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ASSESSMENT OF VELUM MALFUNCTION IN CHILDREN THROUGH SIMULTANEOUS NASAL AND ORAL ACOUSTIC SIGNALS MEASUREMENTS

Ryszard GUBRYNOWICZ[(1), (2)], Danuta CHOJNACKA–WĄDOŁOWSKA[(2)]
Cecylia KONOPKA[(2)]

[(1)]Polish-Japanese Institute of Information Technology
Koszykowa 86, 02-008 Warszawa, Poland
e-mail: Ryszard.Gubrynowicz@pjwstk.edu.pl

[(2)]Children's Memorial Health Institute
Al. Dzieci Polskich 20, 04-730 Warszawa, Poland

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The paper describes the results of several year studies on children speech disorders due to distortions of the velopharyngeal closure, resulting in speech hypernasality or hyponasality. Disorders targeted for the assessment include deficits pertaining to cleft palate, paralysis and adenoids hypertrophy. The patient's nasopharynx status is evaluated by an acoustic method based on a simultaneous measurement of nasal and oral acoustical output during articulation of test utterances containing target speech sounds. A detailed description of the measurements for specific distortions of target sounds is given and their relations to distortions of the velopharyngeal closure are assessed. These evaluations may assist the clinician in targeting functional goals for treatment and follow the progress of speech rehabilitation.

Keywords: velum malfunction in children, hypernasality, hyponasality, acoustic assessment of velar dysfunction in children.

1. Introduction

There are several methods of assessing the status of the nasal/nasopharyngeal airway based on the study of the nasal airflow (McCaffrey and Kern, [9]; Grzanka, [5]), computation of the nasal/oral airflow ratio (Keall and Vig, [7]), speech signal nasality measurements (Fletcher, [3]; Fletcher *et al.*, [4]), simultaneous measurements of nasal and oral acoustical output in speech samples (Gubrynowicz *et al.*, [6]) and flexible fiber-optic nasal endoscopy (Wang *et al.*, [10]). Various factors militate against the use of rhinometry and, in particular, the use of endoscopy in children. Rhinometry is often time-consuming and difficult to perform [5] and measurements of the nasal airway resistance do not take into account the possibility of functional adaptations that may overcome relatively high levels of resistance. Endoscopic examination is invasive, often requires to put children under sedation, and the endoscopic findings have shown limited correlation with histories of nasal obstruction and with radiographic assessments of adenoid size [10]. For these reasons, very often clinicians are trying to detect disturbances, firstly, on the basis of perceptual judgments of speech quality and simple methods like the Czermak's test (mirror-fogging test), before applying more sophisticated and complex tools like flexible fiberoptic endoscopy, computer tomography or MRI. It seems that acoustic methods, which are non-invasive, are very attractive because of their objective character and can be used also at the preliminary stage of medical examination, in assessing a nasal tract dysfunction, especially on the naso-pharynx level. The main advantage of acoustic methods is that they enable to discern subtleties of speech production and give quantifiable, reproducible results. More, speech performance can be compared to standardized peer/group norms. Pre- and post-measures make outcomes easier to evaluate.

The present paper describes the results of several year studies on children speech disorders due to distortions of the velopharyngeal closure, resulting in speech hypernasality or hyponasality. The research was conducted at the Children's Memorial Health Institute in Warsaw (a research institute and highly specialized hospital with a multi-disciplinary outpatient) as part of a comprehensive, prospective study on the application of acoustic methods in preliminary diagnosis of children's speech disorders during the period 1999–2006. The results of the study on the acoustic evaluation of nasalization due to cleft palate are presented in [6]. Quite recently, they have been applied in a prospective study of indications of adenoidectomy and tonsillectomy.

2. Difficulties in children speech analysis and pathology evaluation

The main problem is that the well known norms of adult speech do not have any equivalents to children speech which is developing from the very beginning of the growth and transformation of the articulatory apparatus. After the infant period of speech sound imitation, it is assumed for many languages that children master their articulation of oral vowels during the third year of life. Since the 3rd year, young pre-school children are trying to apply almost the whole speech sounds inventory, however, the full articulation they master at the beginning of the school age, the alveolar fricatives and affricates are in general the latest ones. Thus, the development of articulatory skills of pre-school children can be divided approximately into two stages – the first one, from the 3rd to the 5th year is related to young pre-school children, the second one – is related to the child language development period which ends at the school age (Krajna, [8]). The division into these two periods is not very sharp from the viewpoint of articulatory mastering of specific groups of speech sounds, since the speech development of children is a continuous process depending on many physical and mental growth factors.

