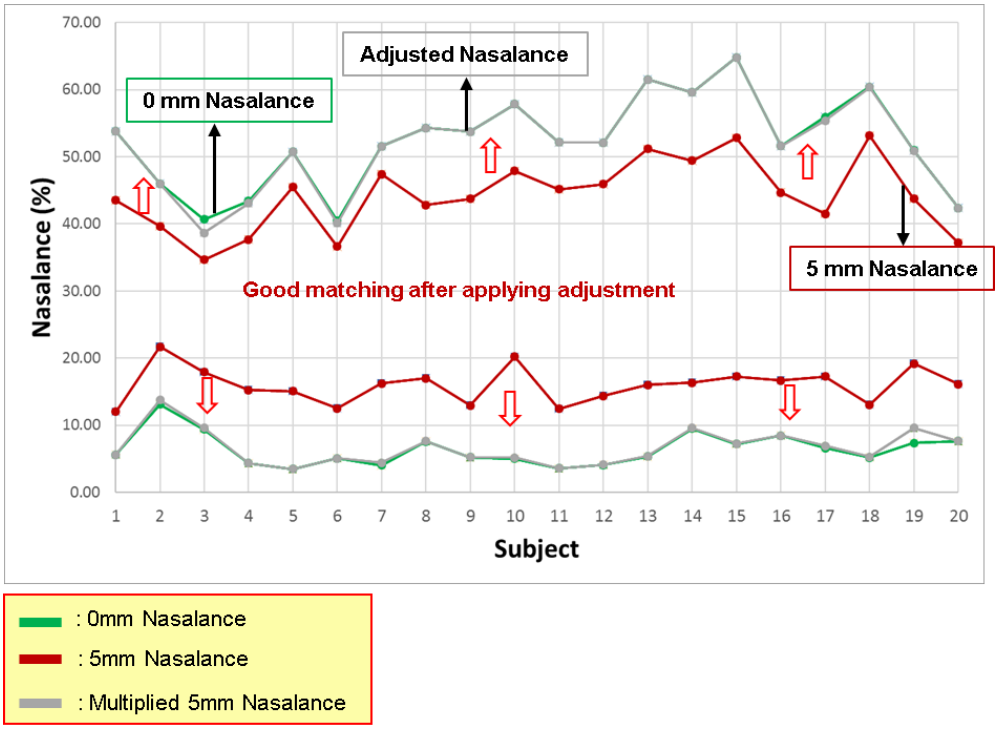


Figure IV.5. Effect of applying adjustment multiplier on syllable level

After applying the multiplier to the 5 mm separator data, we compared the set of nasalance mean of 0 mm vs. 5 mm separator and 0 mm vs. adjusted 5 mm separator using a paired *t test*. The *t test* result shows that before adjustment, the 0 mm and 5 mm mean nasalance is significantly different. On the other hand, applying nasalance multiplier to the 5 mm separator nasalance data can result in good matching with the 0 mm data (no significant difference) on syllable level as shown in Table IV.9.

Table IV.9. Comparison between data before (0 mm vs. 5 mm) and after (0 mm vs. adjusted 5 mm) nasalance adjustment

Level	**Stimulus**	**Conditions**	*n*	*mean*	*SD*	*SE*	*t-value*	*P*
Passage	Nasal sentence	0 mm	20	55.37	6.58	1.50		
		5 mm	20	47.12	4.70	1.05	12.91	0.0001
		Adjusted 5 mm	20	54.24	7.50	1.68	4.16	0.001
	Zoo Passage	0 mm	20	11.47	5.36	1.20		
		5 mm	20	15.67	4.58	1.00	-8.43	0.0001
		Adjusted 5 mm	20	13.08	6.45	1.44	-5.19	0.0001
Syllable	/ma/	0 mm	20	52.19	6.92	1.50		
		5 mm	20	44.20	5.29	1.20	12.37	0.0001
		Adjusted 5 mm	20	52.03	7.14	1.60	1.56	0.135*
	/pa/	0 mm	20	6.38	2.43	0.54		
		5 mm	20	15.96	2.64	0.59	-20.10	0.0001
		Adjusted 5 mm	20	6.60	2.61	0.58	-1.96	0.065*

4.3. Developed Nasalance Measurement System

The proposed nasalance measurement system includes two audio sensors to capture nasal and oral voice energy signal separated by a touchless separator. The touchless and light-material separator was utilized to reduce the intrusiveness to user's mouth/lip during assessment. The device is also combined with headset system for providing auditory feedback during speech therapy (Figure IV.6.).

Figure IV.6. The developed nasalance measurement device

Along with the hardware components, the proposed system comes with a measurement application which is useful for recording and analyzing user's voice behavior. The measurement application is embedded with nasalance adjustment algorithm for equivalent assessment result. The user interface provides the quantitative information of nasalance

mean, min, max, standard deviation value and graph of nasalance as well as oral and nasal energy in real time. The layout of user interface of nasalance measurement application is illustrated in Figure IV.7.

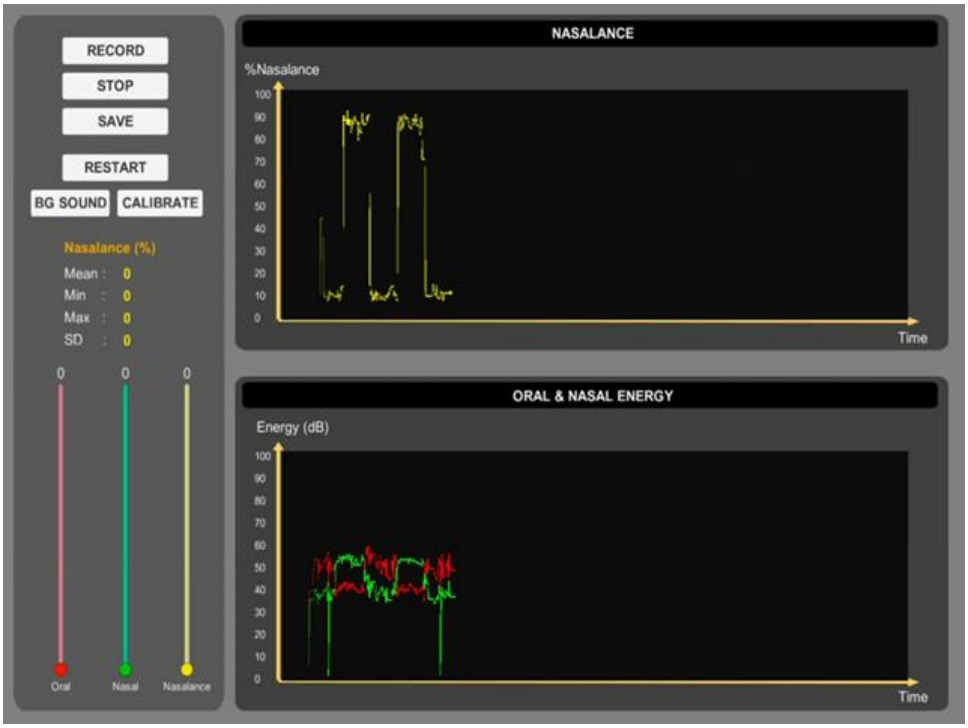


Figure IV.7. Nasalance measurement application

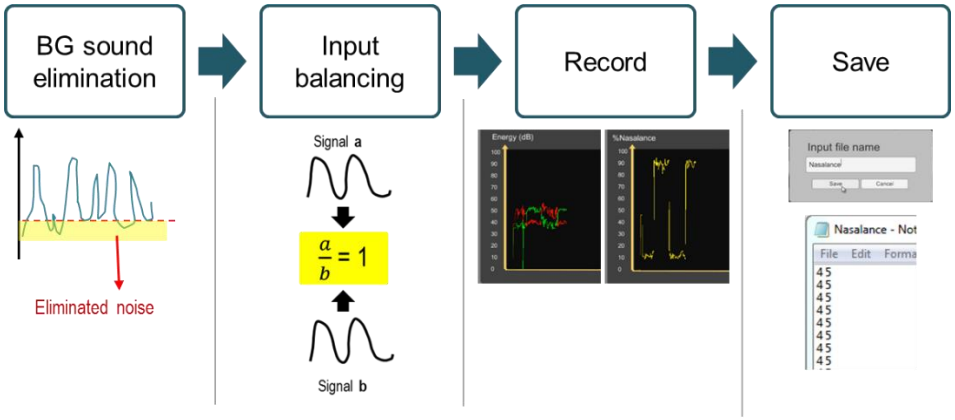


Figure IV.8. Using steps of nasalance measurement application

There are four general steps to utilize this new measurement system which are listed as follows (Figure IV.8).

1. Background (BG) sound elimination: This step is to determine a threshold in order to eliminate unnecessary environment sound. In this step, user do not make any sound during data capturing. This function can be performed by clicking the BG Sound button on the application.
2. Input balancing: This step is to make sure nasal and oral audio sensors capture a balance signal. In this step, user need to put the device into a prepared calibration setting comprises of holder and Bluetooth mini speaker to make a balance sound to each sensors. After that user can start the calibration by clicking the calibration button on the display.
3. Recording: By clicking the record button on the display, user can start to capture voice while reading a particular stimulus.

4. Saving: User can save the recorded data in .txt format for further analysis purpose by professionals.

4.4. Validation Results

Two parts of validation were done for assessing the performance of proposed system: (1) validation of mean nasalance and (2) validation of nasalance pattern. Validation was done by comparing the nasalance data from Kay Pentax Nasometer and proposed system in order to see how much is the result similarity between those sytems. The validation experiment involved four healthy subjects (2 males, 2 females) with no history of resonance disorder.

