DOI: 10.4274/jarem.galenos.2026.59455
J Acad Res Med 2026;16(1):43-53

Comparison of Nasalance Values Obtained with Nasometer-II and Praat-assisted Nasalance Meter

Mehmet Akif Kılıç[1], Muhammed Selman Babar[2], Göksu Tarakçı[2]

[1]Lokman Hekim İstanbul Hospital, Voice-Timbre-Speech-Language Unit, İstanbul, Türkiye
[2]Üsküdar University Faculty of Health Science, Department of Speech and Language Therapy, İstanbul, Türkiye

Cite this article as: Kılıç MA, Babar MS, Tarakçı G. Comparison of nasalance values obtained with Nasometer-II and Praat-assisted Nasalance Meter. J Acad Res Med. 2026;16(1):43-53

ABSTRACT

Objective: This study aimed to compare nasalance values obtained using the Praat-assisted Nasalance Meter (PANM) and the Nasometer II model (NMII) 6450 by examining the effects of hardware and software configurations and evaluating the strength of the linear relationships between measurements derived from these systems.

Methods: A total of 60 healthy participants (17 men, 43 women) aged 18-23 years were included. Acoustic signals were recorded and analyzed separately using PANM and NMII hardware and software configurations. PANM measurements were obtained using 80-1000 Hz and 300-750 Hz bandpass filters, whereas NMII measurements were obtained using a 300-750 Hz bandpass filter. Data were analyzed using Pearson correlation and two-way repeated-measures analysis of variance (ANOVA).

Results: Positive correlations were observed between nasalance scores obtained from different hardware and software configurations ($p<0.05$). Repeated-measures ANOVA revealed significant main effects of both software and hardware across speech materials. NMII software yielded higher nasalance scores than PANM software, whereas PANM hardware produced higher scores than NMII hardware in most speech materials. Similar patterns were observed across different types of speech materials.

Conclusion: The findings demonstrate that nasalance scores obtained from the PANM and NMII systems vary according to hardware and software configurations. Although measurements showed linear associations, the consistent differences observed across speech materials indicate that system-specific technical properties influence score magnitude. Therefore, hardware and software configurations should be carefully considered when interpreting and reporting nasalance scores in clinical and research settings.

Keywords: Velopharyngeal dysfunction, nasal resonance, nasalance measurement, Praat

INTRODUCTION

Nasal measurement is a widely used technique for clinical evaluation of nasal resonance disorders (1). The nasalance score obtained from this measurement is calculated by dividing the nasal acoustic energy by the sum of nasal and oral acoustic energies (also called "total acoustic energy"), and multiplying this by 100 (2). In this context, different systems have different software and hardware to measure nasalance [e.g., Nasometer 6200 (Kay Elemetrics Corp.), Nasometer II 6400 (KayPENTAX, Inc.), Nasometer II 6450 (KayPENTAX, Inc.), Nasometer 6500 (KayPENTAX, Inc.), NasalView (Tiger DRS, Inc.), OroNasal Nasality System (Glottal Enterprises, Inc.)] (1,3).

The aforementioned systems, which play an active role in the diagnostic and therapeutic processes of nasal resonance disorders are usually expensive and/or relatively difficult to access. This may be a challenge for clinicians and researchers dealing with nasal resonance disorders. Therefore, the Praat-assisted Nasalance Meter (PANM) system, which has free software, is easily accessible and requires only low-cost materials was developed by the first author and was standardized by Kılıç et al. (4).

The PANM system consists of hardware with earphones acting as microphones on both sides (upper and lower) of the separator plate to measure nasalance and software to calculate the nasalance score in a computer environment. The software of the PANM system is designed as the Praat (5) plugin and has an easy-to-use interface, which also runs on Praat after installation. Headphones are used instead of microphones to minimize costs and facilitate the accessibility of PANM hardware. Dynamic headphones use the electromagnetic field created by a vibrating diaphragm and a copper coil around a magnet. As a result, they have the same working principle as dynamic microphones. Thus,

ORCID IDs of the authors: M.A.K. 0000-0003-0706-7032; M.S.B. 0000-0001-7974-5774; G.T. 0000-0001-6123-8395

Corresponding Author: Mehmet Akif Kılıç, Prof. Dr.;
E-mail: makilic@yahoo.com

Received Date: 29.01.2026 **Accepted Date:** 13.04.2026
Publication Date: 28.04.2026

headphones, in addition to being cost-effective, can also function as microphones that allow minimal sound transmission between microphones, especially for nasalance measurement (6). Another important aspect of this research is that the pair of microphones used in this study is a matched pair. For this reason, the researchers tested their assumption that a matched pair of headphones can maintain this property when used as a microphone, and when the frequency response curves were analysed, they found that both microphones had a similar frequency response (Figure 1). In this context, it should not be forgotten that an audio interface capable of stereo recording is required to record the acoustic energy from the nose and mouth separately for the PANM system to work correctly.

The aim of this study was to compare nasalance values obtained using the Nasometer II and the PANM by examining the effects of hardware and software configurations on nasalance scores and by evaluating the strength of the linear relationships between measurements derived from these systems.