Speech development, however, can be disturbed when a kind of pathology of central or peripheral origins appears. The process of speech learning is then delayed and some speech sounds distortions or substitutions characteristic for the early language development of young children are still present, even at the beginning of the school education period. However, in the early pre-school period it is not always evident if we have to do with a acceptable speech development delay and speech distortions or they are due to some pathologies involving inappropriate coupling of the oral and nasal cavities.

3. Subjects

The data were collected from about 730 children, pre-school children (3–6 year old – n = 357) and school boys and girls (7–17 year old – n = 373). For 110 patients, two or more recordings were taken down at various periods of the medical treatment, in general the first one before and the next one after the medical intervention. The medical documentation contains the patient's developmental history with special attention paid to symptoms of inappropriate coupling of the oral and nasal cavities during breathing and speech activity (483 patients), mainly due to adenoidal large, medium or even borderline obstructions of the nasopharynx. This pathology frequently leads to a partial or full hyponasality which occurs when the velopharyngeal port is still closed during speech, even for nasalized sounds. The object of our study includes also hypernasality cases (81patients) often due to soft palate defective movements and imperfect velopharyngeal closure for non nasalized speech sounds. In this case, the velopharyngeal port is still open and children with cleft palate, for example, may demonstrate problems with the articulation of high pressure consonants. These consonants include stops, fricatives, and affricates. It should be underlined that children with such velum malfunction may produce voiced stops /b/, /d/, and /g/ similar to the nasal sounds /m/, /n/ or /n'/.

4. Speech materials

Very young children are still learning sounds and expressions, therefore they create very variable speech. Within the utterance repeated several times, the same speech sounds may be underarticulated or hyperarticulated and pronounced in different ways. Early school children (6–7 years old) have a more stable pronunciation, but their speech still differs from adult speech due to articulatory differences and vocabulary and syntax choices. This is the reason why the test speech material to be used should not be too complex, conform to the child's language age-development, and contain the early appearing speech sounds.

The children's speech database included 191 recordings taken down for children of the age of 3 to less than 5 years, 235 recordings for children that were 5 to 7 specific years old, 222 recordings for children that were 7 to12 years old and 82 recordings for those that were more than 12 years old. For all the groups of children the same speech samples were applied for the clinical evaluation of the voice and speech quality. Each child was directed to repeat a sequence of oral vowels spoken in a staccato manner, two sustained vowels (/o/ and /i/) and some test utterances with target high pressure consonants /b, d, g/ and nasal consonants /m, n, n'/, both embedded in an intervocalic context. In addition, some elicited utterances were included to the analyzed speech material. The speech samples were constructed in such a way that they were easy uttered fluently even by very young children. However, in some pathological cases in which the patients were unable to utter the sentence in a fluent manner, they were let to speak it one word by one.

5. Recordings and data analysis

Before starting the recordings, the Czermak's mirror test (mirror-fogging test) of nasal air escape was used for all children. During articulation in a repetitive manner of a CV syllable composed of a plosive + open vowel like pa-pa-pa. . . , the sizes of the fogging circles appearing on the mirror were assessed. We rated the degree of the patients' nasal air escape on a 4-point scale (none = 0; small = 1, medium = 2, large = 3) following the diagrams of the fog pictures presented in Fig. 1. For the test value evaluated as medium, the velopharyngeal incompetence is important and the hypernasality is clearly audible.

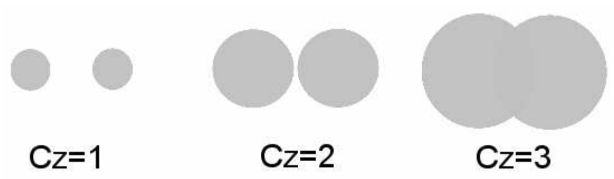

Fig. 1. Rating of the degree of the patients' nasal air escape evaluated by the Czermak's test as small (Cz = 1), medium (Cz = 2) and large (Cz = 3).