Mean nasalance obtained using the proposed system with nasal syllable stimulus (/ma/) showed a similarity with the Kay Pentax nasometer and its normative data (Figure IV.9). The proposed system resulted in nasalance mean = 51.31 (SD: 8.51) while the normative data of Kay Pentax has nasalance mean of 53 (SD: 13). The pattern of both systems were similar, with high nasalance on /m/ character, and lower nasalance on /a/ character resulted in an up and down curve.

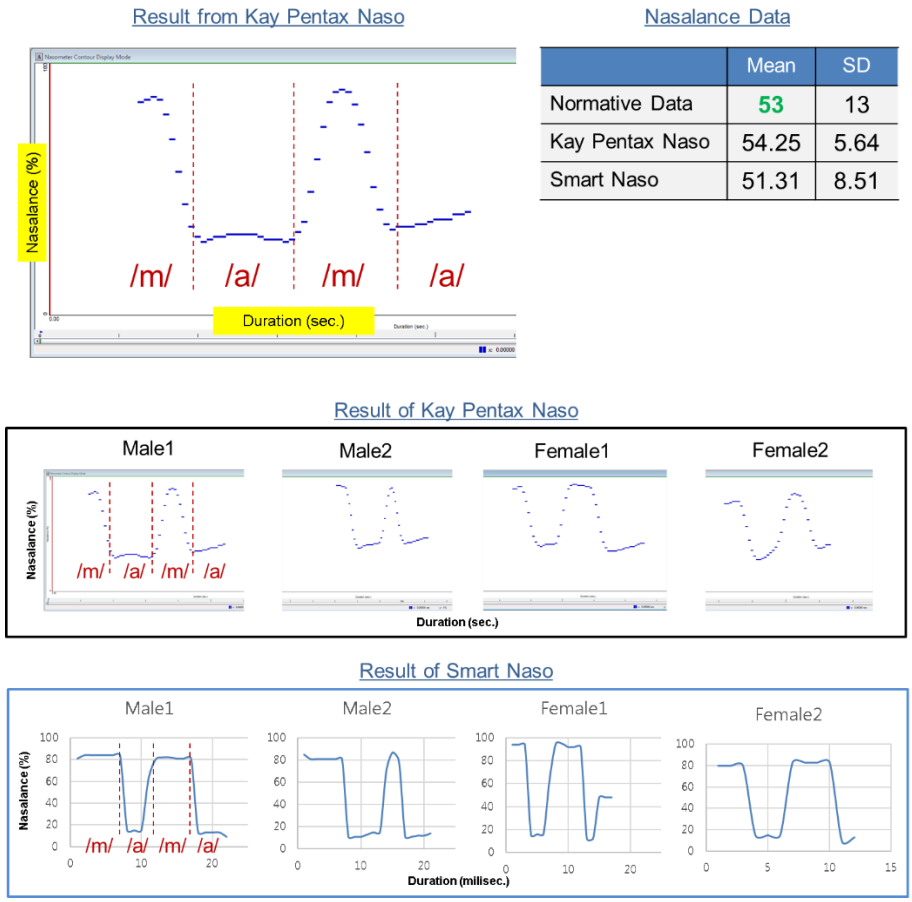
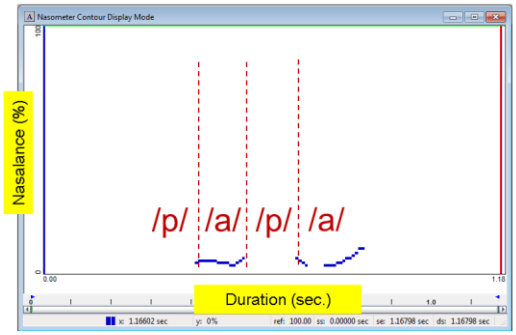


Figure IV.9. Nasalance measurement comparison on nasal syllable (/ma/)

Nasalance measurement using the proposed system with oral syllable stimulus (/pa/) showed a similar mean of nasalance result with the Kay Pentax nasometer and its normative data (Figure IV.10). The proposed system (Smart Naso) resulted in nasalance mean = 7.25 (SD: 1.77) while the normative data of Kay Pentax has nasalance mean of 6 (SD: 3). The pattern of both systems were also similar, which showed low nasalance on the whole pronunciation.

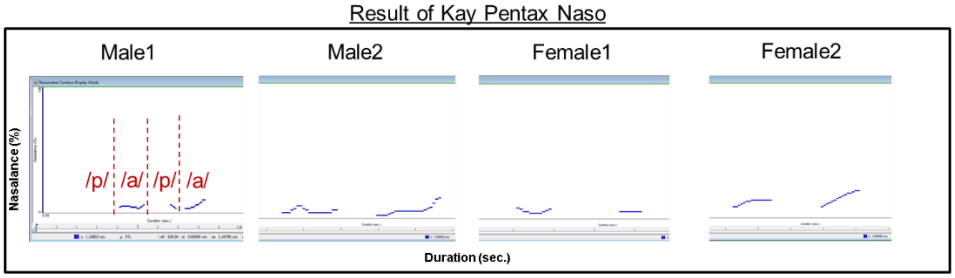
Result from Kay Pentax Naso



Nasalance Data

	Mean	SD
Normative Data	6	3
Kay Pentax Naso	8	4
Smart Naso	7.25	1.77

Result of Kay Pentax Naso



Result of Smart Naso

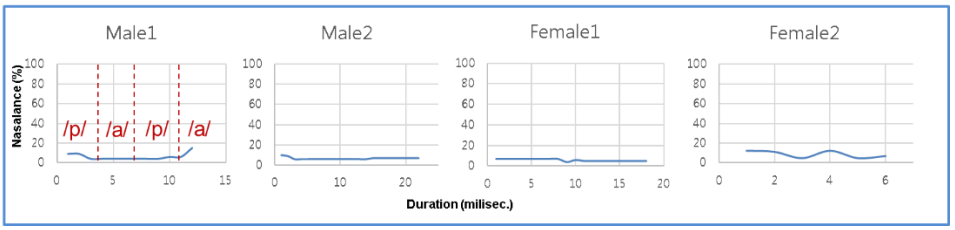


Figure IV.10. Nasalance measurement comparison on oral syllable (/pa/)

V. Discussion

This study proposed an ergonomic system to reduce the disturbance of separator on nasalance by introducing a touchless separator design. Utilizing the touchless separator allows user's mouth and lip to move naturally and comfortably. However, touchless separator system implicates to different nasalance value due to sound energy leakage. Therefore, a new algorithm of nasalance measurement was proposed by examining the effect of separator-lip distance on nasalance measurement. In this study, we conducted experiment to identify the nasalance trend in 5/10/15mm separator gap.

The nasalance measurement experiment on both passage and syllable level shows that the mean nasalance values on 0 mm separator gap (touched condition) and 5/10/15 mm separator gap (untouched condition) are different in a certain manner. More particularly, on the nasal stimulus (nasal sentence & /Ma/ syllable), increased separator gap associates with a saturated decrease mean nasalance. The result shows that the nasalance decreases significantly from 0mm to 5mm separator gap due to nasal voice leakage, and becomes steady on 10mm and 15 mm gap. An excessive leakage effect of nasal voice can be seen between 0mm to 5mm where the sound energy which come from nose is not reflected by the separator to the nasal microphone (Fig. 5.1). Using oral stimulus (zoo passage & /Pa/ syllable), increased separator gap implicates a linear increase to the mean nasalance as the leakage rate also linearly increase. Nasalance of zoo passage shows larger variability comparing to nasalance on /pa/ syllable. This result might occur since zoo passage uses a range of vowel variation (high vowel: e.g. /i/ and low vowel: e.g. /o/) where high vowel

results in higher nasalance than the low vowel.

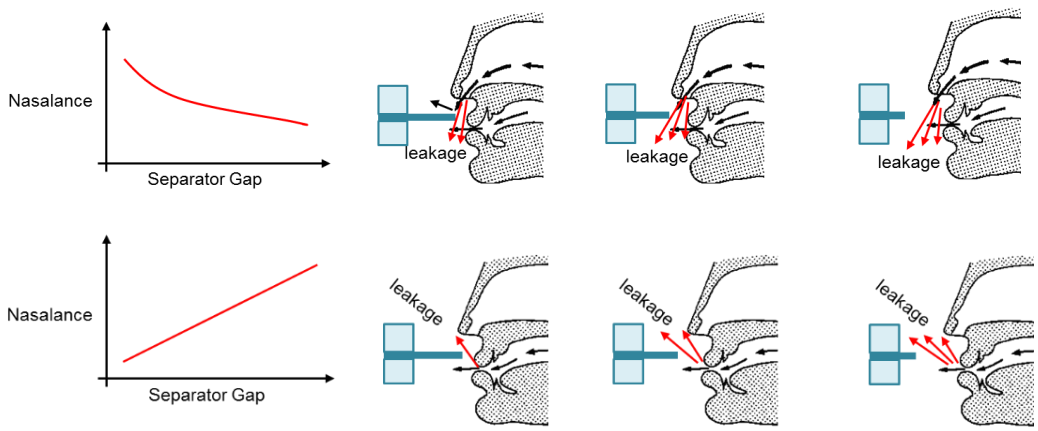


Figure V.1. Nasalance value trend on different separator gap distance

During nasalance measurement study, careful control of user pronunciation related to particular syllable or word is substantial. Present study is dealing with subjects from various nations whose native language is not English. In this research, we conducted experiment on Korean and Indonesian subjects who used to talk in English. However, the effect of pronunciation, dialect, and speech tone may influence the nasalance result. As can be seen from experiment result, nasalance value on nasal sentence of several subjects (male subject: 5, 7, and 8) are lower than normative data collected from United States subjects. Different character used in different language affects nasalance, since some languages do not utilize alphabet system. Several subjects in this study are Korean who use Hangul character system in their language. Since this study was based on standard English passage and syllable

stimulus, a mispronunciation might occur during experiment. For example on /pa/ syllable, some Koreans tended to pronounce using '프' instead of 'ㅃ', which sounds '*pha*' instead of '*pa*'. This character pronunciation difference may have a potential implication on the nasalance measurement value and pattern.