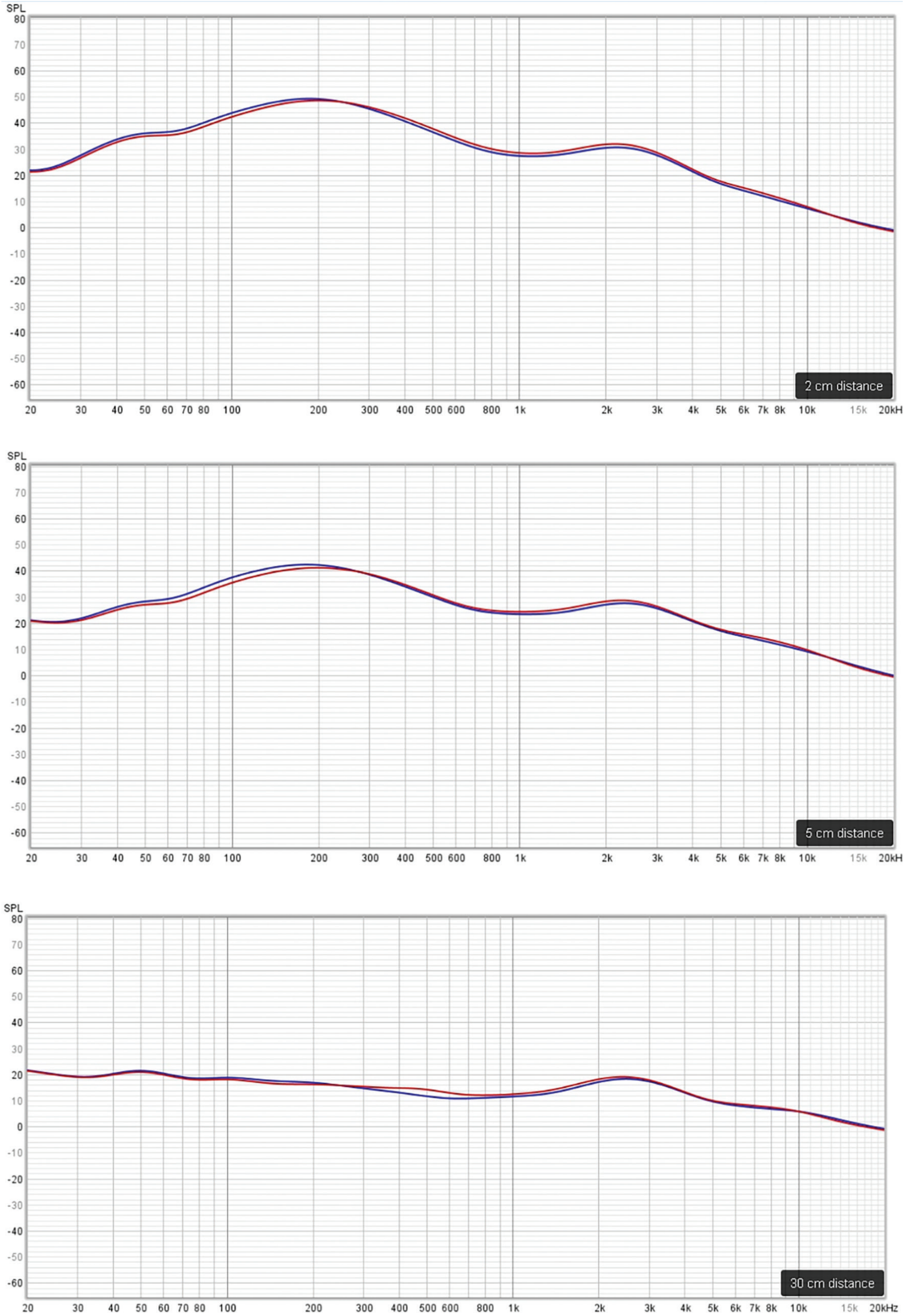


Figure 1. Frequency response curves of microphones at 2, 5 and 30 cm distance

METHODS

Participants

A total of 60 adults, consisting of 43 women and 17 men aged 18-23 years, were included in this study. The criteria for inclusion in the study were (1) not having hearing loss, (2) not having a physiological and anatomical anomaly that would impair speech and speech intelligibility, (3) not having a runny nose and/or nasal congestion during the study, and (4) not having a perceptually significant resonance disorder.

This study was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to participation in the study. Ethical approval to conduct the study was obtained from the Non-Interventional Research Ethics Board (number: 61351342/2020-653, date: 31.12.2020) of Üsküdar University.

Data Collection Tools and Procedure

The necessary information about the programs and instructions for the PANM software were turned into an internet link, shared with the readers in this article (link: https://bit.ly/2Xt6o8x). Necessary documents related to PANM software and hardware are located in the file named "PANM Script". Nasalance score analyses can be easily performed with the "Simplified Nasalance Measurement" button on the Praat interface of the PANM Plugin, and the audio signal recorded with the "TextGrid for PANM," entered via the "Annotate" button, can be divided into target segments and analyzed collectively. Detailed information on this analysis is provided in Appendix 1.

An important distinguishing feature of PANM software from nasalance measurement batteries is that the band filter setting can be changed easily. Therefore, the filter settings used in this study were 80-1000 Hz according to researchers' recommendations (4,7) and the 300-750 Hz filter ranges were preferred for comparing the PANM software with the Nasometer II model (NMII) software. Consequently, two different bandpass-filter settings were used in this research, and the analyses were carried out on these two filter settings.

The PANM equipment comprises a headset (Philips SHE1350) with two microphones on a 3 mm-thick plexiglass plate. One side of the plate has a concave morphology that coincides with the mouth and nose, and an integrated plexiglass handle that separates the energy emanating from the mouth and nose. The headphones use a 3.5 mm jack and are positioned 20 mm from the concave edge of the plate. This distance was preferred because of the low sensitivity of the headphones. An Andrea USB-SA (Andrea Communications, Farmingdale, NY) audio interface was used to transfer the recorded sound to the computer environment. In addition, this enabled stereo recording and was compatible with the jack input of the headphones used. Another nasalance measurement tool used in this study is the NMII 6450 (KayPENTAX, Lincoln Park, NJ, USA). The NMII system utilizes unidirectional microphones in the frequency response range of 50 Hz-15 kHz, positioned at a distance of approximately 50 mm from the nose and mouth. The software has a fixed bandpass-filter range of 300-750 Hz which cannot be changed. Both measurement tools are illustrated in Figure 2.

Two different computers were used to create the frequency response curve of the Philips SHE1350 earphones and the Andrea USB-SA audio interface, and the right side of the reference monitor (speaker) was connected to the first computer. Afterward, the pink noise that was generated in the Audacity® (version 3.7.3; Audacity Team, USA) program was conveyed to the reference monitor via the same program. The microphone system that was intended for frequency response curve generation was connected to the second computer. The microphone system was anchored using a microphone stand and appropriate adapters, and the recordings were taken inside a double-walled audiometric cabin. After this, the microphone system was placed at distances of 2 cm, 5 cm, and 30 cm, respectively, so that it would be aligned with the center of the reference monitor, and pink noise was recorded for approximately 10 seconds. The RMS (-dB) values (left: 40.7; right: 40.7) of the recordings were obtained using the Audacity® (version 3.7.3; Audacity Team, USA) software. Nasalance measurements were analyzed using Praat and the PANM plugin (nasalance: 51%). Finally, using the REW - Room EQ Wizard Room Acoustics Software, the frequency response curve (Figure 1) was obtained at a resolution of 1 dB and the smoothing setting of 1/1.

The participants' voice recordings to be analyzed in PANM software were captured with the portable computer via Praat (version 6.2.22) in "PCM wav" format. The sound recordings to be analyzed in the NMII software were recorded in the ".wav" format using the software interface. All recordings were made in the soundproofed phonetic laboratory at Üsküdar University. They were recorded at 11025 Hz sampling rate and 16-bit stereo format. After the transcription of the speech material used (Figure 3) (a detailed explanation of this stage is provided in Appendix 1), "TextGrid" files were created for analysis on PANM software. Nasalance measurements were carried out after the preparations were completed. The recording and analysis procedures used in the study are summarized in Table 1.