The recording session was preceded by explaining the child the recording procedure in order to avoid emotional influences on his speech. Every child recorded during one session the same speech material two times. The first one was a simply microphone recording with a Sony ECM-44 placed 10–15 cm apart from the subject's lips. The second one was made with a recording equipment including a set of two condenser microphones receiving independently the speech waves radiated from mouth and nose. The research assistant supervised the recordings, especially the right placement of the microphone set to obtain a good separation of the oral air flow from the nasal air flow. Speech signal was sampled at 16 kHz.

The data processing began with a computer coded broad phonemic transcription (SAMPA) of the recorded speech signal. This transcription was in most cases text dependent, only when the sounds were substituted/omitted in the speech signal, this distortion was annotated. The acoustic analysis was implemented in a PRAAT shell [Boersma&Weenink, 2005]. A script program was written for the spectral analysis of selected speech tokens, and for the time analysis of the nose and mouth signal levels. Some specific parameters for target sounds were calculated and a graphic representation of data was obtained (see Fig. 2).

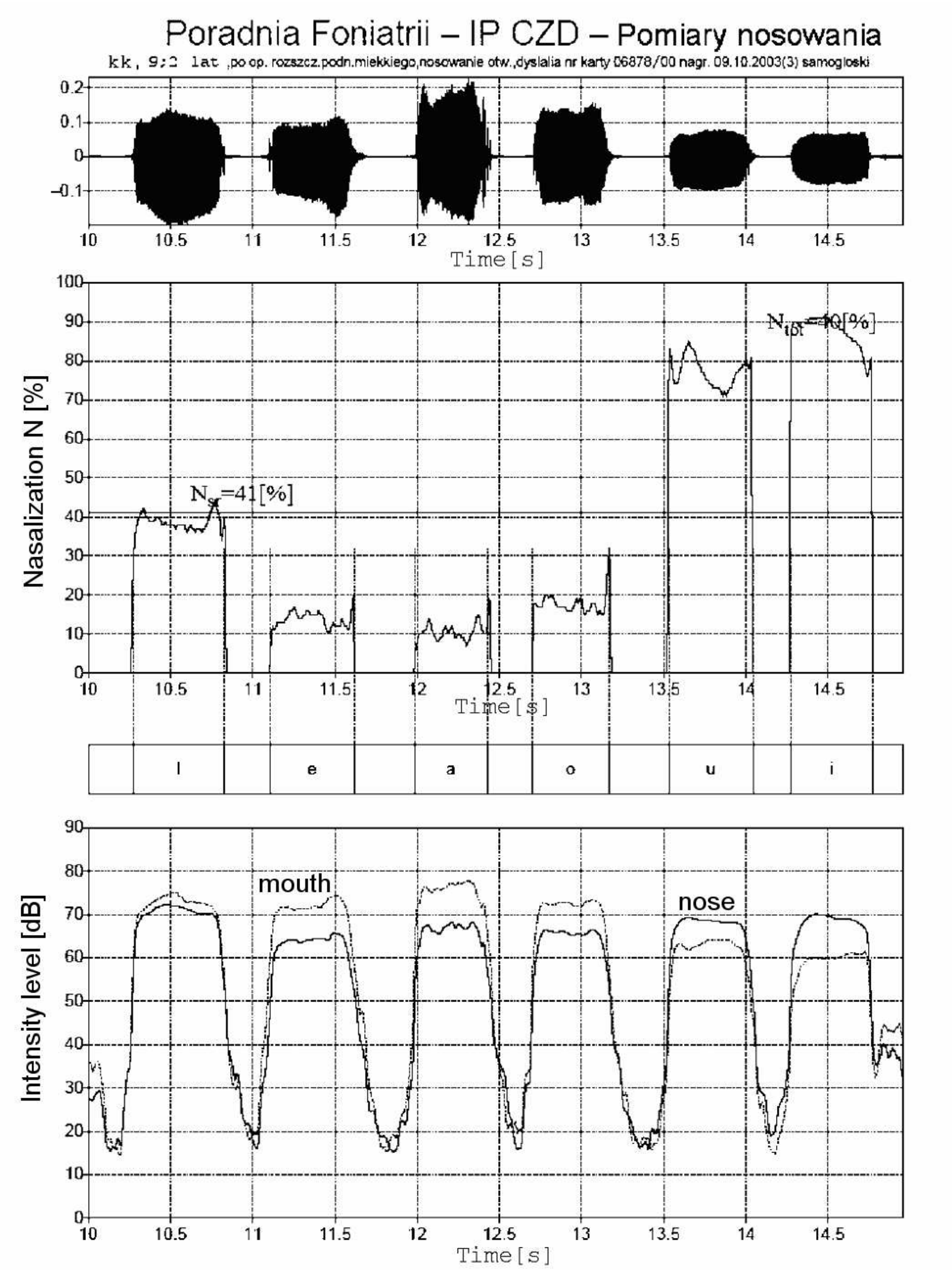

Fig. 2. Analysis of nasalization of the vowel sequence spoken by a girl (9;2 years old) recorded after cleft palate surgery (the recording and analysis made in the Phoniatric Department of the Children's Memorial Health Institute). Time signal (top), measure of the nasalization coefficient (central) and time level variations (bottom) of nose (continuous line) and mouth (broken line) signals.

In normal speech production of stops or of affricative/fricative sounds, the velum do close off completely the pharyngeal passage to the nose. For other sounds like vowels, liquids, the degree of the amount of velic opening is variable, but it is relatively small with reference to nasalized sounds. However, any nasalization of vowels or liquids is perceived by the listeners. The perception of a sound as nasalized depends on the ratio of the sizes of the two openings into the nasal cavity and the oral cavity. When the opening of the nasal port is large in relation to this of the oral port, then the nasality will be perceived.

The main objects of the analysis were the time variations of both the separated mouth and nose signals obtained for the test utterances (Fig. 2). This is an example