Individual adjustment of nasalance was proposed in the previous chapter by considering the individual variability which may occur on subjects. In order to adjust the data individually, we need to address a customized multiplier for each subject. Therefore, a strategy to conduct a calibration for our new system on each subject should be proposed. The calibration procedure should manage to extract a particular multiplier value to adjust the subject's nasalance. In order to have a customized multiplier to accommodate subject's speech, utilizing a learning algorithm to the proposed nasometer will be a potential option. In that case, the system can predict a proper multiplier by identifying one's short speech in the calibration process.

Adjustment algorithm for people with resonance disorders may be different due to different characteristics of their speech production. Subjects involved in the nasalance measurement experiment of this study were people without any or history of resonance disorder. Therefore, even though the touchless separator nasometer with adjustment multiplier can result in an equivalent nasalance value with touched separator nasometer, a study about separator gap effect on nasalance of people with resonance disorder may be necessary. Additionally, a new normative data collected using the new nasometer system may be necessary. According to Bressmann (2005) and Awan & Virani (2013), different systems of nasalance measurement have different standard values and some of their values

cannot be predicted using the other.

Lastly, this study still used a small sample size for the validation experiment (4 persons). Furthermore, the system used in the validation experiment was still a prototype device. Therefore, validation experiment with the complete version of device involving bigger sample size is necessary for further study. It is also potential to identify the effect of individual factors such as intonation, speech tempo, nasal vowel voice, etc. on nasalance.

Additionally, in order to reduce the interference during assessment, a chamber-type design of the device which surrounds the user's head could also be a potential idea. In such wise, the user will not make any physical contact with the hardware during assessment. However, horizontal and vertical positions of nose and mouth relative to the audio sensors are important in nasalance measurement. Therefore, in respect of the chamber-type design, a strategy to control the movement of user's head will become a critical issue.

VI. Conclusion

The main objective of present work is to develop a novel nasometer, which uses a touchless voice separator to avoid interference during speech assessment or therapy. The first objective consists of several sub objectives including measurement and analysis of nasalance on different separator gap distance and development of a nasalance adjustment algorithm so that the nasalance result from touchless separator nasometer is equivalent with the result of touched separator nasometer. The second objective of present study is to conduct a validation test for the newly developed nasometer

First, the present study developed a new system of nasometer for speech assessment or therapy. The proposed system includes two audio sensors to capture nasal and oral voice energy signal separated by a touchless separator. The improvement from Kay Pentax nasometer came from touchless and light-material separator which was utilized to reduce the interference to user's mouth/lip during assessment. Along with the hardware components, the proposed system also comes with a measurement application which is useful for recording and analyzing user's voice behavior.

Second highlight of this study is the development of a nasalance adjustment algorithm for equivalent quantification with standard measurement of patient's resonance. An adjustment algorithm for nasalance value is developed to achieve an equivalent assessment result with existing nasometer which has been the standard measurement system. This study conducted nasalance measurement experiment using different gap of separator (5/10/15 mm) to identify the pattern of nasalance on different separator condition. The experiment showed

a decrease of nasalance on increased separator gap (using nasal stimulus) and an increase of nasalance on increased separator gap (using oral stimulus). The experiment results became the basis of adjustment multiplier determination where the nasalance value is adjusted according to the level of nasalance (high or low).

Lastly, the present study conducted a validation test for the new nasalance measurement system. The validation was done by comparing the nasalance value and pattern result from assessment using existing nasometer and the newly developed system where nasal syllable /ma/ and oral syllable /pa/ were used as stimulus. Results of validation test showed the new system was able to produce an equivalent nasalance value with the Kay Pentax nasometer as well as the normative data. Furthermore, the pattern of nasalance on both stimulus (/ma/ and /pa/) using new system also showed a similarity with the Kay Pentax nasometer.

The smart naso system employing the quantitative assessment methodology of voice resonance developed in the present study would contribute to monitoring, quantitative assessment, therapy, and biofeedback of voice behavior based on real-time measurement. Smart naso device would be the first of its kind, which provides a measurement system using non-intrusive separator for better comfort and accuracy of assessment. The compact design of hardware is aiming for easy use at hospital, healthcare centers, and homes to provide better and frequent clinical services particularly for people with resonance disorder. Compared with the existing resonance assessment methods, such as nasendoscopy (invasive) or nasometer (non-invasive), the smart naso has distinguished features such as better comfort, portability, and competitive price.

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Appendices

Appendix A: Nasalance data (Passage Stimulus; Male:10; Female: 10)

Gender	Day	Trial	Nasalance (%)							
			Without Multiplier							
			Nasal Sentence				Zoo Passage			
			0	5	10	15	0	5	10	15
Male 1	1	1	56.49	50.12	45.55	43.19	7.21	11.71	14.11	18.56
		2	55.47	47.35	45.76	43.90	7.22	9.80	14.45	18.63
		3	55.00	46.87	44.72	43.55	6.02	9.90	13.82	18.71
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	55.65	48.11	45.35	43.55	6.82	10.47	14.12	18.63
		SD	0.76	1.76	0.55	0.36	0.69	1.08	0.32	0.08
		Min	55.00	46.87	44.72	43.19	6.02	9.80	13.82	18.56
		Max	56.49	50.12	45.76	43.90	7.22	11.71	14.45	18.71
		R	1.50	3.26	1.04	0.71	1.20	1.92	0.63	0.15
	2	1	54.74	50.07	46.06	43.97	6.88	9.70	14.54	17.66
		2	56.73	48.53	46.56	43.23	7.66	9.76	13.88	17.69
		3	54.80	48.03	45.22	43.77	6.67	10.15	13.53	17.57
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	55.42	48.88	45.95	43.65	7.07	9.87	13.98	17.64
		SD	1.14	1.06	0.68	0.39	0.52	0.24	0.51	0.07
		Min	54.74	48.03	45.22	43.23	6.67	9.70	13.53	17.57
		Max	56.73	50.07	46.56	43.97	7.66	10.15	14.54	17.69
		R	2.00	2.04	1.34	0.74	0.99	0.45	1.01	0.13
	1&2	N	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
		Average	55.54	48.49	45.65	43.60	6.94	10.17	14.05	18.14
		SD	0.88	1.36	0.64	0.34	0.56	0.77	0.39	0.55
		Min	54.74	46.87	44.72	43.19	6.02	9.70	13.53	17.57
		Max	56.73	50.12	46.56	43.97	7.66	11.71	14.54	18.71
		R	2.00	3.26	1.84	0.78	1.64	2.02	1.01	1.14
	Var. between days		0.16	0.54	0.43	0.08	0.18	0.43	0.10	0.70
Male 2	1	1	56.84	50.71	46.39	43.11	11.78	14.13	17.67	20.65
		2	58.36	49.76	46.25	43.54	10.05	14.00	15.31	19.77
		3	56.50	51.57	46.28	42.70	12.65	13.88	15.61	19.63
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	57.23	50.68	46.31	43.12	11.49	14.00	16.20	20.02
		SD	0.99	0.91	0.07	0.42	1.32	0.13	1.28	0.55
		Min	56.50	49.76	46.25	42.70	10.05	13.88	15.31	19.63
		Max	58.36	51.57	46.39	43.54	12.65	14.13	17.67	20.65
		R	1.86	1.82	0.14	0.84	2.60	0.25	2.35	1.01

Male 3	1	1	58.72	48.87	43.33	41.03	13.66	16.71	20.82	23.28
		2	59.58	48.14	42.64	40.77	13.34	17.20	20.28	22.92
		3	59.45	46.78	43.09	41.30	13.36	17.37	21.06	22.77
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	59.25	47.93	43.02	41.03	13.46	17.09	20.72	22.99
		SD	0.47	1.06	0.35	0.27	0.18	0.34	0.40	0.26
		Min	58.72	46.78	42.64	40.77	13.34	16.71	20.28	22.77
		Max	59.58	48.87	43.33	41.30	13.66	17.37	21.06	23.28
		R	0.86	2.09	0.68	0.53	0.32	0.66	0.78	0.51
Male 4	1	1	50.21	44.01	40.44	38.52	8.20	10.51	16.24	22.13
		2	49.61	44.28	41.26	38.57	8.36	11.07	15.55	22.29
		3	49.65	44.24	41.92	38.97	7.86	11.68	14.76	22.47
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	49.82	44.18	41.21	38.68	8.14	11.09	15.52	22.30
		SD	0.34	0.15	0.74	0.25	0.26	0.58	0.74	0.17
		Min	49.61	44.01	40.44	38.52	7.86	10.51	14.76	22.13
		Max	50.21	44.28	41.92	38.97	8.36	11.68	16.24	22.47
		R	0.60	0.27	1.48	0.45	0.50	1.17	1.48	0.34
Male 5	1	1	43.86	37.24	33.93	32.77	6.39	13.21	16.53	25.40
		2	42.69	38.99	35.52	31.38	5.71	11.64	17.01	25.60
		3	41.74	37.76	35.37	34.19	5.18	11.03	18.43	25.42
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	42.76	38.00	34.94	32.78	5.76	11.96	17.32	25.47
		SD	1.06	0.90	0.88	1.41	0.60	1.12	0.99	0.11
		Min	41.74	37.24	33.93	31.38	5.18	11.03	16.53	25.40
		Max	43.86	38.99	35.52	34.19	6.39	13.21	18.43	25.60
		R	2.12	1.75	1.59	2.81	1.20	2.17	1.90	0.20
Male 6	1	1	51.79	41.68	39.85	36.42	7.54	15.15	17.50	23.39
		2	47.97	43.44	40.92	38.59	8.37	15.60	17.99	23.38
		3	48.21	44.36	41.54	39.31	8.19	14.54	18.25	24.05
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	49.32	43.16	40.77	38.10	8.03	15.10	17.91	23.61
		SD	2.14	1.36	0.85	1.50	0.44	0.53	0.38	0.39
		Min	47.97	41.68	39.85	36.42	7.54	14.54	17.50	23.38
		Max	51.79	44.36	41.54	39.31	8.37	15.60	18.25	24.05
		R	3.82	2.68	1.69	2.89	0.83	1.06	0.75	0.67
Male 7	1	1	43.89	36.52	34.89	34.96	5.01	9.36	14.88	18.04
		2	45.25	38.21	34.91	35.20	4.86	8.52	14.74	18.35
		3	43.52	37.34	35.29	35.46	4.98	8.50	14.89	18.17
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	44.22	37.36	35.03	35.21	4.95	8.79	14.84	18.19
		SD	0.91	0.84	0.22	0.25	0.08	0.49	0.09	0.16
		Min	43.52	36.52	34.89	34.96	4.86	8.50	14.74	18.04
		Max	45.25	38.21	35.29	35.46	5.01	9.36	14.89	18.35
		R	1.73	1.68	0.40	0.49	0.15	0.87	0.15	0.31