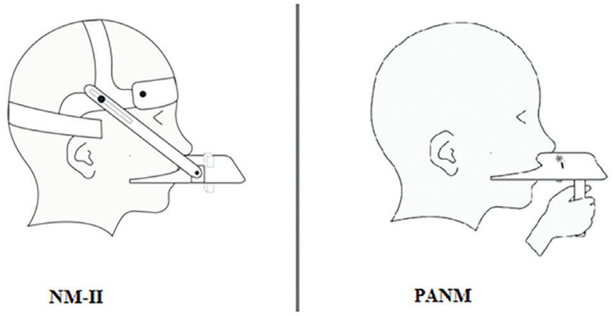
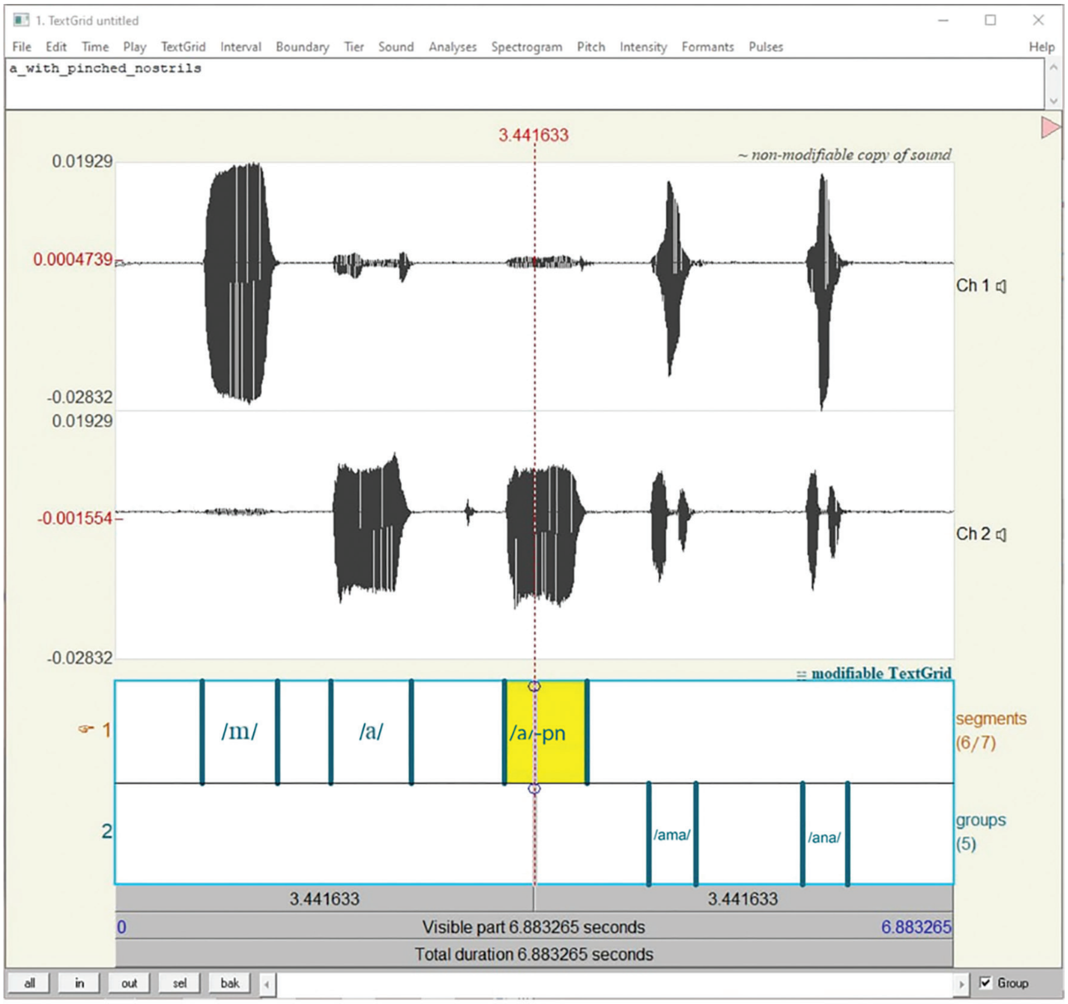


Figure 2. PANM and NMII equipment

PANM: Praat-assisted Nasalance Meter, NMII: Nasometer II model



a_with_pinched_nostrils

Figure 3. Creating a sample "TextGrid" file in the PANM system
PANM: Praat-assisted Nasalance Meter, pn: Pinched nostrils

Speech materials used for nasalance measurement are affected by linguistic differences. Therefore, the recording material used in this study is given in Table 2. Within the scope of the study, audio recordings were obtained using microphone systems from two different devices (NMI-II and PANM). To minimize potential order effects, the sequence of hardware use was counterbalanced. Accordingly, 30 randomly selected participants were first recorded using the NMI-II device and subsequently with the PANM device. For the remaining 30 participants, the order was reversed, with recordings obtained first using PANM and then NMI-II. In addition, the presentation order of the recording materials was counterbalanced to further control for potential order effects. The overall procedure is illustrated in Figure 4.

Statistical Analysis

Data analysis was performed using the Statistics Package for Social Science (SPSS 22.0, IBM, NY, USA). The data were first analyzed with the Shapiro-Wilk normative distribution test, and it was determined that the normal distribution assumption was met. The recording material's sounds, words, and sentences were coded A1, A2, B1, B2, C1, C2, C3, C4, and C5 (Table 2). A two-way repeated measures ANOVA was conducted for each speech material (A1-C5) to examine the main effects of hardware and software, as well as their interaction effect, on nasalance scores. In addition, Pearson correlation analysis was conducted to examine the linear relationship between the measurements obtained from different hardware and software systems.