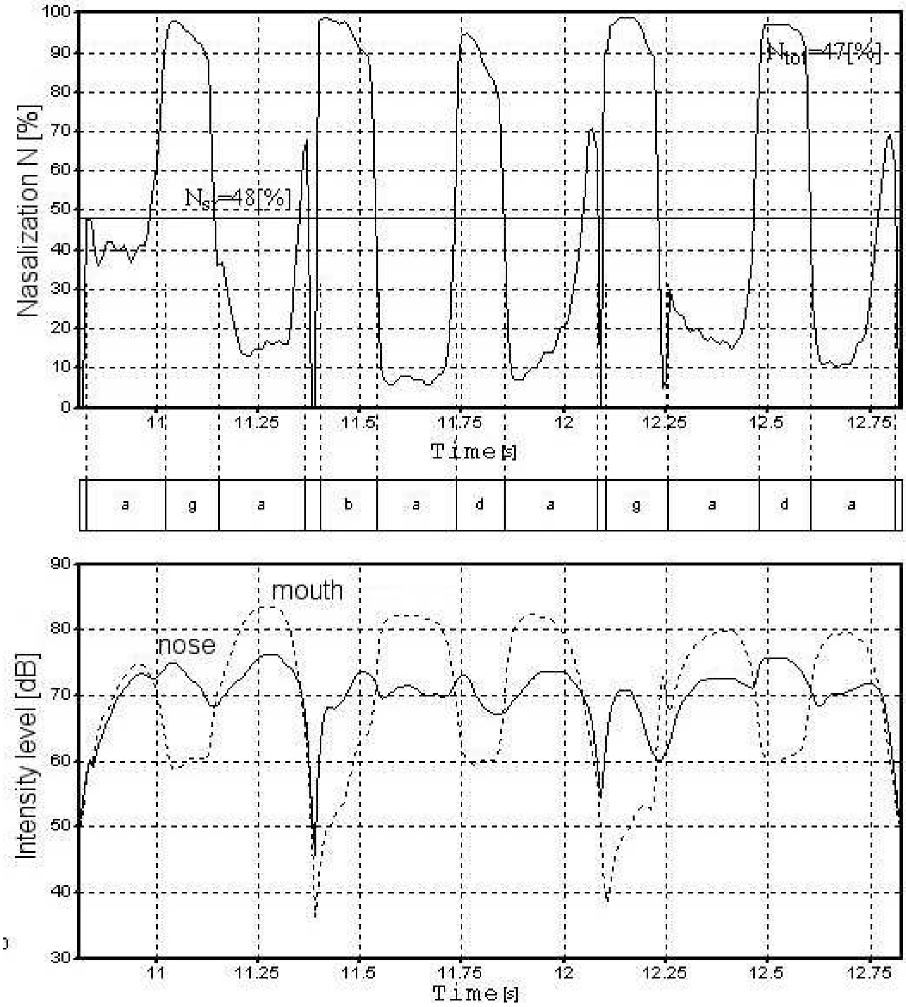

Fig. 3. Analysis of nasalization (top) and the mouth and nose signal levels obtained for the utterance of the sequence /agabadagada/ spoken by a boy (7;3 years old) with a malfunction of the velum.

obtained for a sequence of vowels spoken by a girl, 9;2 years old. It was recorded after cleft palate surgery. The measure of nasalization is calculated as the ratio the nose signal level to sum of the level of the nose and mouth signals. From this picture, it is evident that the measure of nasalization for vowels depends strongly on their type since the open mouth surface determines especially the power of the radiated mouth signal. For this reason, the measure of nasalization is almost always maximal for the vowel /i/ and is followed respectively by the values for /u/, /I/ and /a/. The Czermak's test for this girl is assessed as large and the coefficients of nasalization for the vocalic sequence and sustained vowel /i/ are 41% and 85%, respectively.

These values agree with the Czermak's test evaluation which indicates a strong nasal emission due to wide opening of the velopharyngeal inlet. These results show that after the surgery a palatal rehabilitation