Male 8	1	1	44.07	40.17	40.94	38.76	5.59	12.85	18.63	21.58
		2	44.66	40.49	39.02	40.39	6.84	14.06	19.68	22.27
		3	45.96	40.62	39.72	40.34	6.88	13.89	19.06	21.48
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	44.89	40.43	39.89	39.83	6.44	13.60	19.12	21.78
		SD	0.97	0.23	0.97	0.93	0.73	0.65	0.53	0.43
		Min	44.07	40.17	39.02	38.76	5.59	12.85	18.63	21.48
		Max	45.96	40.62	40.94	40.39	6.88	14.06	19.68	22.27
		R	1.89	0.45	1.92	1.63	1.29	1.20	1.05	0.79
Male 9	1	1	60.20	52.24	47.04	43.47	20.98	24.62	27.50	30.12
		2	60.25	51.93	46.54	43.19	20.65	24.71	27.48	29.14
		3	61.26	52.60	46.81	44.19	22.35	25.67	27.45	29.85
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	60.57	52.25	46.80	43.62	21.33	25.00	27.47	29.70
		SD	0.60	0.34	0.25	0.52	0.90	0.58	0.02	0.51
		Min	60.20	51.93	46.54	43.19	20.65	24.62	27.45	29.14
		Max	61.26	52.60	47.04	44.19	22.35	25.67	27.50	30.12
		R	1.06	0.68	0.50	1.00	1.70	1.04	0.05	0.98
Male 10	1	1	55.45	46.99	42.60	38.42	12.29	17.08	23.19	26.66
		2	54.26	45.96	42.10	39.68	12.88	16.31	22.16	26.31
		3	55.30	45.43	43.37	39.13	11.81	16.98	21.78	26.78
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	55.01	46.13	42.69	39.08	12.33	16.79	22.38	26.59
		SD	0.65	0.79	0.64	0.63	0.54	0.42	0.73	0.24
		Min	54.26	45.43	42.10	38.42	11.81	16.31	21.78	26.31
		Max	55.45	46.99	43.37	39.68	12.88	17.08	23.19	26.78
		R	1.19	1.56	1.26	1.26	1.07	0.77	1.40	0.47
	Between Subjects Male									
	Average		51.862	44.860	41.631	39.505	9.886	14.359	18.553	22.878
	Variability		6.52	5.15	4.22	3.59	4.95	4.63	4.08	3.68
	Min		41.74	36.52	33.93	31.38	4.86	8.50	13.53	17.57
	Max		61.26	52.60	47.04	44.19	22.35	25.67	27.50	30.12

Gender	Day	Trial	Nasalance (%)							
			Without Multiplier							
			Nasal Sentence				Zoo Passage			
			0	5	10	15	0	5	10	15
Female 1	1	1	57.19	50.01	47.15	42.91	6.93	12.80	14.77	19.61
		2	57.56	51.09	47.05	44.17	7.15	12.95	14.90	20.02
		3	56.73	49.37	47.05	44.54	6.92	12.49	14.25	19.97
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	57.16	50.16	47.08	43.87	7.00	12.74	14.64	19.87
		SD	0.41	0.87	0.06	0.85	0.13	0.23	0.34	0.23
		Min	56.73	49.37	47.05	42.91	6.92	12.49	14.25	19.61
		Max	57.56	51.09	47.15	44.54	7.15	12.95	14.90	20.02
		R	0.82	1.72	0.10	1.63	0.23	0.46	0.65	0.42
	2	1	57.19	52.79	48.03	43.49	6.49	11.01	16.00	18.39
		2	57.69	51.81	45.30	43.97	8.04	10.09	15.59	18.63
		3	56.61	50.21	46.33	43.05	7.08	10.65	15.79	17.67
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	57.16	51.61	46.55	43.50	7.20	10.58	15.79	18.23
		SD	0.54	1.30	1.38	0.46	0.78	0.46	0.20	0.50
		Min	56.61	50.21	45.30	43.05	6.49	10.09	15.59	17.67
		Max	57.69	52.79	48.03	43.97	8.04	11.01	16.00	18.63
		R	1.08	2.58	2.73	0.92	1.55	0.92	0.41	0.95
	1&2	N	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
		Average	57.16	50.88	46.82	43.69	7.10	11.66	15.22	19.05
		SD	0.43	1.27	0.92	0.65	0.51	1.23	0.68	0.96
		Min	56.61	49.37	45.30	42.91	6.49	10.09	14.25	17.67
		Max	57.69	52.79	48.03	44.54	8.04	12.95	16.00	20.02
		R	1.08	3.43	2.73	1.63	1.55	2.86	1.74	2.35
	Var. between days		0.002	1.03	0.38	0.26	0.14	1.53	0.81	1.16
Female 2	1	1	62.19	50.74	48.44	46.10	9.77	13.32	16.92	21.69
		2	62.34	49.42	48.24	45.49	9.92	12.47	15.69	21.14
		3	62.47	49.22	48.03	45.44	9.68	13.33	15.69	22.27
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	62.33	49.79	48.24	45.68	9.79	13.04	16.10	21.70
		SD	0.14	0.82	0.21	0.37	0.12	0.49	0.71	0.57
		Min	62.19	49.22	48.03	45.44	9.68	12.47	15.69	21.14
		Max	62.47	50.74	48.44	46.10	9.92	13.33	16.92	22.27
		R	0.29	1.52	0.41	0.67	0.24	0.86	1.24	1.13

Female 3	1	1	54.52	47.84	43.17	41.08	8.51	12.95	16.25	20.53
		2	56.11	47.81	42.19	41.53	7.81	12.69	16.28	20.91
		3	54.05	48.43	42.23	40.86	9.08	11.84	16.55	20.70
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	54.89	48.03	42.53	41.16	8.46	12.49	16.36	20.71
		SD	1.08	0.35	0.56	0.34	0.64	0.58	0.17	0.19
		Min	54.05	47.81	42.19	40.86	7.81	11.84	16.25	20.53
		Max	56.11	48.43	43.17	41.53	9.08	12.95	16.55	20.91
		R	2.06	0.62	0.98	0.67	1.27	1.11	0.30	0.38
Female 4	1	1	70.29	53.93	49.95	48.52	25.23	20.80	22.59	25.67
		2	69.15	53.05	50.19	47.27	24.61	21.77	22.85	28.11
		3	69.00	53.95	49.81	46.99	23.87	22.05	23.99	27.49
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	69.48	53.64	49.98	47.59	24.57	21.54	23.14	27.09
		SD	0.71	0.51	0.19	0.81	0.68	0.66	0.74	1.27
		Min	69.00	53.05	49.81	46.99	23.87	20.80	22.59	25.67
		Max	70.29	53.95	50.19	48.52	25.23	22.05	23.99	28.11
		R	1.30	0.90	0.38	1.53	1.36	1.26	1.40	2.44
Female 5	1	1	55.70	48.01	41.69	39.15	7.88	12.21	16.23	20.86
		2	56.06	48.11	42.61	39.76	8.15	12.31	15.86	20.91
		3	55.87	47.06	41.49	39.30	8.44	11.74	15.98	20.74
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	55.88	47.73	41.93	39.40	8.16	12.09	16.02	20.84
		SD	0.18	0.58	0.60	0.32	0.28	0.30	0.19	0.09
		Min	55.70	47.06	41.49	39.15	7.88	11.74	15.86	20.74
		Max	56.06	48.11	42.61	39.76	8.44	12.31	16.23	20.91
		R	0.36	1.05	1.13	0.61	0.56	0.57	0.38	0.17
Female 6	1	1	54.13	43.61	39.82	38.70	12.33	18.52	22.89	27.07
		2	54.09	43.70	41.58	39.22	12.32	17.74	22.04	27.28
		3	53.67	43.37	38.84	36.68	12.15	17.81	22.01	26.85
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	53.96	43.56	40.08	38.20	12.27	18.02	22.31	27.06
		SD	0.25	0.17	1.39	1.34	0.10	0.43	0.50	0.22
		Min	53.67	43.37	38.84	36.68	12.15	17.74	22.01	26.85
		Max	54.13	43.70	41.58	39.22	12.33	18.52	22.89	27.28
		R	0.46	0.33	2.74	2.54	0.18	0.79	0.88	0.44
Female 7	1	1	60.41	49.57	43.30	40.93	19.06	22.85	25.42	28.16
		2	61.60	48.65	44.14	40.50	19.42	23.43	25.61	28.40
		3	60.91	49.49	43.57	40.10	21.21	24.02	25.30	29.28
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	60.97	49.24	43.67	40.51	19.90	23.44	25.44	28.61
		SD	0.60	0.51	0.43	0.42	1.15	0.58	0.16	0.59
		Min	60.41	48.65	43.30	40.10	19.06	22.85	25.30	28.16
		Max	61.60	49.57	44.14	40.93	21.21	24.02	25.61	29.28
		R	1.19	0.92	0.84	0.83	2.15	1.17	0.31	1.12