Table 1. Recording and analysis procedures used in the study

	Hardware (H)	Software (S)
1	PANM-H	PANM-S (80-1000 Hz)
2	PANM-H	PANM-S (300-750 Hz)
3	PANM-H	NMII-S (300-750 Hz)
4	NMII-H	PANM-S (80-1000 Hz)
5	NMII-H	PANM-S (300-750 Hz)
6	NMII-H	NMII-S (300-750 Hz)

PANM: Praat-assisted Nasalance Meter, NMII: Nasometer II model

Table 2. Recording material used in the study

Isolated phonems	**A1** Sustained consonant production (m)	
	A2 Sustained vowel production (a)	
	A3 Sustained vowel production with pinched nostrils (a)	
Words	**B1** (ɑmɑ)	**B2** (ɑnɑ)
Sentences	**Oral plossive**	**C1** (pɛtɛc kɯɾɯk tahta kapɯjɯ kapat:ɯ)
	Oral plossive with pinched nostrils	**C2** (pɛtɛc kɯɾɯk tahta kapɯjɯ kapat:ɯ)
	Oral sibilan	**C3** (sɛʧil sɯʤak havuzda sɛs:izʤɛ jyzdy)
	Nasal	**C4** (an:ɛm eminɛjɛ nin:i mɯɾɯłdandɯ)
Passage	**C5** (daɹkapɯsɯndan baʃka ajdɯnłɯk ɟiɾɛʤɛc hiʧbiɹ jɛɾi ołmajan dyc:anɯnda tɛc baʃɯna ɟeʤɛ ɟyndyz kɯvɯłʤɯmłaɹ saʧaɾak ʧałɯʃan kɔʤa ali tɯpkɯ kafɛsɛ kɔnmuʃ tɛɾbijɛli biɹ asłanɯ andɯɾɯjɔɹdu)	

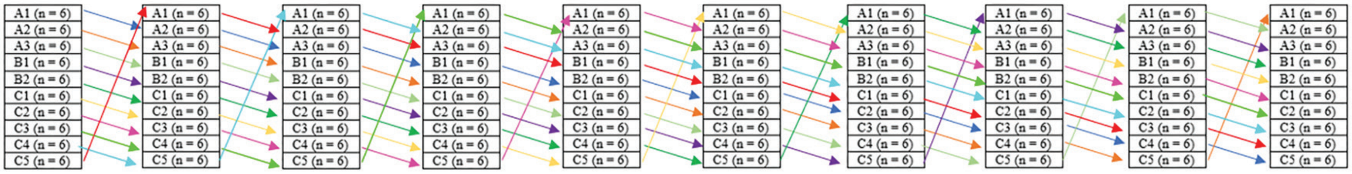


Figure 4. The order of recording acoustic materials

RESULTS

In this section, the results of the correlation and variance analyses will be presented respectively. The relationship between the results obtained in the correlation analysis was examined at two different filter settings: 80-1000 Hz and 300-750 Hz for the PANM software, and 300-750 Hz filter setting for the NMII software. Additionally, the relationship between the nasalance scores obtained when each software was in the filter range of 300-750 Hz was examined for variance analysis.

Correlation Analysis Results

Pearson correlation coefficients were calculated for the isolated phonemes A1, A2, and A3 to examine the relationship between nasalance scores obtained from PANM-H, PANM-S, NMII-H, and NMII-S hardware and software. Additionally, 80-1000 Hz and 300-750 Hz filter ranges were used for PANM-S. Finally, the correlations with the NMII-S, whose default setting was 300-750 Hz, were examined. The results are presented in Table 3.

When the correlations of nasalance scores analyzed with the PANM-S using an 80-1000 Hz bandpass filter and the NMII-S using a 300-750 Hz bandpass filter in Table 3 were examined for A1, there was a statistically significant positive correlation ($p<0.01$) between the measurements of "PANM-H with PANM-S - PANM-H with NMII-S" and "NMII-H with PANM-S - NMII-H with NMII-S" at a high level ($r=0.867$ and 0.918, respectively). In contrast, no statistically significant correlation was found between the "PANM-H with PANM-S - NMII-H with NMII-S" nasalance score measurements for A1 ($p>0.05$). For A2, there was a statistically significant positive correlation ($p<0.01$) between the measurements of "PANM-H with PANM-S - PANM-H with NMII-S", "NMII-H with PANM-S - NMII-H with NMII-S" and PANM-H with PANM-S - NMII-H with NMII-S" at a high level ($r=0.866$ and 0.894, respectively) and low ($r=0.297$). For A3, there was a statistically significant positive correlation ($p<0.01$) between the measurements of "PANM-H with PANM-S - PANM-H with NMII-S", NMII-H with PANM-S - NMII-H with NMII-S" and PANM-H with PANM-S - NMII-H with NMII-S" at the high, moderate and low levels, respectively.

When the nasalance scores analyzed with the PANM-S using a 300-750 Hz bandpass filter and the NMII-S using a 300-750 Hz bandpass filter in Table 3 were examined for A1, there was a moderately positive correlation ($r=0.694$, 0.663, 0.518, respectively) and a statistically significant relationship ($p<0.01$) between the measurements of "PANM-H with PANM-S - PANM-H with NMII-S", "NMII-H with PANM-S - NMII-H with NMII-S" and PANM-H with PANM-S - NMII-H with NMII-S". For A2, a statistically significant positive correlation ($p<0.01$) was found between the measurements of "PANM-H with PANM-S - PANM-H with NMII-S", NMII-H with PANM-S - NMII-H with NMII-S" and "PANM-H with PANM-S - NMII-H with NMII-S" at a high level ($r=0.736$ and 0.880, respectively) and at a moderate level ($r=0.624$), respectively. For A3, a statistically significant positive correlation ($p<0.01$) was found between the measurements of "PANM-H with PANM-S - PANM-H with NMII-S", "NMII-H with PANM-S - NMII-H with NMII-S" and "PANM-H with PANM-S - NMII-H with NMII-S" at a high level ($r=0.805$ and 0.826, respectively) and at a moderate level ($r=0.533$).

The Pearson correlation coefficient was calculated for B1 and B2 (words) to examine the relationship between the nasalance scores obtained from PANM-H, PANM-S, NMII-H, and NMII-S hardware and software. In addition, two different filter ranges, 80-1000 Hz and 300-750 Hz, were used for the PANM-S's software settings, and the correlations with the NMII-S, whose default setting was 300-750 Hz, were examined, respectively. The results are presented in Table 4.

When the correlation results of nasalance scores analyzed using the PANM-S with an 80-1000 Hz bandpass filter and using an NMII-S with a 300-750 Hz bandpass filter in Table 4 were examined for the B1, a statistically significant correlation (p<0.01) was found between "PANM-H with PANM-S - PANM-H with NMII-S" and "NMII-H with PANM-S - NMII-H with NMII-S" measurements at a high (r=0.822) and moderate (r=0.461) levels, respectively. No statistically significant correlation was found between the measurements of "PANM-H with PANM-S - NMII-H with NMII-S" for the B1 (p>0.05). For B2, a statistically significant positive correlation (p<0.01) was found between "NMII-H with PANM-S - NMII-H with NMII-S", "PANM-H with PANM-S - PANM-H with NMII-S" and "PANM-H with PANM-S - NMII-H with NMII-S" measurements at the moderate (r=0.760 and 0.654, respectively) and low (r=0.366) levels, respectively.