is needed (velopharyngeal insufficiency is quite common after cleft palate repair). For normal voices the Czermak's test is 0, even for very young children, and the values of nasalization for the vocalic sequence and the isolated vowel /i/ do not exceed 10–18% and 20–25%, respectively.

Other detailed information about the velopharyngeal closure and velar movements can be obtained by the analysis of mouth and nose signals recorded during articulation of speech samples with target high pressure consonants /b, d, g/ and nasal consonants /m, n, n'/, both embedded in an intervocalic context. Figure 3 illustrates the pathological case, in which the velum fails to contact the pharyngeal wall allowing an important nasal sound radiation during the articulation of high pressure consonants /b, d, g/. The high nasalization measures for these consonants are confirmed by the Czermak's test, both indicating the velopharyngeal closure impairment.

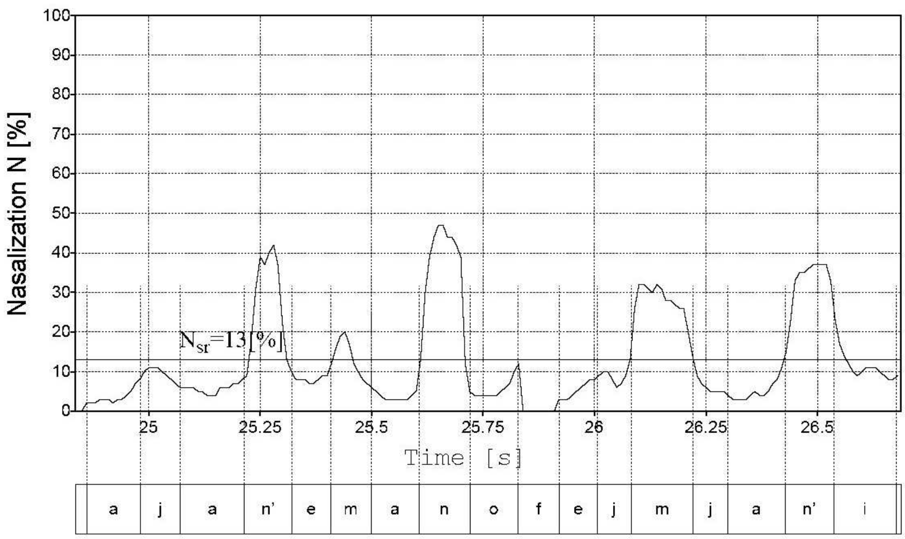

Fig. 4. Time variation of the nasalization coefficient computed for the utterance "Ania nie ma nowej niani" (with substitutions) spoken by a girl 7 years old with very large adenoids obstructing the nasopharyngeal air passage.