Female 8	1	1	59.86	52.94	50.04	47.23	14.32	20.67	24.80	28.46
		2	60.18	53.68	48.25	44.33	14.19	18.86	26.06	29.88
		3	60.47	54.35	49.72	45.95	15.59	19.42	26.03	29.40
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	60.17	53.66	49.34	45.84	14.70	19.65	25.63	29.25
		SD	0.31	0.71	0.96	1.45	0.77	0.93	0.72	0.72
		Min	59.86	52.94	48.25	44.33	14.19	18.86	24.80	28.46
		Max	60.47	54.35	50.04	47.23	15.59	20.67	26.06	29.88
		R	0.61	1.42	1.79	2.89	1.40	1.81	1.26	1.42
Female 9	1	1	57.63	50.19	47.12	43.20	12.64	18.02	22.60	28.65
		2	58.02	50.12	48.36	43.86	11.76	16.53	21.64	27.40
		3	57.20	51.93	46.79	43.11	12.71	17.58	22.65	29.96
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	57.62	50.75	47.42	43.39	12.37	17.38	22.30	28.67
		SD	0.41	1.02	0.83	0.41	0.53	0.76	0.57	1.28
		Min	57.20	50.12	46.79	43.11	11.76	16.53	21.64	27.40
		Max	58.02	51.93	48.36	43.86	12.71	18.02	22.65	29.96
		R	0.82	1.80	1.58	0.75	0.95	1.49	1.01	2.55
Female 10	1	1	57.42	49.16	44.88	41.63	13.91	21.43	26.97	29.95
		2	57.75	48.85	44.98	41.98	12.55	18.96	25.66	30.84
		3	58.43	48.95	45.95	42.93	12.87	20.99	26.48	30.46
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	57.87	48.99	45.27	42.18	13.11	20.46	26.37	30.42
		SD	0.52	0.16	0.59	0.67	0.71	1.32	0.66	0.45
		Min	57.42	48.85	44.88	41.63	12.55	18.96	25.66	29.95
		Max	58.43	49.16	45.95	42.93	13.91	21.43	26.97	30.84
		R	1.01	0.31	1.06	1.30	1.36	2.47	1.31	0.89
	Between Subjects Female									
	Average		59.03	49.63	45.53	42.76	13.04	16.98	20.89	25.34
	Variability		4.53	2.96	3.37	3.03	5.52	4.36	4.49	4.26
	Min		53.67	43.37	38.84	36.68	6.49	10.09	14.25	17.67
	Max		70.29	54.35	50.19	48.52	25.23	24.02	26.97	30.84

Appendix B: Nasalance data (Syllable Stimulus; Male: 10; Female: 10)

Gender	Day	Trial	Nasalance (%)							
			Without Multiplier							
			/Ma Ma Ma/				/Pa Pa Pa/			
			0	5	10	15	0	5	10	15
Male 1	1	1	53.99	42.55	40.58	37.86	5.88	12.24	18.11	22.41
		2	53.25	44.33	40.56	38.42	5.05	12.42	18.04	22.27
		3	54.19	43.64	40.89	38.51	5.83	11.33	17.82	22.29
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	53.81	43.51	40.68	38.27	5.59	12.00	17.99	22.32
		SD	0.50	0.90	0.18	0.35	0.47	0.58	0.15	0.08
		Min	53.25	42.55	40.56	37.86	5.05	11.33	17.82	22.27
		Max	54.19	44.33	40.89	38.51	5.88	12.42	18.11	22.41
		R	0.94	1.79	0.33	0.65	0.84	1.09	0.29	0.15
Male 2	1	1	45.78	40.01	37.97	36.16	12.81	22.08	25.89	29.35
		2	45.64	38.77	37.85	35.82	12.18	21.47	26.24	30.57
		3	46.54	40.06	36.07	34.75	14.28	21.53	25.37	30.53
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	45.99	39.61	37.30	35.58	13.09	21.69	25.84	30.15
		SD	0.49	0.73	1.06	0.74	1.08	0.34	0.44	0.69
		Min	45.64	38.77	36.07	34.75	12.18	21.47	25.37	29.35
		Max	46.54	40.06	37.97	36.16	14.28	22.08	26.24	30.57
		R	0.90	1.29	1.90	1.42	2.10	0.61	0.87	1.21
Male 3	1	1	39.59	33.82	33.11	30.83	9.50	17.67	22.66	28.51
		2	41.10	35.64	32.14	31.43	8.98	17.54	23.20	27.61
		3	41.24	34.51	32.24	30.85	9.62	18.50	21.93	28.69
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	40.64	34.66	32.49	31.04	9.36	17.90	22.60	28.27
		SD	0.91	0.92	0.53	0.34	0.34	0.52	0.63	0.58
		Min	39.59	33.82	32.14	30.83	8.98	17.54	21.93	27.61
		Max	41.24	35.64	33.11	31.43	9.62	18.50	23.20	28.69
		R	1.65	1.83	0.97	0.60	0.64	0.96	1.26	1.08
Male 4	1	1	44.89	36.79	36.58	33.27	4.53	15.03	19.91	25.02
		2	43.17	38.16	34.54	31.79	4.34	15.32	22.49	24.94
		3	42.14	37.99	34.94	32.26	4.17	15.32	21.98	24.95
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	43.40	37.65	35.35	32.44	4.35	15.23	21.46	24.97
		SD	1.39	0.75	1.08	0.75	0.18	0.17	1.37	0.04
		Min	42.14	36.79	34.54	31.79	4.17	15.03	19.91	24.94
		Max	44.89	38.16	36.58	33.27	4.53	15.32	22.49	25.02
		R	2.75	1.37	2.04	1.48	0.36	0.29	2.58	0.08
Male 5	1	1	49.96	45.38	41.44	36.76	3.61	14.33	19.83	23.95
		2	50.74	45.41	40.41	36.25	3.34	15.43	20.43	24.18
		3	51.51	45.60	40.30	35.97	3.45	15.43	20.65	24.64
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	50.74	45.46	40.72	36.33	3.47	15.06	20.30	24.26
		SD	0.78	0.12	0.63	0.40	0.14	0.64	0.43	0.35
		Min	49.96	45.38	40.30	35.97	3.34	14.33	19.83	23.95
		Max	51.51	45.60	41.44	36.76	3.61	15.43	20.65	24.64
		R	1.55	0.22	1.14	0.79	0.27	1.10	0.83	0.69

Male 6	1	1	42.38	37.11	33.96	30.95	7.15	12.17	20.73	23.89
		2	39.53	36.36	32.62	31.62	4.25	13.15	19.98	23.06
		3	39.38	36.42	33.05	31.35	3.73	12.10	20.28	24.01
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	40.43	36.63	33.21	31.31	5.04	12.47	20.33	23.66
		SD	1.69	0.42	0.68	0.34	1.84	0.59	0.38	0.52
		Min	39.38	36.36	32.62	30.95	3.73	12.10	19.98	23.06
		Max	42.38	37.11	33.96	31.62	7.15	13.15	20.73	24.01
		R	3.01	0.75	1.34	0.67	3.42	1.05	0.76	0.96
Male 7	1	1	51.46	49.11	43.56	39.48	4.25	15.77	25.94	32.35
		2	52.31	47.27	43.17	39.72	4.07	16.16	25.77	32.37
		3	50.83	45.79	43.38	40.59	3.75	16.76	25.91	32.52
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	51.53	47.39	43.37	39.93	4.02	16.23	25.87	32.41
		SD	0.74	1.67	0.20	0.58	0.25	0.50	0.09	0.09
		Min	50.83	45.79	43.17	39.48	3.75	15.77	25.77	32.35
		Max	52.31	49.11	43.56	40.59	4.25	16.76	25.94	32.52
		R	1.48	3.32	0.39	1.10	0.50	0.99	0.17	0.16
Male 8	1	1	55.50	42.71	37.32	36.20	7.53	16.79	25.15	30.48
		2	53.23	42.90	38.64	35.98	7.58	16.86	25.36	30.95
		3	54.11	42.73	38.46	36.88	7.67	17.22	25.99	30.87
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	54.28	42.78	38.14	36.35	7.59	16.95	25.50	30.77
		SD	1.14	0.11	0.72	0.47	0.07	0.23	0.44	0.25
		Min	53.23	42.71	37.32	35.98	7.53	16.79	25.15	30.48
		Max	55.50	42.90	38.64	36.88	7.67	17.22	25.99	30.95
		R	2.26	0.19	1.32	0.90	0.15	0.43	0.84	0.47
Male 9	1	1	55.23	42.70	37.34	33.90	5.81	13.14	18.37	25.47
		2	52.73	45.27	38.26	33.67	5.51	13.22	18.65	23.29
		3	53.28	43.19	35.51	33.44	4.31	12.42	19.99	24.87
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	53.75	43.72	37.03	33.67	5.21	12.93	19.00	24.54
		SD	1.31	1.36	1.40	0.23	0.79	0.44	0.86	1.13
		Min	52.73	42.70	35.51	33.44	4.31	12.42	18.37	23.29
		Max	55.23	45.27	38.26	33.90	5.81	13.22	19.99	25.47
		R	2.50	2.57	2.75	0.47	1.50	0.80	1.62	2.18
Male 10	1	1	56.21	46.45	43.70	39.56	5.01	20.29	24.13	29.56
		2	59.23	47.56	41.41	39.70	5.18	20.27	23.84	30.64
		3	58.10	49.62	41.74	40.43	4.87	20.05	26.23	31.46
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	57.85	47.87	42.28	39.90	5.02	20.20	24.73	30.55
		SD	1.53	1.61	1.24	0.47	0.15	0.13	1.30	0.95
		Min	56.21	46.45	41.41	39.56	4.87	20.05	23.84	29.56
		Max	59.23	49.62	43.70	40.43	5.18	20.29	26.23	31.46
		R	3.02	3.16	2.29	0.87	0.31	0.23	2.39	1.90
	Between Subjects Male (10 persons)									
	Average		49.241	41.929	38.057	35.481	6.274	16.067	22.362	27.190
	Variability		6.19	4.58	3.70	3.30	2.97	3.23	2.97	3.62
	Min		39.38	33.82	32.14	30.83	3.34	11.33	17.82	22.27
	Max		59.23	49.62	43.70	40.59	14.28	22.08	26.24	32.52