When the correlation of nasalance scores analyzed with the PANM-S using a 300-750 Hz bandpass filter and NMII-S using a 300-750 Hz bandpass filter, as shown in Table 4, were examined for the B1, there was a statistically significant (p<0.01) positive correlation (r=0.528, 0.413, and 0.662, respectively) between the measurements of "PANM-H with PANM-S - PANM-H with NMII-S", "PANM-H with PANM-S - NMII-H with NMII-S" and "NMII-H with PANM-S - NMII-H with NMII-S". For B2, there was a highly correlation (r=0.840) between "NMII-H with PANM-S - NMII-H with NMII-S" measurements and a moderately correlation (r=0.354, 0.644, respectively) between "PANM-H with PANM-S - PANM-H with NMII-S" and "PANM-H with PANM-S - NMII-H with NMII-S" measurements (p<0.01).

The Pearson correlation coefficient was calculated to examine the relationship between nasalance scores obtained from PANM-H, PANM-S, NMII-H, and NMII-S hardware and software for C1, C2, C3, C4, and C5 (sentences and passage reading). Additionally, two different filter ranges, 80-1000 Hz and 300-750 Hz, were used as the PANM-S's software settings, and their correlations with the NMII-S, whose default setting was 300-750 Hz, were examined, respectively. The results are presented in Table 5.

Table 3. Relationships between nasalance scores obtained from PANM-H, PANM-S, NMII-H and NMII-S hardware and software for A1, A2 and A3 (isolated phonemes)

Software: PANM-S with 80-1000 Hz filter and NMII-S with 300-750 Hz filter			
Correlation	**A1**	**A2**	**A3**
PANM-H with PANM-S - PANM-H with NMII-S	0.867**	0.866**	0.584**
PANM-H with PANM-S - NMII-H with NMII-S	0.238	0.297*	0.285*
NMII-H with PANM-S - NMII-H with NMII-S	0.918**	0.894**	0.839**
Software: PANM-S with 300-750 Hz filter and NMII-S with 300-750 Hz filter			
Correlation	**A1**	**A2**	**A3**
PANM-H with PANM-S - PANM-H with NMII-S	0.694**	0.736**	0.805**
PANM-H with PANM-S - NMII-H with NMII-S	0.518**	0.624**	0.533**
NMII-H with PANM-S - NMII-H with NMII-S	0.663**	0.880**	0.826**

*: p<0.05, **: p<0.01, A1: Sustained consonant /m/, A2: Sustained vowel /a/, A3: Sustained vowel /a/with pinched nostrils, H: Hardware, S: Software, PANM: Praat-assisted Nasalance Meter, NMII: Nasometer II model

Table 4. Relationship between nasalance scores obtained from PANM-H, PANM-S, NMII-H and NMII-S hardware and software for B1 and B2 (words)

Software: PANM-S with 80-1000 Hz filter and NMII-S with 300-750 Hz filter		
Correlation	**B1**	**B2**
PANM-H with PANM-S - PANM-H with NMII-S	0.822*	0.654*
PANM-H with PANM-S - NMII-H with NMII-S	0.212	0.366*
NMII-H with PANM-S - NMII-H with NMII-S	0.461*	0.760*
Software: PANM-S with 300-750 Hz filter and NMII-S with 300-750 Hz filter		
Correlation	**B1**	**B2**
PANM-H with PANM-S - PANM-H with NMII-S	0.528*	0.354*
PANM-H with PANM-S - NMII-H with NMII-S	0.413*	0.644*
NMII-H with PANM-S - NMII-H with NMII-S	0.662*	0.840*

*: p<0.05, B1: Word (ɑmɑ), B2: word (ɑnɑ), H: Hardware, S: Software, PANM: Praat-assisted Nasalance Meter, NMII: Nasometer II model

Table 5. The relationship between nasalance scores for C1, C2, C3, C4 and C5 (sentences and passage reading) obtained from PANM-H, PANM-S, NMII-H and NMII-S hardware and software

Software: PANM-S with 80-1000 Hz filter and NMII-S with 300-750 Hz filter					
Correlation	**C1**	**C2**	**C3**	**C4**	**C5**
PANM-H with PANM-S - PANM-H with NMII-S	0.879^{**}	0.601^{**}	0.876^{**}	0.804^{**}	0.776^{**}
PANM-H with PANM-S - NMII-H with NMII-S	0.540^{**}	0.264^{*}	0.509^{**}	0.200	0.088
NMII-H with PANM-S - NMII-H with NMII-S	0.853^{**}	0.910^{**}	0.862^{**}	0.688^{**}	0.670^{**}
Software: PANM-S with 300-750 Hz filter and NMII-S with 300-750 Hz filter					
Correlation	**C1**	**C2**	**C3**	**C4**	**C5**
PANM-H with PANM-S - PANM-H with NMII-S	0.612^{**}	0.865^{**}	0.526^{**}	0.474^{**}	0.272^{*}
PANM-H with PANM-S - NMII-H with NMII-S	0.660^{**}	0.726^{**}	0.545^{**}	0.470^{**}	0.500^{**}
NMII-H with PANM-S - NMII-H with NMII-S	0.748^{**}	0.853^{**}	0.645^{**}	0.787^{**}	0.608^{**}

*: p<0.05, **: p<0.01, C1: Oral plosive sentence, C2: Oral plossive with pinched nostrils sentence, C3: Oral sibilan sentence, C4: Nasal sentence, C5: Passage, H: Hardware; S: Software, PANM: Praat-assisted Nasalance Meter, NMII: Nasometer II model

When the correlation results of nasalance scores analyzed with the PANM-S using the 80-1000 Hz bandpass filter and NMII-S using the 300-750 Hz bandpass filter in Table 5 were examined for C1, there was a statistically significant positive correlation (p<0.01) between the measurements of “PANM-H with PANM-S - PANM-H with NMII-S”, “NMII-H with PANM-S - NMII-H with NMII-S” and “PANM-H with PANM-S - NMII-H with NMII-S” at a high level (r=0.879, and 0.853, respectively) and at a moderate level (r=0.540), respectively. For C2, there was a statistically significant correlation between “NMII-H with PANM-S - NMII-H with NMII-S”, “PANM-H with PANM-S - PANM-H with NMII-S”, and “PANM-H with PANM-S - NMII-H with NMII-S” (p<0.01; p=0.043; p<0.01, respectively) measurements at high (r=0.910), moderate (r=0.601), and low (r=0.264) levels, respectively. For C3, there was a statistically significant positive correlation (p<0.01) between the “PANM-H with PANM-S - PANM-H with NMII-S”, “NMII-H with PANM-S - NMII-H with NMII-S” and “PANM-H with PANM-S - NMII-H with NMII-S” measurements for high (r=0.876 and 0.862, respectively), and moderate (r=0.509, respectively) levels. It was determined that there was a statistically significant correlation (p<0.01) between the “PANM-H with PANM-S - PANM-H with NMII-S” and “NMII-H with PANM-S - NMII-H with NMII-S” measurements for C4 at high (r=0.804) and moderate (r=0.688) levels, respectively. No statistically significant correlation was found between the measurements of “PANM-H with PANM-S - NMII-H with NMII-S” for C4 (p>0.05). It was determined that there was a statistically significant positive correlation (p<0.01) between the “PANM-H with PANM-S - PANM-H with NMII-S” and “NMII-H with PANM-S - NMII-H with NMII-S” measurements for C5 at a moderate level (r=0.776 and 0.670, respectively). No statistically significant correlation was found between the measurements of “PANM-H with PANM-S - NMII-H with NMII-S” for C5 (p>0.05).