The picture of nasalization is quite different in the case of adenoids hypertrophy. Figure 4 shows the time variations of the nasalization coefficient calculated for the utterance of the sentence "Ania nie ma nowej niani" – /an'a n'e ma novej n'an'i/ (Anne does not have a new babysitter") spoken by a girl (7 years old) with very large adenoids. It is evident from this figure that the nasopharyngeal air passage is strongly obstructed, even for nasal consonants for which the coefficient of nasalization does not achieve the level of 95–98%, which is the usual value for non-pathological voices.

6. Discussion

The nature of the test utterances depends on the specific deficits of the individual patient to be assessed. Two kind of speech abnormalities due to velopharyngeal closure impairments were analyzed : the hypernasality and hyponasality. The test utterances composed of vowels are effective to evaluate the hypernasality of young children (4–5 years old). Especially, the measure of nasalization of a sustained vowel /i/ occurs to be efficient in the detection of the defective velopharyngeal mechanism caused by anatomical defects (cleft palate or other trauma), by the central nervous system damage (cerebral palsy or traumatic brain injury), or by the peripheral nervous system damage. The analysis of others more complex test utterances may be in some cases difficult in achieving unambiguous results. This is due to the fact that we have to cope with abnormal speech. In the case of hyponasality, the nasalization coefficient for a vocalic sequence or sustained vowel /i/ is unusually low (3-5%). For normal voices, vowels are slightly nasalized ($\sim$10%) although this is not audible.

A substantial nasal resonance is usually heard in hypernasal children voices, however due to their high pitch, it can be rarely seen on spectrograms of /i/- or /a/-like vowels. For this reason, all the methods based on a separate analysis of nose and mouth signals seem to be more effective than a one microphone speech signal analysis. The two separated microphone recordings enable also to follow not only the time variations of the nasalization coefficient during a test utterance, but for utterance with target high pressure consonants it is possible to evaluate the air-tightness of the velopharyngeal closure. When the values of the nasalization coefficient for these consonants are high, and close to those of nasal consonants (see Fig. 3), they indicate that the velum fails to contact the pharyngeal wall allowing a nasal air escape. Another important velum movement deficiency can be assessed by the analysis of the nose signal produced during articulation of a specific test phrase with nasal consonants embedded in an intervocalic context. The panel at the bottom of the Fig. 5 shows time variations of nose and mouth signal levels with corresponding changes of the nasalization coefficient (upper panel) computed for the test utterance with target nasal sounds spoken by a boy 10 years old with medium large adenoids. From the diagram of nasalization, it can be deduced that the nasal airway is not totally (on the borderline) obstructed (compare the high value of the nasalization coefficient for nasal consonants), when however the velopharyngeal valve should be open in moments of nasal consonants articulation, the level of