Gender	Day	Trial	Nasalance (%)							
			Without Multiplier							
			/Ma Ma Ma/				/Pa Pa Pa/			
			0	5	10	15	0	5	10	15
Female 1	1	1	53.00	44.56	40.42	38.87	3.23	13.17	16.81	23.85
		2	51.72	45.06	42.13	38.82	3.76	11.73	18.16	23.61
		3	51.69	45.79	38.85	39.00	3.72	12.35	18.17	23.47
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	52.13	45.14	40.47	38.90	3.57	12.42	17.71	23.64
		SD	0.75	0.62	1.64	0.09	0.30	0.72	0.78	0.19
		Min	51.69	44.56	38.85	38.82	3.23	11.73	16.81	23.47
		Max	53.00	45.79	42.13	39.00	3.76	13.17	18.17	23.85
		R	1.31	1.23	3.28	0.17	0.53	1.44	1.36	0.38
Female 2	1	1	52.53	45.55	42.53	37.86	3.50	13.77	20.18	25.25
		2	51.76	46.41	42.17	36.97	4.56	14.52	20.47	24.56
		3	52.02	45.82	40.05	37.17	4.12	14.82	20.86	25.07
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	52.10	45.93	41.58	37.33	4.06	14.37	20.51	24.96
		SD	0.39	0.44	1.34	0.47	0.53	0.54	0.34	0.36
		Min	51.76	45.55	40.05	36.97	3.50	13.77	20.18	24.56
		Max	52.53	46.41	42.53	37.86	4.56	14.82	20.86	25.25
		R	0.76	0.86	2.48	0.90	1.06	1.05	0.68	0.69
Female 3	1	1	61.40	52.03	46.99	44.88	5.04	16.99	21.43	24.15
		2	61.85	51.62	46.56	43.40	5.69	15.41	20.82	23.80
		3	61.23	49.90	45.87	45.42	5.20	15.57	20.42	23.61
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	61.49	51.19	46.47	44.57	5.31	15.99	20.89	23.85
		SD	0.32	1.13	0.56	1.05	0.33	0.87	0.51	0.27
		Min	61.23	49.90	45.87	43.40	5.04	15.41	20.42	23.61
		Max	61.85	52.03	46.99	45.42	5.69	16.99	21.43	24.15
		R	0.62	2.13	1.12	2.02	0.64	1.58	1.01	0.54
Female 4	1	1	58.36	47.87	43.45	41.54	9.42	16.36	22.68	25.97
		2	60.30	49.84	45.31	42.32	9.10	15.40	23.12	24.81
		3	60.15	50.56	43.98	41.91	9.86	17.26	21.39	25.79
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	59.61	49.42	44.25	41.93	9.46	16.34	22.40	25.53
		SD	1.08	1.39	0.96	0.39	0.38	0.93	0.90	0.63
		Min	58.36	47.87	43.45	41.54	9.10	15.40	21.39	24.81
		Max	60.30	50.56	45.31	42.32	9.86	17.26	23.12	25.97
		R	1.94	2.69	1.86	0.78	0.76	1.86	1.73	1.16
Female 5	1	1	63.73	52.84	45.25	43.45	7.75	16.65	23.22	26.41
		2	66.39	52.30	46.33	41.34	6.84	17.83	23.31	28.05
		3	64.20	53.38	44.75	40.52	7.03	17.25	22.36	27.67
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
		Average	64.77	52.84	45.44	41.77	7.20	17.24	22.96	27.37
		SD	1.42	0.54	0.81	1.51	0.48	0.59	0.52	0.86
		Min	63.73	52.30	44.75	40.52	6.84	16.65	22.36	26.41
		Max	66.39	53.38	46.33	43.45	7.75	17.83	23.31	28.05
		R	2.67	1.08	1.58	2.92	0.91	1.18	0.94	1.64

		1	53.61	44.97	41.57	37.25	8.19	16.68	21.44	27.59
		2	51.23	44.53	43.14	39.60	8.36	16.53	21.49	27.46
		3	50.06	44.48	41.06	39.29	8.83	16.68	20.51	26.83
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Female 6	1	Average	51.63	44.66	41.92	38.71	8.46	16.63	21.15	27.29
		SD	1.81	0.27	1.08	1.28	0.33	0.09	0.55	0.41
		Min	50.06	44.48	41.06	37.25	8.19	16.53	20.51	26.83
		Max	53.61	44.97	43.14	39.60	8.83	16.68	21.49	27.59
		R	3.56	0.49	2.08	2.35	0.64	0.15	0.98	0.76
		1	57.02	41.44	35.98	32.93	8.16	17.35	21.21	24.72
		2	57.58	41.09	36.36	34.39	6.80	16.51	20.65	25.13
		3	53.12	41.93	37.40	33.96	4.86	17.87	22.05	25.46
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Female 7	1	Average	55.91	41.49	36.58	33.76	6.61	17.25	21.30	25.11
		SD	2.43	0.42	0.73	0.75	1.65	0.69	0.71	0.37
		Min	53.12	41.09	35.98	32.93	4.86	16.51	20.65	24.72
		Max	57.58	41.93	37.40	34.39	8.16	17.87	22.05	25.46
		R	4.45	0.84	1.42	1.45	3.29	1.36	1.40	0.74
		1	59.02	53.30	46.59	45.35	5.20	11.28	16.09	24.11
		2	61.95	56.34	47.33	45.35	4.89	13.91	16.88	23.85
		3	60.24	49.77	46.85	43.63	5.46	13.84	16.08	23.23
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Female 8	1	Average	60.40	53.14	46.92	44.77	5.18	13.01	16.35	23.73
		SD	1.47	3.28	0.38	0.99	0.29	1.50	0.46	0.45
		Min	59.02	49.77	46.59	43.63	4.89	11.28	16.08	23.23
		Max	61.95	56.34	47.33	45.35	5.46	13.91	16.88	24.11
		R	2.92	6.56	0.75	1.72	0.57	2.63	0.80	0.88
		1	52.04	43.62	36.36	34.78	7.72	18.54	24.45	31.06
		2	51.28	42.83	37.73	35.46	7.80	18.93	26.05	29.94
		3	49.50	44.73	37.68	35.57	6.57	20.08	25.65	30.65
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Female 9	1	Average	50.94	43.73	37.26	35.27	7.36	19.18	25.38	30.55
		SD	1.31	0.95	0.78	0.43	0.69	0.80	0.83	0.57
		Min	49.50	42.83	36.36	34.78	6.57	18.54	24.45	29.94
		Max	52.04	44.73	37.73	35.57	7.80	20.08	26.05	31.06
		R	2.54	1.90	1.37	0.79	1.23	1.54	1.60	1.12
		1	42.71	37.23	34.99	34.10	9.29	16.30	20.58	26.89
		2	42.73	37.26	34.77	34.04	7.41	16.08	19.72	25.84
		3	41.66	37.06	36.41	33.82	6.15	16.00	19.89	25.66
		N	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Female 10	1	Average	42.37	37.18	35.39	33.99	7.62	16.13	20.06	26.13
		SD	0.61	0.11	0.89	0.14	1.58	0.15	0.45	0.67
		Min	41.66	37.06	34.77	33.82	6.15	16.00	19.72	25.66
		Max	42.73	37.26	36.41	34.10	9.29	16.30	20.58	26.89
		R	1.07	0.21	1.65	0.28	3.14	0.30	0.86	1.23
	Between Subjects Female (5 persons)									
	Average		55.136	46.471	41.628	39.100	6.482	15.856	20.871	25.816
	Variability		6.61	5.16	4.19	4.08	1.91	2.05	2.55	2.14
	Min		41.66	37.06	34.77	32.93	3.23	11.28	16.08	23.23
	Max		66.39	56.34	47.33	45.42	9.86	20.08	26.05	31.06

Appendix C: Institutional Review Board Certification and Documents

[POSTECH IRB format #14] Certification of Exemption from IRB Review

Certification of Exemption from IRB Review

Principal Investigator	Name	Affiliation	Position
	Heecheon You	Dept. of Industrial and Management Engineering	Professor
Exemption Number	PIRB-2016-E045		
Title of Research	Development of an Ergonomic Nasometer		
Research Information	■ Human subjects	□ Human biological materials	
Date of Exemption	December 20th, 2016		

The Board confirms that the above research project is Exemption from Review.