When the correlation results of nasalance scores analyzed with the PANM-S using a 300-750 Hz bandpass filter and NMII-S using a 300-750 Hz bandpass filter in Table 5 were examined, for C1, a statistically significant positive correlation (p<0.01) was found between the “NMII-H with PANM-S - NMII-H with NMII-S”, “PANM-H with PANM-S - PANM-H with NMII-S” and “PANM-H with PANM-S - NMII-H with NMII-S” measurements, at the high (r=0.748) and moderate (r=0.612 and 0.660, respectively) levels. For C2, there was a statistically significant positive correlation (p<0.01) at the high level (r=0.865, 0.726, and 0.853, respectively) between the “PANM-H with PANM-S - PANM-H with NMII-S”, PANM-H with PANM-S - NMII-H with NMII-S” and “NMII-H with PANM-S - NMII-H with NMII-S” measurements. A statistically significant correlation (p<0.05) was found between the measurements of “PANM-H with PANM-S - PANM-H with NMII-S”, “PANM-H with PANM-S - NMII-H with NMII-S” and “NMII-H with PANM-S - NMII-H with NMII-S” for C3, which was moderately positive (r=0.526, 0.545, and 0.645, respectively). A statistically significant correlation (p<0.01) was found between “NMII-H with PANM-S - NMII-H with NMII-S”, “PANM-H with PANM-S - PANM-H with NMII-S” and “PANM-H with PANM-S - NMII-H with NMII-S” measurements for C4, which was highly positive (r=0.787) and moderately positive (r=0.474 and 0.470, respectively). For C5, a statistically significant positive correlation (p=0.046; p<0.01; p<0.01, respectively) was found between moderate (r=0.500; 0.608, respectively) and low (r=0.272), and low (r=0.272) measurements of “PANM-H with PANM-S - PANM-H with NMII-S”, “PANM-H with PANM-S - NMII-H with NMII-S” and “PANM-H with PANM-S - PANM-H with NMII-S”.

Variance Analysis Results

In this section, the results obtained when each software was at the same filter setting (300-750 Hz) were included. A two-way repeated measures ANOVA was used to examine the differentiation of nasalance scores for A1, A2, and A3 (isolated phonemes) according to hardware and software. The results are presented in Table 6. In addition, descriptive statistics of nasalance score analyses performed at the PANM 80-1000 Hz bandpass-filter setting regarding the recording material used are included in Appendix 2.

Table 6 shows that nasalance scores for A1, A2, and A3 differed significantly according to software (p<0.01). In addition, significant differences were observed according to hardware for A1 and A2 (p<0.01). No statistically significant interaction effect between hardware and software was found at any level (p>0.05). Examination of the mean values indicated that, for A1, A2, and A3, nasalance scores obtained using the NMII software were higher than those obtained using the PANM software. For A1 and A2, however, nasalance scores obtained using the PANM hardware were higher than those obtained using the NMII hardware.

A two-way repeated measures ANOVA was used to examine the differentiation of nasalance scores for B1 and B2 (words) according to hardware and software. In the software, a 300-750 Hz bandpass-filter set was used on both devices. The results are presented in Table 7.

When Table 7 was examined, it was seen that nasalance scores for B1 and B2 statistically significant difference (p<0.01) according to both hardware and software. It was found that nasalance scores for B1 did not show a statistically significant difference (p>0.05), and B2 showed a statistically significant difference (p=0.031), according to the hardware*software interaction effect. When the averages were examined, it was determined that the averages of nasalance scores obtained from the NMII software were higher than those obtained from the PANM software, and that the averages of the nasalance scores obtained from the PANM hardware were higher than those obtained from the NMII hardware, in common for B1 and B2. Examination of the interaction plot for B2 (Appendix 3) revealed a similar pattern in the hardware*software interaction.

A two-way repeated measures ANOVA was used to examine the differentiation of nasalance scores for C1, C2, C3, C4, and C5 (sentences and reading passage) according to hardware and software. For the software analyses, a bandpass-filter setting of 300-750 Hz was used on both devices. The results are presented in Table 8.

Table 6. Examining the differentiation of nasalance scores for A1, A2 and A3 (isolated phonemes) according to software and hardware

	Software (S)	**Hardware (H)**		**SD**		**F**	**p**
A1	PANM-S	PANM-H	96.75	1.68	Software	60.789	**<0.01**
	PANM-S	NMII-H	94.05	2.62	Hardware	111.909	**<0.01**
	NMII-S	PANM-H	97.87	1.19	Software*hardware	1.842	0.180
	NMII-S	NMII-H	95.55	1.61			
A2	PANM-S	PANM-H	25.64	16.06	Software	36.657	**<0.01**
	PANM-S	NMII-H	15.87	11.59	Hardware	29.834	**<0.01**
	NMII-S	PANM-H	32.50	20.00	Software*hardware	0.483	0.490
	NMII-S	NMII-H	21.39	12.52			
A3	PANM-S	PANM-H	5.27	5.18	Software	34.326	**<0.01**
	PANM-S	NMII-H	3.98	2.75	Hardware	3.780	0.057
	NMII-S	PANM-H	6.75	6.08	Software*hardware	0.433	0.513
	NMII-S	NMII-H	5.84	3.90			

A1: Sustained consonant /m/, A2: Sustained vowel /a/, A3: Sustained vowel /a/with pinched nostrils, PANM: Praat-assisted Nasalance Meter, NMII: Nasometer II model, SD: Standard deviation

Table 7. Examination of the differentiation of nasalance scores for B1 and B2 (words) according to hardware and software