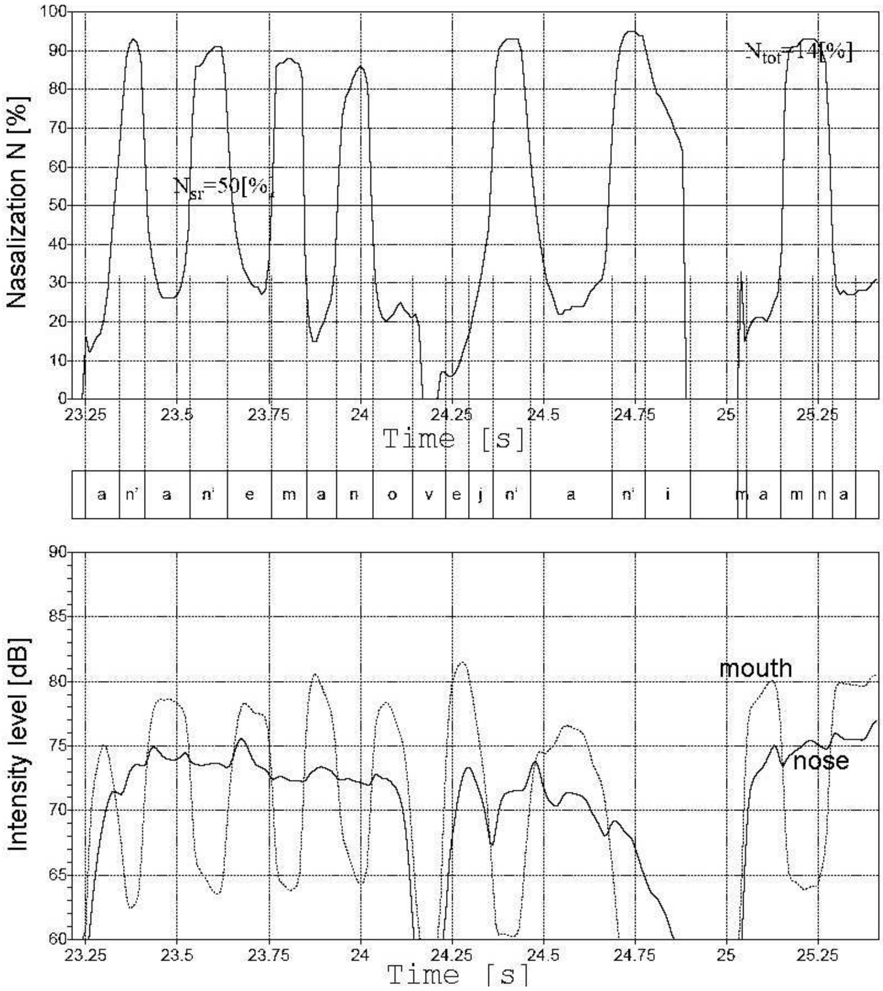

Fig. 5. The variation of the coefficient of nasalization (top) and the nose and mouth signal levels computed for an utterance "Ania nie ma nowej niani" spoken by a boy 10 years old, with large adenoids which are non-obstructing the nasal airway.

the nasal signal is almost constant with no distinct local maxima for the nasal consonant segments. As the nasal airway is almost unobstructed, it can be assumed that it is the adenoid that prevents the velum from moving. The patient does not sound hyponasal (stuffy), because the closure is neither complete nor hypernasal as the velopharyngeal opening is relatively small. In this case, the slight nasal emission is inaudible.

In some cases of strong velopharyngeal insufficiency like large cleft palate, congenitally short velum, velum paralysis, the nasopharynx opening is wide and during articulation of the test phrase composed with nasal consonants and vowels, the nose power emission is nearly constant, however, at a much higher level than in the case of adenoids.

7. Conclusions

The structure of speech samples with target sounds used for the acoustic evaluation of velum closure malfunction are well known to clinicians who use them in a subjective assessment of the inappropriate coupling of the oral and nasal cavities during speech. However, it must be underlined, that these clinical assessments are just valid only at the extremes of either marked obstruction or at no obstruction. The same is true for the velopharyngeal closure mechanism which defection causes hypernasal speech.

The acoustical analysis of the speech signal and especially of nose and mouth speech signals, enables a detailed screening of a defective velopharyngeal mechanism and related specific speech distortions. All children recorded the same set of test phrases, some of them several times at different periods of the therapy and rehabilitation. In most cases of velopharyngeal insufficiency (like cleft palate, velum paralysis, etc.), the clinical interpretations of the nasalization analysis were unequivocally positive. In cases of adenoids, the interpretation of the acoustic analysis is not unambiguous and does not permit to confirm the presence of relatively small adenoids. It must be underlined that in some cases of the adenoids hypertrophy, the inconsistency of the velic closure is detected, although the nasalization of no nasal sounds is perceived. A caution is then recommended with regard to the adenoidectomy which can result in permanent hypernasal speech. Results of these evaluations can assist the clinician in targeting functional goals for the treatment and objective measures can be taken during diagnostic/trial therapy to assess the effectiveness of a therapeutic technique preventing such undesirable sequel to surgery. Of course in general, the acoustic methods alone are, insufficient to establish unequivocally the presence of a given pathology disturbing the velopharyngeal mechanism.

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