※ All researchers need to follow below.

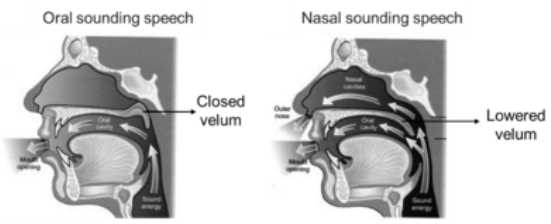
1) Researcher must lead the research as already stated on the research proposal. Please note that the research will be subject to additional review if any changes occur.
2) Researcher must submit reports on the progress of the research if the Board needs.
3) There can be site inspections for research ethics if needed.
4) Researcher must keep the documents and records related to the research for at least 3 years after the completion of research.

December 20th, 2016

Chairman of POSTECH Institutional Review Board

ver 1.0 (Dec 2015)

Research Proposal for Human subjects

Title of Research Project	Development of an Ergonomic Nasometer
Research Project Period	Date of approval: 15/12/2016 ~ 31/12/2017
Research background	**1. Definition and significance of resonance disorders** Resonance disorder often occurs among people with velopharyngeal dysfunction when the nasal cavity is not properly separated from the oral cavity. People with resonance disorders have difficulty in controlling the degree of nasality to produce a proper speech. Nasality or nasal resonance is a production of sound while the velum (soft palate) is lowered (Baken, 1987), whereas the air will resonate in the nasal cavity and escape through the nose during the production of the sound (Figure 1).  Figure 1. Velum movement to control degree of nasality Resonance disorder can occur in 20 to 30% of individuals who have undergone a cleft palate repair and in 5 to 10% of patients with a submucous cleft palate (Woo, 2012). Causes of resonance disorder are classified into three categories: insufficiency (anatomical problem), incompetence (physiological problem), and mislearning (articulation problem) which may occur in both children and adults.

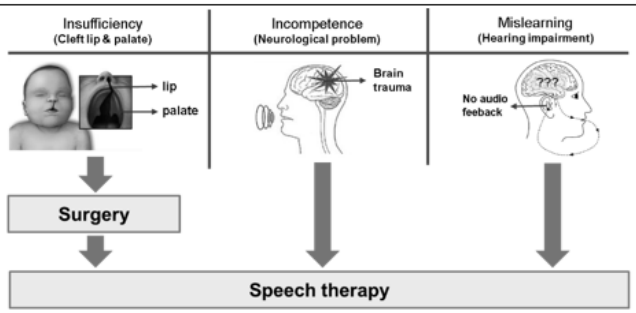


Figure 2. Nasality problem

2. Problem of the existing resonance disorder assessment device

Nasometric measurement has been known to be correlated with the characteristic of velopharyngeal function and has been proven to be a useful assessment for patients with velopharyngeal dysfunction or resonance disorder (Dalston, Warren, & Dalston, 1991). Through a nasometric measurement, the resonance disorder is interpreted by nasalance (%) = (Nasal sound energy) / (Nasal sound energy + Oral sound energy) (Fletcher et al., 1974). A computer based system called Nasometer (Kay Elemetronics Corp., Lincoln Park, NJ) was developed to measure nasalance in 1987. After several modifications, it serves as a golden standard tool to assess resonance disorder (Awan et al., 2010).

The existing nasalance measurement device needs improvements in terms of non-interference of separator, wearability, portability, and affordability.

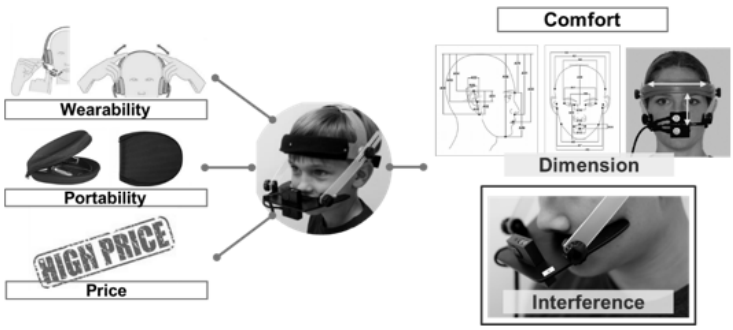
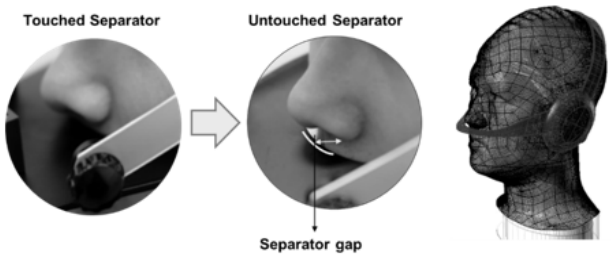
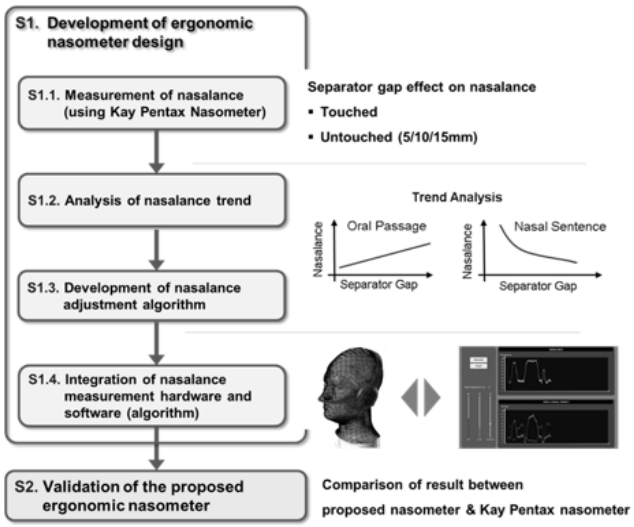
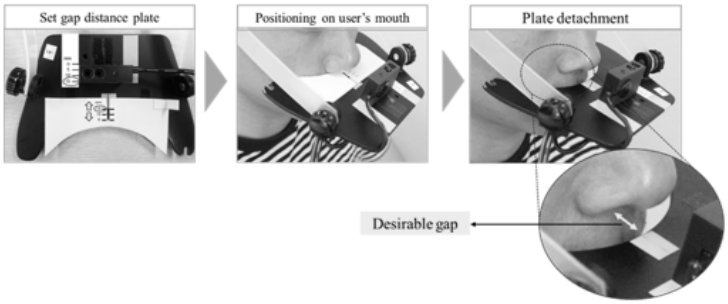
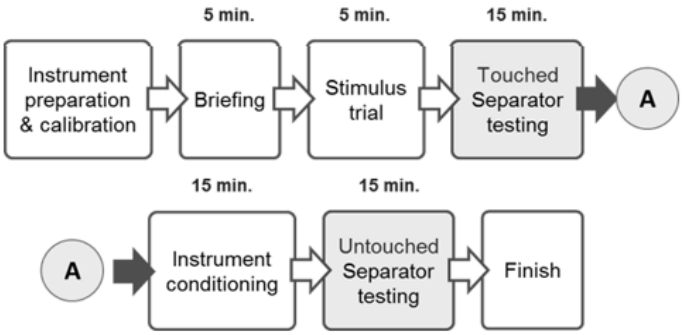


Figure 3. Improvement opportunities of existing assessment device

	3. Development of new resonance assessment equipment Innovation of an ergonomic and practical device for nasalance measurement is needed. This study will propose a nasometer system with ergonomic design by utilizing an untouched separator.  Figure 4. The proposed nasometer design
Research purpose	1. **Develop a novel nasometer**, which uses an untouched voice separator to avoid the interference during a speech assessment or therapy. 2. **Propose a nasalance adjustment algorithm** to set the nasalance result from the untouched separator nasometer to be equivalent with the touched separator nasometer. 3. **Validate** the performance of the proposed nasometer.  Figure 5. Ergonomic nasometer design study

Research subject	The experiment will include **healthy adults** (20~60 years old) with **no craniofacial or neurological problem** which can cause resonance disorder. 1. Craniofacial disorder: cleft lip and/or palate, submucous cleft, short velum, or facial cleft. 2. Neurological disorder or injury: stroke, dysarthria, cerebral palsy, or traumatic brain injury.
Target number of subject enrollment and basis of calculation	**1. Number of subjects** In total, 20 males and 20 females will be recruited for the nasalance measurement and the validation experiment of the proposed ergonomic nasometer. **2. Basis of calculation** Considering there will be four conditions to be applied to the participants, we aim in total 40 participants including 20 males and 20 females. Several key studies also involved participants number ranging from 20~70 people.
Recruitment of subjects	**1. Participation in experiment** Subject recruitment will be done through experiment participation announcement. **2. Confidentiality** We will not disclose personal information of the subjects which will be collected in this experiment or use them for any purpose other than conducting the research. The identity of the subjects will be kept confidential when the results of the research are published.
Informed consent	1. **How to obtain the consent from the subject** The consent form will be provided to the patient after the researcher explains the experimental procedure. **2. Confidentiality**