	Software (S)	**Hardware (H)**		**SD**		**F**	**p**
B1	PANM-S	PANM-H	54.25	11.76	Software	225.152	<0.01
	PANM-S	NMII-H	36.80	11.32	Hardware	210.544	<0.01
	NMII-S	PANM-H	69.52	8.81	Software*hardware	0.093	0.761
	NMII-S	NMII-H	52.52	6.62			
B2	PANM-S	PANM-H	65.80	9.86	Software	88.700	<0.01
	PANM-S	NMII-H	48.14	11.96	Hardware	391.102	<0.01
	NMII-S	PANM-H	75.98	7.50	Software*hardware	4.911	0.031
	NMII-S	NMII-H	55.21	7.60			

B1: Word (ɑmɑ), B2: Word (ɑnɑ), PANM: Praat-assisted Nasalance Meter, NMII: Nasometer II model, SD: Standard deviation

Table 8. Investigation of the differentiation of nasalance scores for C1, C2, C3, C4 and C5 (sentences and reading passage) according to hardware and software

	Software (S)	Hardware (H)		SD		F	p
C1	PANM-S	PANM-H	13.54	6.89	Software	53.183	**<0.01**
	PANM-S	NMII-H	8.20	5.00	Hardware	47.478	**<0.01**
	NMII-S	PANM-H	18.18	8.09	Software*hardware	0.097	0.756
	NMII-S	NMII-H	12.62	4.65			
C2	PANM-S	PANM-H	2.79	2.55	Software	101.268	**<0.01**
	PANM-S	NMII-H	3.95	1.49	Hardware	7.191	**0.010**
	NMII-S	PANM-H	4.50	3.00	Software*hardware	17.239	<0.01
	NMII-S	NMII-H	4.91	1.37			
C3	PANM-S	PANM-H	15.86	8.38	Software	110.032	**<0.01**
	PANM-S	NMII-H	8.80	5.77	Hardware	69.566	**<0.01**
	NMII-S	PANM-H	24.37	9.01	Software*hardware	0.344	0.560
	NMII-S	NMII-H	17.80	6.07			
C4	PANM-S	PANM-H	69.07	9.14	Software	177.937	**<0.01**
	PANM-S	NMII-H	50.80	11.12	Hardware	361.800	**<0.01**
	NMII-S	PANM-H	80.75	5.25	Software*hardware	0.107	0.744
	NMII-S	NMII-H	62.86	5.19			
C5	PANM-S	PANM-H	39.07	9.72	Software	73.679	**<0.01**
	PANM-S	NMII-H	25.71	8.09	Hardware	205.550	**<0.01**
	NMII-S	PANM-H	49.50	9.54	Software*hardware	3.066	0.086
	NMII-S	NMII-H	33.93	4.20			

C1: Oral plosive sentence, C2: Oral plossive with pinched nostrils sentence, C3: Oral sibilan sentence, C4: Nasal sentence, C5: Passage, SD: Standard deviation

When Table 8 was examined, it was noted that nasalance scores for C1, C3, C4, and C5 statistically significant difference (p<0.01) based on hardware and software. Similarly, for C2, statistically significant differences were observed both between the software systems (p<0.01) and between the hardware systems (p=0.010). It was determined that there was no statistically significant difference for C1, C3, C4, and C5 according to the hardware-software interaction effect (p>0.05). C2 showed a statistically significant difference (p<0.01), according to the hardware*software interaction effect. When the averages were examined, the common result for C1, C2, C3, C4, and C5 was as follows: the nasalance score averages obtained from the NMII software were higher than those obtained from the PANM software. In parallel, the nasalance score averages obtained using NMII hardware were higher than those obtained using PANM hardware. Examination of the interaction plot for C2 (Appendix 3) revealed a similar pattern in the hardware*software interaction.

DISCUSSION

The nasalance parameter allows for the quantitative evaluation and description of an individual's nasal resonance characteristics. However, there are many nasal measurement systems in the literature and clinical use, and many studies have compared the different nasal resonance scores obtained using each of these systems (1,8-12). Therefore, this study aimed to compare the nasalance scores obtained from the PANM system, which is equipped with easily accessible and cost-effective materials, as well as free access to the plugin link related to the software, with the nasalance scores obtained from NMII.

The unchangeable bandpass-filter range (300-750 Hz) of the NMII system may have minimal analytical power for variations related to individual differences, phonetic inventory of different languages and/or resonance disturbance. Indeed, Awan (3) pointed out that signal filtering affects researchers' ability to perform acoustic analyses of nasal sound recordings. In addition, one of the essential advantages of the system is that the filter setting of the PANM system can be changed to determine nasal emission (13), which is acoustically characterized by wide-band noise. Unfortunately, publications examining the effect of manufacturer selections, such as microphone position and bandpass-filter range for signal analysis, on the nasalance value are also very limited in line with the available resources.

It is thought that the PANM system may have critical importance in the diagnosis, therapy and biofeedback processes of many different resonance disorders, mainly since different band filter settings can be used in the analyses performed by that system. Furthermore, the acoustic signal can be observed spectrally during the analysis and this signal can be segmented into background or smaller units. As a first step in this study, the researchers performed a correlation analysis in which both software (PANM and NMII) had equal bandpass-filter settings (300-750 Hz), moreover, the correlations of nasalance scores obtained from the PANM adjusted to the 80-1000 Hz bandpass filter range suggested by researchers (4) and obtained from the NMII (300-750 Hz) system, whose filter settings were fixed by the manufacturers, were then examined.

To summarize, the results of the correlation analysis between the nasalance scores obtained using the PANM and NMII software and hardware and a 300-750 Hz bandpass filter for both systems were statistically significant positive correlation and regardless of the hardware used for all signals in the recording material (Table 2). In other words, when only the software systems were considered, linear relationships were observed between the nasalance scores. Additionally, the results show that the nasalance scores recorded using the PANM hardware and analyzed with the PANM software had a statistically significant positive correlation with the nasalance scores recorded with the NMII hardware and analyzed with the NMII software. In other words, when PANM and NMII were evaluated as integrated hardware-software systems, a linear relationship was observed between the nasalance scores obtained from the two systems, provided that the same filter settings were applied. In addition, when the bandpass-filter range for PANM was set to its default setting of 80-1000 Hz, there were some inconsistencies between both software systems for some acoustic signals in the recording materials. We believe that this was caused by different filter settings.