	We will not disclose personal information of the subjects which will be collected in this experiment or use them for any purpose other than conducting the research. The identity of the subjects will be kept confidential when the results of the research are published.
Research method	**1. Apparatus** The nasometer system, separator extension plate, and the nasal/oral passage stimulus will be used in the nasalance measurement experiment as shown in Figure 3.1. The Nasometer II type 6450 developed by Kay Pentax, will be used for measuring nasal & oral sound energy (dB) and nasalance during stimulus reading.  Figure 6. Setting of the untouched separator condition **2. Experimental procedure** The nasalance measurement experiment will be conducted by following six steps lasting a total 50 min. a. Preparation and calibration, briefing (5 min) b. Stimulus trial (5 min) c. Touched separator testing (15 min) d. Instrument conditioning (15 min) e. Untouched separator testing (15 min). I In the briefing session, the purpose and procedure of the experiment will be explained to the participant. Before conducting the real measurement, participant will have 5 min. to read the stimulus

	passages consist of nasal sentence and zoo passage, in order to get familiar with the words and try how to pronounce it.  Figure 7. Procedure of Experiment
Observation item	**Measurement of nasalance** Nasal and oral voice signal of the patient will be captured using two respective audio sensors and will be calculated as a nasalance (%). $\text{Nasalance (\%)} = \frac{\text{Nasal sound energy } (v)}{\text{Nasal sound energy } (v) + \text{ Oral sound energy } (v)}$
Outcome evaluation criteria and evaluation methods	1. **Comparison** of **current experiment result and normative data** of existing nasometer device. 2. Identification of the **nasalance signal trend on different separator gap** (5/10/15 mm from edge of separator to a point between user's lip and nose). 3. Determination of a **nasalance adjustment algorithm.**
Safety evaluation criteria and evaluation methods	1. Nasalance measurement device will be used in this study is registered as standard medical device. 2. In this experiment, subject is expected to have enough rest between each task sessions.

	3. If the subject expresses the occurrence of physical discomfort, he/she may request for break in the middle of experiment. 4. Experimental time is approximately 40 minutes in total, and it is expected that the physical or mental stress will be minimum since the task will not be performed continuously.
Data analysis and statistical methods	1. **Descriptive statistics** According to the normative data and previous studies, the values needed are the *mean, standard deviation, minimum,* and *maximum* of nasalance. 2. **Two sample *t test*** t test is needed to compare a set of mean nasalance of touched separator condition with a set of mean nasalance from untouched separator condition or a set of adjusted mean nasalance of untouched separator condition. 3. **Regression analysis** Regression model will be utilized to identify the trend of nasalance change on different separator gap conditions.
Expected adverse effects and precautions	Nasometer apparatus used in this study was developed by Kay Pentax Medical and met medical standard for UL 60601-1 and EN 60601-1. Therefore, it is considered that there is no adverse effects during or after the test.
Disqualification/withdrawal criteria	In case of 1. **Subject has a medical problem** Even if the subject has agreed to participate in the study, researcher may discontinue the experiment at any time in case of subject has a sudden medical problem. 2. **Subject does not want to continue the experiment** Subject may ask to discontinue participating in the experiment even if they agreed to participate in the study.

Risks and benefits for research subjects	**1. Expected risk of research** There is no specific adverse effect associated with the study. **2. Advantages of participating in research** a) Resonance disorder By participating in this study, it is possible to identify whether resonance disorder symptom is present or not. If symptom occurs, the subject can be educated about the characteristic of symptom and exercise method. b) Monetary compensation Subject will be provided monetary compensation for their participation in this study.
Safety measures and personal information protection for research subjects	**1. Safety measures for the subjects** This study is considered to be a low-risk study. However, in case of subject asks to relax due to physical or mental fatigue of continuous experiment activity, he/she may have a break in the middle of experiment. **2. Personal information protection** Confidentiality of personal information of the subjects which will be collected in this experiment will be kept and will not be used for purposes other than this study.

Informed consent form for Human subjects

Basic Information				
Approval Number				
Title of Research	Development of an Ergonomic Nasometer			
Principal Investigator	Name	Affiliation	Position	Major
	Heecheon You	Dept. of Industrial & Management Engineering	Professor	Ergonomics
	Tel: 054-279-2210		E-mail: hcyou@postech.ac.kr	

This research is study on development of an ergonomic nasometer. Before you decide whether you will participate in the research, please carefully read the instructions and informed consent form. It is important for you to understand the purpose and method of the research. The researcher who will conduct the study will explain this to you. This will take place only when you voluntarily participate. Please read below thoroughly, and discuss with your family or friends if needed. If you have any questions, the researcher in charge will give you detailed answers.
Your signature means that you have been informed of the research and the risks of the research, and it also means that you would like to participate in the research.

1. This research is conducted for research's sake only.

2. The method of research and expected virtues and effects

This research is about development of an ergonomic device for assessment or therapy of resonance disorder. Experiment in this study is intended to identify voice resonance on different gap separator condition. The trend of voice resonance, which will be measured in nasalance unit, will become a basis to propose an algorithm for the newly developed system. Furthermore, after the new nasometer is developed, a validation testing will be conducted to compare the performance with existing nasometer.

3. The expected period of participation and the estimated total number of subjects

The expected participation duration of each experiment session will be 40~50 minutes. This study will involve healthy adults (20 males & 20 females, 20~60 years old) with no craniofacial or neurological

problem which can cause resonance disorder.

4. Test and procedure that you have to go through by participating in the research

If you are selected as a subject for this experiment, you will participate in the research by visiting the Engineering Building 4 of Pohang University of Science and Technology. You will undergo the following experiment procedure.

1) Stimulus trial: reading two standard passages provided by the researcher, or try to pronounce /ma ma ma/ and /pa pa pa/. Researcher in charge will provide example of how to read/pronounce each stimulus as reference.

2) Testing: measurement of participant voice signal during the stimulus reading. This session will be divided into two parts with 5 minutes conditioning before each of session.

   - Touched separator condition: participant wears the nasometer system with separator touches lip (original requirement of Kay Pentax Nasometer)

   - Untouched separator condition: participant wears the nasometer with a determined separator gap from the lip (5/10/15 mm)

5. Risk (side effect) or inconvenience that is expected to be imposed on the subject (or a fetus if the subject is a pregnant woman or an infant if the subject is a breast feeder) by participating in this research

This study uses Nasometer system which is safe and met medical standard. The device also does not require any invasive treatment to use. Therefore, it is considered that there is no known or anticipated side effect, but the experiment task will be conducted within around 40 minutes, so discomfort condition on neck or head may occur. However, since the task will not be continuously done, it is possible to take enough rest for every 8~10 minutes, in such wise the discomfort effect is expected to be minimal. If the subject expresses the occurrence of physical inconvenience, he/she can have a break in the middle of the experiment and can discontinue participating in the study at any time.

6. Benefit that you expect to obtain by participating in the research

Subjects participating in this study will receive a monetary compensation (KRW10,000) for the transportation fee, etc. By participating in this study, it is possible to identify whether resonance disorder symptom is present or not. If symptom occurs, the subject can be educated about the characteristic of symptom and exercise method. Furthermore, participants' information obtained from this study will contribute to the improvement of nasalance measurement device.

7. When the subject refuses to participate in a test

The final decision regarding whether or not to participate in the research is to be made by you. You can

always decide not to participate in the tests and can withdraw your participation in the tests anytime. Even if you refuse to participate in this research, you will not be disadvantaged at all and your decision will not have any effect in the future.

8. Strict confidentiality of personal information (by setting privilege to view, save, manage and delete data, concealment of the subject's identity in publishing the result of a clinical trial

Your private and personal information will be kept confidential and access to it by the general public will be restricted. However, as long as the relevant law or regulation allows, your personal information can be made available to the review board and to governmental institutions with the aim of verifying the reliability of the research procedure and data. However, even in such a case, the information will be kept in the strictest confidence. When the result of this research is published, your identity will remain confidential.

9. The compensation and treatment options for any damage that may incur on the subject due to a clinical trial

If any research-related damage occurs during the experiment, we will take immediate steps to ensure that appropriate medical treatment is available a local hospital.

10. What the subject must observe for this research

During the clinical test, you should comply with the following. You need to abide by general health rules such as getting a good night's sleep on the day before the test, refraining from excessive drinking, and maintaining full cooperation in following the fixed schedule and directions.

11. You can be notified of any new information obtained by a researcher while the research is in progress that may affect yourself.

▶ I would like to be notified ( )

▶ I would not like to be notified ( )

12. The name of the person to contact and relevant phone number in the event you require additional information or if you suffer any injury related to this research are given below.

If you have any questions or with to express any discomfort related to this research, please feel free to contact the researcher below.

<Research Director: Prof. Heecheon You, Contact number (☎) 054-279-2210 or 010-3213-2210

Co-researcher: Gradiyan Budi Pratama, Contact number (☎) 054-279-8246 or 010-9961-9101>

※ If you have any queries regarding your rights as a human subject of research, Please contact the secretary of Institutional Review Board for details and consultation. Tel 054-279-3633

1. I have read this Informed Consent and received the response to each and every question.
2. I have learned the risks and benefits, and received satisfying answers regarding my questions.
3. I would like to voluntarily participate in the research by signing this.
4. I consent to let the researcher collect my information through the research in the boundary of legality.
5. I can withdraw the decision of participation anytime and I understand that it will make me no disadvantages.
6. My signature means that I have received the copy my this consent form and I will keep the copy until the research ends.

Subject (If the subject is a juvenile, his or her legal agent signs below and writes down the name of a juvenile here :_____)
Address /
Contact number /
Date of Informed Consent /
Name / (Signature or stamp)

Researcher who explained about the consent form
Date / Name / (Signature or stamp)

Principal Investigator
Date / Name / (Signature or stamp)