Correlation analyses demonstrated significant linear associations between nasalance scores obtained from different hardware and software configurations. However, covariation between measurements does not imply the absence of differences between them. Therefore, to determine whether mean-level differences existed between systems and to examine how these differences varied as a function of hardware and software factors, the results of the two-way repeated-measures analysis of variance were examined. When the results were evaluated in terms of software, NMII yielded higher nasalance scores than PANM across all acoustic recording materials, regardless of the hardware used. Although identical filter settings were applied, this difference may be attributable to variations in the underlying signal processing algorithms of the software systems. With respect to hardware, PANM produced higher nasalance scores than NMII across all acoustic materials (except C2), independent of the software used. The difference in hardware can be attributed to microphones having different transducer types (dynamic and condenser), frequency response curves, and sensitivity (14,15). Different microphone features have been reported to affect nasalance score results (16). The consistency of the variance patterns related to software and hardware across different task types (isolated sounds, words, and sentence-level materials) suggests that the observed findings reflect systematic differences rather than random variation. The observed difference in the C2 material may stem from the recording material's task-specific characteristics and does not appear to substantially affect the general pattern of findings.

In conclusion, different hardware and software configurations were found to have significant effects on nasalance scores, and these effects emerged consistently across various speech tasks/materials. These findings indicate that nasalance measurements may be influenced not only by filter settings but also by the signal processing approach of the software and the technical characteristics of the hardware. Accordingly, the specific configuration used should be taken into account when interpreting nasalance scores obtained from different systems. To enhance comparability across clinical and research settings, measurement conditions should be clearly reported, and each system should be evaluated within the context of its own technical specifications. In parallel with this, researchers who compared different systems used to obtain nasalance scores and/or other models related to the same system obtained similar results (1,8-12,17).

Study Limitations

Future studies should focus on calculating frequency response curves for the PANM hardware using mixed and matched-pair microphone configurations and investigating the effects of microphone distance on nasalance scores. In addition, the influence of different filter ranges and various speech or recording materials on nasalance measurements should be systematically examined to further refine the system's measurement properties.

CONCLUSION

The findings of this study indicate that nasalance scores obtained using NMII and PANM may differ significantly depending on hardware and software configurations. Although linear associations were observed between measurements, the magnitude of nasalance scores appears to be influenced by the technical characteristics of the systems used.

Accordingly, when interpreting nasalance scores in clinical and research contexts, the hardware and software characteristics of the measurement system should be clearly reported. Although the PANM system offers advantages in terms of accessibility and spectral view, the values obtained should be interpreted with caution.

Appendix 1-3: https://d2v96fxpocvxx.cloudfront.net/68ab204c-182b-49da-b227-bc7efe058632/content-images/fbcd6d7f-bf4e-47c4-a85a-802eba1e09b6.pdf

---

Ethics

Ethics Committee Approval: Ethical approval to conduct the study was obtained from the Non-Interventional Research Ethics Board (number: 61351342/2020-653, date: 31.12.2020) of Üsküdar University.

Informed Consent: Written informed consent was obtained from all participants prior to participation in the study.

Acknowledgment

The corrected version is: "The basis for this study is the second author's (M.S.B.) MSc thesis, which was supervised by the first author (M.A.K.). The third author (G.T.) supported the data collection and the writing process of this study".

Footnotes

Author Contributions: Concept - M.A.K., M.S.B., G.T.; Design - M.A.K., M.S.B., G.T.; Data Collection and/or Processing - M.A.K., M.S.B., G.T.; Analysis and/or Interpretation - M.A.K., M.S.B., G.T.; Literature Search - M.A.K., M.S.B., G.T.; Writing - M.A.K., M.S.B., G.T.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors report that no financial support was received for this study.

REFERENCES

1. Bressmann T. Comparison of nasalance scores obtained with the Nasometer, the NasalView, and the OroNasal System. Cleft Palate Craniofac J. 2005; 42: 423-33.
2. KayPENTAX. Instruction manual: nasometer II, model 6450. Software Instruction Manual, issue C. KayPENTAX. 2010.
3. Awan SN. Analysis of nasalance: NasalView. Clinical Phonetics and Linguistics. London: Whurr-Publishers. 1997: 518-25.
4. Kılıç MA, Tüysüz O, Hanege FM, Paltura C. Praat-assisted Nasalance Meter: a low-cost nasalance measurement system for evaluation of nasal resonance disorders. Hamidiye Med J. 2021; 2: 116-21.
5. Boersma P, Weenink D. Praat: doing phonetics by computer [computer program]. Version 6.2.22. Amsterdam: University of Amsterdam; 2022. (cited 6 Oct 2022). Available from: https://www.praat.org.
6. Stewart J, Kohlberger M. Earbuds: a method for analyzing nasality in the field. Lang Doc Conserv. 2017; 11: 49-80.
7. Tüysüz, O. The effect of nasal surgery on nasal consonants (dissertation). İstanbul: İstanbul Medeniyet University, 2019.
8. Bressmann T, Klaiman P, Fischbach S. Same noses, different nasalance scores: data from normal subjects and cleft palate speakers for three systems for nasalance analysis. Clin Linguist Phon. 2006; 20: 163-70.
9. Awan SN, K Omlar, Christopher RW. Effects of computer system and vowel loading on measures of nasalance. J Speech Lang Hear Res. 2011; 54: 1284-94.
10. Awan SN, Virani A. Nasometer 6200 versus nasometer II 6400: effect on measures of nasalance. Cleft Palate Craniofac J. 2013; 50: 268-74.
11. Lewis KE, Watterson T. Comparison of nasalance scores obtained from the nasometer and the nasal view. Cleft Palate Craniofac J. 2003: 40; 40-5.
12. Watterson T, Lewis K, Brancamp T. Comparison of nasalance scores obtained with the nasometer 6200 and the nasometer II 6400. Cleft Palate Craniofac J. 2005; 42; 574-9.
13. Rollins M, Oren L. Effects of nasal emission and microphone placement on nasalance score during /s/. Proc Mtgs Acoust. 2020; 42: 060001.
14. Patel RR, Awan SN, Barkmeier-Kraemer J, Courey M, Deliyski D, Eadie T. Recommended protocols for instrumental assessment of voice: American Speech-Language-Hearing Association expert panel to develop a protocol for instrumental assessment of vocal function. Am J Speech Lang Pathol. 2018; 27: 887-905.
15. Svec JG, Granqvist S. Guidelines for selecting microphones for human voice production research. Am J Speech Lang Pathol. 2010; 19: 356-68.
16. Zajac DJ, Lutz RW, Mayo R. Microphone sensitivity as a source of variation in nasalance scores. J Speech Lang Hear Res. 1996; 39; 1228-31.
17. de Boer G, Bressmann T. Comparison of nasalance scores obtained with the nasometers 6200 and 6450. Cleft Palate Craniofac J. 2014; 51: 90-7.